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1. INTRODUCTION

1.1 Goal and Background

These proceedings include all the papers that were accepted after being peer reviewed and also presents the major findings and discussions from the Expert Meeting on 'Industrial Technology Development, Transfer and Diffusion'.

The Intergovernmental Panel on Climate Change (IPCC) is in the process of preparing the Fourth Assessment Report (AR4), which will assess the scientific, technical, and socio-economic information relevant to understanding human-induced climate change, its potential impacts, vulnerability to it, and options for adaptation and mitigation. Working Group III (Mitigation of climate change) will again address the mitigation (reduction) of the emissions of greenhouse gases. The writing team will start in October 2004 and its report (Contribution to the Fourth Assessment report of IPCC: Mitigation of Climate change, in brief: WG III AR4) will be presented to the Panel for approval in June 2007.

Several IPCC expert meetings have been organised in order to support the scientific, technical and socio-economic input to the WG III AR4. In this context, the 21st IPCC Plenary session (November 2003) decided to hold an expert meeting on 'Industrial Technology Development and Transfer' as a support to the AR4 of WG III. The Japanese Government, through Mr. Shigetaka Seki of METI, kindly offered to host this meeting in Japan (21-23 September 2004). More information about the background to the Meeting can be read in Annex 5. This meeting should be seen as a step in a process of further improving the relationship of IPCC and Industry, and of further improving our understanding of technology development, transfer and diffusion processes, in support of the preparation of the AR4 of Working Group III.

Industry, through generation of electricity, emissions generated by use of its products, and the manufacture of products, influences a significant part of worldwide greenhouse gas emissions. Industry plays an important role in potential responses to climate change. Industry decisions on investments, operation of equipment, product development, and technological innovation will have an enormous impact on future greenhouse gas emissions. Industry investments in capital exceed governments' investments by far. Industry spending on R&D and technological innovation is also significantly larger than the R&D funding by governments and most of the envisaged 'solutions' to climate change need to be realised by industry.

In the AR4 Report mitigation of greenhouse gas emissions from industry will again be covered. It is important to assess driving factors affecting CO_2 intensive energy systems and what roles different actors can play in such processes. Companies are producing and developing technologies and products that contribute to and help to mitigate future greenhouse gas emissions. In addition, many companies are already considering and implementing mitigation of greenhouse gas emissions in their decisions. In some countries mitigation of climate change has become an important driver for the government's energy and environmental policy, which is affecting private sector decisions. The AR4 will need to reflect these developments.

The objectives of the meeting were:

- To identify key drivers on industrial technology development, transfer, deployment and diffusion to be addressed in the AR4
- To contribute to building the conceptual framework for the assessment
- To gain access to industrial information networks being relevant for the scientific assessment of climate change mitigation and improve the use of publicly available data sources from industry in the AR4
- To explicitly involve experts working in industry in the WG III AR4 process as lead authors, contributing authors and expert reviewers.

The main content questions to be addressed were:

- What are the driving factors of Industrial Technology Development?
- What are the factors that drive or limit the process of transfer and diffusion of technologies?
- How to make accurate estimates of future cost and future market potential of technologies?

The meeting focused on three sectors that produce a major portion of global greenhouse gas emissions, and hence have a large potential for mitigation technology:

- Energy-intensive industry (e.g. cement, metals, chemicals);
- Energy-intensive consumer goods (e.g. passenger cars and fuels, air conditioners and lighting equipment);
- Electricity production and energy carriers (e.g. fossil, nuclear, renewables, less carbon intensive fuels, efficient conversion, hydrogen).

1.2 Organisation

The organisation of the Meeting was undertaken by a Programme Committee, consisting of 11 members with IPCC or industry background (see page 2 of this report) under the chairmanship of Prof. Ogunlade Davidson, co-chair of IPCC Working Group III. During April-August 2004 the Expert Meeting was organised by John Kessels from the Technical Support Unit of Working Group III and a local organising committee chaired by Shigetaka Seki (METI). In addition, the Global Industrial and Social Progress Research Institute (GISPRI) assisted in logistics and organisation of the Meeting in Japan.

Invitations and a call for abstracts were sent out in April 2004 to broad groups of technical experts, identified via IPCC, the International Chamber of Commerce (ICC) and the World Business Council for Sustainable Business Development (WBCSD). Every organisation or company with relevant experts requesting participation was allowed at least one registration. Environmental NGOs were also invited. The abstracts were supposed to focus on one or more of the three main questions and one or more of the three sectors mentioned in the previous section. The Programme Committee assessed all abstracts and successful authors were requested to submit a full paper for presentation at the Meeting in Japan. A total of 38 abstracts were submitted and 30 full papers were conveyed to the expert meeting.

1.3 IPCC Expert Meeting venue and participants

The Expert Meeting took place at the Toshi Center Hotel, Tokyo, Japan, 21-23 September 2004. During the three days 86 participants from 21 countries (Australia, Belgium, Brazil, Canada, Chile, China, France, Germany, Hungary, India, Japan, Macedonia, Mexico, Netherlands, Norway, Sierra Leone, South Africa, UK, USA, Zambia and Zimbabwe). A list with the names and affiliations of all the participants is in Annex 2.

The Meeting was attended by the Chairman of the IPCC and the two Co-Chairs of WG III. The breakdown of experts included a total of 5 Coordinating Lead Authors (CLAs) and 16 Lead Authors (LAs) from WG III who will be involved in writing the AR4.

The CLAs and LAs will be writing in various chapters of the AR4 including the introduction, framing issues, energy supply, transport and its infrastructure, industry, short and medium term mitigation from a cross-sectoral perspective, and short and medium term mitigation.

The Meeting also included a total of 14 experts from academia or research institutions, 12 experts from Government institutions, 20 from industry, 12 from utilities and two from environmental non-governmental organisations. The industry and utility experts were from companies that included Toyota, General Motors, Nippon Steel, ExxonMobil, Rio Tinto, RWE, AREVA, Anglo America, Eskom and Petrobas. There were also experts from several international industry associations that covered the electricity, aluminium, nuclear, fertilizer, steel, cement, gas and chemical sectors.

2. EXPERT MEETING AND PLENARY AND BREAKOUT GROUPS

2.1 Opening Plenary Session

The Expert Meeting was chaired by Ogunlade Davidson co-chair of WGIII. The meeting was over three days and consisted of a series of plenary presentations on the first day followed by breakout group meetings attended by industry experts. On the final day all the breakout groups gathered together to report back and discuss their findings.

Hiroshi Saito, the Director General in Charge of Technology at the Ministry of Economy Trade and Industry (METI), opened the Meeting. In his speech he stressed the importance in Japan of technology in mitigation of GHG emission reductions and that this is reflected in the AR4 as well as consideration given to post Kyoto scenarios.

The Co-Chair of Working Group III, Professor Ogunlade Davidson and Chairman of the Meeting, then explained the Meetings purpose and objectives. He outlined the background and rationale for the Meeting and emphasized the important role that industry plays in technology transfer. He hoped that the industry experts at the Meeting would assist in identifying the key drivers and limiting factors to technology transfer and some options on how to improve transfer and diffuse industrial technology.

Dr Pachauri, the IPCC Chairman emphasized the important role technology will play in AR4. He stressed that mitigation would be driven by technology in the future with no sector better understanding technology than industry. Industry also has the expertise to identify the best technological pathway forward to supply sustainable energy to the 2 billion people without access to electricity. He went on to conclude that with estimates of up to $10 trillion to be invested in the power sector between 2001-2030 it is important to identify the best pathway forward in the transfer and diffusion of industrial technology that will mitigate greenhouse gas emissions.

Hiroyuki Watanabe, the Senior Managing Director of Toyota Motor Company gave in his keynote address a historical overview of the technological development of the automobile and some future predictions of automobile technology development. He expressed that such technology evolutions and revolutions will have to contribute to the mitigation of climate change and new business creation. He also outlined the international growth in numbers of automobiles with Toyota expecting in 2050 a growth in ownership of up to 3.24 billion vehicles in comparison with 740 million in 2000. An explanation of the well to wheel efficiency improvements in vehicles was outlined with a prediction of continual improvement in hybrid and fuel cell technology with the ongoing development of more compact and lighter cars. He illustrated this by describing the Toyota Prius hybrid vehicle. An important driver in developing this technology is the METI fuel cell vehicle development roadmap that has an initial goal of 50,000 fuel cell vehicles by 2010, growing to 5 million by 2020 and full market commercialisation by 2030 with 1,500 million vehicles.

Greg Tosen, the General Manager of Eskom's Research, Development and Demonstration Group discussed some of the existing and new technologies that Eskom is developing to supply the energy needs of South Africa. These technologies included clean coal power generation, gas fired power generation, re-powering, in situ goal gasification, carbon sequestration, wind power, concentrated solar power, hydroelectric power and nuclear. Many of these technologies could be assisted by the use of the Clean Development Mechanism. He suggested the additional revenue from carbon credits with some technologies would contribute to the decision making of Eskom management on whether to implement and proceed with investment in a particular technology.

Teruaki Masumoto, the Vice Chairman of the Federation of Electric Power Companies in Japan and Chairman of the subcommittee on Global Environment of the Japan Business Association explained the important role that electric technologies will play in the mitigation of GHG emissions. He illustrated electric technologies roles with examples of advanced heat-pump technology replacing existing air conditioning and heating devices stock, improving thermal efficiency at the electricity production stage with Advanced Combined Cycle (ACC) and Integrated Gasification Combined Cycle (IGCC). He suggested increasing transfer and diffusion of these technologies through an international framework focussing on multilateral technological partnerships and cooperation through the development of a technology database.

Brian Flannery from ExxonMobil, also a Lead Author in the AR4, identified several key commercial drivers needed for successful development and commercialisation of innovative technologies for GHG mitigation. Those drivers included performance, cost, consumer acceptance, safety, enabling infrastructure, regulatory compliance and to take account of all associated environmental impacts. An important point he stressed was that the weakest driver or element will determine the strength and hence commercialisation and widespread use of a technology, i.e. failure in any of these dimensions will prevent widespread commercial use. Dr Flannery also outlined a private sector view on key roles for private and public sectors in bringing technologies to market. These stressed the need for companies to bear the risks and capture the rewards of commercialising technologies and for governments to establish proper enabling frameworks including rule of law, protection of intellectual property and maintaining a safe and secure environment for workers and communities. Finally, he illustrated that investments over many decades are required even for successful energy technologies to come into widespread commercial use. Over such long periods many factors will change, including relative prices of input materials and competition from other services and products. Hence it is impossible to pick technological winners and losers based on information available at any particular time.

Taishi Sugiyama from the Central Research Institute of Electric Power Industry (CRIEPI) and a lead author in the AR4 outlined a new conceptual framework for the AR4 assessment. His suggestion was a combination of existing IPCC assessments on long-term scenarios and the short term technological mitigation potential in a manner that produces useful information for policy makers involved in designing climate technology policy. He outlined six key driving factors that needed to be incorporated into the scenario analysis, including political salience of the climate change issue, overlapping environmental issues, limitations on facilities and infrastructure, national interests in technology and energy security and lastly the regional resources of a region as this will impact on the viability of a technology. The interplay of these factors could lead to regions making different technology choices.

Cedric Philibert from the Energy Efficiency and Environmental Division of the International Energy Agency (IEA) discussed the challenge of stabilizing global CO_2 emissions and how it would require major changes in energy systems. He stated that all low carbon technologies needed to be used to reach the lowest possible emission levels. He outlined the need to include developing countries and to provide incentives for research, development and dissemination of new technologies; technology-focussed policies would help but not replace policies directly directed to cut emissions. Lastly, emphasis was made that the development and evolution of new technologies are unpredictable and that this uncertainty needs to be considered by negotiators when they are developing future international regimes.

Jae Edmonds and Jose Moreira then explained the concept and application of crosscutting themes for technology in AR4. They prepared a guidance paper on how to consistently and systematically assess technologies in the AR4, notably WG III, taking into account different dimensions including system boundaries, timeframe, and regional differences. This guidance paper is being finalised and will be conveyed to the writing team of WG III AR4.

Upon completion of the plenary session the participants were split into three breakout groups that focused on the three biggest sectors for greenhouse gas emissions from industry.

- **Energy-intensive industry** (e.g. cement, metals, chemicals);
- **Energy-intensive consumer goods** (e.g. passenger cars and fuels, air conditioners and lighting equipment);
- **Electricity production and energy carriers** (e.g. fossil, nuclear, renewables, less carbon intensive fuels, efficient conversion, hydrogen).

The three breakout groups were asked to address three questions:

- **What are the driving factors of industrial technology development?**
- **What are the factors that drive or limit the process of transfer and diffusion of technologies?**
- **How to make accurate estimates of future cost and future market potential of technologies?**

On the third day the three breakout groups all met together to summarise their finding. Several of the papers have been peer reviewed and the full text is in the Annex?

2.2 Energy Intensive Industry

A working group of experts discussed the various aspects of technology transfer and diffusion in the mining, aluminium, iron and steel, cement and fertilizer sectors. Eight papers were presented to provide background and examples of the key drivers facing industry in technology development, transfer and diffusion. The group was co-chaired by the two Coordinating Lead Authors from the Industry chapter in the AR4, Lenny Bernstein and Joyashree Roy. Lynn Price a Lead Author in the Industry Chapter was the rapporteur.

Robert Chase from the International Aluminium Institute (IAI) discussed how aluminium companies are implementing a global response to mitigating greenhouse emissions. To accomplish this, the IAI with its members have developed common standards through an initiative that comprises 9 voluntary objectives and 22 performance indicators. This initiative covers 70% of world aluminium production in developing and developed countries. The goal is to have an 80% reduction of Perfluorocarbon (PFC) emissions per tonne of primary aluminium in comparison with 1990. To achieve this, IAI members have introduced new technologies internationally, monitor progress through an IAI benchmarking program, and emphasize increased aluminium recycling and use of aluminium in transport vehicles to reduce emissions from that sector. Progress is also continually monitored through an Annual Industry-wide Survey. The 2004 Survey showed that the Industry had achieved a 73% reduction in PFCs per tonne of production in 2003.

Jon Davis from Rio Tinto discussed lessons learnt by the mining industry in the commercialisation of new technologies. Interestingly he pointed out that initially many of the technologies were not immediately adopted and in some cases took decades to be implemented due to the high financial risks associated with failure. Of 43 projects in the industry, 16 failed at a cost of $20B. Reasons for failure included poor project phasing, no continuity in project team, turn-key fixed price project, major new technology, and poor management. The key lessons to the successful introduction of a new technology are to carefully trial the technology and demonstrate it as well as have excellent and consistent project management. He stressed that the lessons learned are applicable to the field of carbon capture and storage where current visions emphasize a few large-scale demonstration projects, but where he feels small, medium, and large demonstrations are needed to build confidence and avoid large-scale failures.

Yanjia Wang from Tsinghua University discussed four case studies from the coal, pulp and paper, textile and steel industries in China. The four case studies illustrated problems related to intellectual property rights (IPR), project economics, acquisition of 'software' to accompany hardware, and lack of information dissemination after a successful pilot project. She suggested the three key ways to improve technology transfer are to improve communication between the supplier and receiver, build a platform or database for sharing information and expanding the system for technology selection and assessment.

Francisco Aguayo from El Colegio de Mexico introduced the concept of 'technological regime' which is the complex of scientific knowledge, engineering practices, business and production process practices, standards, regulations, and institutions. He explained that technological change involves all of these elements, is usually incremental, new technologies typically develop in niches and continue to develop while diffusing. He identified a number of aspects that he believes will reduce the speed of technology transfer to carbon free technologies, including the fact that the current energy system is based on hydrocarbons and the status and inertia inherent in established systems will restrict the uptake of carbon free energy technologies. He explained to overcome these barriers depends on capital turnover rates, local absorptive capacity, the economic environment, and industry's ability to identify alternative and complimentary pathways that over time will result in greater adoption of carbon-free energy technologies.

Mr Okazaki from Nippon Steel discussed how the Japan steel industry had through its voluntary initiative taken several technological actions that were resulting in reduced greenhouse gas emissions.

This included utilization of waste plastics and tires, development of eco products such as high tensile steel to increase the energy efficiency of automobiles, and utilization of waste products such as blast furnace slag. He also described international collaboration in technology transfer by introducing energy saving technology into developing countries, such as the Japanese effort to disseminate coke dry quenching (CDQ) and top pressure recovery turbines (TRTs) in China. Nippon Steel is participating in a METI international collaboration effort as well as the International Iron and Steel Institute CO_2 Breakthrough Program.

Bhanu Swaminathan from the International Fertilizer Association (and the Fertiliser Association of India) gave the background of the global fertilizer industry (accounts for 1-2% of global energy use and GHG emissions) and of the evolution of ammonia production technology and how, due to environmental legislation and cost considerations, high levels of energy efficiency and process reliability had been achieved. In developing countries there are now many efficient ammonia plants as a result of changes in global demand for fertilizers, national strategies for food security, transport costs and distribution of raw materials. She also stated that to continually refurbish or build new ammonia plants requires understanding of some key drivers such as regional differences, labour costs, qualifications of professionals and compatibility of equipment. She stressed that a predictable regulatory framework, accessible documentation of real-life performance of new technologies, and ability to secure financing are key technology transfer enabling factors.

Casey Delhotal from the United States Environmental Protection Agency (US EPA) explained the importance of modelling to demonstrate the cost and diffusion of methane abatement technologies for an economy. The US EPA has developed marginal cost abatement curves for 100s of non-CO_2 mitigation options that can be used by both 'bottom-up' and 'top-down' modellers to assess the mitigation costs and savings over time for the coal, natural gas and solid waste sectors. She pointed out that experience indicates there can be policy barriers to technology diffusion such as concerned citizens groups, the rate of return and vintaging issues can affect adoption rates, and that innovation takes place as technologies are used and such changes can vary by regions.

Dr. Izumi from Taiheiyo Cement Corporation explained how the Japanese cement industry has developed technologies that use the wastes and by-products of society as alternative fuel and raw materials. Although there is a slight increase in electricity consumption as a result of having to pretreat the wastes, the outcome is a reduction of total GHG emissions when such wastes, particularly fossil-originated wastes, are co-processed in cement manufacturing instead of simply being incinerated. He believes these processes are key technologies to reduce GHG emissions whilst tackling waste issues, are also applicable in developing countries, and that Japan can assist interested cement companies in developing countries with the technical expertise in transferring the technology.

2.3 Energy Intensive Consumer Goods

A breakout group of experts intensively discussed the various aspects of technology transfer and diffusion in the automobile, energy efficiency and consumer good areas. Eight papers were presented. The group was co-chaired by Bert Metz, Co Chair of WG III and Diana Urge-Vorstz a CLA for the Chapter on the residential and commercial and mitigation options (including services) in the AR4 assessment.

Masayuki Sasanouchi from Toyota discussed CO_2 reduction in the transportation sector. A key factor to recognise in the use of vehicles is rising incomes are directly linked with vehicle purchase. In developing countries there are also similar and additional issues such as ambient air quality.

Toyota is developing several technologies and takes a parallel approach by examining fuel cells, hybrid, electric vehicle and other options. This approach is taken for reasons of competitiveness with not only external competitors but also internal divisions, and also because no company, as he stated 'have no right to press consumers in a particular direction'. This means that companies prepare options from which consumers can choose, and that reduction of greenhouse gas emissions and other environment issues is just one consideration in the consumer's choice of vehicles. Further, the approach will be able to realize the balance between environmental performances and other ones (e.g. drivability, safety and comfort), and faster achievements of R&D.

He also stated that it is important to compare the reduction cost amongst technologies such as between the automobile, industry, forestation, sequestration, and other industries.

Suzana Kahn Ribeiro presentation was on the potential CO_2 reduction through the use of hybrid buses in Brazil. She pointed out that the buses are used widely in developing countries with many bus companies privately owned. She argues for a hybrid bus approach, in which five issues must be addressed to make progress in reducing transport emissions with buses. The five issues to consider are perceptions of advantages; simplicity of application; ease of understanding; product credibility; and reversibility of use.

George Hansen from General Motors identified several drivers that influence the automobile industry including a competitive environment, social factors, safety, environment and regulatory factors. Linked with this is that mobility is essential to economic growth and improved living standards with direct links between vehicle ownership and Gross Domestic Product (GDP). If business as usual trends for automobiles continue it is likely there will be a doubling of GHG emissions by 2050. Therefore the introduction of new transportation technologies is critical. He stressed that it is important not to choose one technology over another and to avoid regulations that lock-in obsolete technologies.

James Sweeney discussed options for hydrogen use in light duty vehicles. He argued that the governmental policy driver for technology development/implementation is not only climate change. In the case of hydrogen technologies in the United States energy security, local pollution and mitigation of climate change all play a role. If critical R&D challenges can be overcome in the creation of fuel cell vehicles, and in economic, safe production, storage and distribution of hydrogen fuels, then hydrogen has a huge potential to reduce emissions in the transportation sector. With breakthrough technological advances in fuel cells and hydrogen storage on-board vehicles, hydrogen could become a substantial energy carrier similar to electricity. But the barriers are huge and there has to be an appropriate feedstock that does NOT accentuate the problem and/or technologies to capture and permanently sequester carbon dioxide. At the moment the current cost estimates for feedstocks indicate that coal (gasification and sequestration) and natural gas are the most economic. He suggested that hybrid vehicles will provide a major competition to hydrogen vehicles during the next several decades and may well be a more cost-effective way of reducing carbon-dioxide releases, absent the needed technological progress.

John Nyboer addressed the issue of how one might critique policies and programmes designed to enhance technology development and diffusion. Given that models are often used in such analyses, he noted that most current models are either bottom up, which tend to underestimate costs and overestimate technology diffusion, or top down, which tend to do the opposite. He described CIMS, a hybrid model his research group developed that endogenously simulates technology evolution over time based on the behaviour of decision makers. He explained how 'discrete choice' modelling helps to empirically define parameters for this hybrid model such that technologies used to provide goods and services are chosen based on an understanding of the behaviour of consumers in industrial, commercial, residential and transportation sectors.

Natasa Markovska illustrated with case studies the key role that capital plays in the transfer of technology. In the case of Macedonia it was also important to recognise that a supportive infrastructure for technology development and transfer as well as public awareness amongst consumers and industry was needed for successful technology transfer.

Sheng Zhongyuan discussed the energy saving potential of China. He pointed out that technology improvement and economic structure change are difficult to achieve over the short term. He argued that China is not as inefficient compared with Japan as assumed, because of mistaken assumptions about exchange rates. He also pointed out that there is massive potential for energy efficiency savings in China with the right technological incentives. Finally, Shigetoshi Seta said with the linking of energy and the economic growth it is important to recognise the use of technological innovation through structural life style change.

The discussion from participants identified several drivers and limitations to transfer and diffusion of technology. The point was made that companies do research and development on technologies to gain a competitive advantage.

Multi-national companies that invest in various countries, operate manufacturing plants and market goods and services play a key role in technology transfer and capacity building in both developed and in developing countries. Again it is competitive advantage, typically in proprietary technology and know how embodied in management systems, that provides competitive commercial opportunities for new investment by companies. Therefore the use of science and technology can be a key proprietary intellectual property right asset for individual companies, and with the proper enabling framework a key driver for technology dissemination and capacity building.

There was a general agreement that the transfer and diffusion of technology must take into account regional disparities for technology development and dissemination. Technologies will be driven by a number of factors within a region, such as the existing legal and market framework and availability of resources in a country at the local or regional level. Access and use of these resources will also be dependent on a region or country having the appropriate infrastructural delivery systems. It was pointed out that because of these factors, technology development and transfer issues will remain different between developed and developing nations and result in implementation issues. There was also the point made that the best technological pathway for one country might not be for another country, such as a preference for hybrid vehicles rather than using biofuel vehicles.

Some key elements for effective technology transfer and diffusion identified were a clear legal framework with protection of property rights, free movement of capital, goods, people and services, and maintenance of safe stable conditions for workers and communities. Across many developing countries the legal system and property rights can differ tremendously in this regard. Other elements included competitiveness as a market driver and consumers purchasing power differences within a country.

The group also discussed the cross cutting model of Jae Edmonds and Jose Moreira. The paper is excellent in defining important input and performance components of technologies that must be considered in assessing how they might compete and emerge in regional global markets. However, the model was perceived as being very data hungry and not yet having an adequate analytical framework with a suggestion that it needed further revision to be effective. Finally, factors related to consumer choice and appeal often play an important role in technology change, and it is unclear how such factors, beyond the strict financial costs should be included in an assessment.

Private sector participants expressed the view that it is not possible to establish accurate costs and market shares for future technologies, or to rely on specific scenarios to assess likely success. Once a new technology begins to penetrate regional markets on a large scale, it will interact with other competing technologies and affect the relative costs of various critical inputs, such as the supply of primary energy from gas, coal or renewables. As well, technologies can rarely be assessed on a single global scale; critical factors differ from region to region that affect relative costs and potential market penetration. In addition, to the extent that a new technology begins to displace other providers, they will react to compete and to re-establish market share. Thus multiple competitive interactions, dependent on numerous participants in the market and the availability and relative price of primary and secondary inputs will affect ultimate costs and penetration rates of innovative technology. Hence, it is considered to be more important to identify and characterise key factors that affect the production and performance of innovative technologies, than to seek to predict accurate costs, for example through particular scenarios.

2.4 Electricity Production and Energy Carriers

A working group of experts intensively discussed the various aspects of technology transfer and diffusion in the electricity production from the gas, coal, nuclear and hydro sectors. Nine papers were presented to provide background and examples of the issues facing industry in technology development, transfer and diffusion. The group was co-chaired by Greg Tosen from Eskom, South Africa, and Jose Moreira a review editor in the energy supply chapter of the AR4 assessment.

Two papers discussed the important role of nuclear power as a mitigation option. Ravi Grover from the Department of Atomic Industry in India and Nicole Dellero from AREVA, France identified several key factors needed for technology transfer in nuclear technology. This included environmental safety, GHG mitigation and the use of new nuclear technology that allows for the possibility of producing hydrogen.

Nicole Dellero stressed the need for common international regulations and institutions coordination in the management of risk, security and environmental protection in the nuclear industry. Ravi Grover brought out the growth in electricity demand in India and the plans to meet a part of this demand based on nuclear power. He said that nuclear growth is hampered by restrictive trade practices in the nuclear industry and there is a need to have a fresh look at these practices.

Jurgen Engelhard from RWE Power AG stressed that any long term CO_2 reduction strategies must consider a sector's specific requirements and the technical as well as economic possibilities of introducing new technologies and the lead times this will require. An example he gave was the research and development of CO_2 capture and the hydrogen turbine. It was also important to recognize that any introduction of new technology in his industry sector would be measured against economic efficiency, security of supply, investment certainty and the expense of developing energy-efficiency power plant.

John Scowcroft from Eurelectric with Emmanuel Matsika from the Centre for Engineering in Zambia identified in their presentations the Clean Development Mechanism (CDM) as a key technology driver for technology transfer in developing countries. They also stressed that if the CDM was to be successful the rules and procedures needed to be simplified and designed in a more business-friendly manner to encourage new technology investment in developing countries.

Two papers on the use of natural gas raised two important issues. The first is the use of Liquefied Natural Gas (LNG) would have a high potential for CO_2 emission reductions if countries such as China or India replaced oil or coal with LNG. There is also a desire in Japan to transfer LNG cryogenic energy utilization technologies to developing countries. The second issue raised was the efficient utilisation of natural gas through distributed generation. Japanese gas utilities are working on developing a model that will allow for distributed energy networks based on cogeneration and utilizing natural gas and they believe this model could also be applied in developing countries.

Ildo Luis Sauer from Petrobras outlined several actions that Petrobras as a developing country power company was doing to enhance energy efficiency and mitigate greenhouse gas emissions. This included a renewable energy project portfolio, fostering the use of natural gas for power generation and the production of biofuels on a large scale in Brazil.

Xiliang Zhang from China discussed how China was encouraging the deployment of renewable energy technology. He said it was important to recognise that China was developing a feed-in tariff and renewable energy portfolio standard based on European experiences. In addition, the Chinese Government is giving direct economic incentives to renewable energy development and deployment as well as supporting research and development in technology transfer.

Many of the papers identified common drivers with electricity sector experts recognizing that the developments needed in energy technology require continuous technical improvements through more research and development especially industrial-scale testing in demonstration plants to assess new technologies performance, cost and environmental impacts. Unlike by many participants in the other breakout groups, the use of CDM was seen in this breakout group as an important driver for developing countries in the transfer and diffusion of mitigation technologies.

Several other common crosscutting themes for all presentations in this group were the need to take advantage of indigenous resource endowments. It was also important that new low emissions technologies, and even CDM projects, be cost competitive with alternative technologies or approaches. The common theme throughout the presentations in this breakout group is that technology transfer and technology diffusion by industry will be governed by concerns regarding economics and competitive advantage.

3. SYNTHESIS AND RECOMMENDATIONS FROM ALL BREAK-OUT GROUPS

In the concluding session, rapporteurs Lynn Price, John Scowcroft and Diana Urge-Vorsatz a Co Chair from the Energy Intensive Consumer Goods breakout group, presented the findings of their groups. There were several common drivers and limitations to industrial technology development, transfer and diffusion identified in the breakout groups.

Industry understands that the substance of the assessment of AR4 is the responsibility of the CLA and LAs. However, it is hoped that the issues and recommendations identified by the breakout groups will improve the assessment of AR4. The following key drivers were identified:

1. **Competitive Advantage**: Many of the industry representatives attending the Meeting work within an open market. The common elements needed to create and use innovative technology included a company being able to maintain their competitive advantage through open markets that allows for protection of intellectual property rights. It was pointed out that companies spend hundreds of millions in research and development to develop better products and as such they want to protect that advantage when they introduce the technology to the market place. Such protections are essential to preserve the ongoing ability to innovate through costly research and development.

2. **Regional Differences**: Participants recognised that there are regional differences and that it is important to understand this when transferring technology. This is particularly important if industries have different definitions of regional differences. For example while a fuel cell/hybrid vehicle may be a possibility in some countries it might be more sensible to use bio-fuels in other countries.

3. **Country Specific Characteristics**: It was pointed out that country's current economic and political infrastructure differs as well as natural resource endowments. Other specific characteristics include limited infrastructure/support services, weak economic conditions with slow economic growth and high deficits, or prevailing corrupt practices by officials. In many countries there was also limited availability of intellectual skills in various fields, such as engineering and management. The scale of facilities can differ and in one presentation the example of China's steel industry was given where there are thousands of small industries in steel making instead of a few in other countries such as Japan.

4. **Intellectual Property Rights**: This was a major issue across all the breakout groups. The IPR issue is seen by many as a key obstacle to get advanced technologies to countries that need it, and to maintain the ability to invest in R&D for future innovation. Companies need to ensure that there investment in the research, development and commercialisation of new innovative technologies is protected under rules of law as explained under item 1 'competitive advantage'.

5. **Improve information links**: The participants at the Meeting were supportive of continuing some form of interaction between the IPCC and the industry representatives attending the Meeting. In addition to the input from Consultants and Academics, it is also important to have access to the expertise and databases of Industry through links with their relevant Associations. It was also recognised that there is a need to improve information on technology options that can help enterprises to have a fully informed choice on the best technological option for them. When preparing future projections or scenarios, it would be desirable to take account of technological realities and limitations by consulting relevant industries on the actual scope for improving their sustainability performance through technical and operational changes/improvements. One suggestion was to develop multilateral partnerships and exchanging of information with a clearer scenario on the implications of the selection of different alternatives.

6. **Leapfrogging opportunities**: It was unclear to whether this concept actually did work and why and how leapfrogging can be encouraged. In some cases, especially where competing in global markets, companies investing in growing developing countries have the opportunity to build modern grass roots facilities that do embody advanced design and manufacturing capabilities that often exceed capabilities in older facilities in developed countries. On the other hand the initial roll out of truly innovative technologies and products may require immediate access to skills, resources and markets that are not readily available in developing countries. It was suggested that some case studies and success stories would be useful to show best practice to the rest of the world.

The point was also made that IPR and leapfrogging were linked and the difficulties in making IPR work when there was a lack of rule of law in a country that fails to penalize firms that replicated technology that was patented.

7. **Education and information awareness**: One of the drivers and also limitations identified was the lack of information between suppliers and users. This has implications for the transfer of technology in developing countries with inadequate information of workers or consumers using the technologies and products. A further issue raised was the likelihood of their being gaps in the literature for the AR4 authors and how industry could assist in the supplying of relevant and eligible information.

8. **Regulatory Frameworks**: Companies work within a regulatory framework and countries differ in their legal and regulatory frameworks and capacity and practice to enforce regulations. However, there are some common elements and that includes the use of government incentives, government commitment to GHG emission reductions, energy security issues and economic development strategies. The point was also made across many of the groups that the rule of law and investment certainty was a factor influencing industry on where they established technologies.

9. **Consumer Acceptance**: A technology is dependent on consumers wanting it. The point was made that many companies respond to consumer demand and that environmental factors are one of many elements that a company will consider. Environmental stewardship is an important factor that was acknowledged by all the breakout groups. It is an important element for companies in responding to regulatory trends, compliance with their own environmental policies and management systems, as well as growing middle class and environmental NGOs concerns in the design of their products. In this context it is important to take due account of the full life cycle of the material or product including all its applications, when seeking a justification for the resources utilized in their production. Another important element linked to consumer acceptance is marketing. Companies use marketing, as a tool to promote and encourage the use of their technology and it needs to be considered in any assessment of technology transfer and diffusion.

10. **Risk Management**: The perceived risk related to technical and economic performance (including safety) and market structure will impact on the development of a technology. A lack of infrastructure and incentives to manage risk are factors that will influence the transfer and diffusion of technology. It was recognised that companies have a responsibility to provide technologies that are safe for the environment as well as for workers and the wider community wherever they operate.

11. **Research and Development**: R&D is a key driver for companies to maintain their competitive position through the development and implementation of new technologies and products. Research and development is expensive and by its very nature is uncertain if a company will be successful in developing a new technology or product. Government's need to recognise the risk associated with research and development and need to be equitable in their distribution of funds for technological research. The example was given that while funding renewable energy technologies is needed it must also be recognised that clean coal and nuclear technologies also play a key role in mitigation of GHG emissions and should not be discriminated against.

12. **Technological Development Pathways**: Among some of the participants the question was raised on how to help decision makers make the appropriate choices on technological development pathways, without picking winners and losers. In China this is a major issue with various studies being undertaken on which pathway to follow in the development of the automobile as well as other technologies. The point was made that technology transfer would also be influenced by the role of human behaviour, regional resources, infrastructure and cultural differences with technological development pathways needing to be designed to reflect those differences. The diffusion of good operating practices can be as significant factor as the technology hardware itself in achieving improved performance.

13. **Cross Cutting Technology Conceptual Framework**: Many of the participants thought the Cross cutting technology framework paper presented in the plenary session by Jae Edmonds and Jose Moreira was a good start but there were concerns about the amount of information that would be required. Some participants felt it was cumbersome and would require a lot of data and could be a Herculean task. A suggestion was made to prioritise items in the framework to make it more efficient and less cumbersome.

14. **Costs and Technology Assessment**: This was a difficult issue to address. Industry takes into account a number of elements when deciding on cost estimates such as the technologies performance, cost to produce and manufacture, consumer acceptability, safety, enabling infrastructure, regulatory compliance and the technologies impact on the environment. Many of the industry participants do not believe it is possible to develop truly accurate estimates for future costs and market potential because significant technologies compete in many interacting ways for raw materials and market share. Thus it is more important to develop better understanding of key characteristics of competing technologies, such as critical inputs and factors that affect relative performance, than to focus on limited scenarios that fail to reveal the complex interactions of modern markets. Some industry experts recommended that making accurate estimates of future costs and future market potentials of technologies is not possible. The different perspectives of the experts on the possible future market potential of technologies in the three sectors covered demonstrates the need for caution and additional research and analysis to provide a valid and consistent, qualitative and quantitative picture of estimating critical factors that affect costs, relative performance against competing technologies and future potentials of technologies. Scenarios that focus on particular pathways are of little value in assessing how competition among potential products and services plays out in modern markets. Industry participants warned that such scenarios often provide misleading information used to justify particular policy choices. However, there were participants that acknowledge that scenario analysis is a key driver in technology transfer.

PROCESS RECOMMENDATIONS

A number of suggestions were made to improve communication of industrial information networks relevant for the scientific assessment of climate change mitigation and to explicitly involve industry input into the AR4 assessment process. One suggestion was that the IPCC use the CLA or LAs as focal points to maintain contact with the industry experts attending this meeting. In this way the appointed focal point could act as conduits to provide information and literature to the writing teams in the AR4 assessment. Another suggestion was that IPCC experts should actively solicit participation of experts from industry. Finally, as in this workshop, it is valuable to engage experts not only in participation at IPCC workshops but also in their planning.

All the breakout groups had volunteers to be Expert Reviewers and Contributing Authors in AR4 that will be followed up by the TSU. There also were offers from the Aluminium Institute, Eurelectric and the World Nuclear Association to identify experts within their membership suitable as Expert Reviewers or Contributing Authors. Participants also recommended more ongoing communication between the IPCC and the WBCSD, ICC, IPIECA and other associations.

To assist in identifying sources of industry information for the AR4 there were a number of suggestions by experts for sources of industrial information and they included:

- To continue contact with industrial experts at this meeting
- To use company-specific environmental/ annual reports
- To use national-level annual surveys of industries
- To examine voluntary agreement program results
- To have follow-up meetings with industry to get feedback/additional information (industry representatives were enthusiastic about continuing to contribute to the IPCC process, and indicated a willingness to help pay for the costs of additional meetings)
- To gather information from industrial sector trade associations and organizations that have made projections and understand their particular sectors technology trends
- To use databases from IIASA, ICARUS, IEA
- To encourage participation of IPCC experts at technical workshops organized by industry associations.

OPENING PLENARY SESSION

Technology and climate change policy in South Africa

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ABSTRACT

Most developing countries have specific needs, linked to their own unique circumstances and associated vulnerability, to assist them in meeting the challenges of climate change. Technology transfer, together with the necessary capacity building, promises to provide an important vehicle to meet many of these needs. The energy sector, including electricity, appears to offer several promising avenues for such actions to be undertaken. South Africa is a middle-income developing country with an abundant supply of mineral resources, including coal. The immediate challenges facing the country are to create a strong and balanced economy to eliminate poverty, develop human resource capacity and compete equitably in world markets. Eskom is a large state owned power utility company supplying over 95% of South Africa's electricity needs. The majority of Eskom's generating capacity is coal fired and thus contributes significantly to the country's overall greenhouse gas emissions. As a developing country, South Africa is not obliged to reduce its emissions of greenhouse gases. Nevertheless, as an organization, Eskom has studied possible mitigation options for the South African electricity sector, with the view of achieving a reduction in the rate of increase of emissions. In this paper, greenhouse gas mitigation is discussed with specific reference to the work done by Eskom. The focus covers both electricity supply and demand side options and possible alternatives, taking into account the role that energy has in economic development, poverty alleviation and sustainable development. This encompasses technological issues, the role of policy interventions and financial incentives that may or could be applied within a developing nation perspective in meeting the challenges posed in reducing carbon dependency. To achieve success, it is essential that any greenhouse gas mitigation project is based on sound technological choice from the points of view of demonstrated feasibility, proven robustness and reliability and solid financial credibility. At the very least such projects must be able to replace or operate alongside existing technologies and must be able to bring about real sustainable development.

[*]*Eskom is a publicly owned power utility company which has an installed generating capacity of 40GW and a transmission grid system consisting of 336000km of power lines with operating voltages of up to 765 kV. It generates about 95% of the electricity used in South Africa and over 50% of that consumed on the African Continent as a whole. Amongst other notable achievements, Eskom received the 2001 Power Company of the Year title at the Global Energy Awards.*

TECHNOLOGY AND CLIMATE CHANGE POLICY IN SOUTH AFRICA

Global climate change constitutes one of the greatest challenges presently facing the world as, although it is often depicted in terms of moderate temperature increases, it is more about serious disruptions of the entire world's weather and climate patterns, including impacts on rainfall, extreme weather events and sea level rise. There is little scientific argument about whether there will be global climate change impacts. It is rather the size and the timing of the impacts and their implications that remain uncertain. Further, it is widely recognized that the developing countries are in general likely to be most at risk to the impacts of climate change (IPCC, 2001). Many such countries have their own specific areas of high vulnerability and, without extensive assistance from the developed world, they may well be unable to take any significant remedial measures to counter the impacts of climate change due to resource constraints.

Although South Africa is a middle-income developing country, it shares many points of vulnerability with the whole Southern African region. Modelling shows that sub-continental warming is likely to be greatest in the northern regions of the region. For South Africa, temperature increases in the range of between 1^{o}C and 3^{o}C can be expected by the mid 21st century, with the highest rises in the most arid parts of the country. Of greater consequence for South Africa, as a semi-arid country, is the prediction that a broad reduction of rainfall in the range 5% to 10% can be expected in the summer rainfall region. This will be accompanied by an increasing incidence of both droughts and floods, with prolonged dry spells being followed by intense storms (Department of Environmental Affairs and Tourism, 2003b). Further, South Africa is vulnerable as it both relies heavily on indigenous coal for its primary energy supply and it is also a significant coal exporter and could therefore be impacted by a down turn in the international coal market that may result from international global greenhouse gas mitigation measures.

Whereas there can be little doubt that coal will continue to provide South Africa's primary energy for many decades into the future, the national government has taken important steps to ensure that the country's energy mix becomes progressively more diversified with time (Department of Minerals and Energy, 2001). Thus the energy sector, including electricity, appears to offer several promising avenues for the development of collaborative technology transfer projects, incorporating the necessary capacity building to ensure sustainability (Davidson and Tyani, 2001: Department of Environmental Affairs and Tourism, 2003a).

At a national level, the government has developed a climate change response strategy (Department of Environmental Affairs and Tourism, 2004) with the primary objective of supporting the policies and principles laid out in the white paper on Integrated Pollution and Waste Management (Department of Environmental Affairs and Tourism, 2000). Whereas any national strategy must recognise international realities, including the growing pressure for quantified commitments of some kind by developing countries, they must be seen within the context of the present economic realties of the country and the inequitable and unsustainable distribution of global development and wealth. The South African Government's national priorities include, *inter alia*, the creation of employment, the alleviation of poverty and the provision of housing, which implies a commitment to the process of sustainable development and advancement. Thus projects such as energization through comprehensive electrification schemes, both grid and non-grid, can continue to be important catalysts in this process. In this context, the national climate change response strategy aims to promote national and sustainable development objectives, whilst simultaneously responding to climate change to avoid negative impacts in areas of specific vulnerability. Specifically, climate change response can offer a specific avenue of opportunity for achieving the sustainable development objectives of those national policies and legislation that are concerned simultaneously with both development and environmental issues. In particular, it is recognized that the Clean Development Mechanism (CDM) of the Kyoto Protocol could play an important role in this process (Goldblatt, 2001). The response strategy also strongly supports related national policies and strategies including those pertaining to agriculture and water and, of particular relevance, the white papers on the Energy Policy of the Republic of South Africa (Department of Minerals and Energy, 2001) and the Renewable Energy Policy of South Africa (Department of Minerals and Energy, 2004). This latter sets a target of 10 000GWh for the renewable energy contribution to final energy consumption by 2012. This is additional to the existing renewable energy contribution of 67 829 GWh/annum, which represents about 9% of the national total consumption. However, although renewable energy schemes will undoubtedly play a niche role in the future, it should be clearly understood that they can only form a part of the overall energy mix. There unfortunately seems to be a misconception in some circles where the mitigation of carbon dioxide (CO_2) emissions is seen to be synonymous with renewable energy projects. This line of thought may be dangerous as it could potentially prevent some important non-renewable energy project proposals from being considered, even though such projects could bring great benefits. In any event, renewable energy schemes that may be practicable in one country may be totally unsuited in another, due to the differences in resource availability.

It is recognized that, although South Africa is a non-Annex I (developing) country and is therefore not required to reduce its emissions of greenhouse gases in terms of the Kyoto Protocol, there could be benefits to be derived from adopting a future strategy that is designed to move the economy towards a more sustainable development path, even though emissions can still be expected to increase with economic development, albeit at a smaller pace than would have happened without climate change intervention (Department of Environmental Affairs and Tourism, 2004). Thus at this stage, a broad range of energy related technology transfer projects needs to be considered, together with their ability to support economic growth and sustainable development initiatives. Attention needs to be focussed on such projects that will assist with the mitigation of, and adaptation to, climate change and address specific areas of vulnerability, whilst providing for the capacity building and skills transfer needed to operate and maintain such schemes. Development and demonstration projects will probably be required to show the advantages and acceptability of a variety of specific technologies related to climate change to avoid South Africa taking on unproven and unworkable technologies to its detriment. However, there would appear to be many opportunities. The government, through the National Committee for Climate Change, is currently arranging to carry out a technology needs analysis so that suitable pipeline of projects can be developed.

Eskom is a large national power utility company which supplies over 95% of South Africa's electricity needs from an installed capacity of approximately 40GW. The majority of the generating capacity is incorporated in 10 coal fired power stations, the largest of which employ six sets each, for a station capacity approaching 4000MW. Thus Eskom contributes significantly to the country's overall CO_2 emissions and, as a consequence, plays a major stakeholder role in national climate change matters. Further, Eskom is a member of the Southern African Power Pool (SAPP), an organization set up to facilitate regional electricity trading across Southern African countries. The demand for electricity in South Africa is currently growing rapidly at over 5% per annum and a phase of rapid new construction has thus been initiated within the industry.

In addition, many of Eskom's existing power stations will be due for decommissioning from about 2015 onwards. Thus, as an organization, Eskom is studying possible climate change mitigation options for the South African electricity sector, with the view of achieving a reduction in the rate of increase of emissions, in line with government thinking on this issue. The scope of this work covers both electricity supply and demand side options and possible alternatives to grid electricity, taking into account the role that energy has in economic development, poverty alleviation and sustainable development. Further, it encompasses not only technological issues but also the role and potential impacts of policy interventions and financial incentives that could be applied within a developing nation perspective in meeting the challenges posed in reducing carbon dependency.

There are what would appear to be several attractive possibilities for projects involving carbon emission offset funding in South and Southern Africa, providing there is a sustainable market for credits within the current European Union (EU) trading range of around Euro 10 /t CO_2(e) (Carbon Market Europe, 2004: Turner, Tyani and Moroka, 2003). Some of the larger projects could be viable with lower carbon trading values, although it is difficult to estimate the bottom end range for viability. Various potential technology transfer projects related to energy are possible (IPCC, 2001). Although the illustrated range is by no means exhaustive, the options explored in the following paragraph are being, or have been, investigated by Eskom.

Clean coal power **generation:** This is potentially one of the most interesting options for South Africa due to the abundance of relatively cheap low-grade coal and the mid-future need to replace existing generating facilities. Obviously there are many possible permutations within this option including integrated gasifier combined cycle (IGCC) and super critical boiler technology, both of which will push up the overall cycle efficiency to reduce CO_2 emissions per unit of generated electricity. They can all be expected to incur significant cost penalties compared to conventional coal fired plant, some of which can be recouped through reduced fuel costs. It is likely that additionality, in terms of the Kyoto Protocol requirements, could be adequately demonstrated in some cases as could baseline CO_2 emission savings.

Gas fired power generation**:** This option includes both open cycle and combined cycle gas turbine installations. Natural gas has recently been discovered in Southern Africa, but not in the large quantities associated with gas fields elsewhere in the world. In addition, the energy cost of natural gas on world commodity markets makes it a very expensive fuel source compared to the cost of in-situ coal in South Africa. A suitable pipeline delivery structure would also have to be funded and, although such projects could also be powered from shipped-in Liquefied Natural Gas (LNG), purchased internationally, this could not be expected to alleviate the fuel cost differential significantly. Further, gas turbine plant needs to be sited near the coast for efficient operation as performance falls off with altitude. Thus such projects would not be suitable for installation on South Africa's highveld plateau, typically 1600m above sea level, where a large proportion of the industry is located. Nonetheless, it is possible that, given suitable carbon credit values, such projects could be viable in coastal locations if supported through CDM. Additionality could easily be established in this case, given the large differential in fuel costs, as could baseline CO_2 emission savings. For more details, see the case study below.

Re-powering: Re-powering can take many forms and may comprise, on the one hand, of relatively minor modifications of existing plant to the complete rebuilding of an entire installation on the other. An example of the former would be over-firing an existing pulverized coal boiler either with natural gas or gas derived from an underground coal seam, either by directly tapping off coal-bed methane or via a process of underground coal gasification. An example of the latter would be the replacement of a pulverized fuel boiler with a fluidized bed combustor to burn low grade coal at high efficiency. The advantages of this approach are that existing infrastructure can be utilized together with some of the electrical and electro-mechanical components of the existing station, in some cases. The soundness of the case for additionality will depend on the individual proposal under consideration would the establishment of baseline CO_2 emission savings

In situ coal gasification: This technology promises to yield some significant emissions savings and would appear attractive for application in South Africa, with its potential ability to extract a very high percentage of available coal stocks from poor grade seams. However, there is some further exploratory research work to be done before it will be possible to make final decisions as to whether to go ahead with the application of such technology. This work is currently being undertaken by Eskom. Further it may be difficult to establish baseline CO_2 emission savings.

Carbon sequestration: Eskom is represented on the Carbon Sequestration Leadership Forum (CSLF), together with the South African Government. Although there may be some viable prospects in the future, it is still too early to define the extent and means by which CSLF can deliver attractive propositions for application in South Africa.

Wind power: Eskom has been operating an experimental wind farm facility near Cape Town for about 2 years and another wind power project was initiated by the Department of Minerals and Energy near the town of Darling in the Western Cape Province. Despite perceptions to the contrary, the wind velocity in South Africa's windiest locations is on average about 2m/s lower than in Northern Europe on the Atlantic seaboard. Thus the potential for wind power is somewhat limited, particularly if using directly imported wind generators that were designed for different wind regimes and, in addition, the overall size of viable installations is likely to be somewhat smaller than in other parts of the world, perhaps only amounting to single megawatt numbers. Nonetheless, Eskom has some valuable operating experience with its facility and, in addition, potential wind power has been extensively mapped for South Africa. Thus the merits and disadvantages are mostly known, reducing the risks associated with such ventures. Additionality could easily be established as could baseline CO_2 emission savings.

Concentrated solar power (CSP): With its very high rate of incident sunshine, South Africa would seem well positioned for the harvesting of solar power. If such installations were relatively cheap, this would undoubtedly be true. However, excessive costs pose a significant barrier to this type of project. Eskom has done extensive studies into the type of solar power installation best suited to South Africa and has performed a detailed feasibility study of a 100MW size solar trough/central collector tower type system, which uses molten salt as heat reservoir. If the cost barrier could be overcome, then this type of installation could be attractive, although this is not foreseen for the immediate future. Additionality could be easily demonstrated as could baseline CO_2 emission savings.
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Generation from ocean currents: Although there is a potential to generate large amounts of electricity by harnessing offshore ocean currents, this has never been practically demonstrated. Eskom has done some research in this area but, even though South Africa does have such resources, this technology is not likely to be available in the short to medium terms, although additionality could be easily demonstrated.

Tidal power: South Africa does not get large tidal variations so this type of technology is not likely to be viable in this country.

Hydroelectric power: South Africa itself is relatively short of water resources and, apart from additional pump storage schemes, is not likely to be able to build any new large storage dams that could provide significant quantities of hydroelectric power. This does not, however, preclude the investigation of small rural community level hydro schemes. The potential for vast amounts of run-of-river power from Inge in the Democratic Republic of the Congo is well known and Eskom, together with other SAPP members, has been instrumental in planning the Western Corridor transmission scheme to bring power into the region and down to South Africa from this source. The use of run-of-river energy obviates the objections surrounding large storage dams. However, the establishment of additionality may be hampered by the overall attractiveness of the project in its own right although it would be easy to demonstrate baseline CO_2 emission savings.

On and off-grid electrification projects: Eskom has been involved in intensive electrification of homes since the early 1990's. In that time, the number of connected households in the country has risen from about 30% to over 70%. There is no doubt that such schemes bring many advantages to the people affected. However, it is possible to show that such schemes also lessen the reliance on fossil fuels as a primary source of domestic energy and, despite the inherent conversion losses in generating electricity from coal, overall CO_2 emissions are reduced due to improved end-user energy efficiency. Some rural villages are located in areas too remote for grid electrification to be considered at all viable. However, the residents of such places can benefit equally, if not more so than those citizens who have received the benefits of grid electrification. Off-grid projects such as active and passive solar energy systems, wind generators, micro-hydro and micro-geothermal systems are well suited to such applications. Eskom has considerable experience in this area, often obtained in partnership with other organizations and institutions. Although such schemes promote community development and are thus desirable in their own right, it should not be difficult to establish additionality. It would be easy to demonstrate baseline CO_2 emission savings in such cases.

Industrial, commercial and domestic energy efficiency: This is an area that still holds out the potential for some significant opportunities and is being vigorously promoted by government and some industry associations, as well as NGOs. Although Eskom has been involved extensively in this area via its demand side management programme, many other South African companies, organizations and institutions have also been active. This is to be expected as reducing energy costs have a direct impact on the cost of production and, ultimately, profitability. Due to the essentially win-win nature of energy efficiency programmes, demonstrating additionality could be problematic but this will depend on the individual case under consideration. It would be easy to demonstrate baseline CO_2 emission savings in such cases.

Nuclear: Despite the current taboo surrounding the proposal of nuclear generation facilities, for CDM funding, there is a growing body of opinion that challenges this stance as being unreasonable and based on emotion, not science. This group clearly see nuclear power as a significant part of the future world energy mix. Baseline CO_2 emission savings would be high and additionality could be easily demonstrated.

The introduction of a combined cycle gas turbine (CCGT) onto the Eskom system has been taken as a case study to illustrate a proposed project that has been analyzed for its suitability for CDM funding. As Eskom uses largely coal fired generating plant, then the CO_2 emission baseline saving was taken to be the energy that would subsequently **NOT** be served by coal fired plant when the CCGT came on line. However, the current growth in demand was projected to continue into the future, given certain assumption regarding load factors and availability. This is illustrated in Figure 1 which shows the impact of the intervention on projected CO_2 emissions.

The carbon credit value required on the basis of offsetting the additional fuel costs alone was first estimated and this was found to be at the top end of the expected available range for such values. The value is sensitive to the exchange rate between the South African Rand (ZAR) and the United States Dollar (USD) as gas prices are quoted in dollars on international commodity markets and South African coal supplies are denominated in ZAR. Even in the unlikely event of the exchange rate halving in favour of the ZAR, then the required carbon credit value would still not fall into the range of realistically expected carbon credit values. It was thus concluded that it would not be advisable to proceed on this basis alone. However, other benefits can be expected by way of decreased maintenance costs for the CCGT plant compared to the coal fired station and in the reduced operational manpower requirements. Taking these into account brings the required carbon credit value down into the median of the range for realizable CDM carbon credits. However, as for the case of the estimations using fuel price differentials alone, the required carbon credit value is somewhat sensitive to the ZAR/USD exchange rate. This is shown in Figure 2.

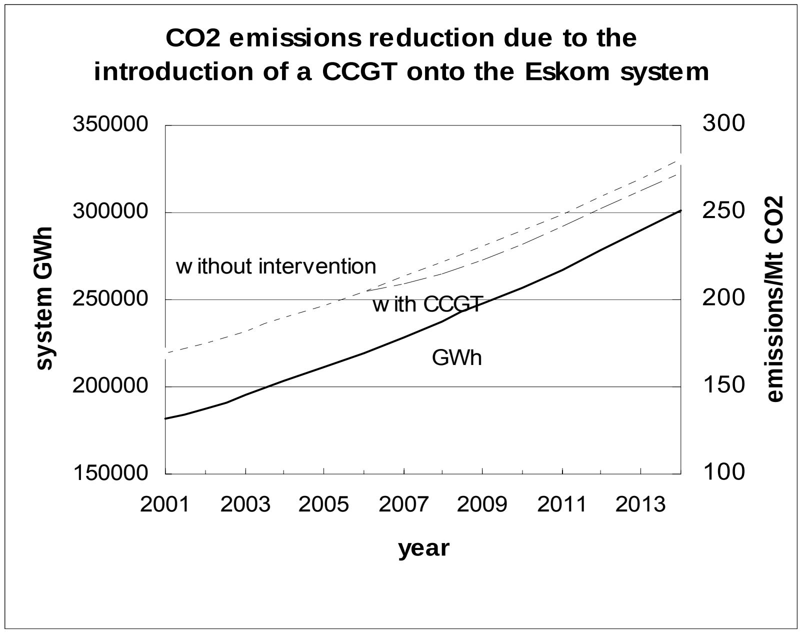

Figure 1: The expected growth in carbon emissions with and without the introduction of the CCGT onto the Eskom system

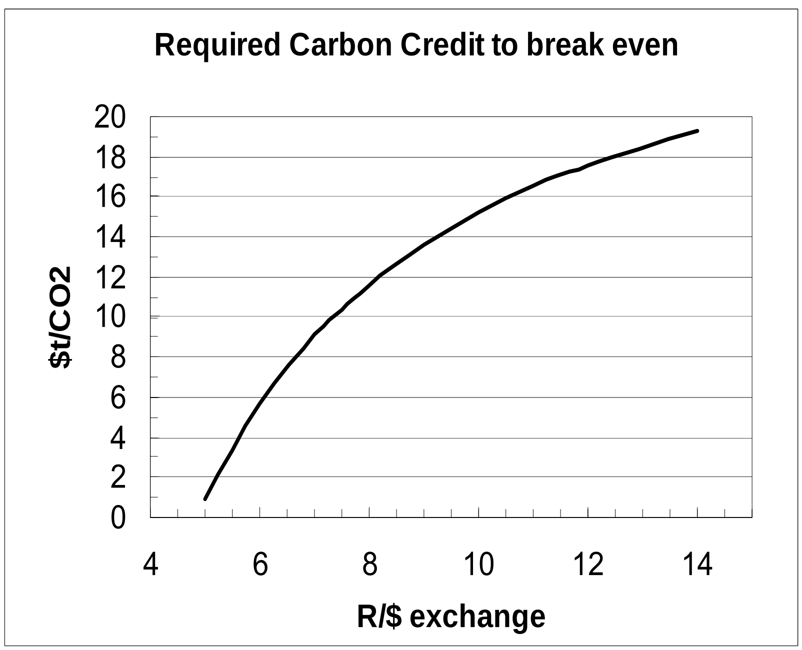

Figure 3: The impacts of the Rand/Dollar exchange rate on the required carbon credit value

Increasing coal prices, in the face of steady gas prices, will also affect the required carbon credit value. A doubling of the ZAR coal price would reduce the required carbon credit value to the bottom end of the expected range. However, although local coal prices are set to rise in the future due to market forces, this is likely to be accompanied by some rise in the price of natural gas.

With regard to capital repayment periods, the longer the assumed period, the greater the required carbon credit value. Although using an assumed write-off period of 20 years gives a median value for the required carbon credit value, doubling the repayment period to 40 years would raise the estimated value to the high end of the range that can be realistically expected. However, lowering the write off period to 10 years would decrease the required value to near the bottom of the range. In fact, the actual write-off period will depend on the required rate of return on capital.

From the analysis it was possible to show that, given an expected range of carbon credit values, Eskom can be reasonably confident of offsetting the costs of opting for a CCGT plant as against a conventional coal fired power station using CDM financing. However, this will ultimately depend on a number of critical factors including, *inter alia*, the ZAR/USD exchange rate and the required capital write-off period. However, the exercise was extremely useful as it has provided information upon which realistic management decisions can be based.

In conclusion, it can be reiterated that, primarily, South Africa's main developmental needs will have to be met by domestic savings and investment, foreign direct investment, donor agency and UN funding (Department of Environmental Affairs and Tourism, 2004). However, the CDM could make important contributions to both development and environmental issues. The process of technology transfer, however, needs kick-starting if this is to happen. It is extremely important to understand the reality and constraints of the South African economy in formulating appropriate response actions to climate change, as it is in all developing countries. However, no door is closed to any action based on sound economic principles, which can bring tangible benefits to the country and its people. To this end, there is no need to embrace an overly conservative approach to climate change response, even though both the physical and economic vulnerability of the country needs to be duly acknowledged. There is no doubt that the next few decades will see major changes, not the least of which will be technological progress. History teaches us that what is far-fetched today will be common practice tomorrow. Thus the developed nations of the world, with their immense capital reserves, need to be encouraged to develop appropriate technologies to mitigate global climate change. South Africa, as an integral part of the developing world, should always be willing to accept new developments, as they become appropriate to achieving its national goals and objectives. There is therefore a large potential for organisations and institutions from developed countries to undertake climate change related ventures in South Africa involving technology transfer. This is particularly true given the fossil fuel base of the South African economy and the relatively developed industrial infrastructure on the one hand, and the overwhelming need for development on the other to eliminate intrinsic poverty. Concrete engagements in this regard, including projects that involve carbon emission offset funding, are thus to be encouraged. It has been adequately shown that there is significant potential for such projects in South Africa.

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Electrical technologies to address the requirement for ultimate resource productivity

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INTRODUCTION

ECONOMIC GROWTH IS INDISPENSABLE TO ALLEVIATE POVERTY, IMPROVE SANITATION IN THE BUILT ENVIRONMENT, TO IMPROVE HEALTH, AND TO REDUCE INFANT MORTALITY, WHILE THE IMPACT ON BOTH THE LOCAL AND THE GLOBAL ENVIRONMENT MUST BE MINIMIZED.

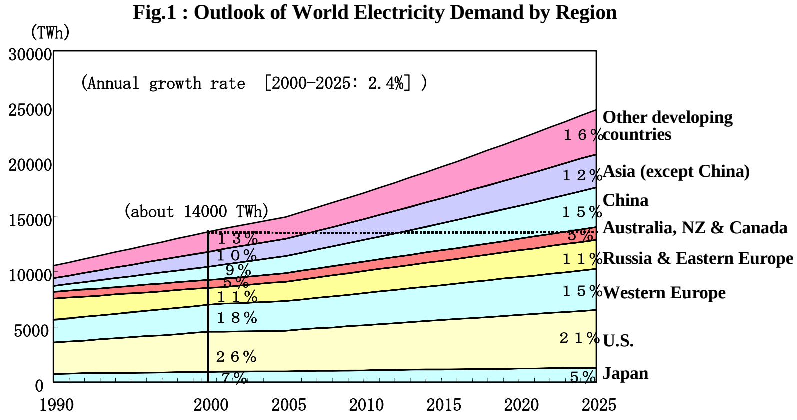
The new challenge is to abandon the exploitation of the past, to recognize the diversity of global regions and countries, and to incorporate optimal resource allocation into the current systems. One method that has emerged is 'ultimate resource productivity', which has been expressed as 'factor 4' or 'factor 10' for whole industries. In the energy field, the energy recovery system applied to hybrid vehicles and to subways, the so-called 'regeneration brake', is one such example, which converts the decelerating kinetic energy into usable electrical energy instead of frictional heat. The aim of the objective is to build a social system that requires fewer fossil fuels.

Electrical technologies are promising options in this context, and international technology partnerships in this field are critically important for alleviating climate change in the future.

OUTLOOK FOR GLOBAL ELECTRICITY DEMAND

According to the International Energy Outlook (Fig.1), global electricity demand will increase by 11,000 TWh by 2025, equivalent to about an increase of 80% over 2000 levels. Assuming that there is not a dramatic change in the configuration of power sources, CO_2 emissions associated with this increase would amount to around several thousand million t-CO_2. A large part of this would occur in the developing countries as a result of economic growth, improved public access and the availability of electricity. There is a general trend towards advances in electrification and increased demand, the result of industrial development, modernization and the urbanization of society, and related economic growth (in Japan's case, the electrification rate was 41.6% as of 2001 *(calculated on the basis of Energy Balances of OECD countries 2000-2001)*). It is therefore crucial to develop technologies to enhance the productivity of electricity use, as well as to disseminate and transfer these.

Fig.1 : Outlook of World Electricity Demand by Region



International Energy Outlook, 2003 (U.S., DOE)

PRODUCTIVITY OF ELECTRICITY USE

Productivity of electricity use could be evaluated in two stages of the product value chain. The initial phase is ***'production and service delivery'*** or 'efficiency arising from the extraction, transport and conversion of primary fuels for the transmission and distribution of electricity as secondary energy' and the second phase is

'consumption' or 'efficiency relating to the end-use of electricity'.

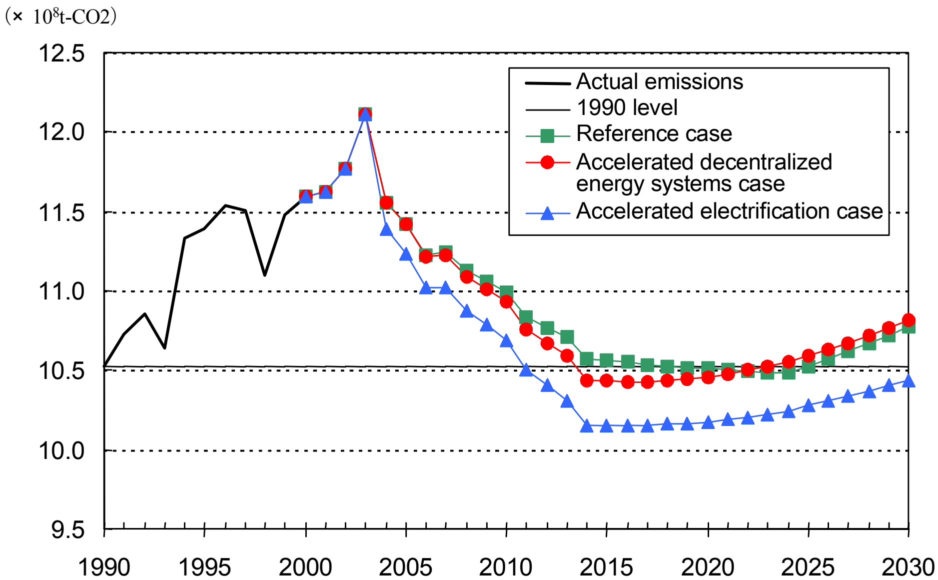
Technologies to improve productivity at the 'consumption' stage
Electrical technologies such as electric heat-pumps are technologies that maximize resource productivity at the 'consumption' stage, which would accelerate the decoupling of economic growth and energy requirements, while ensuring economic benefits.

There have been remarkable advances in the co-efficiency of performance (COP) of heat-pumps in recent years. The COP for domestic air-conditioners (2.8 kW class equipment both for heating and cooling use) reached 6.30 in 2004 (ref. 4.35 in 1997) for the 'Top Runner' models in Japan, and 5.31 (3.37 in 1997) for average models which represent the highest market volumes. For commercial heat-pumps, the screw-heat-pump chiller using the Lorentz cycle has been brought to market (with a capacity of 570 – 3,300 kW). In this the COP exceeded 8.0 *(The Japan Machinery Federation, 2001)*. Taking advantage of CO_2 refrigerants' effectiveness in increasing the temperature from low to high, CO_2 refrigerant heat-pump technology has been applied in a practical manner to domestic hot water appliances in Japan, as the first commercial product of its kind in the world. Comparing the traditional combustion-based water heaters, the new kind of water heaters using CO_2 refrigerant heat-pump systems resulted in substantial energy savings (approximately 30% savings in primary energy consumption) as well as a reduction in greenhouse gas emissions (approximately a 40% reduction based on the current fuel mix of grid electricity in Japan). The product was added to the list of national measures to address greenhouse gas emissions in offices and households, emissions that are increasing rapidly, but which are difficult to reduce.

In view of this expanded application of heat-pump technology, and improvements in efficiency, the Federation of Electric Power Companies, Japan and the Central Research Institute of the Electric Power Industry set out to establish a projection for 2030 for CO_2 emissions associated with fossil fuel combustion (Fig.2). They made a bold assumption for a case of *'accelerated electrification,'* in which the new kind of water heaters using CO_2 refrigerant heat-pump systems were used in every household (Table.1), and assuming that the advanced electric heat-pump systems replace traditional air-conditioning systems (i.e. less efficient heat-pump systems, traditional combustion-based air-conditioning systems) in offices and in commercial buildings (Table.2). For comparative purposes, the simulation included a case of *'accelerated decentralized energy systems'* as another extreme, where 30 GW decentralized systems (fuel cells and CHP with 80% combined efficiency) were installed in households, offices and commercial buildings, and in industrial applications (Table.3). The incremental capacity of nuclear power was assumed to be 20.71 GW for the *'reference'* case (for reference, the current total nuclear capacity was 45.74 GW) and was 14.2 GW for the *'accelerated electrification'* and *'accelerated decentralized energy systems'* cases.

As the result of this simulation, it was projected that the final energy consumption would be 387 million kl oil equivalent, and that CO_2 emissions would be 1,078 million t-CO_2 in 2030 for the *'reference'* case, while for the *'accelerated decentralized energy systems'* case, these remained almost the same (388 million kl oil equivalent and 1,082 million t-CO_2) as the efficiency gains made by these systems were limited compared with the incremental level change in nuclear power. In the *'accelerated electrification'* case, these were 351 million kl oil equivalent and 1,045 million t-CO_2 respectively. The results suggested the scale of potential efficiency gains achieved by implementing advanced heat-pump systems, and by subsequent energy savings and reductions in CO_2 emissions.

Fig.2 : CO2 Emissions Projection for Japan based on Various Scenarios



Reference case

	2000	2010	2020	2030
Total (TWh)	957	1,068	1,187	1,292
Nuclear	321	406	503	524
Coal	176	204	203	200
LNG	251	269	333	389
Oil	122	105	65	96
Hydro	85	80	80	80

Accelerated decentralized energy systems case

	2000	2010	2020	2030
Total (TWh)	957	1,051	1,116	1,203
Nuclear	321	406	473	473
Coal	176	203	199	198
LNG	251	263	305	350
Oil	122	96	57	98
Hydro	85	80	80	80

Accelerated electrification case

	2000	2010	2020	2030
Total (TWh)	957	1,114	1,249	1,350
Nuclear	321	406	473	473
Coal	176	209	204	199
LNG	251	284	359	417
Oil	122	131	130	178
Hydro	85	80	80	80

Central Research Institute of Electric Power Industry/ Federation of Electric Power Companies, Japan, 2004

Table 1: Figures used in estimate: Stocks and COP of New Type of Domestic Water Heater using CO_2 Refrigerant Heat Pump Systems

Year	2004	2010	2020	2030
Stocks (thousand)	240	9,350	34,550	39,700
COP Average	3.7	4.7	5.1	5.2

Table 2: Figures used in estimate: Cooling/Heating Demand and COP of Air Conditioning Systems in Offices and Commercial Buildings

		Cooling/Heating Demand (million-Rt)		COP	
		2004	2030	2004	2030
Large-scale Central Heat Source System	Electric Turbo Chiller	1.9	1.9	4.5	6.7
	Water Cooled Chiller	2.0	12.5	4	6.7
	Air Cooled Chiller	0.6	0.6	3	4.7
	Combustion-based Absorption Chiller	10.5	0	0.9	□
Middle-scale Individual Heat Source System	Multiple Room-type Air Conditioner	5.8	9.2	3	5.3
	Gas Heat Pump	3.4	0	0.9	□
Small-scale Individual Heat Source System	Package Air Conditioner	19.7	20.6	3	5.3
	Gas Heat Pump	0.9	0	0.9	□

Table 3: Figures used in estimate: Stocks of Fuel Cells and Combined Heat and Power (CHP) Installations

Year	2004	2010	2020	2030
Fuel Cells [MW]	0	2,200	10,000	12,500
CHP [MW]	6,500	9,800	15,000	17,500

Advanced heat pump technology would also be an effective measure to address climate change in developing countries, where the demand for air conditioning is expected to grow rapidly in association with economic growth and improved living standards. For example, let us now assume that advanced models (with a COP of 6.0) of domestic air conditioners are introduced when existing stock is gradually replaced, and for new installations in China, where the COP for widely disseminated models is about 2.6 - 3.4. The estimate suggests that the possible energy savings achieved in 2020 through this efficiency improvement would be approximately 150 TWh, and the consequent 100 million t-CO_2 reduction would be achieved annually, assuming the incremental installation of 450 million units (Table.4), mainly in urban areas. This saving is equivalent to about 5% of total electricity consumption in 2000. This means that efficiency gains achieved by introducing advanced models would help to mitigate constraints on generation capacity. If this is combined with thermal storage systems, capacity constraints could be further reduced.

Table 4: Projection of Households and Diffusion Rate of Air Conditioners in China in 2020

	Household [million]	Diffusion Rate [%]
Urban Area	270	150
Rural Area	160	30

Electric heat pumps are also suitable for the efficient collection of untapped energy in the natural and built environment, and for using this in energy services. There is significant untapped energy in ‘ocean and river water’, ‘industrial water’, ‘drainage from households, hospitals and hotels’, ‘discharged water from sewage plants’ and ‘exhaust heat from transmission plants, subways, waste incineration plants’. It is estimated that there could be 18,800 PJ of untapped energy in Japan, which is equivalent to total imported energy (i.e. oil, coal and LNG).

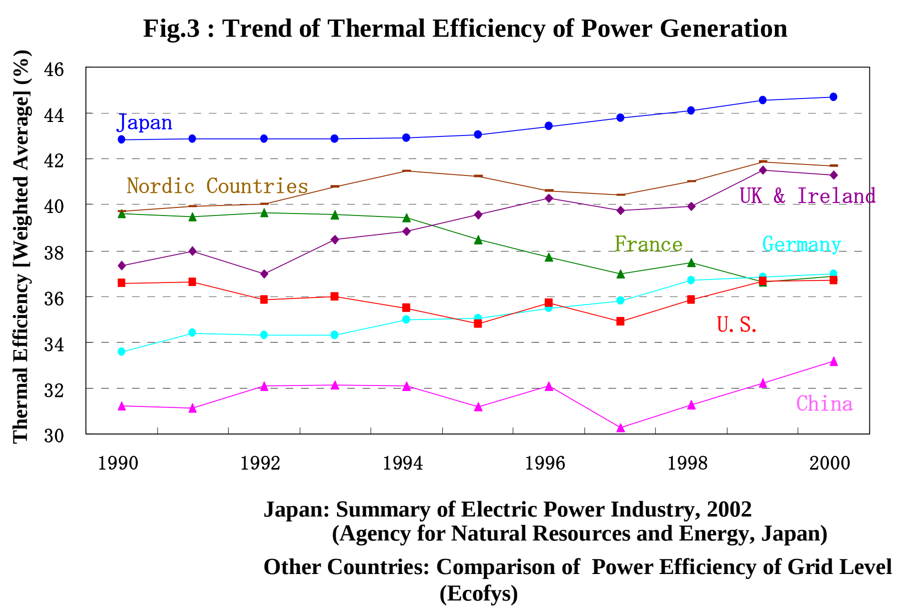
Technological developments that are expected to affect heat pump technologies are;

- Development of heat pump heaters for cold climates
- Further advances in heat pump coolers for households, buildings and transport use
- Development of thermal storage heat pump chillers and heaters for industrial use
- Development of natural refrigerants for higher performance and broader applications, etc.

Technologies to improve productivity at the ‘production and service delivery’ stage

Technologies for thermal efficiency improvement such as ‘Advanced Combined Cycle (ACC)’ and ’Integrated Gasification Combined Cycle (IGCC)’ and non-fossil fuel technologies such as nuclear power and renewables (e.g. hydroelectric, wind, biomass) are the technologies that contribute to resource productivity at the ‘production and service delivery’ stage.

Trends in efficiency improvements at thermal power stations

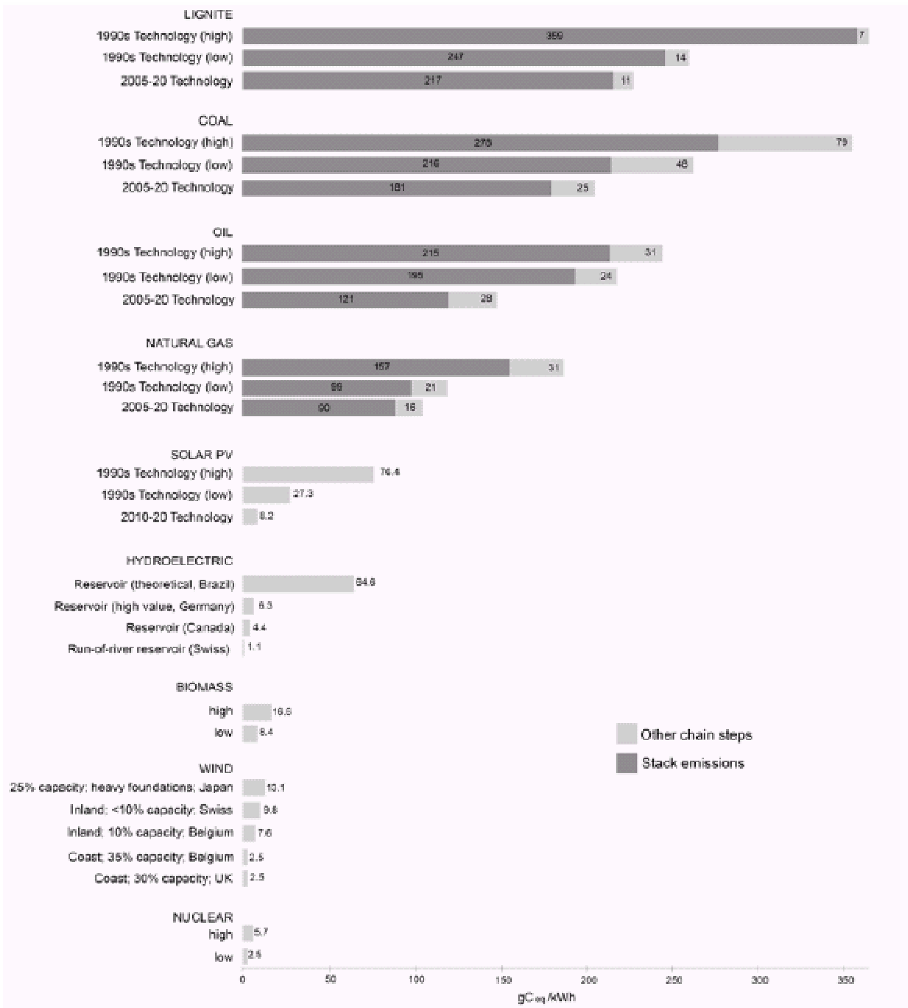


As well as the constraints caused by the shortage of natural resources, the Japanese electric power industry, alarmed by the sharp rise in fuel prices caused by the oil crises of the 1970s, has endeavoured to make efficiency improvements at thermal power stations by continuing to incorporate state-of-art technologies. These include those which facilitate improved steam conditions (i.e. high temperature and high pressure) and combined cycle power generation. The efficiency of the latest combined cycle power plant, or 'More Advanced Combined Cycle (MACC)', attained 59% (LHV), also by using high temperature (1,450 degree centigrade) technologies and heat recovery from the gas turbine unit. As a result, the average thermal efficiency of thermal power plants (weighted average among oil, gas and coal-fired plants by output volume) was 45% in 2000 and was the highest in the world (Fig.3). This was helped by cost reductions, as well as consideration for the local and global environment. In addition, the sound financial profile of the power industry was an important element in facilitating initial investment and continuous improvements.

Lifecycle CO_2 ($LCCO_2$) by type of power generation technology

It is important to reduce the lack of productivity associated with resource use at the 'production and service delivery' stage, represented by greenhouse gas emissions and their potential impact on global climate change. In order to provide a measurement for generation technologies in terms of how effective these are in addressing climate change, the most appropriate is to compare CO_2 emissions over the entire lifecycle (LCCO2), including energy extraction, construction, transport, refining plant operation and maintenance stages. The IAEA estimated total greenhouse gas emissions from the complete power generation chain for lignite, coal, oil, natural gas-fired thermal, solar photovoltaics, hydroelectricity, biomass, wind and nuclear (Fig.4). The different bars for each future option show the range of estimates, including future projections incorporating improvements in the fuel-to-energy service conversion process, reductions during fuel extraction and transport, and lower emissions during plant and equipment construction (these range from advanced technology (2005-2020) to 1990 technology). Even considering technological advances in the various generation options, nuclear power, wind, biomass and hydroelectricity have the lowest full chain emissions, and are likely to remain crucial in reducing climate change. Nuclear power also has an advantage for energy use associated with fuel transport, due to its high energy density. There are 440 nuclear power plants operating worldwide in 30 countries, and 32 new reactors under construction. The study also estimated avoided greenhouse gas emissions of 2,280 Mt-CO_2 by using nuclear power in 2000, under the assumption that non-nuclear electricity sources would expand their contributions proportionately (with the exception of hydroelectricity) to cover the supply of electricity generated by nuclear power.

Fig.4 : Range of Total Greenhouse Gas Emissions from Electricity Production Chains

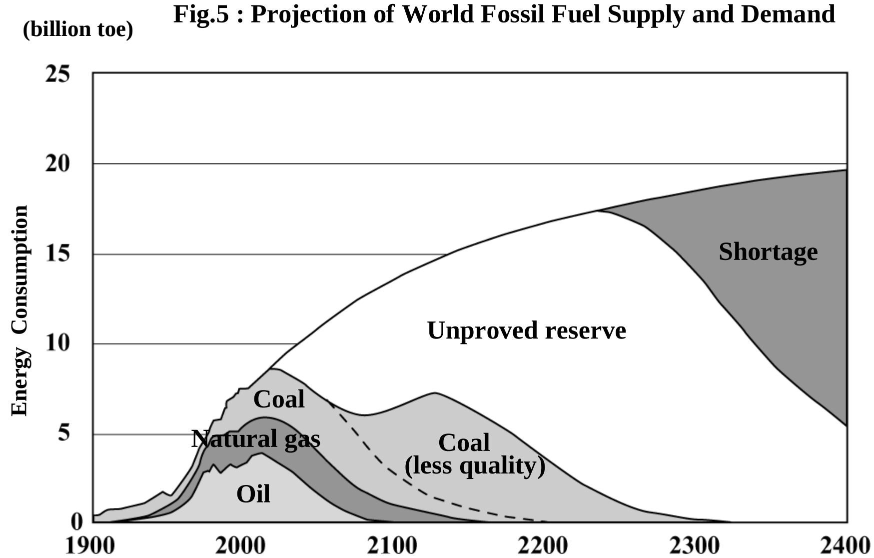


Spadaro et. al., IAEA Bulletin, Vol. 42, No.2

Role of nuclear power and renewables in a resource-constrained future

Long-term energy demand and the fossil fuel supply curve show that oil and natural gas production, from a proven resource, will reach their peak in around 2030, and will then take a downward turn. In the mid-21st century, global energy demand will not continue its reliance on oil and natural gas, and will shift its axis to coal (which has abundant resources and the capacity to retain a stable supply to meet growing global demand). Coal, however, will reach its capacity limit by the mid-23rd century and production will decline after this (Fig.5). In view of the uncertainty surrounding proven/unproven reserves of fossil fuels and their accessibility, as well as economic implications, it is quite important to promote the diversification of energy sources. The further technological development of nuclear power and improvements in the efficiency and affordability of renewables could, therefore, be crucial for our energy future. The Fast Breeder Reactor (FBR) cycle technology promises a huge expansion in the resource availability of nuclear power for up to several hundreds of years. It would also reduce the radioactive toxicity in high level radioactive waste. The High Temperature Gas Cooling Reactor (HTGCR) technology enables non-fossil fuel-based hydrogen production, and would contribute to a goal of decarbonization in the hydrogen economy.

Fig.5 : Projection of World Fossil Fuel Supply and Demand



Uchiyama, Energy Technology and Society, 2003

It is important to recognize the characteristics of each energy option (Table.5), and to use a combination of those options strategically for 2030 and beyond, while preparing further technological developments required for dynamic change.

Table 5: Characteristics of Power Generation by Source

	Fossil fuels	Nuclear power	Renewables
Accessibility (e.g. potential/confirmed resource, stability)	✓ Relatively easily accessible and abundant, given that a lower quality coal resource is included ✓ Threat of oil and gas resource depletion and price instability	✓ Abundant resource including plutonium ✓ Low threat of resource depletion ✓ Accessibility still limited to ensure safety	✓ High resource potential and no threat of depletion ✓ Currently very high in cost ✓ Influenced by geographical conditions
Functionality in operation and reliability	✓ Established supply infrastructure ✓ Efficient functionality and reliability of facilities ✓ High quality electricity output	✓ Established supply infrastructure and ongoing development of nuclear fuel cycle ✓ High quality and highly reliable electricity output	✓ Fluctuation in output, voltage, frequency ✓ Low energy density
Acceptability (environment, safety)	✓ Air pollution and greenhouse gas emissions	✓ High environmental profile ✓ Issue of public acceptance ✓ Issue of nuclear non-proliferation	✓ High environmental profile ✓ Possible constraint in land availability (biomass fuel vs. crop production)

To realize sustainable development in all regions of the world, and also to establish a self-sustainable operational function, two more aspects, 'affordability' and 'an adequate return on investment' shall be added to the above basic requirements. The challenge of the four 'A's, '*providing* ***'accessible energy'*** at an ***'affordable price'***, produced and consumed with an ***'acceptable impact'*** and providing suppliers with ***'adequate returns on their investment'*** *(World Business Council for Sustainable Development)'* is one direction the energy industry will pursue towards a sustainable energy future.

CONCLUSION

The inertia and scale of evolution in various social systems, such as energy systems, requires investment and development with a long-term perspective.

Therefore, it is crucial for the future sustainability of society, in countries with growing and transitional economies, as well as in developed countries, that far-sighted choices are made in relation to their route to economic growth.

It goes without saying that it is technology which always gives us the key to open a new phase in our search for how to solve climate change, and for a sustainable future for the generations to come. The proposal is to constitute an international framework centering around multilateral technological partnerships and cooperation, pursuing continuous economic growth in a sustainable manner, instead of limiting it.

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An Industry Perspective on
Successful Development and Global Commercialization of
Innovative Technologies for GHG Mitigation

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INTRODUCTION

The World Energy Investment Outlook (International Energy Agency 2003) indicated that energy investments would amount to approximately $16 trillion over the next 30 years to meet expected energy needs. Their estimates are based on the use of existing and foreseeable commercial energy technologies that largely utilize coal, natural gas and oil, and emit greenhouse gases (GHGs) - especially carbon dioxide (CO_2), to supply electric power, transportation fuels, heat and industrial process energy. If addressing climate change risks requires a transition to new technologies that supply energy with far lower GHG emissions, they are not likely to be straightforward extensions of technologies we know or understand today (Hoffert et al. 2002).

From the scope of the issue, global energy supply and use, and the scale of investment required even for current energy systems with known technology, new technologies are going to have to be mega-technologies, i.e., integrated, interacting systems of technologies working within appropriate infrastructure for transport, processing, distribution and use of energy. Furthermore, to influence global emissions they would need to be deployed in developing countries as well as the developed countries of the OECD. So, that poses additional challenges to affordability, and to the availability of enabling physical infrastructure and institutional and human capacity.

We frame our discussion in terms of the scope of the challenge in the context human emissions of carbon dioxide (CO_2) and their role in the global economy, the technology and infrastructure that might be required, and then provide some perspectives from a multi-national private sector company on various roles and issues. In particular, we address:
the magnitude of these technologies,
potential rates of penetration into the global economy,
criteria for technology to enter the marketplace on a large scale.

THE CARBON CYCLE AND THE ROLE OF HUMAN EMISSIONS

Both human and natural emissions affect atmospheric concentrations of CO_2. There are vast reservoirs of carbon in the system that can exchange fairly rapidly with the atmosphere, which contains about 750 gigatons (10^9 metric tonnes) of carbon (GtC). The terrestrial biosphere and soils contain about 2000 GtC, the mixed layer of the ocean about 1,000 GtC, and the deep oceans 38000 GtC. These numbers, averages for the 1980s, estimated by the Intergovernmental Panel on Climate Change (IPCC 1995) are reasonably well determined, especially in the context of our subject today. (There are also even larger reservoirs in which exchanges occur on geological timescales, but we will not discuss those.)

As well, there are exchange fluxes of carbon among these systems. The human contribution to emissions to the atmosphere from combustion of fossil fuels, about 5.4 GtC yr^{-1} in the 1980s and about 6.3 in the 1990s, is reasonably well known, within perhaps ± 10% (Prentice et al. 2001). However, estimates of net emissions from tropical deforestation, of about 1.6 GtC yr^{-1}, are far less reliable. Furthermore, land use change as a whole, especially considering reforestation in mid-latitudes, is less certain. Nonetheless, the consequences of tropical deforestation are important. In addition there are vast natural cycles involving two-way exchanges of CO_2 in and out of the terrestrial biosphere through respiration, photosynthesis, and decay, and in and out of the ocean through the mixed layer, through processes of gaseous invasion and evasion. These are on the order of 60 and 90 GtC yr^{-1}, respectively.

If we were to halt growth of atmospheric CO_2, net emissions to the atmosphere must be eliminated, reducing fossil fuel emissions to the net level of sinks from plants, soils and the oceans. While we know the human emissions fairly well, especially from fossil fuel use, we don't know the natural emissions well at all. And they can change. They can change as a result of long-term climate changes. From significant year-to-year fluctuations in the accumulation of atmospheric CO_2 it appears that natural emissions can change also as a result of eruptions of volcanoes, fluctuations in sunlight and other factors that may not be understood. These factors confuse some of the issues of what's going on in the atmosphere recently, what might go on in the atmosphere over the next 100 years if those processes themselves begin to change, and what might be required if some CO_2 limit is to be achieved (Kheshgi and Jain, 2003).

As a major supplier of energy to global markets each year Exxon Mobil Corporation produces an Energy Outlook covering current and projected future emissions typically over the next 20-30 years. Figures 1 and 2 shows recent results from our 2003 Energy Outlook covering the period through 2020. The basis for our energy outlook and these results are described in ExxonMobil's (2004) *Report on Energy Trends, Greenhouse Gas Emissions and Alternative Energy* found at www.exxonmobil.com. Figure 1 shows emissions of CO_2 grouped by demand for energy use in power, industrial, transport, and residential commercial sectors. Figure 2 shows energy sources utilized to meet demand. Results from ExxonMobil's projections differ very little from those produced by a variety of forecasting agencies including those of the International Energy Agency (2004) and U.S. Energy Information Administration (2004).

Two powerful conclusions can be drawn from these projections. First, emissions will continue to grow to meet the demands of society for prosperity and to meet basic needs. In particular even today nearly two billion impoverished people are without access to modern commercial energy. Consequently, growth will be especially high in developing countries. Growth will also be greatest in demand for electric power and transport. Countries like India, China and Indonesia are going to rely on domestic coal to meet growing needs, especially for electric power, and their emissions are going to grow rapidly. Second, fossil fuels will remain the dominant source of energy supply over this period and beyond. Even with rapid year-to-year growth, intermittent renewable energy from wind and solar will remain a small contributor to global energy needs.

Critical assumptions that enter these projections concern population growth, future rates of economic development, and technology change. Over this relatively short period projections depend on trends and technologies that are reasonably well understood. Over the next 30 years, the installed technologies are going to be based on things we know about or can foresee. Over the next 100, they might or might not. But the daunting challenge is that emissions are growing, and they are growing most rapidly in developing countries. In many cases these countries are going to rely on affordable, available domestic coal for a large amount of their energy needs.

Our final information from the climate change arena is shown in Figure 3. This is a further elaboration of what response might mean if society determined that it must stabilize atmospheric CO_2 concentrations. The figure shows fossil fuel carbon emissions from two families of curves. The top family shows three projections of global emissions. In it the highest curve is results from the now familiar IS92a scenario (IPCC 1992) through the year 2050. They rise to about 14 GtC yr^{-1}. The IPCC also produced additional scenarios to examine the question of stabilizing CO_2 concentrations. However, these two scenarios show what track emissions might need to follow: the middle curve in the first family results in atmospheric stabilization at 550 parts per million (ppm) CO_2, the lowest curve in the top family ultimately results in stabilization at 450 ppm CO_2 globally. Of course there are a variety of scenarios that can be used to assess stabilization. For example, Wigley, Richels and Edmonds (1996) devised other scenarios for stabilization at 550 and 450 ppm that could remain higher in early years, but then they would have to fall more rapidly later.

The lower family of curves is taken from the same scenarios as in the top family, but shows emissions only from the so-called Annex 1 countries, those developed countries that agreed to emissions commitments in the Kyoto Protocol negotiations. So, the topmost curve in bottom family of emissions corresponds to Annex 1 parties emissions under IS92a. The next two curves are what emissions would have to be from the Annex 1 countries if the developing countries accepted no emissions commitments, and the world tried to be on track to stabilize at 550 ppm CO_2 or less.

It is the political position of the European Union in the ongoing negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) that the Kyoto Protocol should put us on track to stabilize at 550 ppm or less. Bearing in mind that there are other manmade greenhouse gases, stabilizing greenhouse gas concentrations at the equivalent of 550 ppm CO_2 must account also for growth in methane and other gases. (Note that this 550 ppm target is political. As its ultimate objective the UNFCCC calls for stabilization of greenhouse gas concentrations at a level that prevents dangerous human interference with the climate system. However, science is unable today to draw conclusions about the level of greenhouse gasses that might be appropriate as a stabilization target, and the decisions concerning the criterion dangerous likely involve input from political as well as scientific considerations.)

In any event what would be the consequences for CO_2 emissions of stabilization at 550 ppm or less? To date, major developing countries have rejected taking on quantitative emission commitments. Without obligations by developing countries, stabilizing at 550 ppm would require a phase out in the use of fossil fuels by the middle of the century in the Annex 1 countries. That's a huge step.

It would require large-scale development and deployment of new technologies that are currently noncommercial, and clearly at some point, participation by developing countries, who would have to both accept commitments, and almost certainly would require transfer of resources from the developed world to achieve them. Significant investments in conventional fossil fuel energy infrastructure are underway in the developing world (IEA 2003). Those investments are expected to outpace significantly investments in unconventional energy projects under the Clean Development Mechanism (IPIECA CCWG 2003). That's the scale of the problem.

THE INTRODUCTION OF NEW TECHNOLOGY

Next let's put in context some changes that have occurred over the last 200 years in decarbonization of global energy consumption. Figure 4 (after Marchetti 1985, Ausubel 1996, Ausubel et al. 1998) shows trends in the hydrogen to carbon ratio of energy use over the past 200 years. The progression in fuels with H/C ratios characteristic of wood to coal to oil to methane corresponds to periods requiring about 50 years. The essential drivers in these transitions were clearly performance demands, especially in energy intensity in end use. There were also environmental drivers, especially now, but even in early periods there were environmental drivers in terms of running out of readily available wood. The associated efficiency gains are made possible primarily through changes in combustion temperatures, materials, and the form of fuels. The transitions required numerous, large scale progressions in energy supply and end use technology with significant time intervals for changes in technology. Typically, more than one energy system was available at the same time, and the progression occurred because of the obvious economic advantage of the newer systems. Note that the new systems may not have been less costly per se, but their combination of cost and performance provided powerful economic drivers.

Figure 5, again after Ausubel and Marchetti, shows the progression in efficiency from power generation from motors. Typical doubling times are again about 50 years. And again, material science and materials technology have been among the key enablers in the progression. What made the new technology commercially attractive is enhanced performance to end-users.

Figure 6 shows the progression in transportation infrastructure that accompanied and is part of the set of technology that enables widespread use of new ways to supply and use energy. Again a characteristic time scale for the penetration of technology is 50 years. The new technologies were coming into play as the old ones were still growing. There are overlaps in the various technologies.

Research and development (R&D) advances enabled new forms of technology, but they entered into widespread use because they provided qualitatively new service and higher levels of performance. Powerful economic drivers came about naturally through the operation of markets. With respect to many technologies being championed as potential contributors to address climate change, that is not the case. Rather, with today's performance, they would provide people with the same or reduced service at higher cost. And this poses a real challenge in terms of consumer acceptance and societal economic consequences.

Finally, consider Figure 7, which illustrates the scale of today's infrastructure for transportation fuels and the petroleum industry. Overall capacity supports production and refining of about 3 plus billion barrels per day, producing 1.8 billion gallons of fuel, including about 1 billion gallons of gasoline, and roughly 1 billion gallons of diesel fuel. This massive fuel infrastructure was developed over a period of 100 years, and including ongoing development and efficiency improvements. From the perspective of the climate change issue it is important to note that CO_2 emissions from the use of oil in the world's economy is primarily by end users. Several years ago ExxonMobil estimated the proportion of CO_2 emissions from petroleum industry activities and from use of fuels by customers, averaged across the global economy. We estimate that industry activities in production, refining, manufacturing, and distribution of fuels contribute about 13 percent of CO_2 emissions (largely from energy consumed) while about 87 percent comes from the end use by consumers (largely in the use of transportation fuels). Considerable effort, embodied in ongoing management systems, is directed by industry at controlling emissions in production, refining, marketing and other areas, because such controls are essential both to our economic efficiency and to meet regulatory requirements. However, in overall greenhouse gas emissions from fuels use the real focus must be on end use of fuels, not operational emissions, if climate change proves to be a serious issue.

The discussion in this section highlights timescales associated with widespread use of new energy technology for supply and end use. Introduction of new technology requires advances in research as a prerequisite, but widespread use requires investment, the introduction of essential infrastructure, and-- above all, consumer acceptance based on economic advantage.

TECHNOLOGY OPTIONS AND TIME-SCALES TO ADDRESS LONG TERM CLIMATE CHANGE

There are a number of promising options for mega-technologies that could make a substantial contribution to limiting or eliminating for future emissions of CO_2. None of these solve the entire problem; there are no silver bullets. All of them face challenges today in terms of economics, performance, consumer acceptance and the potential for associated environmental impacts. Consequently, all of them require R&D that address significant barriers, if they are ever to come into widespread commercial use.

Carbon storage in forests and soils does have the potential to make a big difference, but it's not going to solve the whole problem and its effectiveness could decrease over time depending on strategies for long-term maintenance. As well, judging from the complexity of domestic and international negotiations, it is also unclear the extent to which efforts to store carbon in forests and soils might ever qualify for credits under proposed regulatory regimes.

There is major technical potential from intentional separation and sequestration of CO_2 from large combustion facilities. In today's global economy emissions from large facilities account for about 30 percent CO_2 emissions, mostly from utilities, but also from refineries, chemical plants, smelters and other energy-intense industrial operations. Future options for low carbon fuels, for example hydrogen production from coal, could significantly increase the potential scope for carbon capture and storage as a technology to address climate risks. Analyses indicate that separation is the key cost component. Among critical design considerations is whether to combust in air or in oxygen. In either case procedures must be designed to remove O_2 from air and, or CO_2 from flue gas, and then to compress it to high enough pressure to move it somewhere and dispose of it for long periods of time.

Disposal is in many ways the more challenging societal question (IPIECA CCWG 2004). There are lots of options. The options for storage of substantial amounts of CO_2 involve oceans and deep saline aquifers. Of course, it is possible also to put CO_2 into depleted oil wells or gas wells, and in some cases to achieve an economic benefit through enhanced oil recovery. But these options don't appear to have anywhere near the capacity of oceans or deep aquifers. There is a vast potential in deep saline aquifers, and they appear to be fairly ubiquitous. Overall, economic costs are dominated by capture and transport to disposal sites. There are important questions surrounding public acceptance of CO_2 capture and disposal. While ocean disposal may be promising, many environmental groups have mounted campaigns to challenge the option. In any case science and scientists should contribute to the analysis of potential options for disposal, and to the debate surrounding their acceptability. Again it is important to highlight that while this option has the potential to be applicable to roughly 30% of global emissions today, and perhaps far more in the future, that potential can only be realized if the technology can be practiced in both developed and developing countries.

Finally the scale of the enterprise and extent of required infrastructure for large scale capture and storage of CO_2 is daunting. The required scale for movement of compressed gases far exceeds investment in current infrastructure for petroleum and natural gas.

Another 30 percent of global emissions occur from the transportation sector. Here there is significant promising work on advanced vehicles. Vehicles powered by hydrogen fuel cells get most of the attention in the context of climate change. Perhaps some version of these vehicles will enter the economy in a big way, particularly if they can add to the performance of vehicles, but it will require decades before they would have a significant impact on transport emissions, even if the vehicle technology succeeds. But advances in the internal combustion engine and diesel are also going to be significant over that time frame, and hybrid vehicles are already appearing in important numbers. Also, there are several options for fuels to power fuel cell vehicles, including the possible use of onboard reformers to convert liquid hydrocarbons to hydrogen. The essential advantage of this option would be the elimination of a need to create a massive and costly infrastructure for fuel production and delivery -- a new infrastructure that would need to be developed and coexist with conventional gasoline and diesel for decades (National Research Council, 2004). Hydrocarbon-powered fuel cell vehicles could hasten the widespread commercial use of fuel cell vehicles by decades. However, to make deep reductions in CO_2 emissions, hydrogen would eventually need to be produced with low emissions (EUCAR/CONCAWE/JRC 2004), e.g., from fossil fuels with CO_2 capture and disposal. Again, note that transport accounts for 30 percent of global CO_2 emissions.

Production of low carbon fuels from fossil fuels receives significant attention. For instance, it is possible to make hydrogen from fossil fuels in large facilities where it could be possible to utilize CO_2 separation and disposal. Such systems present a huge set of challenges and potential synergies. If society can safely and affordably manufacture abundant hydrogen (without the release of CO_2 to the atmosphere), transport it and use it in various end use devices, especially as a transportation fuel, the net effect would be to provide 100 percent of the energy needed to run the global economy.

Clearly, such systems are not economical today, but, with research and development they might be, say by the middle of the 21st century, in time to address the climate issue if it proved to be serious.

Another option worth considering for research is geoengineering. In particular, technology for control of ambient atmospheric CO_2 offers some promise. If climate change proves to very serious, and society needed to do something dramatic, then we should consider all options. Geoengineering, continues to show potential. Of course the essential drawback is associated potential for significant, possibly unintended side effects (Flannery et al. 1992).

We haven't stressed renewables on our list of mega-options and perhaps they should be there. However, in today's markets, with the exception of hydropower, they only succeed in niche applications. For example, use of byproduct or waste streams in the paper, forest and agriculture industries for energy and cogen has been successful. Outside of such niches, their widespread use is limited because current technology can't compete in cost or reliability with conventional fossil fuels, and many of them face environmental problems, as well. We think that's especially true of biomass and wind if they are deployed on a scale that makes a significant difference to the global economy. It is important to note that intermittent supply from renewable power demands a need for conventional power backup; this cost must be considered in economic analyses of renewables (Royal Academy of Engineering 2004). Yet breakthroughs, e.g., in biotechnology could change renewables' prospects (see, e.g., National Research Council, 1999).

Any of these new mega-technologies require significant enabling infrastructure that must be introduced if the technology is ever to gain widespread commercial acceptance. Why do these large-scale infrastructure changes take so long? Not only must we develop the technology itself, and all of the enabling technologies, we must also assemble the capital investment required for significant market penetration. Historically, in those transitions discussed earlier, public concerns were not a major factor. In fact, the public was encouraging the development of new technologies. They were modern and progressive.

But that may not be the case now. Access for gas or in a CO_2 sequestration era, CO_2 pipelines and the permits required could be problematic -- not in my back yard. Hydrogen production, supply and storage face serious safety concerns that will have to be addressed (Moy, 2003). And CO_2 sequestration will face technical, scientific and environmental challenges. Obviously, there are groups who don't want to see them developed. They want to see their preferred approaches used, and they will fight CO_2 separation and storage, for example, with all the tools they have. That is to say that opposition won't be geared just to defining acceptable criteria for safety, performance and environmental impact, but rather certain options will be opposed simply because adherents favor some other option as the solution.

Penetration rates will be a function not only of the technology development and but also depend on the rate of investment. Here a huge issue is how to introduce these technologies on a small scale and grow them into widespread commercial use, or even how to introduce them into markets to begin. Most analyses envision a desirable final product, one with everything up and running, but how do they evolve successfully from small to large? This is perhaps the central issue.

Finally, the capital investment required is truly staggering. As cited above the International Energy Agency (2003) recently estimated that $16 trillion in investment would be needed over the next 30 years to meet projected energy needs, based on existing commercial technology. If new, currently non-commercial technologies are to make a difference to global emissions even larger investments must be mobilized and for several decades multiple energy technologies would need to co-exist until capabilities could replace existing ones (National Research Council, 2004).

CRITICAL CRITERIA FOR SUCCESSFUL COMMERCIAL TECHNOLOGY

Let us introduce one additional set of considerations that must be addressed: if a technology is to be successful in the marketplace, it has to succeed in a number of critical dimensions. There is a weakest link paradigm at work. If a technology fails on any critical dimension, it won't come into widespread commercial use. For example, battery powered vehicles work and reduce local emissions, but they are expensive, slow or complex to recharge, and they don't have the performance and range that people want. So they haven't come into widespread use. Nuclear power has been confronted with issues of cost, safety and proliferation (Deutch and Moniz, 2003), and has not grown as had been expected decades earlier (Marchetti, 1985).

A list of critical criteria should include at least the following elements:

- Performance
- Cost
- Consumer acceptance
- Safety
- Enabling infrastructure
- Regulatory compliance
- Environmental impacts.

Before a technology can even be considered it must be capable of delivering expected performance. Society faces a major problem if technologies proposed to respond to climate change cost more and perform less well as a substitute for technologies people use today. This is a major barrier. It is not enough to supply technology with improved environmental characteristics that cannot get the job done.

As anyone involved in commercial enterprise will tell you cost maters -- cost really matters. Governments at times subsidize small-scale costs, and governments have at times subsidized early market penetration (National Research Council, 2001), the cost to governments to subsidize widespread global use of new energy technologies would be huge. This is also an issue of regulatory risk for firms dependent on subsidies in the marketplace who want to be early pioneers in an area. As market penetration grows, the government can sometimes removes the subsidies, leading to a possible collapse of entire businesses.

Safety is a key issue; one that is especially relevant for those who promote the hydrogen economy (Moy, 2003; National Research Council, 2004), and carbon capture and storage (IPIECA CCWG, 2003).

Consumer acceptance is essential. It is tied to all criteria listed above and below, but most especially to cost, performance, and safety.

Enabling infrastructure and capacity encompass not just the public and private capital investment associated with hardware such as roads, bridges and pipelines, but also the availability of trained people who manufacture and maintain equipment, supply the spare parts, and design and manage the systems. This requires education and training.

Any new technology introduced on a scale that affects global energy supply will face a variety of issues associated with regulatory and environmental compliance for example in supply of raw materials, manufacturing, use and disposal. Most energy technology also has the potential to have impacts on land use and or access to materials that will raise environmental concerns. Biomass in particular faces an enormous set of environmental issues, especially if it is to be used as a source for liquid fuels (Kheshgi et al. 2000).

To affect global emissions advanced technologies must be appropriate for use in developing countries where cost, enabling infrastructure and capacity will be particularly important.

The important point is that failure in any critical dimension will prevent widespread commercialization. So, as people consider various technology options, the research community should address all of these dimensions, and seek to identify where there are fundamental barriers in any dimension, but especially performance, cost, safety and public acceptance. Research must not focus solely on emissions, separations, or power plants, but also on other dimensions of performance and manufacture that could become important.

One final point emerges regarding the ongoing need for flexibility and ongoing R&D, and the inability of governments or investors confidently to identify long-term technological winners and losers based on information available at any point in time. Over the period required for widespread commercialization of new energy technologies, numerous changes will occur. For example, significant technologies that utilize or compete with natural gas will affect its price and availability in the market. Other investment decisions that depend, for example on the relative price of natural gas, coal, or renewables will be affected. As well, owners of technologies that are adversely affected by the introduction of a new technology will seek performance or cost improvements to stay competitive. Consequently, the relative advantage of various existing and new technologies will continuously shift in response to market demand, public policy and ongoing innovation.

CHALLENGES AND GOALS FOR R&D

R&D to create advanced technology in the future must face the additional challenge that such technologies must enter the market and compete against steady improvement in base technologies. The hydrogen powered fuel cell vehicle doesn't have to compete against today's internal combustion engine; it has to compete against the fleet that will be in place 10, 20 or 30 years from now. That fleet will be more efficient and perform better than today's. In fact, many of the enabling advances in materials that will reduce weight and improve drag will almost certainly apply to all vehicles. This competition against improving performance in the base case is a significant barrier to the introduction of advanced technology in all sectors. Delivering improved performance at a competitive price will make a technology far more attractive than delivering weak performance at an enhanced price solely because of environmental concerns. If R&D provides innovative technologies that are cost competitive and perform better, then there won't be any barriers. There will be suction from the marketplace. Creation of commercially viable options is a goal that R&D should seek to achieve.

Identifying barriers to commercially viable technology, seeking solutions through R&D, and identifying issues for public acceptance are key features that public and private research should address if potential options are to succeed. It is already apparent that there are others with different agendas who are going to search for barriers to be raised against some technical options, as a means to create obstacles to public acceptance. It will be interesting to watch this unfold.

Finally, if promising new options are going to require taxpayer support, then they must compete in research and development with other promising approaches to address global climate change, and they must compete with other important social priorities. R&D options might include end-use efficiency, technologies that address other greenhouse gases and steps that encourage adaptation. All of these are important areas that will be competing for public and private sector funding.

PUBLIC AND PRIVATE ROLES IN R&D AND COMMERCIALIZATION OF ADVANCED TECHNOLOGY

Let us provide some personal observations from scientists with a private sector perspective. Clearly, as an exercise in risk management, the potential for serious risks from climate change justifies some level of public and private effort and expenditure on research and development to create options for technologies with far lower GHG emissions and to improve end-use energy efficiency. Whether or not options are widely deployed in the future will depend both on the outcomes of R&D and on future policy decisions. However, it is impossible today to determine what impact future public policy decisions might have on future economic and commercial decisions; that too involves risk management.

The goal of R&D for technology to address climate risks should be to create commercially viable options for future technologies that make a difference to the global energy mix. Taxpayer funded research and development should seek to identify fundamental barriers that limit promising options, and to find solutions that improve performance, cost, safety, environmental acceptability and consumer acceptability. Such public funding can also encourage training of students and motivate shifts in academic resources towards promising new areas. Such efforts can help to develop human resources and capacity for innovative technology. Governments must also play a key role in creating the capacity and infrastructure that may be required for advanced technologies.

We do not believe that taxpayer funded resources today should be deployed wastefully optimizing currently uneconomic technologies. It is clear that many of these technologies are not going to enter the market in a big way for many years, maybe never. Trying to optimize them for today's conditions (when they are uneconomic) in pilot and demonstration studies, is extremely expensive, and unlikely to deliver anything of lasting value. Effort and resources might be better spent on research to enable different innovative technology paths with the potential for substantially better performance and lower cost (see, e.g., National Research Council, 1999). We think this is a fundamental question concerning the role of research and development for society. Such taxpayer-sponsored initiatives create huge opportunities for boondoggles, inertia, and white elephants. Such projects also pose challenges because they create opportunities for big budgets and employment gains in some areas through politically motivated demonstrations of action that are not likely to lead anywhere.

In modern market economies it is the private sector that should bear the risk and capture the rewards of developing and deploying commercial technology that will ultimately compete in the market. Governments aren't good at doing that. The private sector is far more likely to succeed in commercializing goods, services and processes that compete in real markets, and should also suffer the losses for failures.

Profitable, multi-national private companies that compete in the open markets for goods and services, especially those with a strategic focus on research and development, play an essential role in the creation and global diffusion of advanced technologies. Economies of scale help to spread the costs of risky, expensive R&D and to lower the overall costs of global deployment. Especially for manufacturing companies, it is precisely their organized success in creating and managing advanced technologies that provides the competitive advantage and opportunity to succeed in established and emerging markets. In fact 'know how' and proprietary technology, embodied in management systems and internal R&D capability, are key enablers for successful commercialization of innovative, unproven technologies. Capacity building and technology transfer occur automatically and as a matter of course when private companies invest in and operate facilities where they do business. Technology and the ability to operate it are the fundamental basis for private companies commercial success.

To succeed in playing our role in the creation and use of innovative technology, private companies do require governments to provide an enabling framework. Key features have been described in numerous studies and assessments (e.g., IPIECA 1995); they include:

- Rule of law
- Safe, secure living environment for workers and communities
- Open markets
- Realization of mutual benefits
- Protection of intellectual property
- Movement of goods, capital and people
- Respect for the needs of host governments and communities.

These conditions are not unique for private companies. Many of them also are essential for successful public investment in technology and infrastructure.

THE STANFORD GLOBAL CLIMATE AND ENERGY PROJECT (GCEP): AN EXAMPLE OF A PRIVATE/ACADEMIC PARTNERSHIP FOR INNOVATIVE R&D

ExxonMobil maintains a significant research and development capability with effort in all parts of our business: upstream (exploration and development), downstream (refining and marketing) and chemicals. ExxonMobil's funding and R&D efforts are the largest in our industry amounting to over $650 million per year and within that total significant effort is focussed on breakthrough research with the potential to transform commercial practice. Important examples of this include novel technologies to explore for and produce hydrocarbons, advanced technologies to transform them into commercial products, and work with end-use users of our products, especially to develop fuels and lubricants for advanced transportation systems. Besides independent internal; research, our efforts include research with other companies, government agencies and academic colleagues. It also includes research to assess environmental and health issues and work on advanced technologies that may be extensions of current business or in entirely new areas.

In considering the matter of climate change ExxonMobil has long been convinced that innovative technologies that are commercially viable in all parts of the globe offer the only option to manage long-term climate change risks while preserving and promoting prosperity... including access to affordable energy by all and alleviation of poverty in developing countries. In particular, the world has no easy options to avoid a growing reliance on coal (not a significant business for ExxonMobil) to meet growing demand for electricity.

For these reasons in the year 2001, ExxonMobil decided to explore the possibility of creating an innovative academic/private effort to stimulate fundamental innovation across a broad portfolio of technology options that could provide electric power, transportation and fuels with very low greenhouse gas emissions. We approached Stanford University to undertake the program and recruited a small number of sponsors to fund it. Sponsors include companies with strong internal research capacity, willingness to provide significant long-term research funding, and the ability to commercialize significant technologies on a global scale. As well, in conducting the research and in soliciting input for research leads, Stanford will engage scientists from institutions around the world including participation from experts outside Stanford in both developing and developed countries. The effort to create the project culminated in late 2002 with the launch of Stanford University's Global Climate and Energy Project (GCEP). The project is sponsored by ExxonMobil, GE, Schlumberger and Toyota with funding of $225 million over ten years.

GCEP's research agenda spans a large range of technologies with potential to reduce net global GHG emissions in the supply of electric power, transportation, fuels and includes carbon capture and storage.

The broad portfolio of research areas includes:

- Low GHG electric power generation, storage, distribution
- Advanced transportation
- Production, distribution and use of hydrogen
- Production, distribution and use of biomass fuels
- CO_2 separation and storage, carbon sinks
- Innovative coal, nuclear and renewable energy
- Enabling infrastructure
- Materials, combustion, and systems science
- Geoengineering.

We believe that a broad portfolio is essential both to optimize the potential for success and to allow for synergies. For example, if novel technologies made it possible to store and distribute electric power at lower cost and with far greater efficiency than is possible today, then intermittent renewable energy sources such as wind and solar might become more attractive.

The fundamental approach of GCEP will be to:

- ***Develop concepts*** for innovative technologies with low GHG emissions that can be used globally -- explicitly consider developing country aspects
- ***Identify barriers to commercialization*** (performance, cost, safety, environmental & regulatory, consumer acceptance)
- ***Define & conduct fundamental, pre-commercial research*** to overcome barriers, utilizing academic talent from around the world
- ***Periodically assess progress***, adjust specific research programs to pursue most promising leads

The project is unique not only in its financing, scope and term, but also in establishing an internal, academic research program to assess progress and adjust effort over time.

Today, less than two years into the project, GCEP has already established over a dozen projects involving more than 20 faculty and over 50 post-graduate and graduate students from ten departments. They have also appointed an external Advisory Committee to provide outside guidance on the quality, direction and scope of research.

Stanford is encouraged to publish and disseminate all research results and will hold legal title to intellectual property produced by GCEP. Stanford University, the GCEP sponsors and their affiliates will all hold royalty free rights to all patents and, after a five-year period, can sublicense GCEP patents to anyone. This approach provides a slight lead-time for sponsors to utilize results before others, but makes all results known and available to any potential users.

GCEP adds to the portfolio of actions that ExxonMobil is taking on Climate Change. These include efforts to control our operational GHG emissions by:
Energy efficiency improvements of more than 35% over the past 25 years, and 10% since 1990 with additional opportunities identified of 15-20% using our Global Energy Management System
Industry leading investments in co-generation with 2700 MW (an additional 30% to be added over the next 2 years) supplying more than 60% of the power for our refining and chemicals operations
Extensive flare reduction efforts underway
Work with API and IPIECA to develop reliable, cost-effective industry-wide, voluntary standards to measure and report GHG emissions (e.g. IPIECA 2003).

In addition, as part of the broad range of energy research carried out by ExxonMobil mentioned above, we have conducted research and supported research at leading institutions on climate change (science, economics, policy and technology) for over 20 years, thereby adding to the peer-reviewed literature.

For ExxonMobil, GCEP represents a tangible commitment to our belief that climate risks can best be managed by creating innovative, commercially viable technologies. In this effort, we are convinced that academic talent has an important role to play that can augment our own extensive internal proprietary research on strategic energy technologies.

However, as is clear from this paper, the overall effort to develop and deploy advanced technologies will require decades of research and many trillions of dollars of investment over the century. By combining insight and know how from companies with global reach with outstanding academic capability, we believe that the *Global Climate and Energy Project* will make an important academic/private sector contribution to the effort to develop practical, viable technological solutions.

CONCLUSIONS

Responding to climate change risks through the development and deployment of advanced energy technology will be a vast, challenging, long-term task. In that effort profitable, global, private companies with a strategic focus on R&D will be the principle providers of commercially viable solutions. Experience, science and technology will evolve a great deal over that period. Even successful options will require decades of investment to deploy and over that time information will change in ways that is likely to render early versions obsolete. To make a difference, solutions have to be global and global capacity and capability will also change dramatically over the century. So persistence and flexibility will be essential.

It is a pleasure for us to acknowledge contributions to this paper from many colleagues in academia, industry and government, most especially to James Katzer and Roger Cohen both formerly of ExxonMobil.

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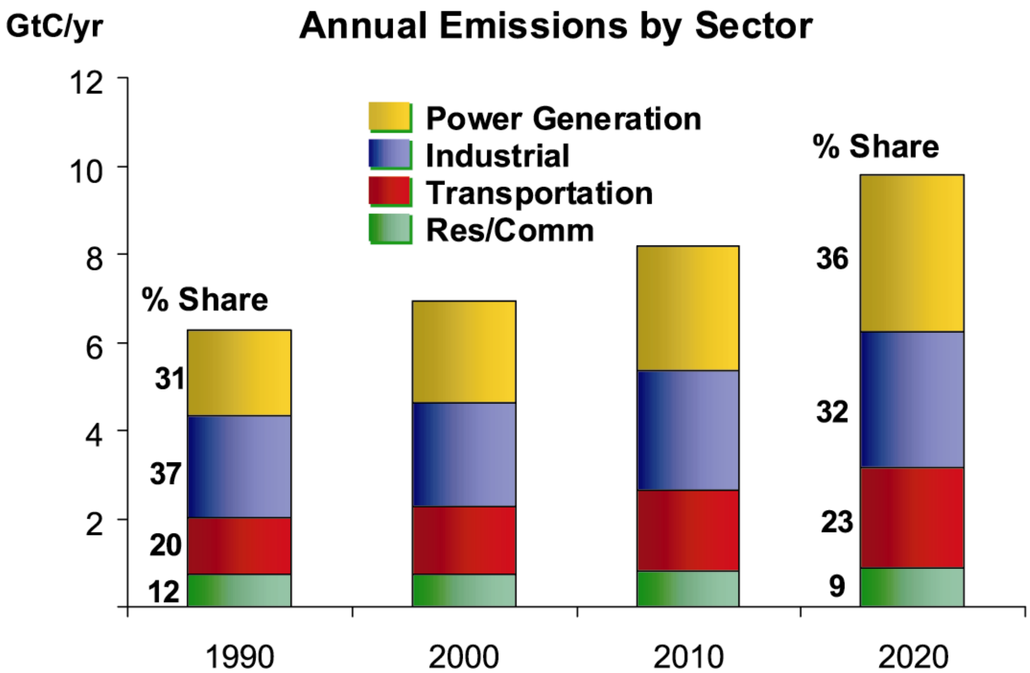

Figure 1: Historical and projected CO_2 emissions from fossil fuel use grouped by sector: power generation, industrial, transport and residential & commercial (ExxonMobil 2004).

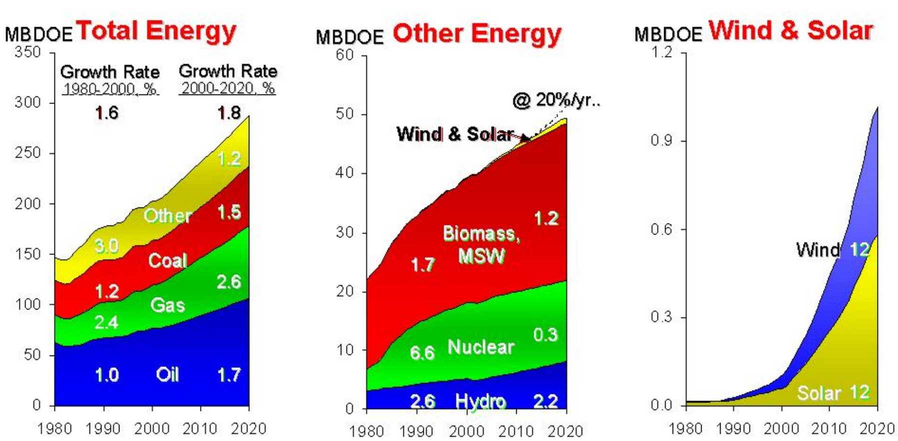

Figure 2: Historical and projected energy demand by primary source. Left hand panel: total global energy demand. Middle panel: energy from non-fossil fuel sources. Right hand panel: energy from wind and solar (ExxonMobil 2004).

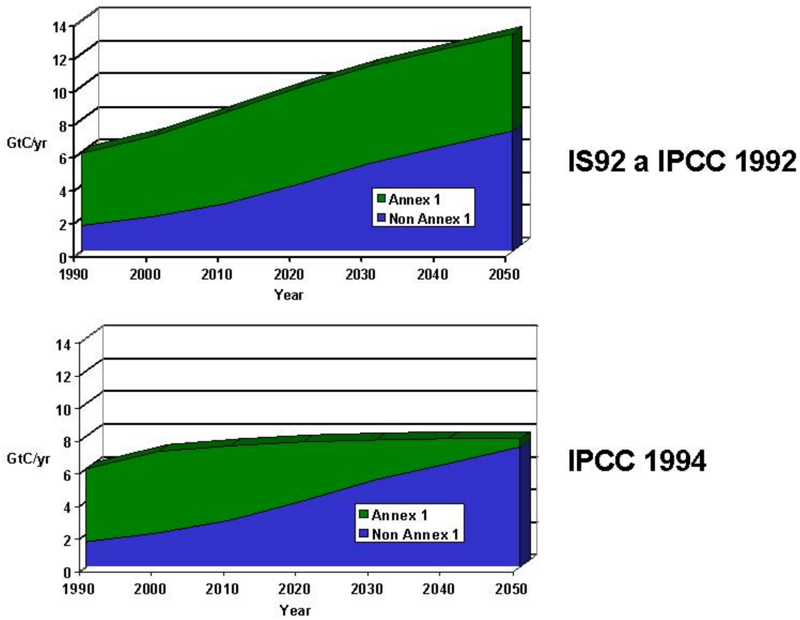

Figure 3: Stabilization pathways and emission scenarios from the IPCC (1994). Top panel: projected global emissions from Annex 1 and and non-Annex 1 countries under the scenario IS92a. Bottom panel: global emissions required to stabilize atmospheric CO_2 concentrations under a scenario leading to 550 ppm CO_2 concentrations. In this panel we show the total relative to an arbitrary assumption in which non-Annex 1 emissions remain as in the top panel. In this situation emissions from Annex 1 countries would need to fall to zero by mid century.

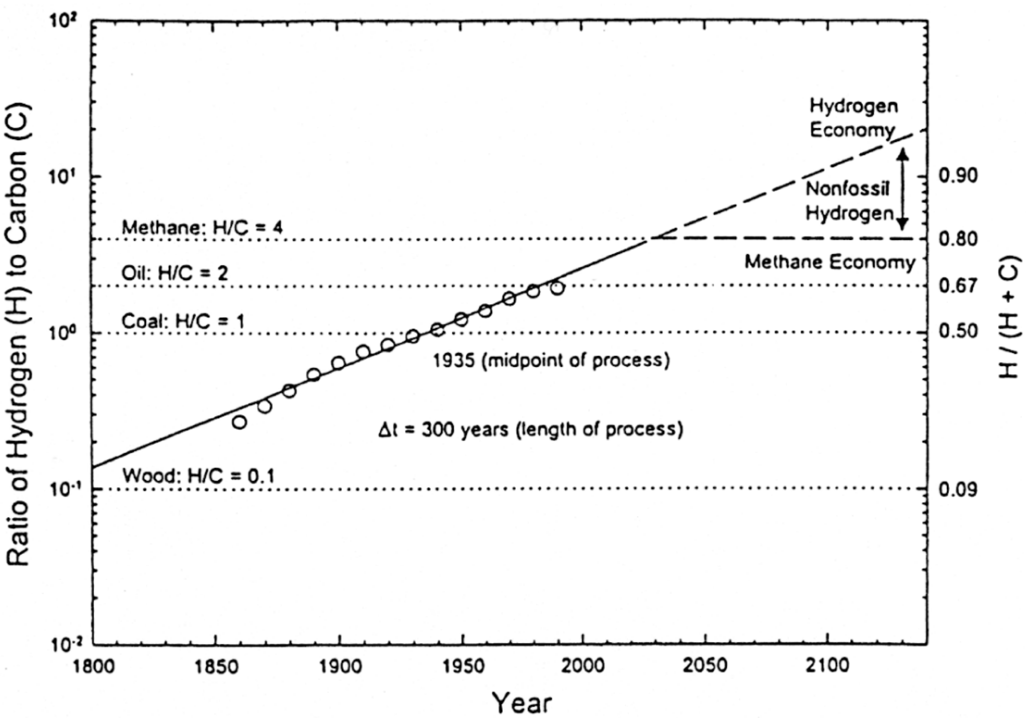

Figure 4: Trends in the hydrogen to carbon ratio of energy use over the past 200 years (after Marchetti 1985, Ausubel 1996, Ausubel et al. 1998).

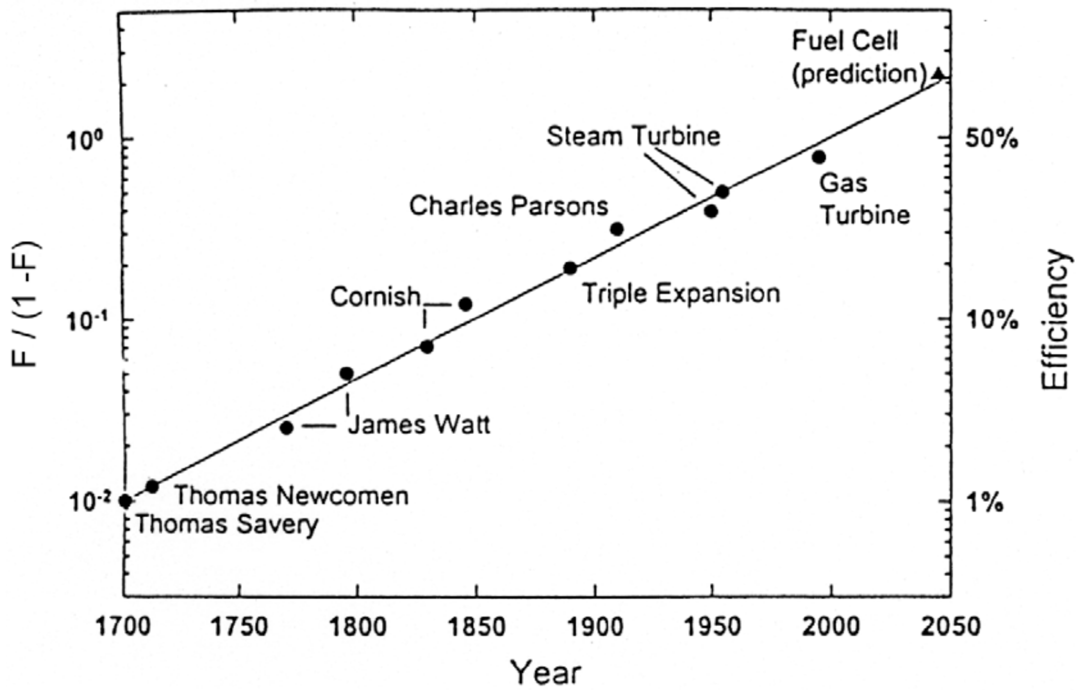

Figure 5: Progress in efficiency from power generation from motors. Typical doubling times are about 50 years (after Marchetti 1985, Ausubel 1996, Ausubel et al. 1998).

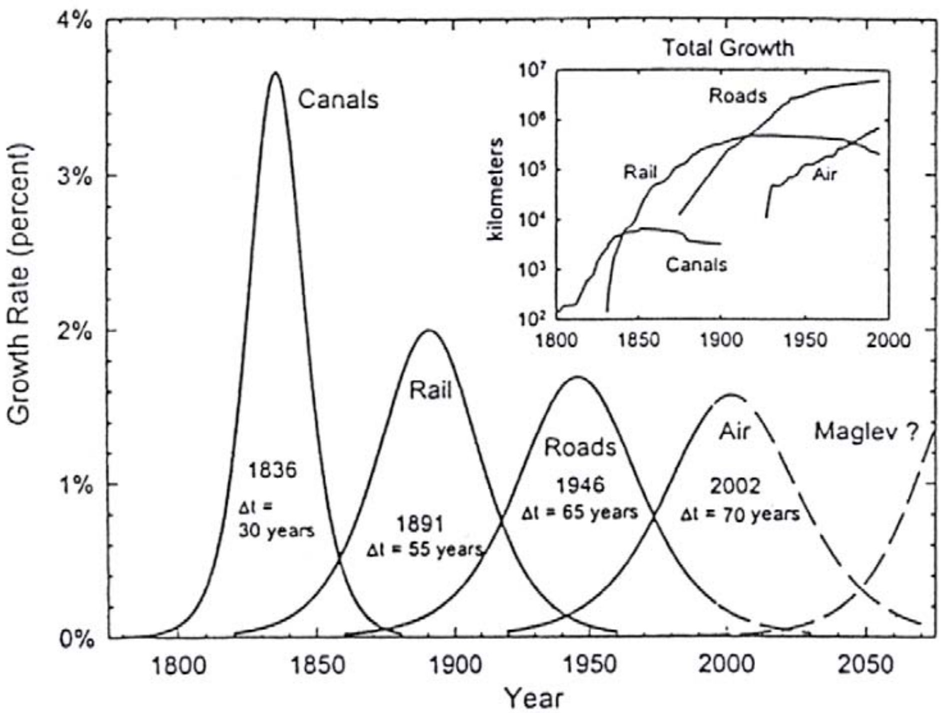

Figure 6: Penetration rates in the United States for various transportation technologies (after Marchetti, 1985; Ausubel, 1996; Ausubel et al., 1998).

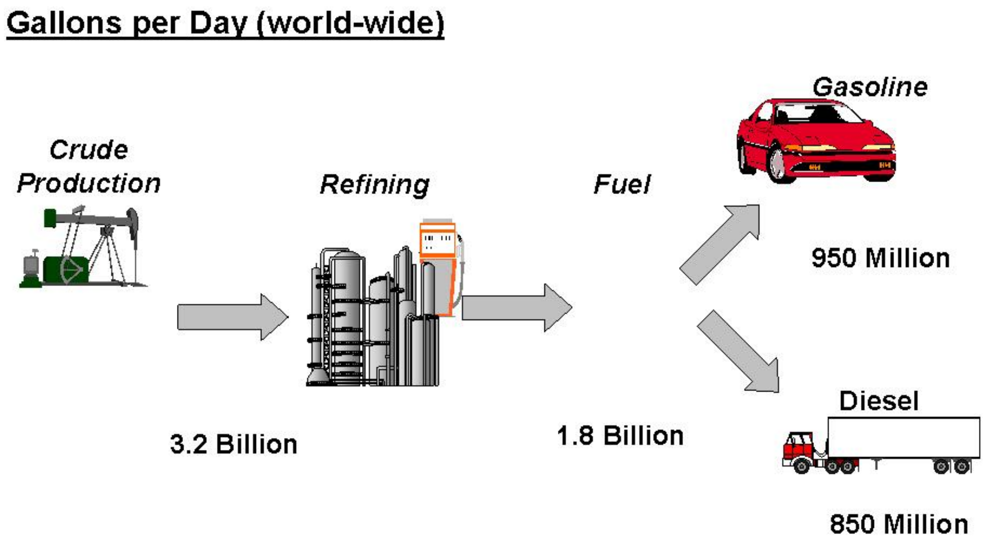

Figure 7: Schematic illustrating global transportation fuels infrastructure.

Scenario analysis of Technology and Infrastructure Transition of Energy Systems

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CRIEPI

ABSTRACT

The author proposes the methodology 'scenario analysis of technology and infrastructure transition of energy systems' as an assessment framework for mitigation technology policy. There have been two frameworks relevant to technology policy in the previous IPCC assessments. One is the assessment of alternative future emissions scenarios up to 2100, including those in SRES and TAR. The other is the assessment of technological potential for emission cuts, including those in TAR. Unfortunately, the results from these two frameworks sometimes were interpreted in a simplistic manner by policy makers and stakeholders: 'there is the emission cut potential, and here are the silver bullets that materialize the potential'. It sometimes ended up with a justification of policies that endorsed popular silver bullets whose environmental effectiveness would be dubious in the long run. In the new methodology, the author proposes that AR4 reviews the publication on alternative future perspective of energy technology and infrastructure development provided by academics, government, and industries. Often, such future perspectives cover only part of time horizon, regions, energy systems, and academic disciplines. An intellectual challenge is to collect, categorize and summarize those alternative perspectives, and further, provide a set of comprehensive and self-consistent scenarios of future development of technology and infrastructure. Such an scenario development activities are useful to analyze the impacts of a short-term emission cut policy on the long-term technological change. Methodologies and illustrative examples are provided with the highlight on the contrast between centralized and decentralized energy systems.

1 INTRODUCTION

The aim of this paper is to propose a conceptual framework in IPCC/AR4. The framework is named 'Scenarios of Technology and Infrastructure Transition of Energy Systems', or *Technology Scenario* in short. It incorporates knowledge from academia, governments, and industrial sector.

The idea does not emerge from the thin air but the author has been enlightened by several resources. First are the existing IPCC literatures, particularly TAR and SRES, which not only assessed the existing research activities but suggested the direction of further research activities. Second are the impressive long-term perspectives provided by national governments and, more importantly, industrial sector. Third are the fruitful debates that led to this IPCC expert group meeting on industrial technology.

This paper will be relevant to many AR4 activities. Most direct relevance will be with WG III chapter 3 which will address long-term technological options. WG III chapter 4 through 10, which will address short term technological options, will be also relevant, since the environmental effectiveness of short-term options is dependent upon the long-term context. The rest of WG III chapters and crosscutting themes (CCT) will be also relevant since the paper provides a way of assessing the energy technology options, which are relevant to some CCTs, with long-term views.

The rest of the paper is structured as follows. In chapter 2, the author will reflect the existing IPCC literature and propose the Technology Scenario as the next step to complement them. In chapter 3, the author describes the characteristics, methodology and the benefits of the Technology Scenario approach as an assessment framework in IPCC/AR4 WG3 activity. In chapter 4, a preliminary technology scenario study is provided for illustrative purpose in order to demonstrate how the proposed framework will work.

2 REFLECTION ON THE EXISTING IPCC LITERATURES

There have been two frameworks used in the previous IPCC assessments. One is the assessment of alternative future emissions scenarios up to 2100, including that in SRES and TAR. The other is the assessment of technological potential for emission cuts, including that in TAR.

Unfortunately, the results from these two frameworks sometimes were interpreted in a simplistic manner by policy makers and stakeholders: 'there is the emission cut potential, and here are the silver bullets that materialize the potential'. It sometimes ended up with a justification of policies that endorsed popular silver bullets whose environmental effectiveness would be dubious in the long run.

The TAR was drafted on the specific issues and sectors. This was a practical choice and effective in gathering the knowledge that remained scattered otherwise. Another characteristic of the TAR was the focus on the short term. It was also a practical choice since the long-term emission cut potential is highly uncertain. However, the long-term perspective was not well incorporated in the assessment.
On the other hand, the SRES provided long-term emission pathways with the assessment on a wide range of scenario drivers. However, the focus was on emissions, not technology and infrastructure.
There are nothing wrong with the TAR and SRES. However, these activities alone were not enough for the technology policy makers to understand the consequence of short-term decisions against a wide range of alternative development paths of energy technology and infrastructure in the future. In order to complement them, an elaboration of the dynamics of the energy technology and infrastructure will be fruitful.

Three examples are provided below to demonstrate that it is important to assess the effectiveness of short-term technology options in the long-term context.

Example 1: END-OF-PIPE OR NOT
The TAR covered the whole energy systems but the future development of energy technology and infrastructure were not presented in the form of self-consistent scenarios. As such, the identified options were sometimes contradictory and a short-term policy choice might not be effective or even adversarial in the long run. For example, switch of fuel from coal to natural gas was identified as one of the short-term mitigation option and they are acquiring popularity in the real world. Certainly it may serve as a short term emission cut options to some extent. However, it may have adverse effects if the geological storage technology, that is also identified as an option for massive emission cuts, are to be equipped to address the mounting social requirement to drastically cut the emissions. The fuel switching can be counter-effective because the energy penalty costs, being the major barrier of the geological storage technology, will likely to be higher for natural gas than coal, particularly in the regions with easy access to cheap coal where most of the facilities are located.

Another example is cogeneration of heat and power. Again, it was identified as an option and the policy to implement cogeneration facilities is getting popular in the real world. However, the policy may have adverse impacts in the long run. Decentralized energy systems, which are likely to emerge by the promotion of cogeneration technology, are identified as being incompatible with the carbon recovery and storage technology.

In both examples, the policies that aim at short term and relatively modest emission cuts may hinder further emission cuts in the long-term, which is important to meet the ultimate goal of the FCCC, that is to stabilize the greenhouse gas concentration in the atmosphere in order to avoid dangerous interference to mankind by human induced climate change . Of course, the conflicts may not occur. It is possible that hydrogen may be produced by renewable energy sources and hydrogen systems, such as fuel cell, may replace the natural gas systems. In such a long-term context, dashing for cogeneration decentralized systems makes sense.

Example 2: INFRASTRUCUTURE IN THE ‘NIMBY’ WORLD
To understand the correlation among key drivers and the pathways for the energy and infrastructure development will be fruitful. For example, growing environmental concerns are necessary condition for strong climate policy. However, the same concerns may enhance the Not-In-My-Back-Yard (NIMBY) attitude drastically, leaving virtually no new sites available for energy infrastructure in the long term. Wind power and any other technology that requires new sites may face the barrier.

Example 3: ENERGY IN HEAVILY WIRED WORLD
A technology scenario building process may identify further key drivers that were overlooked by the SRES. For example, decentralized energy systems may be attractive for rural area in the developing countries in the short term. However, there may emerge non-energy grid systems, e.g. roads, railways, that wire the regions with the rest of the world regardless of the energy systems. If it is the future, the energy infrastructure will be eventually connected to the world, and then there may be less attractiveness for the off grid systems anymore.

3 TECHNOLOGY SCENARIO: A PROPOSAL

In this chapter, the author describes the characteristics, methodology and the benefits of the Technology Scenario approach as an assessment framework in IPCC/AR4 WG3 activity.

What is scenario in general?
High uncertainties are inherent in all key variables regarding the future climate technologies: political salience of climate change, environmental concerns in general, inventions, mobility demands, and so forth. Despite the daunting uncertainty, decisions are made every day at somewhere in the world. Decision makers are interested in knowing, to the extent possible, how the future may evolve depending upon key drivers and their decisions.

Scenario analysis is the methodology to assess how the alternative future may evolve given the wide range of uncertainties in key drivers and consequences. Usually, a scenario analysis is comprised of a set of several alternative scenarios. What differentiates scenario analyses from a naïve speculation is the expertise used to flesh out the scenario. For example, a bunch of numeric model analyses were conducted in the SRES emission scenarios in order to check the self consistency of the assumptions on the variables. The technology scenario would require interdisciplinary knowledge in order to understand the drivers and mechanisms that lead to alternative future development of energy technologies and infrastructure.

What is the technology scenario?
The technology scenarios are the narration of alternative pathways of technology and infrastructure transition of energy systems. The scenarios address the following questions:
What technology and what infrastructure may be deployed, with what condition at which place?
What are the key drivers, mechanisms, challenges and consequences?

The methodology and benefits of the scenario analysis will be described below.

Methodology
The Technology Scenario will be developed with the three steps: reviewing literature, storyline development, and scenario building.

Step 1: Reviewing literature
The scenarios require inputs. We can identify three intellectual resources to be explored by the IPCC: government, academia, and business.

1. Government. The national, international and local governments have published many plans and assessment for the long-term technological and infrastructure development. To name a few, the US government has launched a long-term road map on the hydrogen energy systems in the transport sector (USDOE 2004). Japanese government has launched the New Earth Plan that covers a future perspective on the technological change on whole energy systems up to 2100 (IEA 2003).

2. Business. The business sector is working on the future every day, since understanding the alternative futures is critical to successful business. The business sector invented the methodology to analyze alternative futures: scenario analysis (Schwartz 1991). It was eventually incorporated in the SRES in order to forecast the alternative emission paths. Recently, the methodology is getting more popular in many firms and business organizations. An important benefit of being informed by the business sector is that their analyses often address the political feasibility and economic viability more carefully than those provided by the academia and the governments. Examples among a number of future scenarios by business sector include the WBCSD scenarios which provided qualitative global scenarios, and the perspective on the wind power development in Europe provided by a wind energy association (EWEA 2003).

3. Academia. Interdisciplinary knowledge should be incorporated, including technological performance forecasts from engineering and material science, and technology policy from political science and political economy to understand the causalities from key drivers to the technology and infrastructure development.

Step 2: Storylines development
The reviewed perspectives cover only part of time horizon, energy systems, regions, and academic disciplines. Structure them and *develop several storylines* – what technology and infrastructure may be deployed, with what condition at which place?

Step 3: Scenario building
Elaborate the storylines and distill a set of comprehensive and self-consistent scenarios of future development of technology and infrastructure. Quantify where appropriate (e.g. technological performance). Analyze what are the key drivers, key mechanisms, challenges, and consequences of the scenario.

Benefits
The set of systematic and coherent scenarios will serve as the base for the stakeholders to consider the technology policy to prevent the climate change. It will also serve to identify policies that are robust against the potential events, such as climatic disasters or sudden emergence or delay of the key technologies. Such a scenario analysis on the technology and infrastructure will compliment the sector or issue specific assessment of TAR.

There are four merits in building the Technology Scenarios. First, it is useful to summarize the numerous literatures on future perspectives to several alternative futures, identifying the key drivers, barriers, and possible consequences. Such a systematic presentation of the ideas is instrumental for those who engage in the debates of the climate technology policy. Secondly, it provides the chance to explore the totally different futures in systematic and comprehensive manner. The technology policy designs are often discussed simply as 'issues and options', where the elements tend to be only partial and treated as a set of possible small deviations from the current system. However, a systematic, drastic change of the technological systems is difficult to envisage, if we are methodologically trapped by the existing systems in such a manner. Thirdly, the scenario analysis contributes to facilitate the debates among policy makers and stakeholders in a streamlined manner by setting the appropriate scenes. Forthly, it serves as the vehicle for the outreach from scientists to policy makers.

4 A PRELIMINARY TECHNOLOGY SCENARIO ANALYSIS

The author provides a set of scenarios in order to sketch how the scenario building activities may look like. The analysis is highly preliminary. It only reflects personal ideas and limited knowledge of the author. Needless to say, the scenarios that will emerge after an IPCC/AR4 process will be totally different from the ones the author illustrates here, in terms of the elaboration and the rich knowledge. In what follows, key drivers and mechanisms are identified at first. Then, the storylines of three scenarios highlighting the contrast between centralized and decentralized energy systems are described as a consequence of the set of assumptions on the drivers and the mechanisms in play.

Key Drivers
The author identifies the following as the key drivers that influence the way as to how technology and infrastructure transition may occur.

1. Political salience of climate change issue
In past, political salience of climate change issue has been low or diverse across countries. It may be changed in the future – by climatic disaster or change in political circumstances. Possible consequence of political salience would be higher carbon price, stringent energy efficiency standards, and/or enhanced research and development of climate technology.

2. Interests in environmental issues other than climate change
Political salience of climate change issue will be correlated with the political salience of other environmental issues. It is not likely that people are interested in climate change issue only without having concerns with others. This correlation may have either positive and negative impacts for the development of climate technology.

The positive impacts are well known as co-benefits. The policy to cut local pollution often result in reducing CO_2 emissions. The negative impacts, that were not the subject of heated debate so far, may worth an attention. Often, the climate policy to reduce CO_2 contradict with the local environmental concerns. This consideration may lead to dilemmas to be addressed. For example, given the strong environmental concerns, wind power may be promoted to cut CO_2 emissions, but it may face strong oppositions due to its impacts on other environmental issues such as landscape and noise. Another example is decentralized fossil fuel combustion systems. There are benefits such as utilizing waste heat, but they may cause urban pollution on the other hand, and the latter constraint will be getting more stringent as the environmental concerns are mounting in the future, if the emissions are not appropriately treated.

3. Constraints on facilities and infrastructure at new location (NIMBY attitude)
It is constantly getting difficult to agree with local people upon building large facilities and/or large grid systems at new sites. Examples include large dams, nuclear facilities, large scale electric power transmission lines and large scale gas pipelines. New energy technologies can not escape the problems as well. Wind power is also difficult to be built in densely populated area. Again, this tendency seems correlated with the political salience of climate change and other environmental problems. A possible way out for such technologies to be developed would be to use the existing sites without exploring new ones. For example, the capacity of transmission lines and gas pipelines can be enhanced at the same location. Hydrogen pipelines may not find problems if they replace the existing gas pipelines at the same location.

4. National interests in technology
Even if the political concerns on environmental issues including climate change are weak, there is the possibility that other interests may drive the technological change that will eventually contribute to mitigate climate change. Historically, countries often allocated large budget to the research, development and diffusion of cutting edge technologies out of long-term competitiveness concerns or military security concerns. The resources mobilized by such incentives have been dwarfing the ones mobilized by environmental concerns. For example, new materials for highly efficient photovoltaic cells or hydrogen container may emerge from such activities, with nothing to do with the resources dedicated for the climate purpose.

5. National interests in energy security
Another example of non-environmental driver is energy security. Countries have mobilized a lot of resources for the purpose, ranging from nuclear power to energy conservation, primarily for energy security.

6. Regional endowments
Regions in the world have distinctively different endowments that affect the viability of specific technology development policy. For example, wind power has been popular in west European countries, because the wind resources are rich, population density is low, and popular support is high so that they can avoid the NIMBY problem at new sites. Ethanol automobiles have been diffused in Brazil because of rich biomass resources. A lack of endowment, such as lack of domestic energy resources and high energy costs, let Japan seriously pursue energy conservation policy. Countries with rich fossil fuel resources have begun to seriously consider the geological carbon storage technology to make their fossil fuel production compatible with climate change mitigation. Norway and the US are examples of such countries. The lessons are that the endowments differ across countries and so do the attractiveness and political support for the development of specific technologies.

Key Mechanisms
Key mechanisms are at work in the causality pathway from the drivers to the scenario outcomes. When several drivers point to the same directions, a strong movement may take place toward the rapid development of specific technology and infrastructure. The author identifies the following two as examples of the key mechanisms at work in the scenario analysis.

1. Green and Greedy Coalition
This coalition is the most famous one among many possible combinations of the drivers. Environmental regimes can be significantly progressed when environmentalists (green) in favour of stringent regulations and business sector (greedy) that benefits from the regime form a coalition. Examples include Montreal Protocol of ozone layer protection regime and wind-power promotion in Germany in 1990s. In both case, key manufacturers, supported by environmentalists, have lobbied for the stronger policy so that they can make profits. A danger of such coalition is that the regulations may be promoted at a large expense of the rest of the economy.

2. International spill-over of technologies
Once an environmental technology is developed and economically viable, it will be used in the rest of the world, depending mostly upon the level of environmental regulations. The market size grows accordingly. Creating a niche market for nascent technology is important part of technology policy, but the size of the market for the first stage of technological development does not have to be the global size. Typically, a serious program with one big country is enough. Examples of such niche markets include wind power in Germany and Denmark in 1990s, flue-gas de-sulferization technology in Japan in 1960s, automobile emission regulation in the US in 1970s.

Storylines
Three Scenario storylines are provided below. They are: ‘Small and Clean’, ‘Large and Clean’, and ‘Mosaic World’. For all scenarios, characteristics of the energy systems, the narrations of storyline including the assumption on key drivers and mechanisms, and the identified challenges are described in turn.

Small and Clean Scenario
1. Characteristics of the energy systems
In general, large scale energy infrastructure gives way to small and decentralized energy systems. More specifically, solar photovoltaic, wind and small scale combustion technology diffuse. Natural gas grid expands and the gas is combusted at demand side for cogeneration of heat and power. Large-scale combustions by fossil fuel power plants, large hydro and nuclear fade away. Hydrogen is produced by renewable energy and hydrogen automobiles replace petroleum fuelled vehicles. The power transmissions are mostly at local level hence large scale transmission lines fade away.

2. Narration of storyline
Concerns on climate change issue is mounting, and there emerges a strong support to make a swift departure from the current mainstream energy systems This change takes place as a part of a swift change of the societal and economic systems as a whole. Being negative to the existing energy systems, people prefer to make local decisions and implement decentralized energy systems. Centralized energy systems encounter severe resistance at every decision making levels and fade away.

Local pollutions, such as pollutant emissions from stationary sources near habitations, remain as the consequence of choosing local energy systems, but people accept them as the consequence of their own decisions. Renewable energies are perceived as contributing to the national interests in energy technology and energy security. Fortunately, all countries and regions find their way to switch from centralized to decentralized energy systems that fit their regional endowments, thanks to the massive investment of resources toward the development of renewable energies.

Decentralized energy systems is promoted by a coalition with the popular support represented by strong green parties in most countries and energy equipment manufacturers. The decentralized energy facilities become popular traded goods in the world, contributing to the economic growth and rapid international dissemination of the technological development.

3. Challenges to be assessed
Compared to the current cost level, a drastic cost reduction is necessary for many technologies. The costs can be prohibitively high even after a massive technological development. If there are continuous popular supports, such costs reduction may be possible for many technologies. There have been some examples in past. To name a few, Germany created a domestic market for wind-power, and Japan implemented a coherent solar photovoltaic promotion policy from research and development to subsidies for initial deployment. In future, for example, transport sector may lead the hydrogen related technology from fuel cell to hydrogen production by renewable energy.

Another challenge is other environmental issues, with which the concerns are generally very high in this scenario. Wind power may have problems with noise and landscape. Biomass may have problems with other land-use priorities such as nature conservation and less intensive agriculture.

A drastic invention such as low-cost and high-efficient materials for solar photovoltaic may lead to this scenario. Still, it is difficult to imagine that the costs of such technology can compete against fossil fuels in fossil fuel rich region.

Large and Clean Scenario
1. Characteristics of the energy systems
In general, large scale energy infrastructure continues to dominate but they are getting de-carbonized. Small scale energy systems play a limited role. More specifically, both electricity grid and natural gas grid expand. Nuclear, fossil fuel and large scale hydropower continue to be the mainstream of energy supply. In order to address environmental concerns, small scale combustions give way to large scale combustions with end-of-pipe environmental equipment. Geological storage technology is used for such large point sources. Hydrogen is also produced from fossil fuel, with CO_2 stored underground. While renewable energy supply increases, it remains a small fraction in the total energy supply.

2. Narration of storyline
Concerns on climate change issues is mounting and there are also mounting concerns on other environmental issues, hand in hand with strong NIMBY syndromes to any new energy facilities in new sites. Renewable energies turns out to be problematic with two problems. First, technological development of renewable energies fail to cut the costs down. Second, the strong concerns on local environment and NIMBY syndrome kill the possibility of new situation of those technologies.

With such developments, countries do not see decentralized energy systems as a possible candidate for the future energy systems any more, and they redirect the ir resources to develop the energy systems that do not require new situation. Large scale power plants and long-term transmission of electricity remain the key systems. Geological storage of CO_2 is also welcomed since CO_2 is stored mostly in the existing fossil fuel field or deserted area remote from any residential area.

Fossil fuel rich countries develop zero emission fossil fuel energy systems with CO_2 geologically stored and resource poor countries develop nuclear energy, to meet the energy demand and the requirement of energy security. Local environmental qualities improve drastically with no combustion in the decentralized emission sources near the residential area.

Strong environmental concerns are also a key driver in this scenario, but the way it is addressed is different from the Small and Clean scenario. This Large and Clean scenario describes how the world may cope with the climate change with the modest change in the current society and economy.

3. Challenges to be assessed
While this scenario may be economically viable and clean, lack of popular support to the large technologies may be a barrier. For example, the views to geological storage technology by environmental NGOs are mixed as of writing.

The costs are also a potential barrier. However, niche markets are being created and the costs may be eventually brought down. Countries with rich fossil fuel resources, Norway, the US, Australia and others, have launched a series of demonstration programs. A characteristic of this technology is that it can reduce emissions while allowing the existing fossil fuel dependent economy to survive (Sugiyama, 2000). If a fair part of costs is shared by the rest of the economy, fossil fuel energy suppliers may support the technological development and more stringent regulation.

Global Mosaic Scenario

1. Characteristics

In general, the global energy systems are composed of 'Large and Clean' region and 'Small and Clean' region. More specifically, different endowment and political situation across countries lead to the creation of niche market for the different technologies. The EU provides niche market for wind power and natural gas cogeneration systems. The USA, Australia, Canada, Norway do it for the geological storage technologies, Japan, China and Korea, do it for the innovative energy conservation technologies. Each technology diffuses in each niche market and the costs are brought down by the technological learning and mass production in the region. Eventually, the technologies spill over to the rest of the world. Summary of the scenario is shown in Figure 1.

2. Narrations of storyline

While **s**trong concerns to the climate change are shared by the all countries, this scenario assumes that the way to address them differs by countries. Narrations given in the 'Small and Clean' are applicable to some countries and regions and 'Large and Clean' are applicable to the rest.

3. Challenges to be assessed

The challenges of 'Small and Clean' and 'Large and Clean' scenario apply to the countries which takes either path. The challenges can be easy if the countries take the appropriate path compatible with local endowments and political situation. A potential danger of the scenario is that such division of labours may end up fragmented and weak activities. A challenge is to keep the coherence and mutual understanding among those activities toward the same goal – controlling environmental problems.

Mosaic Scenario
Small & Clean *and* Large & Clean

Category	Resource endowment	Potential countries	"Global niche" for which technology?
Small & Clean	Rich wind resources and access to nat. gas	West EU	Wind Power
Large & Clean - "haves"	Rich fossil fuel resources	US, Australia, Norway, Canada	Geological Carbon Storage
Large & Clean - "have-nots"	Without rich energy resources	Japan Korea China	Energy Conservation

Figure 1: Summary of the Global Mosaic Scenario

Implications of the Scenarios

While being at a preliminary stage, the followings are drawn as the possible implications from the scenario analysis.

- *Short-term decision and long-term context.* Promotion of decentralized energy systems will be compatible with 'small & clean' future. However, it may have adverse impact if the future is 'large & clean'. – and vice versa.
- *Mosaic World.* Regions have distinctively different parameters regarding the key drivers. In addressing the climate change problem, the world may develop as the mosaic of Large & Clean region and Small & Clean region.
- *Global Niches.* At early stage of the mosaic, 'global niches' may emerge to foster the technologies that are compatible with regional endowments and political situation. A political effort to keep the coherence among these activities toward the goal may be fruitful.
- *Decentralized vs. Centralized. (or, Small & Clean vs. Large and Clean* Decentralized energy systems may have difficulties with the local environmental concerns, while centralized energy systems may have difficulties with securing popular support. Decentralized energy system may be costly in terms of money and level of requirement to change the existing economic systems. Centralized systems may be viable with less economic

and social costs, since it requires modest change on energy, economic and social systems.

- *Countries with and without existing infrastructure.* Many developed countries have developed the energy infrastructures already, and it is difficult to build new ones due to NIMBY attitudes. As such, the system is somehow 'locked' already. What is likely to happen is to replace the existing infrastructure systems, such as increasing the capacity of power transmission lines, replacing gas grid by hydrogen grid at the same location, and so on. Anticipating the mounting interests in local environment, decentralized facilities may have problems with new locations, unless it is perfectly nuisance free. The developing countries, whose infrastructure is yet to be developed, may have the alternatives – centralized or decentralized systems. With slow urbanization and rapid development of renewable energies, the decentralized renewable systems may be an attractive option for rural area.

5 CONCLUDING REMARKS

The author suggested *Technology Scenario* an assessment framework with which the existing IPCC assessments on the long-term emissions scenarios and the short term technological mitigation potential are complemented in the way that it produces a usable knowledge for the policy makers engaging in climate technology policy.

Scenarios are *not* the answers, but it provides the opportunity for business stakeholders to exchange strategic views as to how to cope with the climate change. It also provides an opportunity for policy makers to consider technology policies base upon systemic assessment of the alternative long-term context.

The scenario analysis provided in the paper is highly preliminary. However, the author wishes that the preliminary scenario analysis met the purpose, that is to illustrate the key characteristics and the potential benefits of the *Technology Scenarios* activity. The author also wishes that the readers may be interested in further developing the methodology under the IPCC/AR4 assessment.

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Energy demand, energy technologies and climate stabilisation

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ABSTRACT

Drawing from various recent pieces of work undertaken at the IEA, this paper first recalls the IEA projections about CO_2 emissions and investments in the energy sector, and confronts them with IPCC scenarios for stabilising GHG concentrations. It briefly reviews the various energy technologies that could respond to the development needs with lower emission paths in the short and long run: energy efficiency improvements at end-use and transformation levels, fuel switching, non-carbon energy sources such as nuclear and biomass, and use of fossil fuels with carbon dioxide capture and storage. The paper then discusses the merits and limits of various policy tools at national and international levels that could drive the deployment of these carbon lean technologies. It concludes with some remarks on how future mitigation regimes could be set at a global scale.

ENERGY DYNAMICS AND CLIMATE STABILISATION

Energy-related greenhouse gas emissions are the dominant human contribution to climate change. The burning of fossil fuels is responsible for at least three-quarters of anthropogenic carbon dioxide (CO_2) emissions; fossil fuel production and use also emit methane (CH_4), nitrous oxide (N_2O), ozone-precursors, and black soot.

Global energy-related CO_2 emissions are estimated at 24 billion tonnes CO_2 per year in 2000. The *World Energy Outlook* (IEA 2004a) foresees 38 billion tonnes CO_2 per year in 2030 - about 62% above current levels. Two thirds of the increase will come from developing countries. By 2030, developing, OECD and transition countries would account for respectively 47%, 43%, and 9% % of emissions – though per capita emissions remain much lower in developing countries and converge only very slowly through 2030. The projected paths of greenhouse gas emissions reflect population growth and the expected continued increases in living standards and energy use.

The United Nations Framework Convention on Climate Change (UNFCCC) has as its main objective *'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.* Such a level '*should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.'*

Stabilising carbon dioxide concentration – at any level – requires the eventual reduction of net global CO_2 emissions to a fraction of their current levels. A balance between emissions and system uptake of CO_2 might be reached when emissions are reduced to approximately half of current levels. However, as the long-term release of CO_2 from the ocean into the atmosphere continues, to achieve the stabilisation of atmospheric concentrations would require even greater reductions. Thus, over the span of the next few centuries, emissions will need to decline to the level of persistent natural land and ocean sinks – equal to a few percent only of current emissions.

A key determinant in the final level of concentrations is the timing of reductions: the sooner the reduction in global net CO_2 emissions, the lower the stabilisation level. Stabilising CO_2 atmospheric concentrations at levels of 450 ppm would require global anthropogenic CO_2 emissions to drop below 1990 levels within a few decades. To limit concentrations to 550 ppm would require global emissions to peak by 2030, and drop to below 1990 levels before 2100, and to limit concentrations below 1000 ppm would require reductions below 1990 levels within about two centuries. In each case, once 1990 levels had been reached, emissions would need to decrease steadily thereafter to ensure that concentrations had indeed been stabilised (IEA 2002a).

Pacala and Socolow (2004) have recently suggested an interesting approximation: stabilisation at 500 ppm would need that global CO_2 emissions be stabilised at their current level of about 25 $GtCO_2$ for the next 50 years – while they are currently on course to more than double. They would have to decline thereafter.

Many conclusions can be drawn from the contradiction between emission projections and stabilisation requirements. The most important might be the following:

1. To achieve low concentration levels it is important to speed diffusion of existing low-emitting technologies and to change consumers' behaviour as possible;
2. To achieve stabilisation the energy system will have to undergo profound changes; the existing set of low-emitting technologies may not be sufficient; more radical innovations might be required;
3. Unless additional action is taken, developed countries' aggregate emissions will continue to climb;
4. The stabilisation of CO_2 concentrations will be impossible to achieve unless developing countries, as well as developed countries, take part;

5. Lower stabilisation levels require earlier integration of developing countries into the global mitigating framework.

ENERGY TECHNOLOGIES

Reducing energy-related CO_2 emissions can arise from technical improvements at different levels and involve:
End-use energy efficiency improvements in all sectors (household and commercial, industry, transport), and conversion efficiency improvements;
Fuel switching from coal to oil to gas;
Phasing in non-carbon energy sources, such as nuclear power and renewable energy sources;
Fossil fuel use with CO_2 capture and storage.

Excluding any of these options is likely to drive higher costs for achieving any concentration objective. To put it otherwise, excluding any of these options would drive higher concentration levels and therefore more climate damages for a given willingness-to-pay for climate mitigation. With this key message in mind we will briefly consider these various options.

Opinions vary as to the readiness of existing technologies to reduce emissions. According to the IPCC (Moomaw and Moreira 2001): *'Known technological options could achieve a broad range of atmospheric stabilisation levels, such as 550 ppm, 450 ppm or below over the next 100 years or more'.* Known technological options refer to technologies that exist in operation or pilot plant stage today. It does not include any new technologies that will require drastic technological breakthroughs. Hoffert et al. (2002) criticised this statement as representing a 'misperception of technological readiness.' Pacala and Socolow (2004) responded indirectly to this criticism by suggesting that existing technologies allow stabilising global emissions for the next 50 years – a path compatible with stabilisation of atmospheric concentrations at 500 ppm.

However, sufficient penetration of 'known technological options' is likely to require numerous incremental improvements allowing to reduce costs and improve performance – not to mention the necessity in the longer run to power the global economy while essentially eliminating CO_2 emissions. Some carbon free technologies already exist. Light water nuclear reactors, wind turbines, concentrating solar and biomass-fuelled power plants, biofuels, photovoltaics are industrial realities Important technical improvements will still be required, however, to deal with physical and, ultimately, cost constraints. And in many cases, these improvements may not be only incremental.

For example, the future of nuclear may rest with entirely new reactors that could be safer, save resources, produce less hazardous waste and prevent proliferation. While various concepts have been suggested, industrial realisations remain hypothetical only (IEA et al., 2002). The intermittent character of many renewable energy technologies – and costs (for PV at least) – will limit wind or PV expansion. Concentrating solar plants matching peak loads with heat storage will be built in the coming years but will not be competitive before some more years. Carbon-free hydrogen production exists on paper, as do hydrogen-fuelled cars and planes, but there is a long road and significant technological challenges between today's dreams and future realities (Appert 2003). While in the future, hydrogen from renewable or nuclear power might become an option (Barreto et al. 2003), in the near to middle term renewables would more efficiently replace fossil fuels in the power sector than in the transport sector (Eyre et al. 2002).

The current technological portfolio is unlikely to allow reaching the ultimate objective of the Convention, unless the willingness-to-pay is extremely high. Moreover, short-term decisions in this arena might have large long-term implications – and different cost implications for achieving similar concentration levels. Finally, technology change tends to be cumulative rather than resulting from single major shifts. All these factors combine to make the technology dimension of climate change mitigating policies critical in any future effort to meet the Convention's stabilisation objective.

Energy efficiency improvements

Energy efficiency improvements are crucial for any sound strategy to mitigate climate change, as in the short term they probably represent the most powerful tool to curb emissions. As shown above, short term action will determine the level of CO_2 concentration at which stabilisation could occur at a later stage.

According to Moomaw and Moreira (2001), sufficient technical options exist to hold annual global greenhouse gas emissions through 2010 to levels close to or even below those of 2000 -- and even lower levels are possible by 2020. For energy-related CO_2 emissions alone, the technological potential exists for reductions of between 1,350 MtC/y and 1,900 MtC/y in 2010 and of 2,950 to 4,000 MtC/y in 2020. More than half of the potential comes from the aggregate effect of 'hundreds of technologies and practices' for end-use energy efficiency in buildings, transport and manufacturing. Most of this potential may be tapped by 2020 with direct benefits – notably in the building and industry sectors.

The *World Energy Investment Outlook* (IEA 2004a) showed an 'alternative scenario' reducing global CO_2 emissions by 16% below the reference scenario in 2030. Energy efficiency improved would account for 58% of the overall emission reductions. This alternative scenario would require more investments at end-use level, but lesser investments on the supply side. This is mainly due to the fact that in this scenario faster energy efficiency improvements reduce the investments needed in the energy sector and this reduction more than offsets the higher capital costs due to a greater share of decentralised and/or renewable energy sources. This tends to confirm earlier similar results from Roehrl and Riahi (2000).

Energy conversion efficiency is no less important. Electricity generation accounted for 39 per cent of global carbon emissions in 2000. Over the next twenty-five years, developing countries are expected to build up to 900 GW respectively of new coal-fired power generation capacity (IEA, 2004a). These new plants will partially replace older ones, thus increasing the average energy efficiency of the sector. If new capacities were of an advanced super-critical design rather than the classical sub-critical design, their efficiency would be increased by a further seven percentage points and their CO_2 emissions reduced by about 15 per cent. Here, the critical issue may not be costs, but technology transfer, as even with low coal prices, subsequent fuel savings would pay for the incremental cost of investing in the most efficient technology.

Another important way to raise the efficiency of energy use is simply to use the heat that cannot be converted into electricity in 'combined heat and power' (CHP) systems. CHP might reduce CO_2 emissions by 20 to 40% - depending on the assumptions made on the reference case. Stationary fuel cells could also provide distributed combined heat-and-power. More than 80% of current CHP capacity is used in large industrial applications. Further CHP expansion in industry and commercial and residential sectors would be facilitated by more distributed energy systems, where power generation is closer to end-users.

Manufacturing sub-sectoral energy intensities declined significantly until the last half of the 1980s. However, since then, the fall has almost come to a halt after oil prices felt in 1986. If manufacturing is to return to the situation of the 1970s and 1980s when energy per output fell enough to avoid growth in manufacturing energy use, improvements of energy efficiency need to be resumed (IEA 2004b). Variable speed electric motoring is often considered as the largest potential for energy savings not linked to a specific process.

Space heating remains the most significant residential energy end use in most industrialised countries. Until 1990, the upward pressure resulting from bigger houses and fewer people per dwelling was more than offset by significant reductions in the amount of heat used per floor area. After 1990, space heating demand has grown in most countries. Saturation effects and improved appliances efficiencies have limited the growth of the demand by dishwashers and refrigerators, but there is a strong growth of use of other appliances – from home electronics to office equipment and small kitchen appliances. Two IEA publications (IEA 2001; IEA 2003a) show how stronger policy measures could save significant amounts of electricity from the use of appliances (see also in section 3.3.2 below).

With respect to transport it is very likely that no radical change in the supply chain is likely before decades, beyond increased use of bio fuels, and might require significant breakthroughs in various technologies (hydrogen). Shifts from energy-intensive modes (cars, trucks and planes) to less intensive ones (busses, trains, ships) and improvements in energy efficiency of vehicles through weight reduction or more efficient motoring and transmission (what hybrids to, for example), seem to offer the largest short and mid term potentials for emission reductions.

Fuel switching

In the near term, switching from coal to oil or gas can play an important role in emission reduction. Supposing energy conversion efficiencies similar for all fuels, a shift from coal to oil would imply a reduction in carbon emissions of 26 per cent, from oil to gas 23.5 per cent, and from coal to gas 43 per cent per unit of primary energy. When fossil fuels are used to produce electricity, the advantage of natural gas is increased by the higher efficiency of current, state-of-the-art, combined cycle gas turbine technologies over oil and coal-fired power plants.

Proven reserves might provide about 60 years of consumption at current rates; total estimated resources, including undiscovered gas, represent from 170 to 200 years of supply. However, geographic constraints may limit fuel switching toward natural. 70 per cent of world reserves are located in the former Soviet Union and the Middle East. The reserve/production ratio of 65 years globally is unevenly distributed, from 250 years for the Middle East to only 9 years for North America. The ratio of natural gas reserves to total energy consumption is lower than three years for China, India and the USA, which all have large coal reserves.

Additional gas resources exist in sea-floor methane gas hydrates (clathrates), and may represent twice as much energy potential than all other fossil fuels combined (including the large coal and unconventional oil resources). No technology currently exists to use this enormous energy resource. If a technology were to be developed, it could have, with respect to climate change, a kind of Janus' double face. On the bright side, it could stimulate the near-replacement of coal and oil.

On the dark side, it could prolong the era of fossil fuels and ultimately add a supplementary 10 000 Pg of carbon into the atmosphere (on top of the 5 000 Pg from the combustion of the currently known fossil resource base).

Non-carbon energy sources

Second only to energy efficiency improvements, increased nuclear and renewable in power generation account for 20% of the emissions cuts in the alternative scenario proposed by the World Energy Outlook (IEA 2004). What are the merits and demerits of the various energy sources and technologies at stake?

Nuclear power

Nuclear power accounted in 2002 for about 16.5 per cent of world total electricity generation. Its growth has stalled in recent years, mainly because lower fossil-fuel prices have made coal- and gas-fired generation more attractive economically, and also because of increasing public concern, heightened after the Chernobyl accident in 1986. The IEA projects that the nuclear sector will continue to lose its share in the world energy mix after 2005 as older plants are retired. Other than in Asia, relatively few new plants are being proposed or built. New nuclear capacity has not been added as it is often too expensive in a time of deregulation and as carbon emissions are not regulated. However, nuclear plant life extension is progressively introduced and may delay the future reduction of installed nuclear capacity. There are also signs of a renewed interest for this option in some countries.

The availability of final repositories for all types of radioactive waste, enhancements of nuclear safety as well as improved proliferation resistance measures would improve public acceptance of the technology.

Current ‘evolutionary’ technical development efforts tend to build on experience gained with light water reactors to simultaneously reduce costs and increase safety, in particular by incorporating more passive safety features. More innovative designs may also become attractive (IEA et al., 2002). Without the nuclear option, stabilisation is likely to be costlier – or to take place at a higher concentration level (IEA, 2003d).

Wind energy

Wind, solar and other renewable energy sources such as geothermal and tidal energies provide only 0.5 per cent of global demand for energy. Wind power is the fastest growing energy source – albeit from a very narrow base – with a worldwide capacity of about 46 GW at the end of 2004. The problem of public acceptance of wind turbines, while it varies from country to country, implies that the future of wind power may lie in the waters. Offshore wind farms cost 35% to 100% more to build, install and connect to the grid, but may access more regular wind resource and produce more energy – simultaneously alleviating public acceptance and intermittence problems. Power generation costs are typically US cents 4 to 7 per kWh on land and 7 to 12 per kWh off-shore (IEA, 2003e).

The limits arising from the intermittent character of wind is disputed, and may vary with countries’ situations. The general assumption is that there is a limit; only about 20% of peak demand can be provided from wind for the electricity mix to remain manageable. Proposals for addressing this limit are varied, and include options for energy storage, but this would add to the costs of wind power.

Solar energy

Solar energy received by the planet is about 9,000 times current energy consumption. Even though its technical potential is much less (and depends on factors such as land availability), lower estimates for supply exceed current global energy use by a factor of four. For example, building integrated photovoltaics offers a significant electric potential that represent significant shares of current electricity consumption, ranging from 15% (Japan) or 19% (Finland, Sweden) to 30% (UK, Germany, Canada), 45% or more (Australia, Italy, Spain) and up to 58% (the US). However, large reductions in costs and innovative storage systems are still needed for this technology to compete with fossil-fuelled power plants – even taking into account some pricing of avoided externalities such as carbon dioxide.

For economically competitive large-scale power production where solar resources are sufficiently intense, concentrating technologies may offer the best prospects. Nine plants in the Mojave Desert close to Los Angeles have provided 354 MW_e of power since 1989. Concentrating technologies address intermittence problems through back up from fossil fuels or heat storage using the same conventional part of the plant. They offer much cheaper electricity than PV, and it has a higher value for utilities. However, prices are still higher than those of fossil fuels. Costs in the range of 3.5 to 6.2 US ¢/kWh – close to competitiveness - could be reached after 5,000 MW of new plants will be built (Sargent & Lundy Consulting Group, 2003). In the future, concentrating solar technologies might be used to produce hydrogen or other energy carriers. Various projects are under consideration in the world’s sun-belt, the most likely to be realised in 2005 or 2006 being in Spain and Nevada (USA) (Philibert, 2004b).

Today, however, solar heating and cooling, including water heating, is probably the most important form of direct solar energy. Using a conversion factor of 0.7 kWth per m^2 of solar collector area, the installed capacity of solar thermal systems has been calculated at about 70 GWh (thermal), based on the 2001 data from the IEA Solar Heating and Cooling Programme for solar thermal collectors. This estimate does not necessarily include all ‘passive’ forms of solar energy use in heating or cooling buildings that tend to be merged with energy savings or other applications such as solar drying of crops, solar cooking, etc. Some of these uses are already competitive – notably hot water and passive solar use in buildings.

Biomass

Combustible renewable energy sources, including waste, provide 11 per cent of world total primary energy supply – equal to its share in 1973. The growing of biomass on a sustainable basis leads to no net build-up of CO_2 in the atmosphere, because CO_2 released in combustion is balanced by CO_2 extracted from the atmosphere during photosynthesis. However, the share of traditional biomass use may soon start declining. For health, local environmental and sometimes growing scarcity reasons, renewable combustibles are often replaced by more efficient fossil fuel sources in poor households in developing countries. The development of household stoves with improved combustion might reduce indoor pollution and health risks for users.

Developments in technology may reverse the trends toward a decline in the relative use of biomass, particularly as biomass finds its way into the power sector, in particular through gasification. Current agricultural and forestry practices provide considerable biomass volumes from crop residues as well as from areas specifically cultivated for biomass energy production. Biofuels provide another way of replacing fossil fuels with biomass products. As they offer a way to replace gasoline, an oil product dominating energy consumption in transport, they offer significant advantage for energy security – as well as possible new development areas for agriculture. But biofuels represent a costly means to reduce CO_2 emissions, and biomass might be more effectively used for heat and process heat during the coming decades. However, photosynthesis is a relatively inefficient process (in terms of energy output by solar input on a given surface) and land availability will put an upper limit on what might reasonably be expected from biomass as an energy source.

Others

Hydropower provided in 2002 the same percentage of world electricity generation as nuclear. Hydropower is expected to increase in absolute quantities over the next two decades, and its economic potential world-wide remains important. However, its development remains largely dependent on resolving public concerns about the environmental and social consequences of building new facilities – particularly large dams. Environmental effects include methane emissions due to rotting vegetation and carbon inflows from the catchments, which might have a warming potential of the same order of magnitude as a fossil-fuelled alternative, especially in the Tropics (WCD, 2000). Another important barrier is the increasing distance between still non-exploited resources and potential consumers. Progress in superconductivity could be a key for further development.

Other renewable energy applications include geothermal energy and marine energy (e.g., wave, ocean current, ocean thermal and tidal). As with many of the renewable energy options, given the current and projected low levels of use, it will take considerable policy ‘push’ to stimulate the growth of such technologies to an appreciable market share over the next thirty to fifty years.

Fossil fuel use with CO_2 capture & storage

Various technologies are now available for CO_2 separation, transport and underground storage, which are best suited to dealing with emissions of large point sources of CO_2, such as power plants and energy-intensive industries, rather than small, dispersed sources such as transport and heating. They include pre- and post-combustion technologies. Post-combustion CO_2 capture consumes large amounts of energy. Pre-combustion technology necessitates that hydrogen becomes a more widely used energy carrier. It might have greater prospect with gasification of coal, given the abundance, cost and world distribution of this resource. Both technologies might be greatly facilitated by oxyfuel combustion.

IPCC estimates for storage capacities range from 1,500 to 14,000 GtC; this scale suggests that storage is not likely to be a major constraint on CO_2 removal and sequestration potential, provided current knowledge is improved and long-term storage guaranteed. Injection of CO_2 in the ocean raises serious environmental concerns; it would not be effective to maintain concentration stabilisation, as in the long term it would not modify either atmospheric and ocean carbon contents.

Atmospheric CO_2 concentration stabilisation will be less costly if capture and storage are included in the mitigation options – but leakage rates from underground reservoirs might be a critical issue. A recent modelling exercise at the IEA (2004c) suggests that a price of US$50/t CO_2 – translating into an electricity production cost increase of 1 to 2 US cents per kWh – would lead to 30% more emission cuts (4.9 Gt CO_2 in 2030; 7.9 Gt CO_2 in 2050) if capture and storage is considered.

A role for hydrogen

It is not yet clear what role hydrogen would play in stabilising CO_2 concentration. Most studies suggest that for years or decades emission reductions will remain cheaper through electricity decarbonisation and substitution to direct fuel use in most uses than through using hydrogen as a transport fuel. In the transport sector itself, much can be done with hybrid cars, perhaps biofuels and shift towards urban and interurban mass transit systems. A particularly interesting option might be 'pluggable hybrid cars' allowing most urban trips to be made on electricity from the grid (provided it's CO_2-free) and an efficient fossil-fuel use for trips into the countryside. Though it may have important benefits for energy security, the emergence of a 'fuel economy' based on hydrogen cars might be currently the most difficult and expensive way to reduce carbon emissions (Eyre et al. 2002); and using oil in the transport sector might be the best thing to do as long as some carbon emissions remain compatible with stabilisation. Hydrogen could also be one of the methods to store intermittent energy resources - but not necessarily the easiest and cheapest one. Eventually, however, hydrogen may play a role in long term climate change mitigation as a clean carrier when net emissions will have to come closer to zero.

Technical change, behaviour and price

The role of technology versus that of behaviour may be characterised in two polar views. According to the first view, technology alone solves the climate problem. It provides energy systems with no or very low carbon emissions. No behavioural change would be needed or implied to get this result. In transport for example, fuels would become carbon free, manufactured from nuclear or renewable energy, or carbon in fossil fuels would be captured and stored. This may require deep changes in the way cars and trucks are conceived and built – such as replacing current motor technology with fuel cells – and would allow people to keep their travel and commuting habits unmodified.

The opposite view would give a less important role to technical change. In this worldview, changes in behaviour would achieve a significant part of the emission reductions. People would reduce their use of carbon-intensive materials and services. With respect to transport, for example, use of cars should be regulated, either by higher fuel prices or by restrictions for use in cities, or both; more efficient mass transit systems should be given priority in land-use and public investments, to incite people to switch transport modes. People could be induced to reduce travels in distance and frequency, through pricing or other policies. Urban planning and related policies (such as, for example, credit policies for construction work) would tend to maintain or increase density in urbanised arenas, not expand them.

In both cases, however, new standards for energy efficiency should be imposed on carmakers, which could modify the size and the weight of most cars. Behaviour also rests on collective decisions: use of mass-transit systems depend on proximity, frequency, comfort, safety, and cost. Eventual determinants might be the numerous factors that determine the density of cities and suburbs – from consumer choices to policies by local authorities, credit facilities and the like.

Technical change and behavioural change are in fact often linked. For example, bus systems might be instrumental in paving the way toward cleaner fuels and motors. As pointed out in a recent IEA study (IEA, 2002b), '*For many alternative fuels, infrastructure is undeveloped and unfamiliar to consumers. This will be less a problem for* [public] *transit vehicles since they are centrally fuelled by staff that can be trained to maintain vehicles properly and handle fuel safely*'. However, to be able to accomplish this, bus systems must first become more efficient. More rapid bus systems, protected from gridlock of other vehicles, become more attractive. They carry (faster) more passengers that could pay (justifiable) higher fares. This makes bus companies wealthier, enabling them to eventually buy new, more modern buses, and perhaps moving up the technological ladder towards cleaner fuels and motors. Interestingly enough, the changes that would allow a number of commuters to switch to bus systems will save more fuel and reduce more air pollutants and CO_2 emissions than a fuel change or technology upgrade to the bus itself could achieve. These changes may require some small technological improvements – such as information systems, automatic priorities and modern ticketing – but would mainly rest on different kind of policy decisions – such as building bus lanes and thus restricting the public space allotted to private traffic.

However, behavioural and technical changes may also conflict. This is the case for example with the so-called 'rebound effect' that sees people using more of a given service as its energy efficiency increases thus reducing usage costs. For instance, more-efficient cars might be able to travel longer distances at lower cost – but the lower cost may induce drivers to use their cars more frequently and for longer trips – offsetting some of the efficiency gains. The increase in real income derived from increases in efficiency can also be used for other activities – some of which may themselves lead to increases in emissions. If, however, technical change is primarily driven through pricing carbon emissions, this rebound effect is less likely to be seen, as direct or indirect taxation of externalities tend to influence both technical evolution and behaviour.

POLICY TOOLS

Improvements and dissemination of existing technologies, but also more radical innovations and some behavioural changes will all be needed to effectively mitigate climate change. But what can governments do to drive these changes? This section considers drivers for technical change before examining what tools governments have at hand.

How technologies change?

The view that technology deployment in the marketplace – not only research and development efforts – is a key element to speed up technical change, is borne out by lessons from past technological developments. They reveal that the costs of technologies decrease as total unit volume rises. The metric of such change is the 'progress ratio', defined as the reduction of cost as a consequence of the doubling of cumulative installed technology. This ratio has proven roughly constant for most technologies – although it differs significantly from one technology to another. However, the fact that the progress ratio is usually constant means that technologies learn faster from market experiences when they are new than when they are mature. The same absolute increase in cumulative production has a more dramatic effect at the beginning of a technology's deployment than it has later (see IEA, 2000). This is why new techniques, although more costly at the outset, may become cost-effective over time if they benefit from sufficient dissemination. Figure 1 below shows this phenomenon in the power-generating sector.

However, distinguishing the effects of R&D efforts and those arising from market deployment may not be that easy, as Clarke & Weyant (2003) point out. Learning curves literature usually misses a detailed history of R&D expenses, while R&D literature often ignores learning effects. Moreover, the coexistence of increased market shares and decreased costs does not necessarily demonstrate that the former caused the latter. The causality relationship works both ways: when cost decrease, niche markets increase.

This feedback process from markets to technical improvements, creating increasing return, has numerous consequences. It tends to create 'lock-in' and 'lock-out' phenomenon: it is not because a particular technology is efficient that it is adopted, but rather because it is adopted that it will become efficient (Arthur, 1989). Technological paths might very much depend from some initial conditions. As such, technologies having a small short-term advantage may 'lock-in' the technical basis of a society into technological choices that may have less long-term advantages than others technologies, which are consequently 'locked-out'.

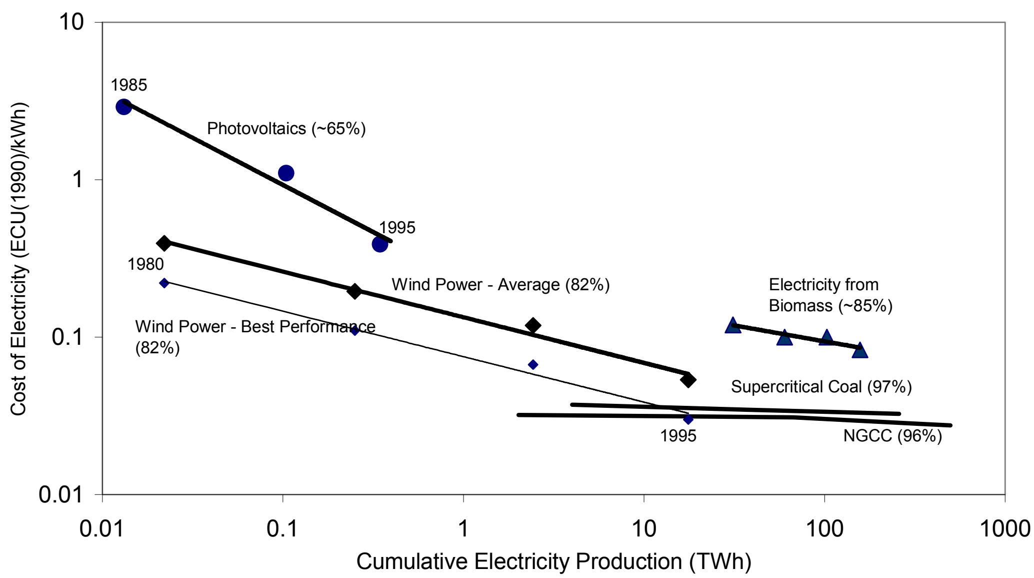

Figure 1: Learning curves. Numbers in parenthesis are estimates of progress ratios. They indicate the change in cost when market size doubles. Thus, for example, if the size of PV markets doubles, the cost of PV electricity is reduced to 65% of its previous value. Source: IEA, 2000

The systemic and cumulative nature of technological change leads to clustering effects, or technological interdependence, and possible phenomena of increasing returns: the more a technology is applied the more it improves and widens its market potential. Change goes in a persistent direction based on an accumulation of past decisions. As noted by Roehrl and Riahi (2000), '*as a result, technological change can go in multiple directions, but once change is initiated in a particular direction, it becomes increasingly difficult to change its course.*'

However, increasing returns might be bounded and scale economies exhausted. Entrepreneurs facing new pressures might want to break technology barriers and even technologies that lost out in the first round of technical competition by chance (or lack thereof) can eventually become successful.

Several policy conclusions emerge from that analysis. The first might be that redirecting technical change in order to reduce CO_2 emissions in a number of places has to build on 'learning-by-doing processes'. Laboratory research and development efforts are unlikely to be sufficient to produce sufficient progress so as to impose new technologies on competitive markets in one shot. As detailed below, creating markets for new energy technologies necessitates broader efforts.

Another, no less important policy conclusion has to do with the timing issue in the context of the technological inertia arising from learning-by-doing effects just described. As pointed out by Roehrl and Riahi (2000), '*research, development and demonstration efforts as well as investment decisions in the energy sector over the next two to three decades are critical in determining which long-term technological options in the energy sector may be opened, or which ones may be foreclosed*'.

Towards competitiveness?

It is often believed that climate policies should mainly aim to accelerate the introduction of carbon-free or carbon-lean energy technologies in competitive markets. Implicitly, this view supposes that sooner or later these technologies will become fully competitive on their own merits, and will be able to compete with increasingly scarce carbon emitting fossil fuels. Inherent in this view is that if we support pre-competitive technologies, they can ultimately take over in the market.

This perception tends to fuel the vision that technological change alone is the key for solving the climate change problem. But it may well be that this vision rests on an incorrect perception of market and technology dynamics.

The fossil fuel resource base contains much more carbon than the atmosphere can likely accommodate in a way that would respond to the ultimate objective of the climate change UN Convention. While all conventional oil and gas resources could be burned without driving CO_2 concentrations above a 450 ppm level, unconventional resources and, first and foremost, coal are plentiful and their full use would drive concentrations to very high levels.

Moreover, the fossil fuel industry has demonstrated a great capacity to react to changing energy prices by reducing costs through technological changes. In the early 1980s cost of oil from new deep-water platforms was estimated to be around US $25/bbl. Today such fields are still being developed with production costs of about US $ 10/bbl – thanks to many technical improvements.

Other technology refinements have effectively alleviated– at least to some extent –concerns for the local environment arising from the production and use of fossil fuels. Air pollution has been significantly reduced in developed countries. Environmental regulations have and will continue to add costs to using fossil fuels – although not necessarily enough to make them costlier than alternatives. 'Ancillary benefits' of CO_2 emission reduction strategies must be factored in, but there should be no presumption that fossil fuels will become uncompetitive if local environmental issues are given more weight in the future.

While some experts see current high oil prices as 'the beginning of the end' and the demonstration that global oil consumption is approaching a 'peak' after which production will hardly mach demand, others consider that the current shortage of production capacities result not only from the conjunction of various crises affecting oil production (Iraq, Russia, Nigeria, Venezuela and even Norway) but also from a deliberate lack of investments in the Persian Gulf. High oil prices, they say, will prove (again) self corrective and lead to another equilibrium through increased production capacities and reduced (growth rate of) demand.

While conventional oil and gas resources inexorably move toward eventual exhaustion, the magnitude of the coal resource suggests that almost any energy future will likely rest (at least in part) on coal, and may well include massive conversion of coal into synthetic fuels. Such technologies already exist and their deployment will likely drive costs down. There is no guarantee that non-carbon sources or capture and storage will ever be fully competitive with coal-based synthetic fuels for transport or home use – and even less with coal-fuelled electric power.

As a consequence, there is no guarantee either that strategies focussing on research and development (including dissemination efforts) of carbon-free technologies will ever be successful. This is particularly true if unchanged market conditions alone rather than pricing of climate change externalities are expected to ensure elimination of CO_2 emissions. Thus, the level of stabilised atmospheric CO_2 concentrations possibly achieved following strategies focussing exclusively on technological change 'push' is unknown.

Technology-focused vs. comprehensive policies

This section does not list all possible policy instruments that governments might use. A fuller examination of all possible instruments would have to include public procurements, outreach and education policies, agreements with industry, other fiscal instruments than taxes such as tax credits or accelerated amortisation, and others. Instead, the purpose of the section is to compares technology-focussed policy instruments, notably standards, and less specific instruments (such as taxes or emissions trading regime) likely to have indirect effects on technical change and innovation. It shows that technology-focussed instruments cannot fully substitute to more comprehensive ones – although they have their own merits and usefulness.

Subsidising R&D

Research and development subsidies are a traditional area for government policies. Results from R&D efforts have many characteristics of public good – in particular when investing companies face difficulties in ensuring excludability due to spill-over effects. As such, they are often undersupplied by markets. This is all the more true at early stages of technological development, when success is uncertain.

However, public funding for research and development in the energy sector have been declining over the last two decades and currently amount to 8 billion USD per year (IEA 2004c). Information about private R&D funding is less well known, but it does not clear that an increase on this side is offsetting the decrease on the other. More likely the overall energy R&D expenditures have been declining.

Developing advanced technologies requires not only applied research and technology refinement, but also the innovation that stems from advances in basic science. Knowledge flowing from basic research is what will feed the development of new approaches that could reduce clean technology costs. It could also lead to new, unforeseen technologies and novel approaches to providing energy services. Effective linkages between basic science and applied technology will be important to ensure that these opportunities are opened up (IEA, 2003f).

Public support to research and development can take multiple forms from direct support to public laboratories and universities to public-private partnerships, tax credits, and others.

Technology and performance standards

There are situations where technology and performance standards could prove an effective tool to disseminate effective and environmentally friendly technologies. For example, a recent IEA study looking at the energy consumption of appliances provides clear evidence that standards can address one area of market failure. Most households and small business do not care much about electricity costs – and those who do may not have the correct information on how to make savings, or the resources to make even the small up-front investments required. A softer kind of standard may be provided when the mandate is to give information to consumers rather than set limits on manufacturing. These often take the form of labels. Labels directly address the market failure arising from the lack of information of end-use consumers. They have already proven effective in most Member countries for appliances, sweeping the least efficient ones out of markets (IEA, 2003a).

Application of technology and performance standards is much more controversial from the industry perspective. Such concerns arise from clear economic principles: standards are usually considered more costly than market-based solutions. There are two reasons for this: (1) regulators cannot accurately know the abatement cost curves of all industries and (2) even if costs are known, implementing efficient reductions risks being perceived as unfair and faces strong opposition. Command-and-control regulations tend to force firms to take on similar shares of the pollution-control burden, regardless of the costs.

Another objection to standards is that they are often set at a more stringent level for new plants than for existing plants. While such differentiation seems legitimate – it is sometimes much costlier to adapt old plants than new plants to new standards – one possible perverse effect is to raise the costs of new plants and drive companies to prolong the lifetime of older, sometimes much more polluting installations.

Mandatory technology requirements could help eliminate the least efficient technologies from markets and promote the more efficient ones that are already available. However, they are usually ill suited to stimulating technical innovation, as they do not give any incentive to the development of even more efficient technologies. (OECD, 2001).

Performance standards can be of different types. The European Union traditionally tends to base required performance standards on either the ‘best available technologies’ (BAT) or ‘the best available technologies not entailing excessive costs’ (BATNEEC). In other developed countries, notably the U.S., governments or local authorities sometimes set more ambitious targets than can be met through existing technologies, with the aim of ‘forcing’ technology developments. This approach that has been suggested for dealing with climate change. However, while it has proven effective in some cases, in others it has not, for example the ‘zero emission vehicle’ percentage set in California. The standard proved too demanding for the auto manufacturers to meet – and the dates have been rolled back several times. The difficulty in setting over-ambitious standards is that regulators do not know the exact amount of improvement that is feasible; standards thus run the risk of being either lax or of being ultimately unachievable. To make things worse, companies often anticipate that political authorities will waive the target if technological improvements are insufficient, particularly if the consequences of enforcement would be very costly and politically difficult. The dynamics of incentives for innovation is unclear in such a case. While there remains a strong incentive for innovators, companies subject (even indirectly) to the regulation might prefer not to develop the appropriate technologies and lobby the authorities for their waiving the target. And in some cases – as in the automobile industry – only companies potentially subject to regulation have the financial and technical resources to fully develop radically new technologies. However, the California standard has clearly promoted the use of hybrids, and the global auto manufacturing effort to reduce emissions has been in large part driven by California laws. (Philibert, 2003).

Subsidising dissemination

A wide number of approaches have been taken to subsidise technology developments, from earmarked taxes to straightforward government (or government-run specialised agency) subsidies, to tax exemptions to other fiscal arrangements (e.g., allowing accelerated depreciation of clean investments). However, given public fiscal limitations, governments are increasingly seeking to have consumers rather than taxpayers subsidise renewable energy technology developments.

However, governments continue to provide direct subsidies to technology. Ongoing policies are a reaction – given the need to take action – to the difficulty in setting up market-based instruments such as taxes or a cap-and-trade system. While subsidies are a ‘second-best’ instrument, they are politically acceptable. It has also been argued that some technologies require further ‘learning’ investments to become competitive in markets – even if all externalities were fully incorporated into the price. Governments have a long-term interest in promoting more efficient technologies – in the case of climate change, carbon-free or carbon-lean technologies – and ensuring they will be available in the future at acceptable price. One way of ensuring this is to bring such technologies further down their learning curve; the tool for doing so is to subsidise them.

Taxes and cap-and-trade systems

Pigouvian taxes and cap-and-trade systems are not specifically designed to foster technical change but they do have innovation effects: both systems modify the price of using the commodity that creates the externality. As noted by Hicks (1932, 1963), ‘*A change in the relative prices of the factors of production is itself a spur to invention and to inventions of a particular kind – directed at economising the use of a factor which has become relatively expensive*.’

Generally speaking, cap-and-trade systems and Pigouvian taxes offer important advantages over more focussed policy tools. They are economically efficient by equalising marginal cost of reduction all over the board. They tend to foster technical improvements by ‘pulling the demand’, influencing a priori all behavioural elements in the technical change chain. Of course, taxes and cap-and-trade systems do not distinguish between the values of technical change versus behavioural change.

The efficacy of all market-based instruments, however, can be questioned from the viewpoint of ‘market failures’. Although they themselves are intended to correct the important market failure of ‘externality’ issues such as pollution, they are efficient if markets are efficient – and there are many other market barriers that may need to be overcome. Insufficient or incorrect information (for example, consumers do not perceive how costly it is to own a power-guzzling air conditioner) represent a vast category of market barriers that can be dealt with standards or labels, as discussed above.

However, from a technology development perspective, perhaps the most important ‘market failure’ is that created by the short-term vision of most economic agents. Even if agents and firms might anticipate future allowances to be further restricted under cap-and-trade systems, or future tax levels to increase, they might not engage in the extent of near-term technology development that would be required to allow deep reductions when they will be needed. This problem is one of timing – and inherently leads the market to invest in technologies that meet near-term goals rather than discounted, longer-term objectives. Thus, for example, actions in some sectors characterised by very long lifetime of infrastructures – such as building, or transport – might be too costly to implement; most of the benefits are only likely to materialise after agreed near-term caps are in place – say, after 2012. Similarly, the research, development and demonstration efforts needed to make some renewable energy technologies or other greenhouse gas mitigating options competitive in the long term may be too costly given their likely limited payback in the short term. This provides a compelling argument for policies and measures to complement those that exclusively seek to modify market prices.

Conversely, using only technology-focussed instruments to dealing with climate change is likely to be unsatisfactory, first because it may fail to price carbon emissions and thus make achieving competitiveness an impossible task for some low carbon emitting technologies; and second because it may fail to give enough incentives to early emission reductions, thus leading to higher concentration levels.

Although existing cap-and-trade systems have been based on legally binding targets for all participants, it is conceivable that some of them be given only ‘non-binding’ targets. While they would be able to sell allowances if their emissions were below their target they would not be supposed to cover any allowance deficit in the opposite case. It has been suggested that non-binding targets could help developing countries participate into any future international emissions trading scheme at no risk for their economic development (Philibert, 2000; Philibert & Reinaud, 2004).

CONCLUSION

Three main conclusions emerge. First, the depth and breadth of necessary cuts in global CO_2 and other GHG emissions to achieve stabilisation will likely require deep changes in our energy systems and technologies. Technology-focussed policies will be necessary, in particular to bring about the new technologies needed in the future, but comprehensive instruments aimed at providing direct incentives for emission reductions will be required to (i) price carbon and speed diffusion of existing low carbon-emitting technologies, thus allowing comparatively lower concentration stabilisation levels to be achieved; (ii) allow newly emerging technologies to benefit from learning-by-doing and become competitive.

Second, the need to pull developing countries into mitigation on a broader scale may require further elaboration of international agreements, in particular to provide incentives for developing countries to take part into forthcoming international emissions trading regimes. There is a variety of options for doing so, in particular the non-binding target option. International collaboration on research, development and dissemination of new technologies can speed the process (Philibert, 2004a). However, it can hardly substitute to the elaboration of an international regime mandating emission reductions.

Third, energy contexts and technological evolutions remain largely unpredictable. This should be an important consideration for negotiators in elaborating future international regimes; they will have to seek and develop the most appropriate ways to adapt and modify their objectives given the unforeseeable evolution of abatement costs – while still pulling effective mitigation action. This seems contradictory, but may not be so, as alleviating concerns arising from cost uncertainties might in fact help policy makers adopt more ambitious policies.

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Cross-Cutting Theme:
TECHNOLOGY IN AR4

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1. INTRODUCTION

Technology is a term with many uses and a long and rich history and literature[1]. For the purposes of the cross-cutting theme (CCT), we will refer to technology as the broad set of processes covering know-how, experience and equipment, used by humans to produce services and transform resources[2]. It is important to note that technology is not just devices. Devices can be part of technology, but devices alone do not define a technology. Technology includes devices, tools, and other artifacts and the ways in which they are employed by humans, individually and in the larger social setting. As a consequence, technology is a pervasive concept affecting issues addressed throughout the three working groups of the IPCC.[3]

The purpose of CCTs is 'To facilitate and improve cross Working Group co-operation and to achieve better integration and consistent treatment of key issues throughout the AR4.'

To this end, this paper seeks to provide guidance on how to treat technology in the three working groups of the IPCC in the AR4 in three different areas:
Consistency of assessment - the paper will discuss the need for a common set of definitions for technology components and technology systems, recommend qualities of technologies to be identified and characterized and to distinguish the role of technology from issues of costing and valuation;
Technological change - the paper will discuss the issues necessary to understand technology dynamics, the factors which determine technology creation, development, demonstration, deployment and diffusion and make recommendations for its consistent treatment.
Technology transfer - the paper will make recommendations for the treatment of new information regarding technology transfer, including the availability of mechanisms to understand technology transfer and diffusion, including appropriate references on capacity building, and on policies for fostering technology development and deployment.

There are many links between the CCT on technology and other CCT themes. This is especially true for the areas of water, sustainable development, and adaptation and mitigation. While numerous references will be made to these interactions, this document does not attempt to provide a comprehensive treatment of those interactions.

As a guidance paper, we do not seek to do the work of the lead authors in the AR4. This document is not a treatise on technology and climate change. To the extent that this paper discusses technology it does so to motivate thinking about technology as a cross-cutting issue. Neither does this paper seek to draw policy conclusions about the role of technology.

The remainder of this paper is structured in five sections. The next section erects an intellectual structure in which to consider technology and to motivate its consideration as a cross-cutting theme. Section 3 goes on to discuss the characteristics of technology important to their consideration in the context of climate change. Section 4 goes on to discuss the relationship between technology, its characteristics and cost. Section 5 discusses issues that are known to bear upon the way by which technology changes over time. The final section summarizes our guidance and recommendations for moving forward. Three appendices add a preliminary identification of the most important technologies for each WG. From these three texts it is possible to identify technologies, technology barriers and limits, sectors of human activity most relevant to and impacted by climate change in each of the IPCC Working Groups.

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[1] See Rip and Kemp (1999) for a discussion of technology, the variety of uses of the term, and a discussion of technological change in the context of human society.
[2] This definition is in keeping with the definition of technology transfer developed in IPCC (2000).
[3] The three working groups and their foci are:
- Working Group I assesses the scientific aspects of the climate system and climate change.
- Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it.
- Working Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.

2. TECHNOLOGY AS A CROSS-CUTTING THEME

Technologies relevant to the AR4 are deployed across all of human society. They can be aggregated or disaggregated. The flavor of technology is different in each of the working groups. For Working Group 1 technologies for measurement, monitoring, and verification (MMV), inventories, remote sensing, computation, and data management hold center stage. In Working Group 2 technologies such as those associated with agriculture, forestry, livestock, water (both fresh water and coastal zone management), space conditioning, energy supply (e.g. production in tundra or hydroelectric power), health, and technologies for dealing with extreme events, and minimally managed ecosystems as well as MMV are important features of the assessment. Technology is a pervasive issue in Working Group 3 as well. The energy system, including production, transformation, transport and storage, and energy utilization to provide energy services involves technology. But, important technology components and systems do not respect IPCC Working Group boundaries. MMV technologies are important to all three working groups. Agriculture (including crops, commercial biomass, pasture and livestock), land-use, forestry, water use, technologies appear in both Working Groups 2 and 3. Other examples can be found in the three appendices at the end of this document.

3. IMPORTANT CHARACTERISTICS OF TECHNOLOGIES

Technology Components and Systems: There is as yet no existing vocabulary that describes technologies in an exhaustive and mutually exclusive way. Technology descriptions exist for levels of aggregation ranging from the most general to the most particular. All of these levels of aggregation are relevant. None gives a complete picture. At the fine scale a technology description can identify a potentially important option for emissions mitigation, for example a fuel cell. A fuel cell[4] can use hydrogen (H_2) as a fuel input and produce only water vapor as an output[5], while providing electricity for stationary and mobile applications. Yet, absent a larger scale conceptualization of technology, important information relevant to mitigation is lost, namely the origins of the H_2. Depending on how the H_2 is derived greenhouse gas emissions may or may not occur.[6]

The electric power sector might be disaggregated into many individual technologies ranging from pulverized coal power plants to nuclear fusion. The focus on central power generation leaves important components of the overall system unaddressed. The application of dispersed generation to the buildings and industrial sectors is unaccounted. The effect of the grid and grid management technologies are unaddressed. The question of how to treat the application of a fuel cell that is deployed on a vehicle, but which is also employed by the user to provide energy services to a building is unaddressed. All of these pathways need to be incorporated in the AR4 analysis of technology. Similar issues arise for each of the sectors.

The important point is that there is an important distinction to be made between technology components and technology systems. Information from both is important and should be assembled within the AR4. Emissions mitigation and adaptation is the consequence of all interactions across all technologies in the economy. If technology components each provide smaller emissions than an alternative, yet changes in the composition of techniques raise total emissions, no net emissions mitigation has occurred. Thus, the aggregate economy provides the ultimate integration of technology components and systems and AR4 authors are strongly recommended to consider this level of aggregation.

MMV and Social System Technologies: MMV technologies are different in character from what might be called, 'social system' technologies. MMV technologies have relatively small impacts on the aggregate scale of human activities. As a consequence, the information that is important to understanding the role of MMV technologies will vary somewhat compared to the information important to understanding technologies that have extensive impacts on the scale of social systems. In some instances MMV technologies make possible the measurement and description of the characteristics of social system technologies.

Characteristics of MMV Technologies: MMV technologies make it possible to measure, monitor and verify processes and activities. This capability is important in all of the working groups. The technologies span a broad set of specific technologies (see the appendices). Nevertheless a common set of information is needed to understand their nature. Important characteristics include those given in Table 1:

Table 1: Characteristics of MMV Technologies

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4 A fuel cell itself is an aggregation over a variety of specific instances of the genre.

5 Despite the fact that water vapor is a potent greenhouse gas, it's concentration in the atmosphere is governed by far larger scale bio-geo-chemical processes.

6 If the H_2 is derived by steam reforming methane and the carbon is released to the atmosphere, there may be no net mitigation of greenhouse gas emissions. Similarly if the H_2 is derived using electrolysis, the source of the electricity will affect the system scale release of greenhouse gases to the atmosphere. Furthermore, the presence or absence of carbon capture and disposal technologies can change the picture yet again.

1	Description of technology
2	Trends in technology change (past)
3	Expected shift in future (with uncertainty)
4	Cost of technology (past and future)
5	Implications for change in technology on key issues in each of the Working Groups
6	Issues in transfer/diffusion of technology

Characteristics of Social System Technologies: Social system technologies are different than MMV technologies in that, by definition, they affect the scale of human activities. Having defined a distinction between technology components and technology systems it is useful to ask what kinds of information should be assembled? Table 2 provides a preliminary sample of the kinds of information that would be useful.

These characteristics define the technology component or system, describe the products or outputs of the technology including those which are desired and those which are unwanted (greenhouse gas emissions and pollutants), identify the factors that go into providing those outputs, and finally identify pathways by which changes in climate including for example, temperature, precipitation, CO_2, sea level, and extreme events. Thus, Table 2 can be viewed from the perspective of Working Group 3, for example, as considering technologies, and particularly potential future technologies in the context of potential concurrent climate change and adaptation. Consider for example, the production of oil and gas in high latitudes against a background of climate change. Or, consider the total and seasonal demand for electricity at various latitudes[7]. Table 2 can also be viewed from the perspective of Working Group 2, for example, as considering technologies, and particularly potential future technologies, in the context of potential concurrent emissions mitigation regimes[8]. It is important to note that values proposed in Table 2 are not specified in terms of financial flows.

Values for items in Table 2 may or may not be constants across sectors or regions or over time. For most technologies sufficient variation exists that some latitude is available in its implementation and operation. That is, it may be possible to grow the same crop using techniques which emphasize labor and capital differently. Economic cost of inputs can exert an influence on their employment even after production from a facility has begun.

Variation in values for Table 2 can also be expected by geo-political region. There will also be differences between new investments in technology and historical practice. These should be noted and documented. There is also no reason to believe that these values should be expected to remain static in time. These changes can affect both the new, frontier versions of the technology and existing technologies (via retrofit technologies and changes in management practice). Entry 2 in Table 2 implies that where resources are an issue, as for example with the abundance of fossil fuels, availability of wind or solar resources, geologic carbon reservoirs or other critical resources such as uranium or thorium, additional information must be provided. Information on the magnitude of both reserves and resources, by grade are needed. These data should include both resources that are available with present technology and those which could become available in principle. The latter concepts are particularly important to understand the role of technology over a 100-year time scale. At the 100-year time scale resource limits can begin to become important. However, over this time scale, the economically relevant fraction of the resource base can also change dramatically. Thus, resources that are not considered relevant under present circumstances, such as oil shales, could become relevant in 100 years under appropriate technology development scenarios.

Table 2: Technology Characteristics

7 At low latitudes electrical demand for space cooling could increase if climates warmed. At high latitudes electricity demand could shift from winter peaking to summer peaking.

8 For example water demands could be affected by the addition of commercial biomass crops as a major land-use activity.

1	Technology description, system boundaries. System connections, interactions with other technologies. What for example, is assumed about institutions and infrastructure?
2	Are there resource limitations. Are the resource limitations amenable to technological change? Are there deployment limitations associated with intermittency?
3	Output (units) per scale unit
4	Output Emissions of greenhouse gases per unit output
5	Output Emissions of non-GHGs and other pollutants per unit output
6	Health and safety issues per unit output
7	Production Inputs: capital (common discount rate)
8	Nominal technology lifetime (to be distinguished from the economic lifetime)
9	Production Inputs: labor (education requirements?)
10	Production Inputs: energy (form, common price)
11	Production Inputs: water
12	Production Inputs: land, other resources, exotic metals
13	Climate Interaction: Temperature
14	Climate Interaction: Precipitation
15	Climate Interaction: Direct CO_2 effect
16	Climate Interaction: Sea Level
17	Climate Interaction: Extreme events

4. TECHNOLOGY AND COSTS

Technology also interacts strongly with cost and valuation. The cost of making changes to the global energy-land-use-economic system to address climate change has been a contentious issue from the beginning. This is due at least in part to the fact that this notion of cost is framed as a difference. That is, the cost of a mitigation option is the difference between emissions associated with one technology option and another compared to the difference in the expected value of the two technologies.

Each technology produces desired and undesired outputs which have value, as well as employs resources that also have value. These values are set at a point in time, and often in the future. To understand the role of technology in climate change requires that technology characterizations be assembled technology by technology (as opposed to simply reporting differences between two alternatives), that valuation metrics including rates of return and values for inputs and outputs be developed separately, and that costs be reported as contingent on the valuation metrics employed. A clear description of technologies can go a long way toward illuminating the sources of disagreement.

The relative merit of different technologies in responding to climate change will depend importantly on the unit cost of resources employed by the technology, the value of the output(s) produced, as well as the value of the emissions and pollution mitigation[9]. Numerous examples exist of switch points. That is combinations of input prices and values of carbon at which technology choice is altered. For example, utilities might consider three choices in responding to a value of carbon for an existing coal fired power plant. They could pay the tax and continue to operate the facility. They could shift to a natural gas combined cycle unit, or they could purchase an integrated gasification combined cycle unit with carbon capture and disposal. The wealth maximizing choice depends not only on the value of carbon, but also on the prices of coal and natural gas. At low carbon values it is better for the operator to pay the fee and continue to operate the unit. At some point it is less expensive to replace the unit. The choice of replacement unit will depend on the value of carbon and the cost of natural gas. If gas is cheap, it pays to simply install a new gas unit. At higher values of carbon and natural gas the optimal choice changes and the installation of the integrated coal gasification combined cycle unit becomes profit maximizing. Collecting technology information, such as that recommended in Table 2, can facilitate a better understanding of these relationships by allowing comparison of technology options using common assumptions for input and output prices, emissions values, and rates of return.

The cost and relative desirability of a technology depends on valuation of both market and non-market goods and services. One of the reasons for accumulating information such as non-greenhouse gas environmental emissions, health, and safety characteristics is to enable the development of a fuller understanding of the character of technologies. The distinction between technology and valuation of cost is particularly important for non-market characteristics. Variation in valuation of non-market characteristics can be large at any time scale. Some of that uncertainty is due to the fact that non-market valuation of costs and benefits is an imprecise measurement. Prices are not observed in the open market and recorded on a regular basis. But, an-

9 Taxes and subsidies affect markets. The carbon tax is the obvious example.

other important component of this variation is due to the regional variety of valuations. Air quality for example, varies from place to place, and thus, values for non-greenhouse air pollutants also vary from place to place. This is not to undermine the importance of non-market valuation, but rather to recognize the degree of difficulty and uncertainty that surround these values.

Similarly, differences in the rate of return applied in the evaluation of the levelized cost of alternative technologies can also lead to very different results. As interest rates decline capital intensive technologies become more attractive relative to those that rely on non-capital production inputs. The appropriate rate of return to employ is the subject of substantial body of research. Focusing on the characteristics of technologies rather than the single, summary metric of cost can go a long way toward distinguishing whether or not the debate is over technology or other assumptions such as the rate of return on capital or background price assumptions for inputs and outputs.

The valuation of a technology can be dramatically different depending on whether the technology is in place or a new investment. Technologies with larger capital components will have a greater difference in valuation between *ex post* and *ex ante* occurrences. Once a technology enters into operation, capital no longer plays a role in determining its continued operation. Once built, a technology becomes a 'cash cow.' It will not be taken out of operation until it can no longer cover its operating costs. This can be an important point to bear in mind in the evaluation and comparison of technology options.

It is impossible to usefully compare technologies unless they are evaluated using a common rate of return and at uniform set of values for inputs and outputs (including both market and non-market). A financial flows version of Table 2 can be reported, contingent on a specific set of values of inputs and outputs set in a specific place and time. Because future values for inputs and outputs are uncertain the range of entries for the financial flows version of Table 2 will have a greater variance than the technical version of the table.

Technology characteristics also vary with scale. It is one thing to produce fuels from waste biomass, and another to produce tens to hundreds of Exajoules them from crops grown expressly for the purpose of providing energy. At small scale a technology can contribute to the global economy as a niche application. At large scale, the deployment of that technology can have implications for many other activities. Costs also vary with the scale of deployment. As we discuss below, becoming large scale is usually associated with falling costs. But, technologies can also expand beyond those instances in which it is most suited. For example, the deployment of commercial biomass crops can reach the point where it competes directly with other land uses. Increasing demands for land will inevitably increase the rate of return on land and therefore the cost of all activities that employ land. Scale effects can also press the limits of other resources as discussed previously.

5. TECHNOLOGY AND TIME-TECHNOLOGY DEVELOPMENT, DEMONSTRATION, DEPLOYMENT AND DIFFUSION

Technology is constantly under pressure to change. Even existing plant and equipment can find itself evolving in place. For example, old power generation boilers in the United States may have a nameplate that is 50 to 75 years old, but many of the components are far newer. Both the average practice and frontiers of technology are also evolving.

Average practice will vary from best practice both because there are often variants of a technology that can be deployed at any point in time, and the fact that there are pre-existing versions of the technology that have already been deployed. It is useful to distinguish between technologies that are widely available, those which are just entering the market, those for which demonstration facilities exist, and those under development. Such distinctions can be important in describing the existing state of technology.

There are at least four periods worth considering in the AR4. These are given in Table 3. It is important to document the distinction between the character of technology presently in place with its regional diversity, and the character of new technology investments that are currently available and being deployed. It is also important to distinguish between technologies that are in general use and those which my have niche deployment. The first entry in Table 3 asks for the distribution of technology that has been deployed over time. This may not always be a significant issue. But, where a technology has substantial historical vintages, that information can form an important point of reference in evaluating the role of technology in mitigation and adaptation.

Table 3: Time Frames for Technology Characterization

Period	Comment
Distribution of technology in place	Date of installation; Regional variation
Character of year 2000 investments	With range for parameters; regional variation
2020 Technology development	With uncertainty as it appears in the literature
2050 and beyond	Technology potential With uncertainty as it appears in the literature

While technologies clearly change over time, the processes which change technologies are only partially understood. Technological change includes both the creation of entirely new technologies which did not previously exist[10], the evolution of existing technologies, and the migration of technologies that already exist from place to place, sector to sector, or environment to another.

The creation of entirely new technologies is usually associated with research and development (R&D). R&D itself comes in a variety of different types. One type of research is curiosity driven. While this type of research is unlikely to develop any particular type of technology, it can create the knowledge base upon which purposeful research can build[11]. There is also research motivated by a desire to develop a fundamental understanding of nature, but which is motivated by potential use. Such research holds the potential to more quickly lay down the foundations upon which to build subsequent technology. It is also possible to pursue research motivated primarily by the development of new applications, but without any motivation to acquire a fundamental understanding of basic natural processes.[12]

The mechanisms by which best available technologies evolve in the context of a fixed regime of scientific knowledge have been categorized but are primitive in their predictive value. These include:
1. Applied research
2. Learning
3. Scale economies
4. Adaptation of technologies from related sectors and regions
5. Serendipity.

The rate of technology development, demonstration, deployment and diffusion depends on actions in both the public and private sectors. Both have roles as do institutions and social settings. In market economies R&D can be affected by expected profits, and declining energy prices can signal the decline in investments. Institutions can also play a role. Deregulation of energy sectors frequently coincides with reductions in sectoral investments in long-term energy R&D. Investment in basic science is generally regarded as subject to underinvestment that is the consequence of inappropriability and is generally considered an appropriate province for government intervention. The interface between public and private R&D is not well-defined and relative roles and appropriate interactions differ from society to society and over time. Spillover effects can be extremely important. Technology developments in one sector may be impossible until developments in other unrelated sectors occur. 3-D seismic technology in the oil industry required the development of advanced computational machines and CAT scan technology. The natural gas combined cycle turbine was made possible by advances in aircraft turbine technology.

The gap between 'best' and existing practice can be large. As noted above this will invariably be the result of a wide array of factors ranging from the presence of existing capital stock to differences in information, economic, social and institutional circumstances.

The IPCC prepared a special report on this question, which summarizes the literature in this field (IPCC, 2000). This report defines the term 'technology transfer' as a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, NGOs and research/education institutions. Therefore, the treatment of technology transfer in that Report is much broader than in the UNFCCC or of any particular Article of that Convention. The broad and inclusive term 'transfer' encompasses diffusion of technologies and technology co-operation across and within countries. It covers technology transfer processes between developed countries, developing countries and countries with economies in transition, amongst developed countries, amongst developing countries and amongst countries with economies in transition. It comprises the process of learning to understand, utilise and replicate the technology, including the capacity to choose and adapt to local conditions and integrate it with indigenous technologies.

[10] Of course, in a world in which there is nothing that has no origins in anything else, the notion of an entirely new technology is somewhat contrived.

[11] Stokes (1997) refers to this type of research as Bohr's Quadrant. Bohr's Quadrant research is motivated by a desire for fundamental understanding, but unmotivated by any potential further application. Stokes contrasts this to Pasteur's Quadrant, which is motivated by use as well as a quest for fundamental understanding (p.73).

[12] Stokes (1997) refers to this type of research as Edison's Quadrant.

Technology for mitigating and adapting to climate change interacts strongly with other environmentally considerations and sustainable development. Sustainable development on a global scale will require radical technological and related changes in both developed and developing countries. The fastest rates of economic development are found in developing countries, but it will not be sustainable if these countries simply follow the historic greenhouse gas emission trends of developed countries. Development with modern knowledge offers many opportunities to avoid past unsustainable practices and move more rapidly towards better technologies, techniques and associated institutions. The literature indicates that to achieve this, developing countries require assistance with developing human capacity (knowledge, techniques and management skills), developing appropriate institutions and networks, and with acquiring and adapting specific hardware. Technology transfer, in particular from developed to developing countries, must therefore operate on a broad front covering these software and hardware challenges, and ideally within a framework of helping to find new sustainable paths for economies as a whole (IPCC 2000, Technical Summary).

Of special note is the role of national and regional innovation systems. These hold the potential to accelerate the diffusion process geographically and across sectors. Special note should be taken of progress since IPCC (2000) in each of the working groups.

Prices and markets play important roles in providing signals to decision makers regarding directions in which to apply efforts to develop, demonstrate, deploy and diffuse technologies. Those forces are frequently supplemented by technology policy. Interactions between sectors of the economy can be extremely important. Other sectors of the economy interact in two ways. They provide a source of existing technologies that are available to be mined, generating spill-over that can be extremely large. For example, the integrated combined cycle gas turbine was the result of investments in military technology to develop improved aircraft engines. The application of resources in any field also means that those resources are unavailable for use in other applications. To the extent that technological progress in the energy sector, for example draws resources away from the pursuit of other ends, progress in other sectors of the economy is retarded thus imposing a cost to society. One factor contributing to the dramatic and persistent decline in energy R&D is the fall in energy prices post 1986.[13] Reductions in energy prices mean reductions in expected profitability on investments in energy R&D. Other things equal, this should in turn lead to shifts in R&D resources from the energy sector to other parts of the economy. This having been said, there has been little economic incentive to develop and deploy new technologies that would address climate change.

6. RECOMMENDATIONS

Information about technology needs to be assembled in a consistent way across all of the working groups. The foregoing discussion can be summarized in a series of recommendations to authors as they go about their duties in the AR4.

Recommendation 1: Describe MMV technologies in terms of characteristics identified in Table 1 wherever possible and identify knowledge gaps wherever this proves impossible.

Recommendation 2: Describe social system technology components and systems in terms of characteristics identified in Table 2 wherever possible and identify knowledge gaps wherever this proves impossible.

Recommendation 3: Provide technology characterizations in Table 2 for the time periods identified in Table 3 wherever possible and identify knowledge gaps wherever this proves impossible.

Recommendation 4: Keep technology characterizations separately from cost and valuation. This is particularly important when considering such issues as,

- Scenario dependence of market prices,
- Inherent uncertainty surrounding non-market valuation,
- Variation in rate of return values (e.g. social discount rates versus observed internal rate of return requirements), and
- Valuation of existing capital stocks versus potential investments.
- Create a financial version of Table 2 for time periods described in Table 3.

Recommendation 5: Assess the impact of scale on technology characterizations-what may be feasible for niche technologies may be impossible for major technologies.

[13] It is certainly not the only factor. Other factors that have been suggested as contributing to the decline in public and private sector energy R&D include deregulation and the desire by governments to balance their budgets.

Recommendation 6: Provide a unified statement of present knowledge regarding technological change - the creation and deployment of new technology options as discussed in Section 5. This is a general statement that summarizes the forces that determine the general rate of technological change in economies as well as the rate of advance of particular sub-system and components.

To accomplish this end we further recommend that the IPCC convene a small working group with members drawn from across working groups to jointly write an assessment of the present state of knowledge of technological change (see Recommendation 6 and Section 5). This section would provide a common point of reference to which authors in all of the Working Groups could point.

Recommendation 7: Assess developments in understanding of technology transfer since the special report, *Methodological and Technological Issues in Technology Transfer*.
To accomplish this end we further recommend that the IPCC convene a small working group with members drawn from across working groups to jointly write an assessment of the developments in understanding of technology transfer since the special report, *Methodological and Technological Issues in Technology Transfer* (see Recommendation 7 and Section 5). This section would provide a common point of reference to which authors in all of the Working Groups could point.

Recommendation 8: Convene a small working group with a representative from each of the working groups to identify system boundaries and definitions for technology components and technology systems. This work is intended to provide a consistent vocabulary that can be used in describing technology across the working groups. This group would be tasked to provide a list of specific definitions for technology components and technology systems that should be considered in the AR4. As necessary this group should draw on expertise from the professional community.

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APPENDIX 1: TECHNOLOGY IN THE CONTEXT OF WORKING GROUP 1

Working Group I's mandate is to assess the scientific basis for climate change, which provides the fundamental background and context for any discussion of technology in the climate change arena. Thus, its assessment of process-level scientific understanding forms the scientific cornerstone for understanding the needs for and impacts of technological developments in mitigation and adaptation assessed in other WG's. The assessment of climate impacts is especially closely tied to the assessment of the physical processes underlying climate change, and other sections provide a clear and illustrative synthesis of many and broad relevant impacts and physical climate issues including clouds, water vapor, coastal zones, extreme events, etc.; that discussion will not be repeated here.

The IPCC Special Report on Safeguarding the Global Ozone Layer and the Climate System presently underway provides an example illustrating WGI's specific role in providing the scientific basis for a key environmental issue. In that report, WGIII's role is to evaluate technological options that relate to possible mitigation solutions while WGI provides the scientific basis in process understanding that underlies the need for them.

WGI's assessment of climate models provides the tools to evaluate how a given change in concentration of a GHG or aerosol will likely influence the climate system, with full account taken of key competing processes, feedbacks, atmospheric transport, chemical conversions, and other relevant processes. WGI uses IPCC-approved emission scenarios to assess future climate changes in a range of complex ocean-atmosphere GCMs. These in turn are used particularly within WGII for assessment of impacts and related technological issues, as discussed in Section 3 above. WGI also assesses the capabilities of simpler models.

Simple Climate Models (SCMs) are frequently used in studies of mitigation and related technological options analyses. The key properties of complex ocean/atmosphere climate models need to be carefully reflected in these simpler models to ensure their accurate representation of key feedbacks and phenomena. In the AR4, it is likely that published studies using Earth Models of Intermediate Complexity (EMICs) to evaluate technological issues relating to mitigation options and their effects will also need to be assessed. WGI's assessment of the full range of models and their inter-relationships will provide the foundation and guidance regarding use of these tools for the evaluation of a corresponding range of technological options throughout IPCC.

Technologies for the measurement of key climate variables are a component of the evaluation of observing systems in Working Group 1. This is an area that also intersects strongly with activities in Working Groups 2 and 3. A hallmark of the scientific literature in climate change processes and hence in the assessment of WGI is a systems-based approach that carefully considers the composite picture provided by observations by a range of different techniques including ground-based, in-situ, and satellite observations, and their comparison to models. These considerations apply across atmosphere, ocean, ice, and land-based aspects of climate change processes, trends, and understanding. It is, however, noteworthy, that the uncertainty in many observations is often considerably smaller than the uncertainty in understanding of physical processes and models. Thus technological issues in observing systems are most often related to possible approaches to advance our understanding, but less so to many of the most important questions regarding current understanding.

APPENDIX 2: TECHNOLOGY IN THE CONTEXT OF WORKING GROUP 2

Human activities experience the effects of changes in climate and atmospheric composition. Energy production and use are affected. Agriculture, forestry and other land uses are also affected. Hydrologic systems (see the Water CCT) are a major potential point of impact. In addition, there are potential impacts from changes in climate and atmospheric composition on environmental pollutants and health. Coastal zones are potentially affected from sea level as well as the direct effects of climate and atmospheric composition. The interface between human society and climate change is invariably mitigated by technology.

Developing countries tend to be more vulnerable to climate change than developed countries. Developing countries are expected to suffer more adverse impacts than developed countries[14]. This is due in part to simple geographical location as present climatic conditions in the low latitudes are already sub-optimal. This means that technologies able to create agricultural varieties more resistant to warmer weather, as well as technologies successful used in irrigation will be extremely important to face climate change in the tropical countries. Such technologies need to be pursued everywhere and especially in the presently developed nations, and subsequently deployed to and between the presently developing nations.

Extreme weather events frequency and magnitude increase would have adverse effects through sectors and regions[15]. Heat-related mortality is likely to increase with higher temperature. On the other hand availability of indoor temperature control is restricted to a small share of the population living in developing countries due its high initial cost and due its electricity demand. Passive cooling process should be more used and investigate. These technologies may have more economic feasibility than active indoor weather control. Houses and buildings must be designed with the help of these technologies, including popular households. It should include urban planning, as well as an-conditioning systems.

Floods and high temperature may lead to the spread of water-related and vector-borne diseases. Sanitation technologies must be further developed in order to prevent the occurrence of such diseases at a more modest cost. Technology transfer of chemical and biological products preparation, as well as for their application must occur. It is also important more investment in urban planning.

Not all climate impacts are linear. In some instances non-linear impacts can occur such that relatively small changes in macro variables such as global mean temperature can lead to large impacts on living conditions and the quality of life. For example, urban air quality may be of this character. Technology can play a critical role in moderating the adverse effects of climate change on air quality through the application of technologies to mitigate the sources of pollution. Such technologies could provide better emission and traffic control[16], either by fostering public transportation, or by reducing emission from vehicles through the use of catalytic conversions, smoke stacks, and better quality of the fuel.

Extreme weather events may cause more challenges to transmission and distribution electricity networks and to specific industries related to agro-activities, tourism and construction. Better technologies must be used in electric grids and construction must be designed to be resistant to floods and land slides and able to provide comfort level even at extreme temperature. Tropical cyclones, tornadoes, ice storms, which may increase in hot weather[17] are other challenges for buildings and transmission systems of electricity, asking for better technologies. Such technologies must be mainly available to protect large urban areas in developing countries. And they should be used intensively due the probable migration of rural communities to these centers induced by adverse climate change weather. Adaptation to the consequences of climate change will be needed, but can be costly, particularly using present technology. Mitigation to large urban centers should foster air quality problems and this is one more reason to invest in a preventive way in better air quality.

Protection of coastal urban settlements due to sea level requires construction of walls, which requires very good technologies to keep cost low. A 40 cm sea water rise will cost tens of billion US dollars for some countries like Egypt, Poland and Vietnam.

Extreme heat and cold waves can be disruptive to the resource base (e.g. agriculture, human health, and demand for heating and cooling). Technologies to guarantee more electricity, transportation, and protection to agriculture from hot and cold weather may be needed.
Planning may be necessary for settlements and their infrastructure, and for placement of industrial facilities to reduce the adverse effects of events that are of low (but increasing) probability and high (perhaps rising)

[14] IPCC 2001b, p.287.
[15] IPCC 2001b. p.288
[16] IPCC 2001b, Table TS-5, p.261.
[17] IPCC 2001b p.255.

consequences. Soft technologies like market based tools for pollution-control, demand management and waste reduction, mixed-use zoning and transport planning, environmental impacts assessment, capacity studies, strategic environmental plans, environmental audit procedures, and state-of-the environment reports[17].

Coastal Zones due the increases in sea-surface temperature, sea level, decrease in sea-ice cover, changes in salinity, wave climate, and ocean circulation may suffer economical consequences due decrease in fishing activities[18]. Adaptation by expansion of marine agriculture may partly compensate for potential reduction in ocean fish catch. Marine agriculture, which is growing, may be limited by ocean stocks of herrings, anchovies, and other species used to provide fishmeal to feed cultured species. Also, decreases in dissolved oxygen level associated with increased seawater temperatures and enrichment of organic matter creates conditions for the spread of diseases in wild and agriculture fisheries[19]. Pollution and habitat destruction that can accompany agriculture also may place limits on its expansion and on the survival success of wild stocks[19]. Technologies for better management of agriculture sites and for other fodder development are important ways for adaptation. Episodes of coral bleaching over the past 20 years have been associated with increasing ocean temperatures. Future sea-surface warming would increase stress on coral ruffs and results in increased frequency of marine diseases[19] impacting fisheries. Technologies may be needed to control marine diseases in areas where fisheries are important.

Coastal areas may also require more elaborate technologies to face drainage problems that are showing up due to sea-level rise. In heavily populated areas subsurface waters withdrawals are a common practice to fulfill water demand. This action combined with sea-level rise drives salinization of potable groundwater. Technologies for providing drinkable quality water to these regions may be needed to avoid water shortages.

Since the SAR adaptation strategies for coastal zones have shifted in emphasis away from hard protection structures toward soft protection measures (e.g. beach nourishment), managed retreat, and enhanced resilience of biophysical and socio economic systems, including the use of flood insurance to spread financial risk. In particular beach nourishment may require transportation of significant amount of land and technologies to perform such tasks (e.g. ducts) may become important.

Managed forests adaptation will include salvaging dead and dying timber, replanting new species that are better suited to the new climate, planting genetically modified species, and intensifying management[20]. This means that technologies dealing with genetic modifications, and with tree nursery, may be well demanded.

Inland water is vulnerable to climate change and other pressures owing to their small size and position downstream from many human activities. The most vulnerable elements include reduction and loss of lake and river ice, increases in extinction and invasion of exotics, and potential exacerbation of existing pollution problems such as eutrophication, toxics and acid rain[19]. This means that to reduce pressure over such vulnerable elements a more efficient control of human promoted pollution may be desirable. Technologies to treat water and soil pollution may be used more often and require improvements.

Degradation of soil and water resources is one of the major future challenges for global agriculture. Those processes are likely to be intensified by adverse changes in temperature and precipitation. Land use and management have been shown to have a grater impact on soil conditions than the indirect effect of climate change. Thus, adaptation has the potential to significantly mitigate these impacts[21].

Climate directly affects energy usage, which in turn affects technology selection and performance. For example, rising temperatures, particularly in the winter will reduce winter heating requirements. The same phenomenon will also increase summer cooling requirements. In lower latitudes rising temperatures will increase cooling requirements particularly in places where development is occurring and increasing portions of the building sector are being cooled.

Energy production technology will also be affected. For example, natural gas production at high latitudes relies on winter freezes to work natural gas gathering pipelines. Present technology involves movement of heavy equipment, which is impossible unless the ground is frozen hard. High latitude pipelines, built over permafrost, could also be challenged. Significant warming would require shifts in technology. Another example is hydroelectricity production. Climate changes may impact rainfall distribution over time and site. This means that river flow can change impacting electricity production.

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18 IPCC 2001b, p.252.
19 IPCC 2001b, p.253.
20 IPCC 2001b, p.251.
21 IPCC 2001b, p.249.

APPENDIX 3: TECHNOLOGY IN THE CONTEXT OF WORKING GROUP 3

The literature on technology is deep and growing with regard to Working Group 3. Working Group 3 assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change. Greenhouse gas related emissions flow from an extremely broad array of human activities all of which are mediated by technology.

Because the most important greenhouse gas is carbon dioxide (CO_2), and CO_2 is released in the combustion of fossil fuels, the backbone of the present global energy system, it is impossible to discuss greenhouse gas emissions without discussing the global energy system. This includes the technologies used to produce, transform, transport, store, and utilize energy. Because the utilization of energy is involved in virtually every human activity from the conditioning of the spaces in which human live and works, to the movement of passengers and freight, to the creation of objects and services, the breadth of the technology suite involved in understanding the global energy system is immense. In addition, some specific industrial practices produce CO_2 emissions as a consequence of the process itself, in addition to emissions associated with fossil fuel use.

Through technological progress it was possible to reduce energy intensity[22] in the last 100 years. It had also been possible to reduce carbon intensity[23]. Nevertheless, these decreases were modest and if they continue at the same historical rate they should be unable to bring GHG concentration to levels below 550ppm at the end of the century[24].

MAJOR RELEVANT CONCLUSIONS FROM WG III REGARDING CLIMATE MITIGATION THROUGH ENERGY TECHNOLOGIES ARE:

Disperse technological improvement must be pursued, but it is not enough to reduce GHG atmospheric concentration below 550ppm.

Technologies to be used in appreciable amount up to the year 2020 are already developed, either commercially or in final stage of development.

Technologies under planning or at early stages of development will be able to make significant contribution on climate change only after 2020.

Available technologies or the ones at the early stages of market introduction could reduce GHGs emissions, at world level, up to 2020. Some have negative costs and some may costs up to US$100/tC[25].

Major barrier for such technologies to diffuse more quickly are of economic and socio-economic origin.

Economic barriers could be overcome by market creation, reduction of market failures, and increased financial and technology transfer. In particular, there are large evidences that by increasing their market participation marginal technological improvements bring costs down. Most of these cost reductions obey a general rule and usually each doubling of production reduces cost by only 10 to 20%.

Socio-economic barriers should be addressed simultaneously with economic barriers.

Energy efficiency improvement can occur in the supply and demand side. In the short term (up to 2020) demand side energy has better prospects to make larger contribution than supply-side. This is essentially due to the large inertia in the supply-side where investments have a longer return period.

In the energy demand side technologies that can make significant contribution to climate change are:
energy savings in buildings (construction & operation)
automobile efficient improvements in manufacturing process
natural efficient improvements in manufacturing process.

Changes in land-use constitute an additional source of net flux of carbon to the atmosphere. In principle, land-use changes can generate either positive or negative emissions.[26] Land-use emissions are tied both to

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22 Energy intensity is defined as energy use per unit of value added.
23 Carbon intensity is defined as carbon emission per unit of energy used.
24 IPCC 2001b. Q5,
25 Cost evaluation for this conclusion considers only economic cost (investment and energy saved values).
26 Though the present balance is thought to be positive with net emissions of 1.6±1.3 petagrams of carbon per year. IPCC (2001a).

technology and society. Technology plays an important role. Relevant technologies cover a broad suite ranging from the explicit use of soils and standing biomass stocks as carbon reservoirs to the means by which crops are produced, harvested, stored, and distributed. The concentration of soil carbon is affected by cropping practices. The extent of lands engaged in cropping, pastures, and forestry depend on productivity as well as the demand for the services provided by crops, livestock and forest products. The use of biomass for energy is a potentially important point of intersection between the land-use and energy systems.

CO_2 is not the only greenhouse related gas. A variety of other gases have either direct or indirect effects on the radiative balance of the planet. These include methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), ozone, and such manufactured gases as the chlorofluorocarbons, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexaflouride (SF_6). Aerosols and dark particles exert a strong influence on climate, particularly locally. Finally, gases such as carbon monoxide and nitrogen oxide compounds (NO_x) are not major greenhouse gases in their own right, but do play indirect roles in determining the concentration of greenhouse gases such as ozone and methane.[27] All of these gases have anthropogenic sources and associated technologies.

Methane, for example is associated with energy production and use (coal mining and natural gas production and transport). Landfill emissions constitute another important source with a potential overlap with the energy system, as technologies exist for capturing and utilizing the methane releases from landfills. Beyond those sources methane release is associated with wetland rice cultivation and ruminant livestock. Agricultural practices such as slash and burn agriculture constitute another source of a wide array of greenhouse related emissions.

Similarly nitrous oxide emissions have origins lined to technology, including emissions from the cultivation of soils, with and without the application of fertilizers, as well as specific industrial applications such the production of adipic acid. As the nitrogen budget is not closed, additional anthropogenic links to technology may emerge.

Gases such as HFCs, PFCs, and SF_6 are of human origin. Both the process by which they are produced and losses occurring with their employment are associated with technology and therefore must be considered. HFCs, PFCs, and SF_6 are sometimes referred to as 'high GW_p' gases, as they have high global warming potential coefficients[28] and long lifetimes implying that on a per molecule basis, these gases can exert an extraordinary degree of change to the Earth's energy balance. Emissions of these gases are associated with technologies that are as diverse as aluminum production, space conditioning (in buildings and transportation), foam blowing and the manufacture of semiconductors.

The production of aerosols and dark particles is entirely different in character from the high GW_p gases. Here sources are more similar to those of CO_2. Yet they are not identical and emissions coefficients are greatly different. Sulfate and organic compounds originate from emissions of sulfur dioxide, organic gases, and smoke from the burning of fossil fuels and vegetation. Specific technologies such as smelting can also be important.

[27] The Kyoto Protocol (United Nations, 1997), was negotiated under the United Nations Framework Convention on Climate Change (FCCC), but as of the writing of this paper has not entered into force. It placed limitations over emissions if the following greenhouse gases: CO_2, CH_4, N_2O, HFCs, PFC, and SF_6.

[28] One measure of per molecule impact of various gases on the Earth's radiative balance is the global warming coefficient (GWP). The GWP compares the release of on kilogram of a gas on the Earth energy balance over a specific period of time, e.g. 100 years, to the release of one kilogram of CO_2. The 100-year GWP for CH_4 is 23, while the GWP for N_2O is 296. The lifetimes for these gases are approximately 12 and 114 years respectively. See IPCC (2001a). GWPs for SF_6 and HFC-23 are 22,200 and 12,000 respectively. Their lifetimes are 3,200 and 260 years respectively.

ENERGY INTENSIVE INDUSTRY BREAKOUT GROUP

The IAI Global Aluminium Sustainable Development Initiative

Robert Chase
Secretary General,
International Aluminium Institute
22 September, 2004

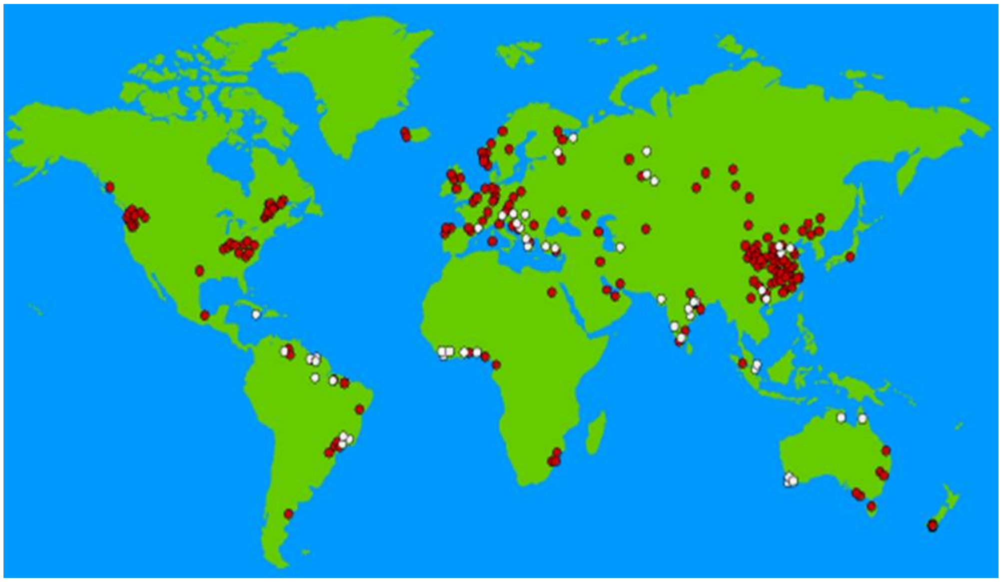

Figure 1: Global distribution of bauxite mines (o) and aluminium smelters (●)

Primary aluminium producers are split 50/50 between OECD and Non OECD countries, developed and developing in terms of world production – so the Industry needs a global approach tailored to all regions. Because aluminium is a global commodity, Stakeholders are also looking for common standards as regards sustainability criteria. Any local underperformance in whatever region of the world is likely to be picked up in this era of mass communication. It will reflect badly on the Industry as a whole and undermine the image of the metal. It is encouraging to note that some of the best performing and most energy efficient plants are located in developing economies such as Brazil, Mozambique and Argentina, which demonstrates that excellence can be achieved throughout the world, if the workforce are provided with the correct technologies and training.

The Industry needs to take account of the priority concerns of outside stakeholder groups, which include; the decoupling of economic growth from resource consumption; Assurances over raw material availability in the future, the rate of depletion and the minimising of waste. Stakeholders are looking for assurances that the aluminium industry can grow and still reduce its greenhouse gas emissions.

The Aluminium Industry has therefore opted for a global response to these concerns, the Aluminium for Future Generations Initiative, which is reinforced by parallel action by the national and regional aluminium associations. The Initiative is a voluntary undertaking by the Institute Members, 26 CEOs representing over 70% of world production. In the words of the IAI Chairman Travis Engen 'The Initiative unites IAI's Member companies in their shared commitment towards sustainable development across the three pillars of environmental footprint, economic growth and social progress. It is an essential requirement for our industry's success and long-term future'. Figure 2 shows eight Voluntary Objectives of the Initiative.

Global Aluminium Industry Sustainable Development Objectives

1. An 80% reduction in Perfluorocarbon (PFC) greenhouse gas emissions per tonne of aluminium produced for the Industry as a whole by 2010 vs 1990;
2. A minimum of a 33% reduction in fluoride emissions for the Industry as a whole per tonne of aluminium produced by 2010 vs 1990. This target figure to be reviewed after 3 years;
3. A 10% reduction in smelting energy usage for the Industry as a whole per tonne of aluminium produced by 2010 vs 1990;
4. A 50% reduction in the Lost Time Accident Rate and Recordable Accident Rate by 2010 vs 2000 for the Industry as a whole, with a review of the 50% target in 2006;
5. Implementation of Management Systems for Environment (including ISO 14000 or equivalent certification) and for Health and Safety in 95% of Member plants by 2010;
6. Implementation of an Employee Exposure Assessment and Medical Surveillance Programme in 95% of Member plants by 2010;
7. The Industry to monitor its recycling performance globally and to use the data to establish a voluntary target. The Industry will develop a global action programme in support of the voluntary targets, thereby encouraging a significant increase in the volume of aluminium metal from old (post consumer) scrap;
8. The Industry will monitor annually aluminium shipments for use in transport in order to track aluminium's contribution through light-weighting to reducing greenhouse gas (GHG) emissions from road, rail and sea transport.

Figure 2: Eight Voluntary Sustainability Objectives Adopted by the Global Aluminium Industry

To assist Member companies to achieve these voluntary objectives the Institute has available a team of Consultants recruited from recently retired top technical experts from the industry, who can provide advice and training on good practice.

Twenty-two Performance Indicators were developed designed to encourage an improved performance by the Industry in all 3 aspects of Sustainable Development.

TWENTY–TWO SUSTAINABLE DEVELOPMENT PERFORMANCE INDICATORS

Environmental:

1. Global PFC emissions and average PFC emissions per tonne of aluminium produced;
2. Aluminium shipment to the transportation sectors;
3. Global annual total of old and new scrap recycled and the total of the resulting metal;
4. Fresh water consumption (m^3 per tonne of aluminium produced);
5. The global percentage of plants with EMAS and/or ISO.14001 qualifications for environment as well as the global percentage of plants that have Health and Safety management systems in place;
6. Average land used for mining and percentage of mined areas rehabilitated annually;
7. Global SO_2/BaP/Particulate emissions and average emissions per tonne of aluminium produced;
8. Global fluoride emissions and average fluoride emissions per tonne of aluminium produced;
9. The Global Energy Mix showing energy use, including renewable resources, for aluminium production;
10. Tonnes of bauxite residue deposited per tonne of alumina produced; tonnes of spent pot lining deposited per tonne of aluminium produced; percentage of bauxite residue and spent pot lining processed or re-used; tonnes of salt slag deposited from dross sent for processing by Member Companies, per tonne of aluminium produced;
11. Global GHG emissions (CO_2 equivalents) and average emissions per tonne of alumina and aluminium produced.

Economic:

12. Global primary aluminium and alumina production statistics;
13. Use of aluminium (as consumption per head of the population);
14. Contribution to GDP (measured as net-added value);
15. Total direct employment (to include an indication of the indirect employment multiplier effect);
16. Level of investment (to include new assets, maintenance, environmental protection and research and development);
17. The wages ratio (average aluminium wages as compared to the national average wages).

Social:

18. The global percentage of plants with formal mechanisms for consulting the local community;
19. Percentage of plants with workforce training/education schemes and youth employment programmes. (Training performance/hour/person/year);
20. Community Initiatives to improve health, education, environment and the local community;
21. The global percentage of plants that have employee exposure assessment and medical surveillance programmes;
22. Global Recordable Accident Rate (number of recordable accidents per million working hours) and Global Lost Time Accident Rate (lost time accidents per million working hours).

Many of the best performers are operating in non-OECD countries, where some governments do not regulate GHG emissions. Despite this lack of regulatory pressure, the companies are still participating in the Industry's global effort to reduce its greenhouse gas emissions and environmental footprint. As can be seen in Figure 3 a number of the key indicators are already moving in the right direction e.g. emissions, energy consumption – accidents are all on downward curve.

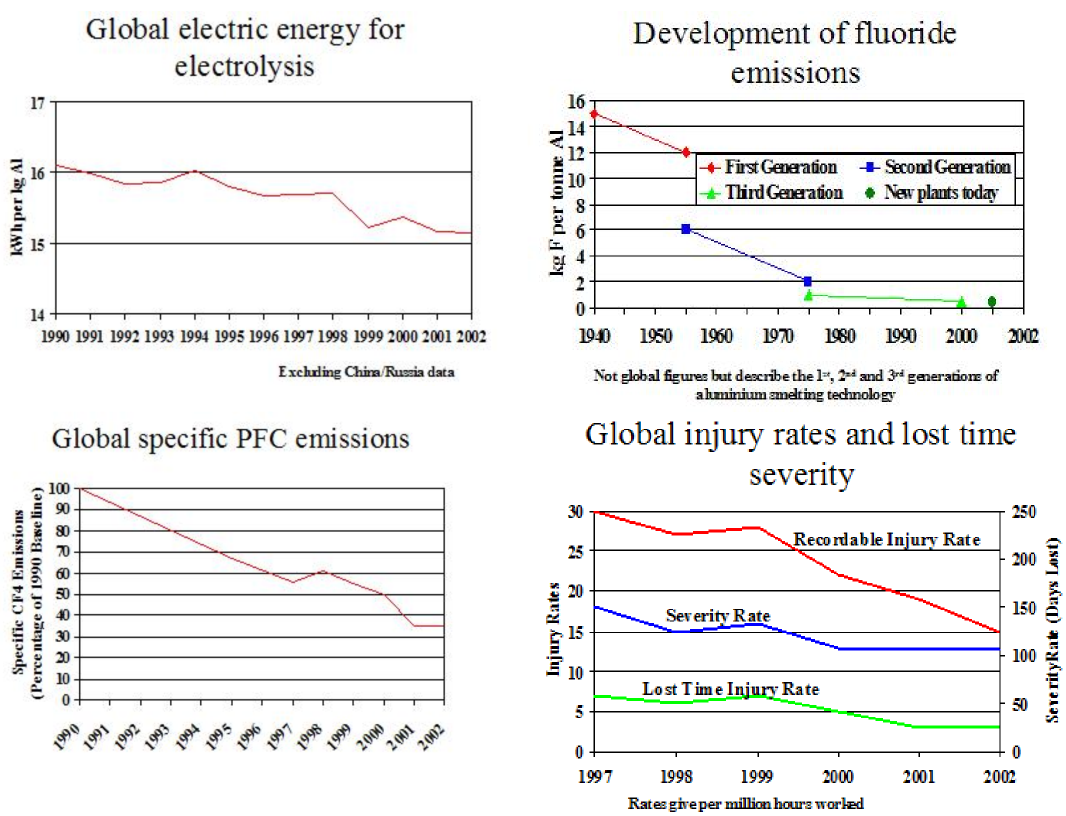

Figure 3 Performance on Global Sustainability Key Performance Indicators

A key part of this Initiative is the programme to make the Industry less greenhouse gas intensive. In particular how to achieve the Voluntary Objective of an 80% reduction in PFC emissions per tonne of aluminium produced

In judging the performance of materials the aluminium industry strongly supports a total life cycle view.[29] The aluminium life cycle is shown in Figure 4. The aluminium industry has identified three ways at different stages in the life cycle of aluminium to reduce its greenhouse gas emissions.

1. Reducing perfluorocarbon emissions per tonne of primary metal produced through investment in modern technology and greater attention to good operating practices;
2. Maximising the potential for aluminium recovery and recycling;
3. Encouraging applications of aluminium in transport, which reduce weight and greenhouse gas emissions from transport, a sector responsible for a third of GHG emissions globally.

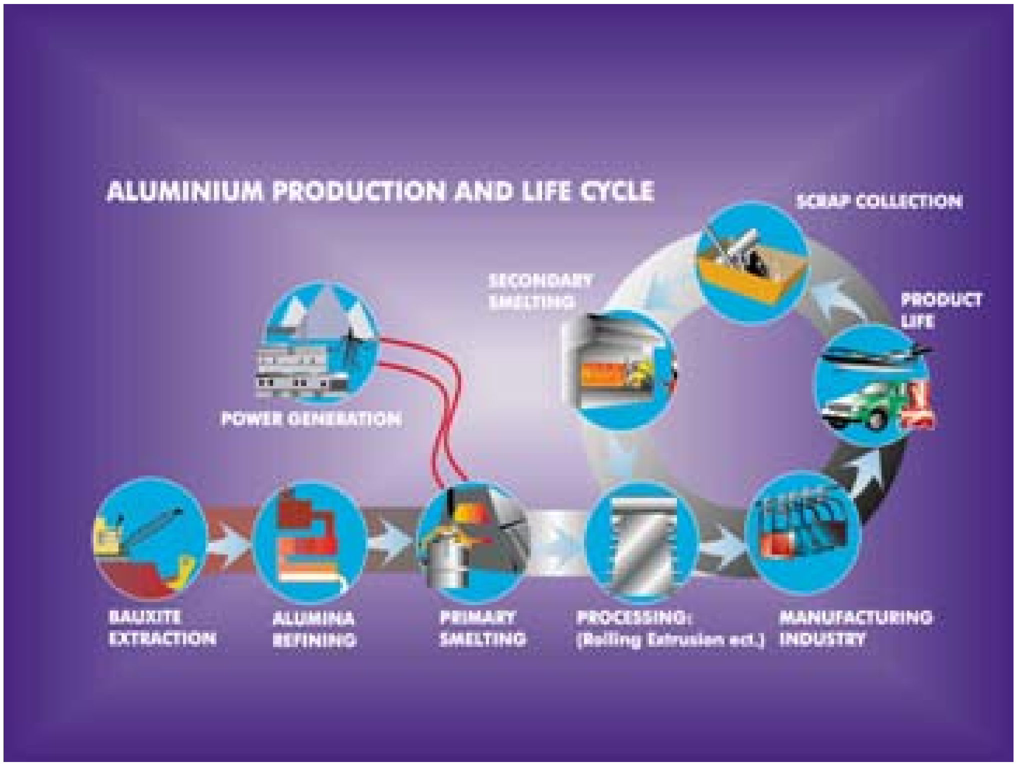

Figure 4: Life Cycle for Aluminium Products

What is being done to reduce PFC emissions and why are they significant. PFC emissions accounted for about 0.4% of total 1990 anthropogenic GHGs. Primary aluminium production is responsible for the majority of these PFC emissions. In recent years however the global electronics industry has also become a significant additional source of PFC emissions and may exceed the aluminium industry's emissions for C_2F_6 emissions. Tetrafluoromethane (CF_4) and hexafluoromethane (C_2F_6) are potent global warming gases as compared to carbon dioxide (CO_2) and have long atmospheric lifetimes. The two PFCs, CF_4 and C_2F_6, have the equivalent greenhouse gas warming potentials of 5,700 and 11,900 times that of CO_2, respectively. (These are IPCC Third Assessment Report values and the calculations contained in the graphics use the SAR GW_p values of 6,500 and 11,200 consistent with Kyoto protocol target reductions). During normal operating conditions in an electrolytic cell used to produce aluminium, no measurable amounts of PFCs are generated. They are only produced during brief upset conditions known as 'anode effects'. These conditions occur when the level of aluminium oxide (the raw material for primary aluminium) drops too low and the electrolytic bath itself begins to undergo electrolysis.[30]

In 1990 the global total emissions were 117 million tonnes of CO_2 equivalents of which 86 million tonnes (73%) came from the PFCs emissions and 31 million tonnes (27%) of CO_2 itself from the electrolysis process. The Institute carries out annual surveys of PFC emissions and sends out benchmarking reports, so individual plants can compare their performance with other de-identified plants using the same technology. The IAI has introduced a benchmarking programme. Each CEO of a reporting smelter receives a performance graph showing where it ranks in relation to the performance of other de-identified plants with similar technology. In order to encourage an appropriate level of awareness of the Climate Change Challenge and its being

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[29] International Aluminium Institute, 'Life Cycle Inventory of the Worldwide Aluminium Industry with Regard to Energy Consumption and Emissions of Greenhouse Gases,' London, May 2000.

[30] Jerry Marks, Alton Tabereaux, Diana Pape, Vikram Bakshi and Eric Jay Dolin, 'Factors Affecting PFC Emissions From Commercial Aluminum Reduction Cells, Light Metals 2001, pp 295 – 302.

treated as a top priority at all levels of the Member companies. The CEOs are also briefed at every IAI Board meeting on the results of the annual PFC Surveys.

In order to encourage still greater participation in the IAI PFC survey and reduction programme, a report, which sets out the operational benefits of reducing anode effects is being finalised. The reduction in the frequency and duration of anode effects has dual benefits. It reduces PFC emissions and optimizes process efficiency. The IAI Member companies have agreed a Protocol based on the WRI/World Business Council on Sustainable Development model. The template for Corporate Greenhouse Gas Inventories, will provide a consistent set of inventory development tools throughout the Industry. Companies are being encouraged and where appropriate, assisted by the IAI Consultant to carry out actual sample measurements at the aluminium production facilities. The measurement results can then be used to improve the accuracy of inventory results calculated by using technology average slope factor calculations. This also helps to provide a solid base for constructing the inventory back to 1990, which would be suitable for third party verification. The Industry is collaborating with national regulatory agencies, and international bodies like the UNFCCC, IPCC, ISO and WRI/WBCSD to develop better PFC inventories. The IAI PFC Consultant is also available to advise companies on good practice and a manual advising on best operating practice compiled by leading experts in the Industry is being prepared.

The data shown in Figure 5 from the 63% of world aluminium production that participated in these surveys shows that the specific emission rate (per unit weight of aluminium production) for CF_4 was reduced by 70% over the 1990 to 2001 time period while the specific emission rate for C_2F_6 was reduced by 71% over the same period.[31] Aluminium production, shown in Figure 6, has increased by around 24% since 1990 and yet there has still been an overall reduction in the total annual emissions of PFCs. This is an example of where the global emissions of a greenhouse gas from an industry sector are actually in decline. Much of this reduction was due to the phasing in of new plants. As a result the older HSS, VSS and SWPB technologies represent an ever smaller proportion of the production. The technology mix changed between 1990 and 2002 with Point feed prebake up from 32% to 63%, Centre work prebake down from 16% to 7%, Side work prebake down from 13% to 4.5%, Vertical stud Soderberg down from 27% to 16.5% and Horizontal stud Soderberg down from 11% to 8.8%.

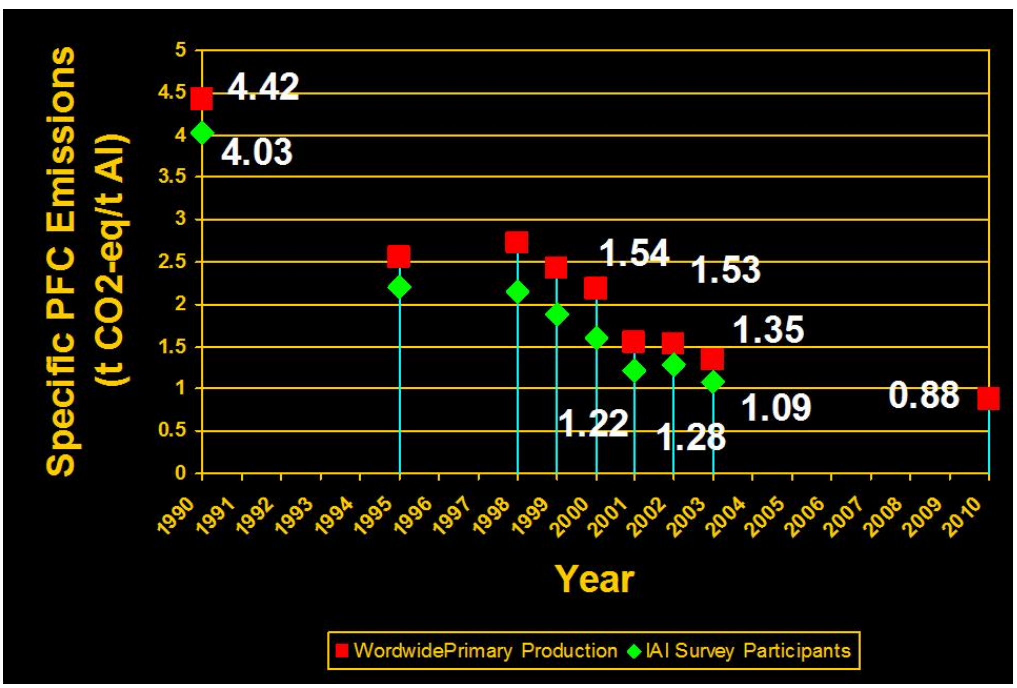

Figure 5: Reduction in Specific PFC Emissions

31 Willy Bjerke, Robert Chase, Reginald Gibson and Jerry Marks, International Aluminium Institute Anode Effect Survey Results, Light Metals 2004, pp 305 – 309.

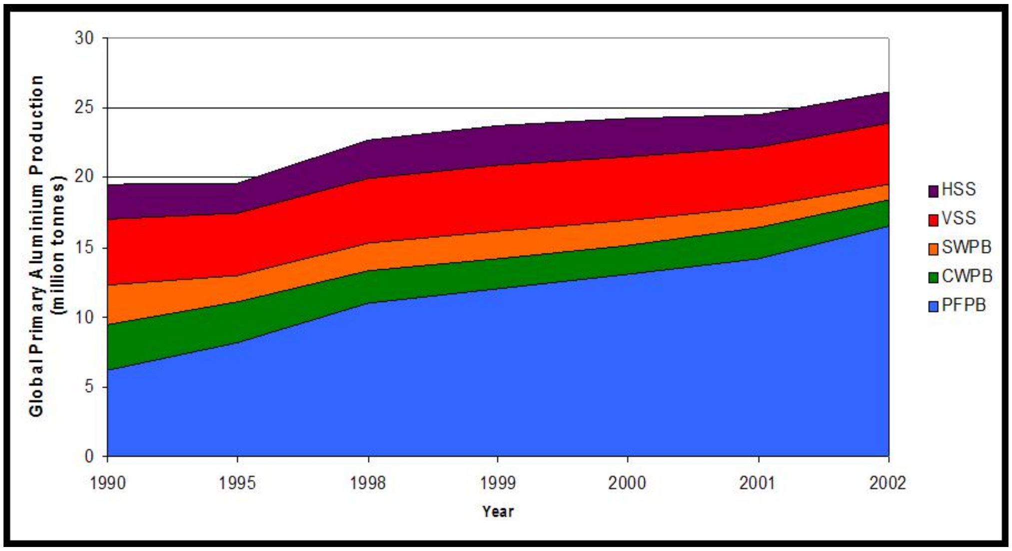

Figure 6: Growth in Primary Aluminium Production by Reduction Technology Type

There is still however scope for further improvement in operational practices given the wide variations in performance revealed by the benchmarking graphs in each of the different technology categories.

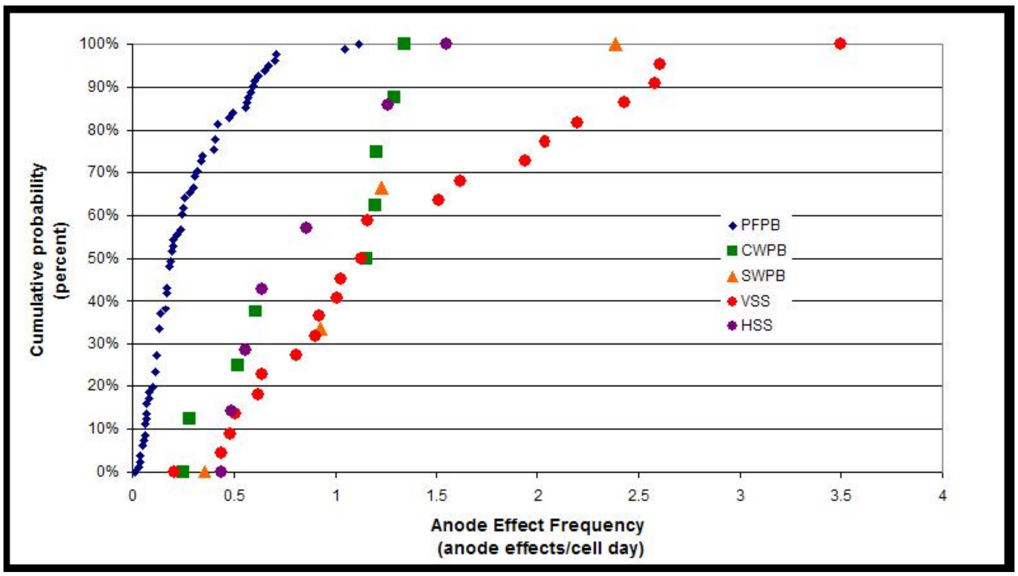

Figure 7: Cumulative Distribution Plot for 2002 IAI Anode Effect Frequency

The amount of PFCs produced in smelting is impacted by both the frequency of anode effects and the duration of those anode effects (voltage rises above 8 volts). The anode frequency graph shown in Figure 7 highlights not only the significant difference in performance between the modern Point Feed Prebake Plants in blue and especially the Vertical Stud Soderberg red circles and the champion emitters the side work prebake orange triangles. It also highlights the wide spread of performance within all the different technological categories. The challenge is to flatten all these individual curves in line with the best performance levels for each technology type. There is also a big variation in performance in terms of anode effect duration, where the reaction time to kill an anode effect again various significantly from 0.6 of a minute to 3.5 minutes.

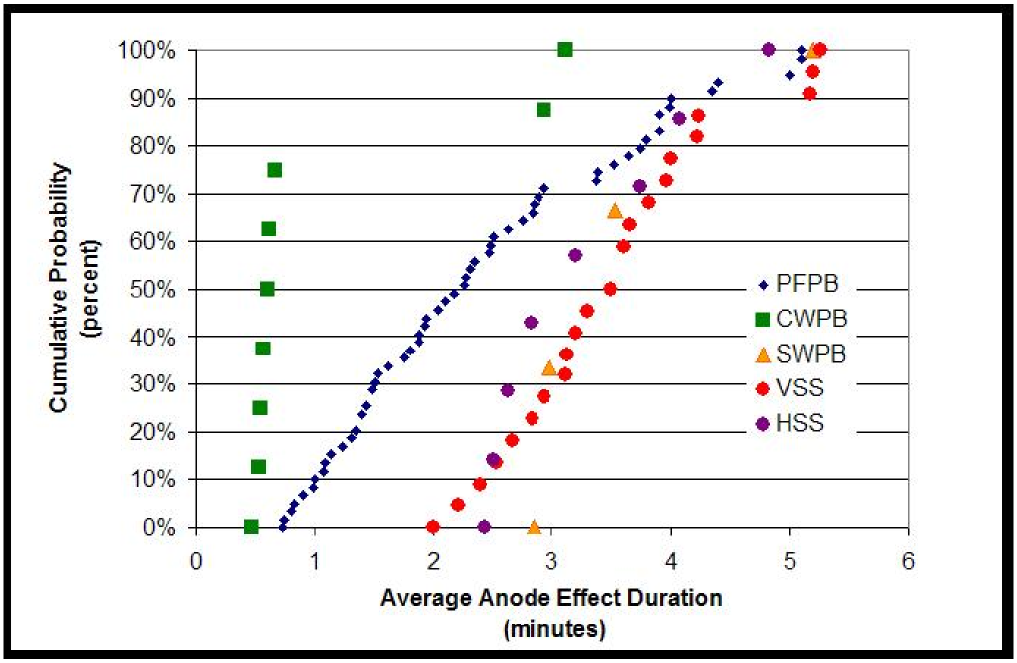

Figure 8: Cumulative Distribution Plot for 2002 Anode Effect Duration Survey

It is also essential that plant managements continue to focus on operational good practice to reduce PFC emissions as a top priority in order to avoid any deterioration in performance. For example, the results of the 2002 PFC Survey did not show a steady improving trend, but slight deterioration in performance over 2001. Fortunately this small rise was more than compensated for by the reductions achieved by 4 out of the 5 technology categories in 2003, which resulted in an overall reduction per tonne of around 73% since 1990, thus continuing the progress towards the industry's voluntary objective of an 80% reduction in PFCs per tonne of production by 2010.[32]

Now the second way to reduce aluminium's greenhouse gas intensity is to encourage more recycling. Recycling saves up to 95% of the energy required to produce primary metal and avoids the corresponding amounts of emissions required to produce primary metal, including greenhouse gases.

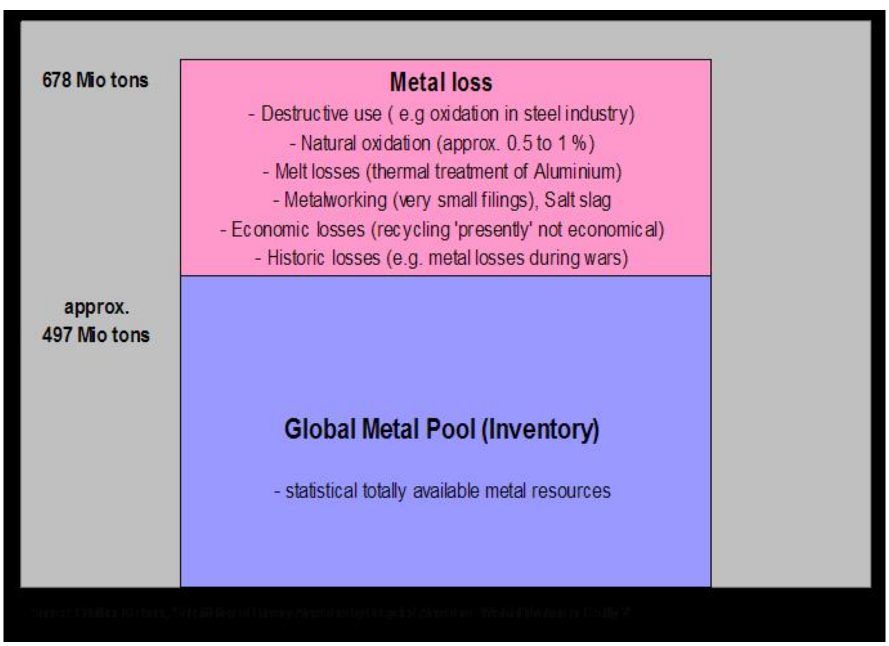

Figure 9: Fate of Primary Aluminium Produced Since 1888

32 Robert Chase, Reginald Gibson and Jerry Marks, International Aluminium Institute 2003 Anode Effect Survey Results, Light Metals 2005, in press.

Aluminium is profitable to recycle and it can be recycled again and again without loss of value or its metal properties. Since 1888 660 million tonnes of aluminium have been produced of which three quarters are still in productive use. This represents a vast inventory of material, which will eventually become available for recycling once the planes, cars, trucks, ships, doors, window frames, trains etc. reach the end of their useful lives. The inventory has been growing faster in recent years as a third of all primary aluminium was produced in the last decade. Over a third of the total demand for aluminium is now met from recycled metal and recycled metal production has been growing in Europe by 4% annually. The ratio of this recycled metal tonnage to total industry product shipments has increased from 17% in 1960 to 33% in 2000 and is projected to increase to around 40% by 2020.

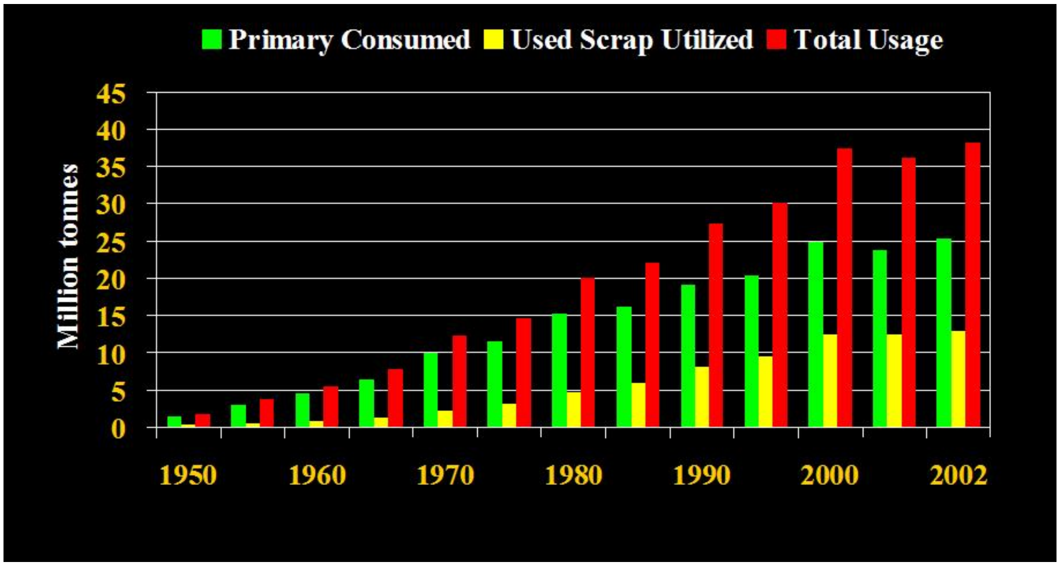

Figure 10: Increases in Recycling to Meet Global Demand

The IAI set up the Global aluminium recycling committee to oversee the annual collection of global recycling statistics and study scrap flows in order to identify the scope for further growth in recycling. The Global Aluminium Sustainable Development Initiative has as its objective to monitor its recycling performance globally and to develop a Global Action programme designed to encourage a significant increase in the volume of aluminium metal from old post consumer scrap. The committee found there were some important regions where no data was collected and that there was little data on how much metal was being lost to landfill. It was therefore decided to complement the data collection by developing a recycling or sustainability model based on the model originally developed by Paul Bruggink of the Alcoa Technology Center. The model's data and assumptions have been subsequently refined by the IAI Global Aluminium Recycling Committee.

Modelling Objectives were to;

1. Gain a better understanding of past and current worldwide aluminium recycling flows:
   - Quantify 'post consumer scrap' flows based on
     - Past product shipments by market sector,
     - Estimated product lifetimes,
     - And end-of-life recovery rates by market sector
2. Predict future recycled metal flows and the extent to which future anticipated aluminium market demand may be met by recycling versus new smelter capacity.

Figure 11 provides a very simplified illustration of how the model functions with the data inputs and annual outputs. The inputted data comes from both outside sources and internally generated industry data. It covers such factors as product net shipments by geographical region and by market segment e.g. transport, construction, packaging, aerospace etc. It also factors in product lifetimes, reported Global Recycle Rates by market segments and market growth rate projections e.g. transport. This gives us the overall mass flow picture and estimates of the global recycling totals. The incomplete statistical data collected by the IAI and the various aluminium associations from around the world gives a total of 10.1 million tonnes of recycled metal for 2001 while the Model estimates 12 million tonnes.

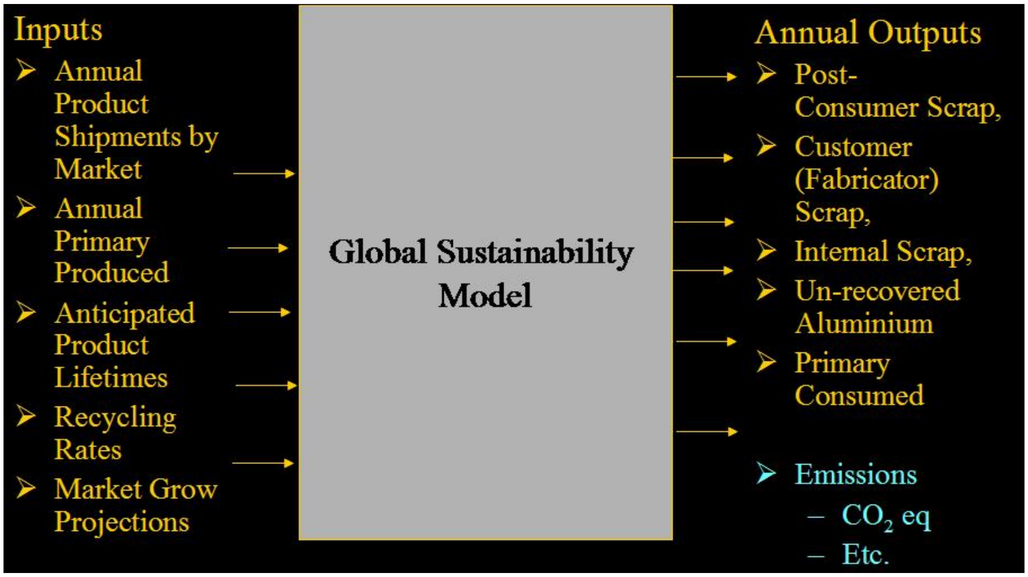

Figure 11: Global Aluminium Sustainability Model Diagram

Other Potential Uses of the Model

- Test completeness / validity of scrap data
- Test anticipated product lifetimes assumptions and reported recycling rates.
- To carry out sensitivity analyses for example on the;
  - Impacts of improving recycling collection and recovery rates
  - Impacts of shifting markets
  - Impact of recycling scenarios on future primary production requirements.

It also helps to pinpoint the applications, where the metal is not yet being recycled to its full potential. It points to several million tonnes per year not being recovered. The Committee is looking into what can be done to encourage further recycling in these applications.

The Model when fully developed will have the capability of being used to determine past current and projected greenhouse gas emissions from the worldwide industry, based on any future production/demand/product mix scenario that may be of interest. It can also be used to make projections on progress towards making aluminium less energy intensive and less GHG intensive. On average worldwide aluminium products are becoming less GHG intense on a per tonne shipped basis due to;

1. An increase in the percentage of recycled metal relative to primary metal and
2. A 73% reduction in PFCs emissions from primary aluminium facilities. 4 tonnes of CO_2 equivalents per tonne in 1990 have been reduced down to 1.2 tonnes of CO_2 equivalent per tonne in 2003.

The third factor in addition to reduced smelter emissions and increased recycling is the contribution aluminium shipments make to the reduction of GHG emissions from transport, the fastest growing source of GHG emissions. The IAI's life cycle analyses have demonstrated that for every additional kilogram of aluminium used to replace heavier materials results in savings of 20 kilograms of CO_2 emissions over the lifetime of an average vehicle (reference 1). The largest emissions and reduction potential is linked to the operation of the vehicle and not to its construction i.e. materials and assembly. This analysis has also been applied to other modes of transport with similar and sometimes even greater savings e.g. fast ferry, city bus or urban delivery vehicle but sheer volume means cars are the main source of savings. These results can be fed into the Sustainability Model in addition to the PFC and recycling data to produce projections on the contribution or impact of the industry on the climate change process. The graph shows that despite all the PFC reductions and meeting the 80% per tonne reduction target, total emissions would still be on the increase due to growth in production. However, if the Industry succeeds in bringing all primary and recycling operations up to today's best practices by 2020, this could stabilise the global emission from aluminium production and flatten the curve. When both best practice and the GHG savings from transport applications are factored in, there is the potential, as shown in Figure 12, for the Industry to become climate neutral by 2020 and by 2015, if the Industry were to be successful in its efforts to accelerate the spread of today's best practice.

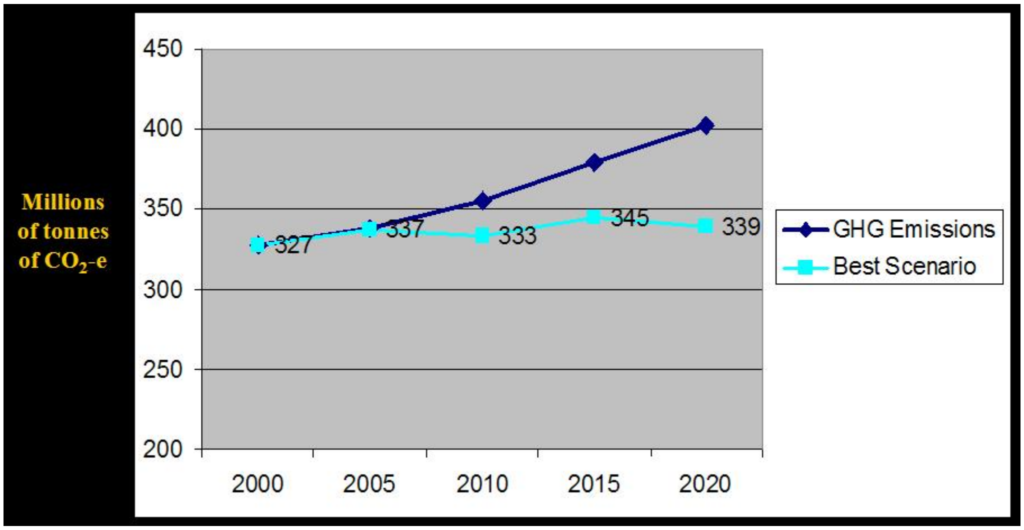

Figure 12: Impact of Adoption of Best Practices on GHG Emissions

In summary the aluminium industry has the potential to achieve a position, where the net impact on society of the use of aluminium as a material will be seen as making a positive contribution to the challenge of global climate change.

Mining Industry Experience and the Commercialisation of Carbon Dioxide Capture and Storage Technologies

J. J. Davis, Head – Energy Technology Group, Rio Tinto Technical Services
S. L. Kleespie, Principal Advisor, Climate Change, Rio Tinto

'About the bravest thing anyone can do in Australia is to erect a greenfields mineral processing plant. They cost zillions of dollars; they take years to build; they blow up; the state-of-the-art process that was perfected in the laboratory mysteriously won't work in the field; and the plants never, ever run right the first time you press the button.'

'Pierpont', writing in the Australian Financial Review

ABSTRACT

As one of the largest diversified mining companies in the world, Rio Tinto has an extensive history in project development and in the management of technology research, development and demonstration (RD&D).

This paper examines minerals industry experience in the commercialisation of new technologies, in particular why minerals industry projects succeed or fail, and possible lessons for the commercialisation of carbon dioxide capture and storage (CCS) technologies, a major potential response to greenhouse gas (GHG) emissions mitigation.

Minerals industry experience shows that transforming any technology from a potentially good idea to real world deployment requires firstly good RD&D management in the development of the component technologies; and secondly excellent project management to integrate these technologies into a successful large-scale operation.

Reducing minerals industry project risk to acceptable levels requires a deliberate process of technology development, followed by systematic pilot plant and demonstration-scale operation. Developing experience with the technology in the new application is crucial, even when component technologies have been used in other processes. Such efforts however open a path to accelerated commercialisation at lower cost.

In addressing climate change, the utility sector faces a significant medium term issue, one solution to which could be the widespread implementation of CCS technologies. Conventional wisdom suggests that this implementation will follow the successful operation of between six and ten large demonstration projects. Given the high anticipated cost of these demonstrations and the importance that is attached to their success, this paper examines the lessons that can be learnt from the minerals industry around the introduction of new technologies.

INTRODUCTION

Rio Tinto is a large diversified international mining company headquartered in London. The Group's activities span the world, but the company is strongly represented in Australia and North America, with significant businesses in South America, Asia, Europe and southern Africa. Rio Tinto's operating structure consists of six product groups (Iron Ore, Copper, Aluminium, Energy, Diamonds and Industrial Minerals), supported by Technology and Exploration Groups.

In conducting its core mining and minerals processing businesses, Rio Tinto has gained extensive experience in both project development and the management of technology research, development, and demonstration (RD&D) activities. Rio Tinto makes a substantial annual investment in projects ranging from plant expansions, through the uptake of newly developed processing technologies, to the construction of new mines, smelters, refineries, railroads and pipelines.

In the area of technology RD&D, Rio Tinto manages both large and small-scale proprietary research, and partners with industry and government in collaborative technology development efforts. Internal technical development includes HIsmelt,[33] a very promising advanced steelmaking process; external collaborative R&D includes:
Participation in the FutureGen[34] alliance – a group of major coal producers and coal burning utilities that is interested in collaborating with the US government in the development of a large scale project to demonstrate the production of hydrogen from coal, with the concurrent sequestration of CO_2 emissions in geologic reservoirs, and

[33] Further information on the HIsmelt process can be found at: http://www.hismelt.com/technology/.

[34] Further information on FutureGen can be found at: http://www.fossil.energy.gov/programs/powersystems/futuregen/.

The Rio Tinto Foundation for a Sustainable Minerals Industry[35] – a partnership with the Australian government to develop new technologies contributing to energy efficiency improvements and greenhouse gas emissions reductions in the mining industry.
Sponsorship of the Global Energy Technology Strategy Program[36] – Phase II – an international public/private collaborative program assessing the role that technology can play in addressing the long-term risks of climate change.

TECHNOLOGY DISSEMINATION IN THE MINERALS INDUSTRY

The minerals and electric utility industries share a number of important similarities. Both industries are highly capital intensive, and assets are expected to operate for decades. With individual projects being extremely expensive, failure can have a significant impact on the parent company. The result is a necessarily conservative approach to new technology development.

In recent years a number of excellent studies have examined the dissemination of technology throughout the mining industry. Industry folklore insists that the minerals industry is open and transparent to technology change, due to the easy and continual movement of staff around the industry and regular and open technical reporting and commentary.

As Twigge-Molecey (2003) explains, 'It has always been an assumption that the ore-body gave the competitive advantage and that appropriate technology could be purchased. Consequently there was no real competitive advantage to be gained by developing technology internally.'

But is this in fact the case?
Table 1 examines the industry uptake of three of the most important minerals industry technological innovations of the last century – the introduction of mineral flotation, open pit mining and solvent extraction/electrowinning (SX/EW). The inference is clear: dissemination of the technology was in fact slow. This is a surprising observation given that each of these technologies represented a genuine breakthrough, significantly altering the underlying industry cost structure. However, early adopters were able to retain – and profit from – the competitive advantage conferred by introducing or quickly adopting these technologies for a considerable length of time.

Industry folklore of rapid technology adoption in fact applies to incremental or evolutionary technology change, where operations are familiar with the application and can immediately see the advantages of the improvement and copy/implement/further improve it.

Table 1: The time taken (in years) for different sectors of the minerals industry to adopt significant technological breakthroughs (after Marsden, 2004)

	Type of Technology			
	Flotation	SX/EW	Open Pit Mining	Average
First mover	0	0	0	0
Fast followers	15	2-12	13-23	8-18
Conservative followers	15-35	20-30	33-43	23-35
Laggers	>35	>30	>43	>35

But if such competitive advantage confers from revolutionary technological advances, why are such breakthroughs in fact so infrequent?

An intriguing answer comes from recent studies into large-scale minerals industry projects by Twigge-Molecey (2003) and McNulty (1998). These studies address complementary aspects of the issue - Twigge-Molecey (2003) concentrated primarily on management practices, whereas McNulty (1998) focused greater attention on the nature of the technology being implemented.

Twigge-Molecey (2003) studied 43 projects undertaken in the mining and minerals sector in the previous decade. Forty seven percent of the projects were located in North America – and hence the results may be particularly relevant to the commercialisation of CCS there – while the balance were distributed around the world. Half of the projects bore capital costs between US$100 million and US$500 million each; 10% were

35 Further information on the Rio Tinto Foundation for a Sustainable Minerals Industry can be found at: http://www.riotinto.com/library/microsites/socEnv2003/casestud/131_foundation.htm.

36 Further information on the Global Energy Technology Strategy Program can be found at: http://www.pnl.gov/gtsp/index.stm.

smaller and 40% were larger. The projects covered both greenfield developments and brownfield expansions.
The analysis makes sobering reading. The projects resulted in over $20 billion in non-productive capital investment, and sixteen of the projects resulted in bankruptcies, closures and write-downs. Table 2 summarizes the most significant issues contributing to project failure identified by Twigge-Molecey (2003); the lessons are that a successful project needs carefully trialed and demonstrated technology that is allied to excellent and consistent project management.

Table 2: Factors present and/or contributing to project failure (from Twigge-Molecey, 2003)

Poor Project Phasing	70%
No Continuity in Project Team	63%
Turn Key Fixed Price Projects	42%
Major New Technology	50%
Front End Issues[37]	40%

McNulty (1998) studied 41 minerals processing plants constructed between 1965 and 1995, measuring their productivity – expressed as the percentage of design capacity – as a function of time after commissioning. The data were found to divide into four categories, each of which was then averaged to construct a family of curves (see Figure 1). The problem plants required far longer than anticipated to reach design throughput and recovery rates.

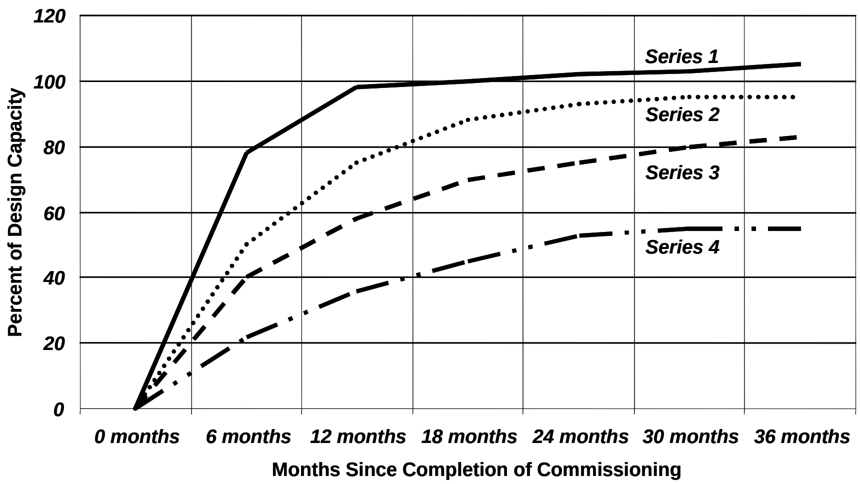

Figure 1: Plant capacity versus time since commissioning *(after McNulty, 1998)*

In analysing the underlying drivers of project performance across these 41 plants, McNulty (1998) found the projects in each series shared a number of important characteristics:

37 'Front end issues' include factors such as budget cuts without scope cut, late scope changes, or key information ignored (from geology, pilot plants, etc.).

Table 3: Project characteristics affecting the productivity of minerals processing plants (after McNulty, 1998)

Series 1 Projects • Little or no technical risk • Low cost • No competitive advantage	• Mature technology • Experienced project owner • Standard equipment • Thorough pilot testing
Series 2 Projects • Low risk • Low cost • Limited competitive advantage	Faced one or more of the following challenges: • First licensee • Prototype equipment in a key technology • Incomplete pilot testing • Incompletely characterized geology
Series 3 Projects • Moderate risk • Reduced development cost • Considerable competitive advantage	Faced one or more of the following challenges: • Limited pilot testing • Fast-tracked engineering • Inexperienced management • Misunderstood geology
Series 4 Projects • Highest risk, but… • Greatest potential competitive advantage	Common causes of failure included: • Complex interdependent flow sheet • Prototype equipment in critical areas • Misunderstood geology • Equipment or design compromised to save capital • Ill-conceived project drivers • Overly aggressive or promotional management attitude

Halbe (2003) analyzed the financial implications of McNulty's (1998) findings, using a simplistic economic model of a gold mine and hydrometallurgical processing plant and assuming a capital cost of $146 million and a discount rate of 8%. As can be seen from Table 4, this analysis demonstrates that project finances deteriorate significantly as plants take longer to reach design throughput and recovery.

Table 4: Economic performance of the four project categories identified by McNulty when applied to a hypothetical gold mine and processing plant (from Halbe, 2003)

Startup Type	Internal Rate of Return (IRR %)	Net Present Value (NPV, $ million)
Series 1	21	285
Series 2	15	150
Series 3	7	-28
Series 4	---	-311

In other words, and unsurprisingly, high-risk technological breakthroughs can pay off significantly, but when they fail the costs can be severe.

Halbe (2003) then analysed the potential benefits of additional front-end work – a point also made by Twigge-Molecey. He first evaluated the project as a Series 3 operation, which typically achieved 60% of design capacity in 12 months and 85% of design capacity in 36 months. According to McNulty (1998), this type of operation would typically suffer from one or more of the following: limited pilot-scale testing with some important process steps excluded, ore mineralogy not fully understood, insufficient attention to product quality, serious design flaws and/or precipitously fast-track engineering.

To address these challenges, Halbe's (2003) analysis then added an additional year and $5 million to the project schedule, the additional time and capital being utilized in the analysis to firm up geological testwork and engineering design. The analysis assumed that the additional work reclassified the project as a Series 2 startup using McNulty's (1998) criteria, with the performance expected of a typical Series 2 project. The results of the analysis, incorporating both the additional expenditure and performance, are shown in Table 4.

Table 5: The impact of increased expenditure on process engineering before construction (from Halbe, 2003)

Startup Type	Internal Rate of Return (IRR %)	Net Present Value (NPV, $ million)
Series 3	7	-28
After additional pre-work	13	116

The conclusion is that confirming and validating the engineering and science for a project is vitally important *before* construction starts.

IMPLICATIONS FOR CCS COMMERCIALISATION

CCS is recognized as holding tremendous potential for the abatement of greenhouse gas (GHG) emissions; and if CCS is found to be a viable technology, proponents would like to see it deployed on a global scale beginning as quickly as possible. The necessary prerequisite for its widespread use is approval from the public, policymakers and regulators.

Securing this approval is generally held to require a global portfolio of 6-10 successful large (utility-scale) geosequestration demonstrations across a range of reservoir types. With permitting, engineering, construction, injection and post-injection monitoring, these large scale projects could easily take 15-20 years to complete, and costs could be as much as US$1 billion per project.

The key lessons from the preceding analysis of minerals industry RD&D and project management seem to pose a dilemma for proponents of the rapid large-scale deployment of CCS technologies as a climate change mitigation measure. A strategy that relies heavily on undertaking a limited number of large scale demonstrations in order to jump start the accelerated deployment of CCS technologies runs counter to minerals industry experience with technology development, where such an approach would incur an elevated risk of project failure for the reasons outlined above. High profile failures within a small portfolio could severely impact the deployment of CCS technologies.

The question is whether there is a path to rapid commercialisation of CCS that simultaneously incorporates the key lessons from minerals industry experience.

The first observation is that minerals industry experience would underscore the need for good RD&D and project management, and would also consider the following practices necessary to reduce the risk of project failure.

- A staged, deliberate and thoughtful approach to scale-up.
- Ensuring the underlying science is appropriately understood at all stages of scale-up.

Even with these precautions, successful project operation cannot be taken for granted when assembling proven component technologies in a new application.

A second observation is that there may well be an alternative strategy for pursuing CCS scale-up - if CCS is examined in a different way.

CCS demonstrations effectively consist of three component technologies: capture, storage and monitoring and verification. At this time, the technologies are at varying stages of development.

Carbon dioxide capture ranges from gasification-based CO_2 capture, which is widely used in the petrochemical industry at the required scale, to amine-based CO_2 capture from flue gas, which is used in the food industry at significantly smaller scales. With technology development substantially complete, the primary need is for integration at scale, and to demonstrate that the process of CO_2 capture need not interfere with the core utility function of reliable power delivery.

Underground storage of CO_2 involves both the physical placement of CO_2 underground, and the subsequent demonstration of the permanence of storage.

The pipelining and pumping of CO_2 underground is a mature technology, widely practiced in enhanced oil recovery, and can draw on available and widely disseminated oil and gas industry expertise. The purposes of large-scale demonstrations would be to gain experience in systems integration and to expand the experience base with the two most widely available geologic reservoirs – saline aquifers and deep unminable coal seams.

Hence the mechanics of placing CO_2 in the ground are well understood, and the significant issue that must be addressed before CCS can deploy on a large scale will be to transparently demonstrate the permanence of geologic CO_2 storage.

Monitoring and verification technologies are at a considerably earlier stage of development. The crucial significance of measurement in CCS applications is not solely for *engineering* purposes, but principally to demonstrate to a potentially sceptical public that the CCS process is under control, permanent, and being openly, accurately and transparently monitored. This means that before CCS can deploy on a very large scale (e.g., mitigation on the scale of gigatons of CO_2 per year), monitoring and verification technologies must be mature, reliable and accurate.

As described above, CCS demonstration projects have two objectives:
- Developing the component technologies as required, and
- Demonstrating successful integration of the component technologies.

The lessons from the mineral industry are clear: the odds for successfully achieving these objectives will be significantly improved if the component technologies are developed and scaled up separately, and are also integrated at scale. The rapid implementation of CCS will therefore require a portfolio approach to CCS demonstrations.

Small-scale demonstrations (up to some tens of thousands of annual tonnes of CO_2) will be required for:
- The cost-effective development and demonstration of monitoring and verification technologies.
- Early demonstration of new capture technologies.

Medium-scale demonstrations (up to some hundreds of thousands of tonnes of CO_2 annually) will be required for:
- Scale-up testing of monitoring and verification technologies.
- Demonstrating new CO_2 capture technologies (e.g., flue gas capture) at scale.
- Demonstration of geological storage of CO2 at sufficient scale to begin realistically testing the host geology in a variety of reservoirs.

A number of *large-scale demonstrations* will be required internationally for:
- Integrating and testing the component technologies in industrial applications (the short term objective).
- Demonstrating the viability and permanence of carbon dioxide storage with full-scale testing of the host geology across reasonable timeframes (a decade or more).

Capture is the most expensive component of a large-scale demonstration by a significant margin. For a hypothetical $400M 70MW gasification-based CCS project, up to 80% of the capital budget would be expended on generation and capture infrastructure. The capital required for monitoring and verification would also be relatively small.

In pursuing a portfolio approach, however, the total cost of proving CCS technology can be minimized since the expensive CO_2 capture component does not require replication on all demonstrations at all scales. It is interesting to note that almost all existing and currently proposed large-scale demonstrations of CO_2 storage in geologic structures use available and relatively inexpensive byproduct CO_2 - Sleipner, Snohvist, Weyburn and possibly Gorgon and In Salah.[38]

CONCLUSIONS

Minerals industry experience shows that reducing project risk to acceptable levels requires firstly good RD&D management in the development of the component technologies; and secondly excellent project management to integrate these technologies into a successful large-scale operation.

A CCS development strategy that emphasizes either process at the expense of the other will increase the risk of expensive project failures with uncertain consequences for public acceptance and widespread deployment. Developing a portfolio of CCS projects that achieves both objectives will therefore facilitate the long-term implementation of CCS technologies.

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Barriers of Technology Transfer - Analysis of Four Case Studies

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Abstract

Through an analysis of four technologies transfer projects in which the authors have participated, this paper summarizes the factors limiting the success of technology transfer and the diffusion of technologies in China. These cases cover four industry sectors including steel, pulp, coal and textile, respectively. The barriers of technology transfer have various impacts in each case because of the differences in technology suppliers, receivers and the technology itself.

The coal case study indicates that initial governmental interventions could overcome some barriers, but that market conditions play the decisive role in the final process of technology transfer.

The pulp case study shows that the high transaction cost is one of the major factors limiting the technology transfer, especially when the technologies were developed, as well as used, by medium and small sized companies.

Textile case shows that know-how or software transfer is a major factor of assuring the complete success of technology transfer. The overall success of the technology transfer could not be realized if advanced hardware were purchased without the relevant software.

Steel case reveals that technology demonstration is the first step for technology transfer, but many follow-up steps have to be implemented in order to complete the whole process of transfer. An independent third party could play an effective role in the process.

Unsuccessful technology transfer cases have negative impacts on technology transfer, especially for the technology receivers.

INTRODUCTION

Technology transfer receives much attention from technology receivers as well as suppliers. Many efforts have been made to promote technology transfer from developed countries to developing countries. Since 1997, the US/China Energy and Environment Technology Center (EETC) was established in Beijing to enhance the competitiveness and deployments of U.S. clean energy technology/ equipment/service in China (www.us-china-eetc.org). The U.S. Department of Energy (DOE) and the U.S Environmental Protection Agency (EPA), along with the contribution from private sectors, initially funded the EETC. The Ministry of Science and Technology (MOST) of China also cost-shares the operation in China. Tulane University and Tsinghua University jointly operate EETC.

EETC's major goal is to enhance the competitiveness and adoption of U.S. clean energy and environmental technology in China, and to advance efforts to protect the local, regional, and global environment through the use of such technology, especially clean coal technology developed by DOE. EETC's efforts to decrease global environmental impacts associated with China's rapid economic growth are paying off. A partnership has been established in China that is friendly to the U.S. and dedicated to global sustainable development. Through the years, EETC has made some progresses and learned lessons on technology transfer. Four cases have been chosen for analysis on the barriers experienced but the highlights are the lessons learned.

COAL CASE STUDY

A clean coal technology has been developed by The TEK-KOL Partnership, a U.S. company which processes coal to produce liquid fuels from light compounds of coal and high heat-value coal by de-moister (EN-Coal 1993). This technology is a part of DOE's. Clean Coal Program (DOE 1993). DOE recommended this technology to Chinese officials through EETC. Chinese officials believed that China could be benefited from this technology. The potential benefits come from two aspects: first, liquid fuels are in demand in China; second, less traffic volume by removing moisture from coal. Significant efforts were made to set up a major demonstration facility in China. Specific actions taken included:

Shipped Chinese coal samples to the U.S. for testing;

Tested different coals from China to identify which coal mining area is suitable for building the demonstration facility;

Visited candidate coal-mining areas that may have suitable coal resource;

Performed simple cost-benefit analysis based on the local situations.

Because of the supports of both governments, the technology supplier as well as the technology receiver

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both actively worked on this project. The TEK-KOL Partnership, supported in part by DOE, covered the cost of testing coal samples, travel and other initiative costs. Several Chinese coal companies (simply call Company Cs) in Shandong Province, Inter-Mongolia and Yunnan Province provided the necessary resources for shipping coal samples, arranging site visits and other expenses. When the technology transfer was negotiated, the international oil price was dropping and thus the financial returns of liquid fuel from of this project were lower than originally expected. Further, all suitable sites were far from export ports, such that the technology supplier was not able to gain additional capital by exporting coal to the international market. There is a very good start of the transfer process but in the end this was not a completely successful technology transfer case. By reviewing the whole process of this case, we learn the following points:

(1) Government-to-Government interactions, i.e. the U.S.-China Clean Fossil Energy Protocol (DOE 2003), can provide a valuable platform for initiating and enhancing the technology transfer process. These exchanges enhance the confidence of the decision makers and also may impact on policy changes.
(2) Government support can provide a very good beginning for technology transfer. Business parties trust their government and often are willing to start the transfer process before the potential profits are clearly identified.
(3) Although technology transfer could be driven by governmental decision at the initial stage, in the end market force play decisive role. All business decisions are based on the results of cost benefit analysis. Governmental policies and subsidies could reduce the cost or increase the profit to some degree; but the market price still dominates the decision-making, especially for projects that require major investments such as this demonstration project which was estimated to cost billions of U.S. dollars.

3. PULP CASE STUDY

Black liquor discharged by pulp and paper plants pollutes water bodies in many areas of China. Because most small-scale paper plants use straw as raw material for pulp making, the mature black liquor treatment technology utilized worldwide doesn’t work well in China. Although many new technologies and processes have been developed, none was considered well enough to deal with this problem.

ThermoChem, Inc. a U.S. company has developed a technology that could recover some energy and chemicals from black liquor from straw as raw material (TRI 2003). EETC organized a workshop at Tsinghua University and invited the technology inventor to describe the technology (TRI 2003). The workshop was attended by many Chinese policy makers, business executives, industry professionals and researchers. As a consequence, immediately following the workshop, a week-long site visit was conducted in Shandong Province where a large number of paper mills are located. Many paper plants (simply call Company Ps) were interested in this technology and expressed willingness on building treatment plants. However, when the discussion went to a detail-working plan, the project faced a number of problems.

First, the technology is new; there is no plant in the world based on this technology. As such, the Chinese government preferred to build one treatment facility to demonstrate the effectiveness of the technology. The government’s position was that it would pay all the costs *after* the technology was successful because there were so many unsuccessful experiences in the past involving demonstration of new black liquor treatment technologies. But ThermoChem, Inc. was seriously concerned that this technology could be copied illegally and requested the Chinese to pay up front to build the plant. The negotiation was in a chicken and egg position. The Chinese insisted on successful first demonstration followed by payment; ThermoChem insisted on getting paid first. But there was no third party or mechanism to guarantee the performance for this first demonstration plant.

Company Ps promised to provide land and infrastructure with the exception of the capital for building the black liquor treatment plant. However, Chinese commercial banks will not grant loans to Company Ps that adopt a brand new technology that has not been demonstrated. On the other hand, if ThermoChem, Inc. developed a project in which at least twenty treatment plants were packaged, it could possibly get loans from international banks (Burciaga, 2003).

The technology transfer process in this case study stopped at the first round of negotiation. Even though both sides expressed the willingness to communicate further; the relatively high travel cost prevented them from visiting each other because all companies involved were medium and small sized companies. The major factors affected the black liquor treatment technology transfer to China can be summarized as followings:

(1) There is no effective financial system supporting small businesses in the acquisition of new technology since typically only large projects may obtain loans due to the high financing costs.
(2) Most small and medium sized businesses give up at the early stage of technology transfer because of high development cost such as travel for site visits.
(3) Concerns over intellectual property rights can hinder the technology transfer process.

4. TEXTILE CASE STUDY

Electronic control technology innovation and utilization can bring revolutionary changes in traditional industries. When EETC conducted an energy efficiency project at a textile plant (simply call Company D) in China, it was found that all spinning machines and looms were equipped with digital control systems. Company D followed the worldwide trend to import digital control equipment from developed countries since the1990s. The hardware upgrade made Company D one of the top ten enterprises in China's textile industry. In this sense, it was a successful case of technology transfer. But after detailed energy auditing, EETC found that there was a huge potential in energy conservation. When EETC analyzed why such a plant with advanced equipment had low energy efficiency, EETC found that Company D decided to acquire the full hardware equipment but only *part* of the software because of budget limitation. This decision resulted in a plant operating 1990's equipment with the management skill of the 1970's. In this sense, the technology transfer is a failure. Now Company D plans to make further investment so that the technology could function to its maximum capacity.

It is obvious that hardware and software both are equally important parts of the technology and equal attention should be paid to them in any technology transfer case. Now more and more people in China recognize this point; but when they are asked to pay, most of the time, they still wonder whether the software is really valuable.

5. STEEL CASE STUDY

This is a simple software transfer case. A steel plant (simple call Company B) purchased a software package developed by Tsinghua University for optimizing steam system for the plant and used it in its daily operation. After a three-month trial operation, it was estimated that the annual profits from more efficient energy use by adopting this technology would be forty times of the cost of acquiring the technology (Zhou et. al. 2001).

More benefits from energy efficiency improvement would be gained if many other steel plants adopted this technology. However, after development of the software package there were no further efforts at dissemination of the product due to lack of funding and time. This case had a good start and successful result in the demonstration stage, but it didn't go forward to complete whole process of transfer that could realize the fully potential of the technology.

6. CONCLUSIONS

Through above four cases analysis, it is obvious that technology transfer is not easy. There are many factors affecting the entire transfer process. Any one factor can put a stop to the process if any improper decision was made. The following suggestions wouldn't guarantee a successful transfer; but they could make the technology transfer process better.

Improved communications between technology supplier and receiver: Because of the differences in culture, history and development level, normally there are always some communication gaps. Sometimes a seemingly small or simple issue could evolve to a major communication gap. A successful transfer process must get these gaps minimized. Better communications, understanding and trusting each other is the base for a successful transfer process.

Building a platform for sharing information: Most small and medium sized business in China is experiencing shortage of manpower with sufficient foreign language skills to communicate with developed countries. EETC at Tsinghua, with the support of MOST, is building a new technology database using Internet intended to help the businesses track new development of technologies.

Expanding the system for technology selection and assessment: Non-profit organizations (NPOs), such as EETC, can play important roles in introducing the technologies and maintaining the momentum of project implementations. The NPOs must understand what technologies are needed in their country, and meanwhile, NPOs must have knowledge on the technology to be transferred. Such a system could significantly reduce the transaction cost for technology transfer.

The difficulties of access to capital for small and medium size enterprises have been received attentions in China. According to a survey conducted by People's Bank of China in August 2003, 98.7% of capital for small and medium size enterprises came from domestic commercial banks. The banks take almost all risks (Au 2004). Many suggestions are raised to deal with these issues which include building credit rating system, setting up a development funds and credit guarantee system (Zhang 2003).

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**Stepping off the hydrocarbons regime:
the challenge of technological transition
for Latin America**

Francisco Aguayo*

ABSTRACT

This paper approaches the diffusion of new process technologies as a problem of technology adoption and replacement. The diffusion of environmentally sound technologies (EST's) is viewed as a transition process from a technological regime based on hydrocarbons. From this we identify specific technological and economic barriers to technology replacement in Latin American economies. The first section elaborates on the concept of regime transition, where sunken costs and organizational inertia associated with embedded, large scale technologies generate important barriers to technology replacement and innovative absorption of technologies. These rigidities to change have a negative circular causation with the production of new technological capabilities, which adds to the more traditional drivers of technology adoption (prices, regulation, and investment and market rates). The second section examines key macroeconomic and technological factors gravitating over decommissioning, capital replacement timing and accumulation of technological capabilities. A heuristic framework is presented to characterize the interaction of capabilities and investment decision as drivers of technology selection under different economic environments. Two broad sets of factors determining macro-environments of selection are identified and characterized in the region.

INTRODUCTION

Energy systems and energy intensive industries are among the largest sources of anthropogenic greenhouse gases (GHG) (The list includes also transport systems, which are excluded from this analysis). The multifaceted technological regime of hydrocarbons upon which these systems rely constitutes a generalized unsustainable metabolism in the planet. All medium and long-term projections suggest that hydrocarbons will still be the dominant energy source for at least the first half of the 21st century. IEA World Energy Outlook 2002 projects that non-hydro renewables will only account for 4.4% of world primary energy by 2030 due to their minimal actual share, while hydro-power share will slightly diminish to 14%. The same report indicates that 90% of the increase in energy demand will be satisfied with fossil fuels, mainly natural gas. Under such a scenario, and despite the shift to a less emission-intensive fuel like gas, greenhouse gases (GHG) emission will continue to grow. Mitigation goals in the next decades can therefore only be met by enormous efforts in energy efficiency and GHG capture.

The limited availability of hydrocarbons, together with multiple and uncoordinated efficiency requirements in final use of energy, and regulative pressures from environmental concerns have established since at least the 1970's a visible yet very weak front of selective pressures for alternatives. Nevertheless, search efforts and innovation capabilities are very unequally distributed. While most R&D in energy alternatives is concentrated in the industrialized world, most of the increase in energy consumption and GHG emission will come from developing countries. The nations of the South will have to include the technological switching in their energy systems as a development condition, and even when the transition seems inevitable in the long run the process will be far from being automatic. The critical question then is how, and at what cost different societies will adapt and transform their economic and institutional resources to qualitatively change their technological base.

The outline of the paper is as follows. In the first section we examine the technological profile of Latin America, distinguishing its current fuel mix structure and recent trends. Next, we present some basic insights from the literature on the technology diffusion behind large-scale energy transitions, and elaborate on the concept of technological regimes. We highlight the role of systemic inertia and sunken costs as sources of inertia in regime configurations.

The second section identifies systemic barriers to absorption of new technologies in energy systems and energy intensive industries in the Latin American region, focusing on key macroeconomic and technological factors gravitating over decommissioning, capital replacement timing and accumulation of technological capabilities.

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I the third section a heuristic framework is presented to characterize the interaction of capabilities and investment decision as drivers of technology selection under different economic environments. End-of-pipe versus clean technologies are examined as alternative and complementary transition paths. Latin America's financial constraints and technological efforts are broadly characterized, before we conclude identifying key aspects in the regional development pattern critical for reversing unsustainable trends.

SECTION 1 - ENERGY TRANSITIONS, TECHNOLOGICAL TRANSITIONS

The record of the global diffusion of energy technologies as a process of multiple substitution among primary energy sources has been documented extensively.[39] In these models (formally inspired in Fisher and Pry, 1971), technologies diffuse in a sigmoid way with more efficient technologies out-competing older ones. Several paradigmatic solutions co-exist in time and compete for use shares. This approach shows a flow of technological succession resembling a sort of 'struggle' for dominance among primary energy sources: wood, coal, oil, gas, and nuclear, each one networked with complementary developments in other technologies and infrastructure (railroads, steam lines, steel making and electrification with coal; automotive transport and petrochemicals with oil). This models project natural gas as the dominant source of primary energy for at least the first half of the 21st century, a development that is an already visible trend in energy statistics. New versions of these modeling efforts have projected detailed regional patterns of primary sources substitution considering different scenarios of growth and technical change orientation[40]. The actual pattern of substitution at the regional and national levels, especially those of areas with different resource endowments, may look considerably different, but the general picture of energy sources substitution is a good reference of the sort of technological dynamics hidden behind.

In the following sections we examine a set of relevant determinants for energetic transition in Latin America. These determinants constitute the broad structural context of diffusion and technology transfer in energy systems and energy intensive industries in the region. It is of course a partial analysis since the linkage to the transport sector is excluded, in order to narrow the scope of the paper. After reviewing the current energy profile we will turn to the conceptual framework on technological of large technological systems.

ENERGY SOURCES IN LATIN AMERICA: WHERE DO WE STAND?

With grossly 9% of the world's population, Latin America contributes with 3.6% of global GHG emissions, due to its low per capita energy consumption and its high shares of hydroelectric power in the world (IEA, 2003). But GHG emission and energy profiles are highly differentiated in the region. Brazil and Mexico are among the 15 countries with higher industrial emission of CO_2, while Central American countries are among the lowest rank. If we consider the use of hydrocarbons (both gas and oil), it seems clear that use patterns differ mainly due to the local availability of oil, and to the relative degree of industrialization. Excepting Argentina and a small subgroup of Caribbean countries, renewables hold shares of more than 10% of total primary energy in the region (Coviello and Montalvo, 2003). Paraguay and Costa Rica get 90% of their primary energy from renewables, while hydrocarbons reach between 80 and 90% of total primary energy (TPE) in countries like Argentina, Ecuador, Mexico and Venezuela.

In comparison with the structure of TPE in the rest of the world, Latin America holds relatively low amounts of coal, and higher amounts of hydro-power. Additionally, in comparison with industrialized countries it is relatively more intensive in oil, and less intensive in nuclear energy and natural gas. While the first feature can be attributed to energy resource endowments, the second is clearly due to the pattern of differential diffusion of energy technologies. Graph 1 summarizes the two dominant patterns of energy shares in total primary energy (TPE), considering the 9 countries that comprise 95% of TPE in the region[41]. Renewable sources account for 23% of TPE, a very high level for world standards. Within renewables, 51% comes from hydropower and 48% from biomass, and 1% geothermal. Groups 1 and 2 barely differ in oil use, but they strongly contrast in the relative importance of gas versus renewables, given a much higher importance of biomass in group 2. From this superficial information, it can be asserted that countries in group 2 have better options to improve their TPE fuel profile, because a higher diversity of sources and wider room for substituting gas for oil. Group 1, on the contrary, looks much more locked into oil due to the exploitation of local resources.

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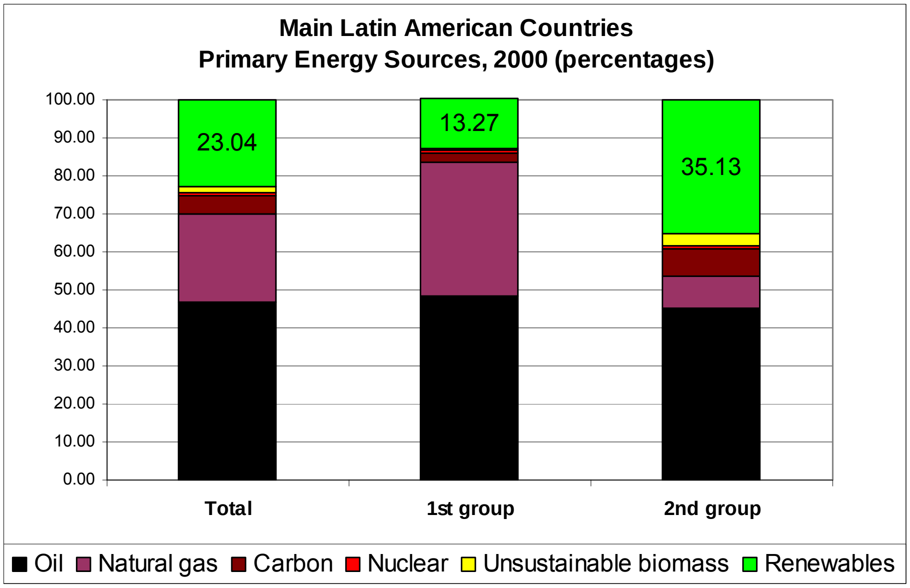
39 See Marchetti and Nakićenović (1979), Grübler and Nakićenović (1988), Nakićenović, Grübler and A McDonald (1998). This view has also been incorporated in the design of energy transitions developed for the IPCC (see Mart, Nakićenović and Nakićenović, 2000). A comprehensive historical account can be found in Smil (1994).

40 See IIASA-WEC (1995).

41 Group 1 includes Argentina, Ecuador, Mexico and Venezuela; group 2 includes Brazil, Colombia, Cuba, Chile, Paraguay and Peru.

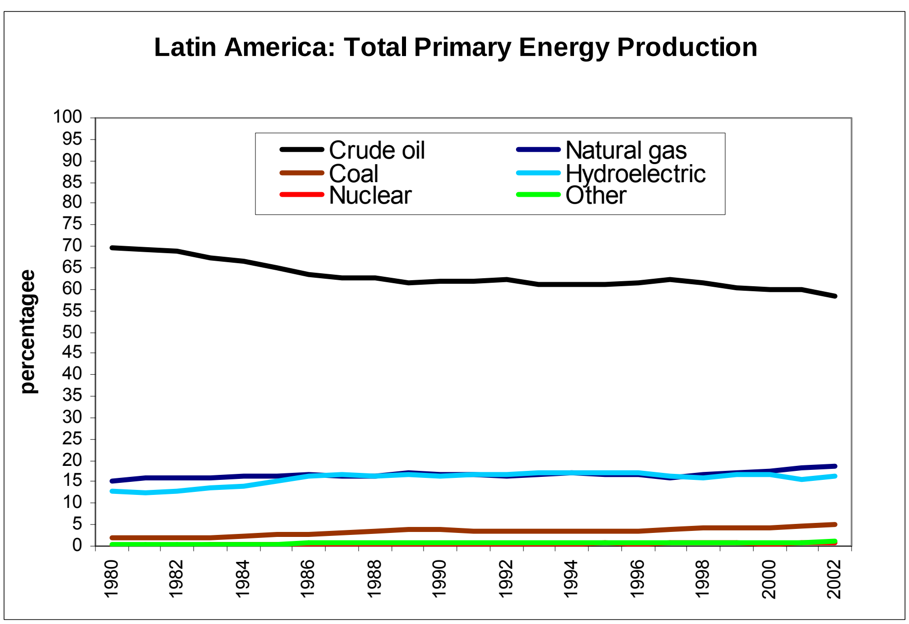
GRAPH 1



Source: Own calculations based on Coviello and Montalvo, 2003.

Considering only oil shares in TPE, a slight 'de-carbonization' trend can be appreciated (see graph 2). This has been remarked as a signal of global development in energy source substitution (Nakićenović, 1997). Nevertheless, in absolute terms there is no such a trend. Energy consumption in Latin America doubled between 1980 and 2002, growing annually at a 3.1% rate. Oil share in TPE reduced in the period, but at a slower rate than it did in the rest of the world. Still, even when all other fuel types grew at faster rates, oil consumption increased at a healthy 2.3% each year from 1980 on. Moreover, if we break down the period, oil accelerated slightly in the 90's with respect to the previous decade. Economic growth and low energy prices re-aligned the existing consumption pattern. If we break the period down a little bit more (in 5-year subperiods), it is clear that in absolute terms oil accelerates again in the nineties, while all other fuels slow down.

GRAPH 2



Source: International Energy Annual 2002, Energy Information Administration.
Notes: TPE excludes biomass. 'Other' refers to net geothermal, solar, wind, and wood and waste electric power generation.

Even when most developing countries are experiencing a reduction in the share of oil in their energy profiles, oil is the dominant energy source at the global level. Energy consumption will rise 59% between 2000 and 2020 (IEA, 2003). In Latin America, energy requirements are projected to grow almost 60% in the next two decades. Oil will continue to represent at least 40% of total energy until 2020. From 1973 to 2003, oil consumption grew at 1.6%, with reductions in many countries triggered by the oil crisis of 1973 and 1979; projections nevertheless account for absolute increases in oil consumption from 75 million barrels a day in 1999 to 120 million in 2020, growing at 2.3% each year. Developing countries will be consuming approximately the same amount of oil than developed countries by the third decade of the 21st century. Conventional oil production capacity, nevertheless, will have reached a limit of 100 million barrels a day; the gap of 20 million will have to be fulfilled by non-conventional oil and coal.

The process of substitution of gas (and hydro-power in the case of LA) for oil shows signs of a strong inertia that keeps the 'old' fuel growing in absolute terms by spurts, while at the same time its smaller competitors accelerate and de-accelerate also irregularly. The trend in oil dominance in Latin America, despite a higher share of hydroelectric power in comparison to the rest of the world, is signaling a lag in the gas-based intermediate period of hydrocarbon substitution.

As we will discuss below, the region shows a scattered presence of clean sources (hydro, geothermal, solar, wind), and cleaner fuels (ethanol, sustainable biomass); but niche presence of alternative technologies is not 'strategic' at all; i.e., it is not directed to systematically test, redesign and develop technology alternatives in order to increase their shares massively. Instead, niche presence is held by very thin technological and institutional pins, while economic forces constitute enormous barriers for introducing non-fossil technologies.

What are the forces behind energy transitions? What are the lessons we can learn from theories about the structure of technical change and the persistence of large technological systems?

DIFFUSION, ADOPTION AND SUBSTITUTION DYNAMICS

The original problem addressed by the economic literature on technology diffusion was why it takes time, and the methodological focus centered on the micro-economic determinants of the rate of diffusion (Mansfield, 1961). Later models explained lags by relating the time distribution of adoptions to the distribution of differences among users, picturing full adoption as an equilibrium adjustment process. This type of models introduced structural criteria as an explanation of adoption delays (David, 1969), but shared with the Mansfield model the assumption of an unchanging technology.

As a reaction against this assumption, other studies introduced diffusion as part of a longer developing process of technologies, where a progressive flow of innovations results from a cumulative learning process through diffusion (Rosenberg, 1976, 1982; Dosi, 1982; Sahal, 1981). This approach acknowledged that innovations perform badly at the moment of their introduction, and very rarely remain unchanged during its diffusion. Sometimes, changes in design are pre-requisite to its adoption. Other changes accelerate its diffusion, and some others facilitate its adoption beyond their original domains. Moreover, diffusion of innovations never takes place in isolation; most of the time it consists in the substitution of a new technique for the old, and the character of one tends to affect the character of the other.[42] The central insight is that technologies change while diffusing, and that these changes feedback into the diffusion process.

The relationship between diffusion and innovation demands focusing attention to the contexts in which new technologies diffuse. Innovation takes place via learning, i. e. through cumulative investment in new skills and technical knowledge, generating new articulations between organizations, new institutions, and new rules. These investments root technologies into the routines of the organizations that use them, reshaping the latter and enabling routes for further advance. The feedback channels between diffusion and innovation, as well as between technologies and their knowledge bases, structure the nature and scope of technological change. This structure consists of trajectories of incremental change, following basic designs or guideposts (Sahal, 1985) and paradigms of techno-scientific design and heuristic principles (Dosi, 1982). Such avenues of gradual change are eventually disrupted by the emergence of qualitatively new trajectories triggered by radical innovations and new paradigms. The long term pattern of technology evolution is then a mixture of continuity and change, cumulative synthesis and structural discontinuities.[43]

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42 Many times, competition from substitutes triggers intense improvements in old technologies, extending their lifetime, a development popularized as the 'sail ship effect' by Rosenberg (1982).

43 Levinthal (1998) associates this view of change with the 'punctuated equilibria' of evolutionary biology.

The dynamics of energy transitions suggested by Grübler, Nakićenović, et. al. (mentioned above) resembles these ideas of structured technological change in long waves of persistence and discontinuous change. Causes of persistence or 'stasis' are key factors hindering the transformation of energy systems and diffusion within them.

DIFFUSION WITHIN LARGE SYSTEMS: TECHNOLOGICAL REGIME TRANSITIONS

Energy systems are large complexes of technologies. The dynamics of gradual change and disruption incorporate hundreds of changes in their components and networks. Diffusion within them can then be approached as a process of adaptation of a system, within which the introduction of new components (and the practices associated to them) is spreading. A systems' view focus its attention to the interrelatedness of specialized components of a system, a property that is crucial to understand change. This property implies simply that modification in one component demands changes in other components, triggering and adjustment process that is transmitted through a hierarchical network. To a certain degree, diffusion can therefore be considered as equivalent to structural change in a system. What, then, prevents systems to change and adapt? Or, to get closer to our issue, what gives energy producing and energy using technologies their observed persistence?

Large systems like infrastructures and energy systems have very strong internal and external technological and economic linkages. We state that sunken costs and organizational inertia associated with embedded, large scale technologies generate important barriers to technology replacement and innovative absorption of technologies.

Take for example the components of power systems. Power systems are constituted by related parts and dedicated components (in generation, transformation, control, and utilization functions) connected by transmission and distribution networks. This configuration is embedded on a large base of technological and scientific knowledge, standards, and operative rules. To follow a physical metaphor, a large system has mass (machines, devices, structures, physical artifacts where capital has been invested), velocity (rate of growth), and direction (goals): 'The momentum arises also from the involvement of person's professional skills, business, government agencies, professional societies, educational institutions and other organizations that shape and are shaped by the technical core of the system' (Hughes, 1983:15).

A contemporary group of scholars has coined the term 'technological regimes' to characterize rigidities in large systems. As defined by Kemp, Smith et al. (1994, p. 15) a technological regime encompasses 'the overall complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, institutions and infrastructures which make up the totality of technology.' The behavior of agents is then structured by 'the dominant practices, rules and shared assumptions that guide private action and public policy in a field' (Kemp and Rotmans, 2001). Socio-economic and technological factors drive and shape each other. Regimes are of course dynamic configurations where changes are fundamentally oriented towards optimizing the system along defined trajectories, but its embedded-ness in practices and routines, and the 'momentum' gained by its 'mass', together with vested interests and interlocked demand and supply, prevent the transformation of its technological base in a radical way.

System innovation involves then changes beyond the realm of simple components. Adapting to the irruption of radical innovations implies that the whole socio-economic configuration must then develop 'new linkages, new knowledge, different rules and roles, a new 'logic of appropriateness', and sometimes new organizations' (Kemp and Rotmans, 2001).

The learning metaphor should not overstate socio-technical factors over economic rules, but rather the interfaces between them. Technology changes and incorporation of new knowledge realize only through new investments. Past investments and their influence on the structure of future capital flows reinforce socio-technical persistence and barriers to adoption in a dynamic way.

THE PAST AMONG US: OLD INVESTMENTS AND SUNKEN COSTS

When substitution and replacement are involved, capital turnover is a key leveler of technology diffusion. The productive life-time of plants and equipment is a barrier to introduction of new equipment, with disregard of price movements in inputs and products, and even when new technologies have proven more efficient in certain niches. The weight of sunken costs against replacement is bigger the higher the indivisibility of investments and the larger the unit of capital. When capital units are large, it is much easier to introduce additional (peripheral) investments than replace the whole unit, even when the latter additions have smaller impacts on efficiency and revenue. This is why investment in most capital-intensive systems involves a long-term commitment with pre-

sent technologies, the technological design of which is to remain practically unchanged during the life span of the facility.
This is the core of the well known ‘vintage capital’ argument (Salter, 1960), where technology adoption is subject to an adjustment process involving the cost-revenue distance from past investments to best technique. The crucial factor in this process is that capital costs (obsolescence, amortization and required profits) are relevant for investment decisions only *ex-ante*. Once gross investments are transformed into equipment, these capital costs become rents[44]. Various rules can alternatively govern equipment replacement and decommissioning criteria (for example: a) when unit variable costs of old equipment exceed total unit costs of current best practice; b) when unit variable costs exceed the price attained per unit of output).

Decommissioning criteria are then crucial standards for technological succession in energy intensive industries, and probably the central levelers in the transition to new energy sources.

The lesson from dynamic models where technical change is incorporated in capital goods (Silverberg, 1984; Soete and Turner, 1984) is that the feedback between investment and profitability can create waves of investment biased to certain technological configurations. The share of preferred technologies in the total capital stock will follow replicator dynamics. If learning and innovation derives from use, technologies that benefit from investment flows are more explored and eventually become cheaper; in turn, profit rates of those technologies increases, making subsequent investments more attractive, and so on. From the perspective of latent new EST technologies, the argument works the other way around. As long as investment is kept off alternative technologies, the latter will remain untried and expensive and short-term flows will restrict to existent technological configurations. This is why tapping the development potential of technological alternatives by redirecting investment flows into niches and explorative fields becomes crucial for increasing diversity and breaking the inertia of technologies ‘crystallized’ in the capital stock.

Capital turnover and economic growth are closely linked. But in the case of a large technological regime, sunken costs constitute a formidable source of inertia and directed momentum. Capital replacement in energy intensive industries with slow growth and high excess capacity is unlikely without incentives and strong market regulation. Facing new regulations, the ‘gravity’ of sunken costs may attract resources into end-of-pipe solutions and technological efforts into enlarging the life cycle of dominant technologies. But more importantly, sunken costs raise the performance and cost requirements of alternatives and delays application decisions downstream and upstream any interconnected system. Especially in the case of energy systems due to their high interconnectedness, sunken costs set ‘hurdles’ of minimum profitability for substitute technologies, narrowing their domains of application, retarding the accumulation of experience and hindering their development and diffusion. Turnover of capital in heavy, long-life units gravitating one over the other can only come from strong growth and heavy investment rates, which become a requirement for technological development.

TAPPING ALTERNATIVES

Since dominant regimes have co-evolved with application domains, shaping each other to their own image, alternative configurations can only emerge developing in ‘strategic niches.’ Niches are local domains where new or non-standard technologies are used. These domains provide a development field where new options can be learned and further improvement be stimulated. Firms create niches for strategic reasons; a heterogeneous demand can also build niches for differentiated products; governments create and nurture niches systematically as part of their industrial and technology policies.

Candidates will only show its potential after a period of test, correction and improvement, once ‘bugs’ have been cleaned up and interrelated systems’ adjustments have cleared the way to more exploitative applications. No technology can be picked-up without uncertainty and it is not possible to assert *a priori* that an emerging candidate is the best among alternatives. Technologies that show increasing returns to adoption can easily ‘lock-in’ sub-optimal solutions (David, 1985; Arthur, 1989). But in order to overcome rigidities and previous ‘lock-in,’ the choice menu must be broadened and development must be stimulated. Increasing diversity is crucial in order to achieve resilience. The stability of established technological regimes is relative. Following Berkout, Smith and Stirling (2003), it is ‘shifts in the relative strength of the selection pressures’ which generates opportunities for change.

To assess a technological transition from a technological regime approach suggests focusing on four aspects:

[44] Salter recalls here that ‘the stock of existing capital goods is comparable to land, and forms the rationale for Marshall’s dictum that the earnings of existing capital goods are quasi-rents’. He also recalls the insistence of J. B. Clark that ‘such earnings are pure rents indistinguishable from those of land’ (Salter, 1959, p. 61).

the goal or projected end state; the different phases through which that goal can be pursued; the barriers that characterize each phase (the cost of adoption, resistance of vested interests, and uncertainty about the best option); and the internal and external selection forces shaping the outcomes of the transition.

Managing the transition implies then focusing on multidimensional levels influencing the process, in order to identify proper policy and institutional drivers oriented to system innovation in conditions of high uncertainty.[45]

A transition is the result of long-term developments in stocks, and short-term developments in flows. Stepping off the hydrocarbons regime will demand to unlock energy carriers from fossil fuels, while at the same time reducing GHG emissions by capture and increasing energy efficiency. This challenge will come from developing new energy sources and sustaining its diversity, but also from technological learning and investment everywhere in the subsystems of conversion, grids, final consumption, and suppliers of equipment.

How prepared are Latin American economies and their technological systems to face this large scale demands of coordinated technological efforts?

SECTION 2
REGIONAL SELECTION ENVIRONMENTS

This section identifies systemic barriers to adoption of new technologies in energy systems and intensive industries in the Latin American region, focusing on key technological and macroeconomic factors that characterize their economic structures. Despite the pointed differences in fuel mix profiles among Latin American countries, the types of structural constraints to adoption and assimilation are very similar in the region.

Meso-level: local capabilities and distributed knowledge bases

Approaching technological diffusion as the assimilation of new varieties into pre-existing structures and organizations has immediate consequences for technology transfer to developing economies. The literature on technological capabilities (developed closely to the evolutionary views on technology mentioned above), stresses that costs of diffusion and imitation as well as of original innovation can be reduced once an autonomous capability has been established, contrary to the common sense idea of late-comers-advantage. Moreover, local technological capabilities determine the nature of what is transferred and the deepness of technology diffusion.

The probability of adoption of new technologies, just as the scope and deepness of absorption depends critically on the accumulated experience of firm's in dealing with technological change. In turn, making incremental, adaptive, and innovative modifications to selected technologies depends on assets qualitatively distinct from those required to efficiently manage and operate production units (Bell and Pavitt, 1997). The absorptive capacity of economic organizations is determined by their ability to identify, assimilate and exploit external knowledge (Cohen and Levintal, 1989), which takes place in defined circuits of productive and technological linkages, framed by institutions and policies constituting industrial and national systems of innovation (see the contributions in Edquist, 1997).

Perez (1983) and Freeman and Perez (1988) have argued that the absorption of new technologies depends on a 'proper' match between the techno-economic system and appropriate institutions (including legal frameworks, labor relations, and cultural attitudes). These institutions may only adapt with considerable delay and in a somewhat discontinuous manner. Of course, we can only guess what types of sociotechnical systems will 'match' the emergence of new sources of energy. A 'proper' match can only emerge after intense institutional adjustment base in trial-and-error, a flexible coordination directed to clear goals and wide social involvement.

In order to identify specific barriers and drivers for change technological regimes must be focused at a mesoeconomic level. We identify here the mesoeconomic level, in tune with Cimoli and Dosi (1995) with the level of networks of linkages between firms and other organizations, both within and outside their primary sectors of activity. Technical knowledge is unevenly distributed across such networks, and this immediate realm of interaction critically enhances or hinders a firm's opportunities to improve problem solving activities. The historical path followed by science and technology institutions, which shape this meso-economic realm in particular industries, explains at a very large extent the differences in technological development across countries. [46]

It is crucial here to distinguish between capabilities to 'efficiently use and manage equipment', from capabilities

[45] 'Transition management does not attempt to choice the best path but attempts to learn about various options and to modulate dynamics [of myopic agents] towards societal goals. An energy transition policy contains the current climate policy, but adds three things to it: a long-term vision, an impulse for system innovation, and a framework for aligning short-term goals and policies to long-term goals' (Kemp and Rotmans, 2001).

[46] As stressed by Katz (1997), Kim (1997) and Lall (1997), differences in the historical paths of industrial and S&T policies are crucial in explaining the diverging paths of technological learning between South East Asian and Latin American countries

to solve critical engineering problems and re-design the architecture of technologies and systems, and the latter form capabilities to change engineering paradigms and generate radical innovations. Transfer is never totally successful and sustainable when local learning is restricted to the knowledge of 'how to use' a technology. Demands on the local sociotechnical environment does not stop there; even when incremental innovation is possible in laboratories and research centers, successful application into new domains requires additional financial, managerial (and sometimes marketing) skills (Amsden, 2001).

Energy technological regimes in Latin America developed in a pattern of fast growth based on import substitution. This development model pushed industrialization and urbanization in larger nations at very fast rates, pressing for a correspondent pace in capacity of energy supply without stimuli for qualitative diversification. Scale and income barriers of energy demand, together with difficulties of developing clusters of specialized equipment suppliers, set limits to technological diversification in energy systems which revealed after the oil crisis in the mid 1970's. Only Brazil was able to develop a significant capital goods industry[47]. Oil reserves in Argentina, Brazil, Ecuador, Mexico, and Venezuela biased heavily investment policies to exploitation rather than exploration (in the technological sense). The debt crisis, its following effects during the 1980's, and the structural adjustment programs instrumented afterwards acted as 'massive selection mechanisms' on the national industrial technology base in all countries in the region (Katz, 1997). Privatization, foreign direct investment, and corporative restructuring have profoundly reshaped the industrial organization at different levels, but the accumulation of technological capabilities has tended to focus on already acquired competencies rather than to diversify them. Of course, these general trends have important exceptions, and many Latin American energy firms and their suppliers have developed networks across many technological areas, and specialized technological competencies.[48]

Approaching a technological transition simply as a problem of technology transfer from abroad (understandable in the early stages of development, but self-defeating for capability building) reduces the probability of upgrading technological regimes, but more importantly asphyxiates the creation of innovation niches. Specifically, the exclusion of active industrial and science and technology policies has only reinforced the Latin American syndrome of buying, rather than building, technological skills.

Since the 1950's many Latin American countries developed national research institutes to supply technology to their energy sectors. These institutions, have acted as catalizers of technology transfer and technology development, and have accumulated a significant degree of expertise in innovation and technology development capabilities. Nevertheless, these innovative efforts have very rarely acquired the critical mass to consolidate proper innovation systems. Even when inventions and patent registry has become routinized in many Latin American R&D institutes, there are serious barriers to absorb these capabilities at fast learning rates early at the energy production level (and at the production level, in the case of energy intensive industries). It is at this stage of the innovation process where local firms are surpassed by transnational companies, with century-long accumulated capabilities in development and market introduction. Sometimes, local industries end up importing substitutes of technologies they can replicate at the research level but cannot spin-off from the lab.[49] Of course, the insights gained through research help local industries to identify and adapt successfully new technologies through transfer, but the process at the national level does not open tracks for further advance and new applications.

Research capabilities may be weak (and financially constrained), but it is the absence of market development and manufacturing capabilities at early stages of introduction which critically hinders the feedback channel between knowledge generation and productive systems. Structurally, this systemic mismatch is reflected in the absence of local firms specialized in supplying the vast majority of capital-goods nurturing their energy and energy-intensive technological regimes. As is the case with most technologies in Latin America and the rest of the developing world, transfer and diffusion of embodied technologies has not included the accumulation of a critical mass of technological capabilities directed to creative imitation and autonomous replication.[50]

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[47] Electricity and oil industries in Mexico import around 70% of capital equipment; the gross of local suppliers provide relatively simpler components and building infrastructure.

[48] A salient example is the Techint Group, based in Argentina, an industrial holding of large firms specialized in seamless steel pipes for the oil industry. This merge of Argentinean, Brazilian, Italian, Japanese, Mexican and Venezuelan leaders controls 30% of the world market.

[49] Aboites, Loria and Rosado (2004) show that, despite the innovation capabilities of PEMEX's R&D institute (the National Oil Institute, IMP) in catalytic processes, the transnational oil companies are the main suppliers.

[50] Creative imitation is a threshold concept when assessing technology transfer into underdeveloped economies (see Kim and Nelson, 2000: Introduction). Creative imitation (this is, imitation with a plus of originality at some level of the technology) is important in three ways; first, for realizing the necessary design adaptations to make technology appropriate to the local environment (both in technical and economic senses); second, as the outcome of a deep learning process, that contributes to the ac-

The technological knowledge base surrounding dominant energy and energy-intensive technologies is broad (comprises very different engineering areas), deep (demands profound specialization), and science based (the boundaries between basic and applied research are blurry). As the technological regimes of energy production evolved at the global level, technological competence has spread to specialized suppliers of equipment, while at the same time, R&D demands for up-stream and downstream incumbents have increased.

Renewable, carbon-free energy technologies are 'well known' to engineers and university researchers in Latin America. Plenty of organizations and associations promoting the diffusion of solar, wind, biomass, and hybrid technologies and components are to be found all around. The point, however, is that technological applications do not occur driven by systematic forces, but against them. Technical knowledge and opportunities are restricted to small circles and remain out of reach of other important stakeholders and decision makers, many times inside the same institutes and corporations. Moreover, institutional and regulation frameworks at many levels of government prevent this technological and engineering base of nurturing potential strategic niches (Huacuz, forthcoming).

While some sustainable alternatives like wind and industrial biomass seem to have relatively simpler knowledge bases (in comparison with oil, gas and petrochemical families of technologies), others do not. This may raise technological barriers to assimilate technologies when investment and scale obstacles are still easy to overcome. The knowledge base of new technologies tends to be broader and less codified at the moment of their introduction. As Pérez and Soete (1988) argue, this 'learning' barrier tends to diminish with exploration and standardization of technologies, but by the time this happens investment thresholds have already rose up. Some scholars have argued that many emerging technologies (biotechnology, nanotechnologies, and) rely on broader and more complex knowledge and competence bases than its predecessors; this would be the case of the fuel cell compared to the internal combustion engine (Mytelka, 2003). Some views about future energy configuration also point at higher degrees of complexity, with more elaborated systems of energy conversion and delivery, and 'leading to ever more sophisticated energy systems and higher-quality energy carriers' (IIASA-WEC, 1995). Since technology is a strategic asset, this will probably require more sophisticated forms of generating, appropriating and controlling technology. Both aspects could build bottlenecks to early assimilation, leading Latin American economies to repeat the pattern of late, passive technology absorption.

MACRO-STRUCTURAL BARRIERS

The macroeconomic landscape behind technological transition from hydrocarbons looks quite complicated for Latin American economies. The construction of large energy systems in the region, from the 1950's until the late 1970's, occurred in conditions of sustained GDP growth, low inflation rates, stability in exchange rates and positive financial transfers from the outside. The crisis in the Bretton-Woods system of trade and exchange rates, together with the excessive accumulation of foreign debt brought to an end the inward oriented industrialization patterns developed in the region. But economic reforms after the 'lost decade' have failed in assuring growth, stability, and structural change based in technology upgrading.

Since the topic is broad (and surely controversial), we would focus here on three features of the macroeconomic profile shared to a similar degree by all Latin American economies. First, since the late 1980's macro stability has relied upon the systematic contraction of the domestic market and high interest rates in order to keep down inflation and exchange rates, neutralizing anti-cyclical policy instruments. Second, adjustment in public finances has relied mainly on cutting down public expenditure without increasing public income; this, next to the persistence of foreign debt obligations, has curtail the ability of the government to 'steer' the economy through times of adjustment and transition. Third, globalization and liberalization of the financial systems in the region have installed fragile scenarios characterized by high volatility in capital markets, exchange rates and interest rates. Even though exports have increased as a share of output, trade deficits continue to be structurally embedded into economic growth (see Graph 3). Despite the aims of 'structural adjustment,' the trade profile of the region reveals it is trapped in a low technology, resource-intensive path, unable to capture and secure dynamic efficiency gains. External debt services constitute a permanent tax to growth (see Graph 4). Capital flows in the form of FDI, have not recovered after the short boom during the 1990's, and the region is entering a trend of negative net capital transfers.

Volatility, high interest rates, slow growth and technological lags in the industrial base form a syndrome of systemic risk that hinders diffusion and innovation:
retarding productive investment and capital turnover

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cumulation of technological capabilities and competitiveness (dynamic efficiency), finally, both appropriateness and learning are needed to guarantee the economic viability of technological up-grading in the long run.

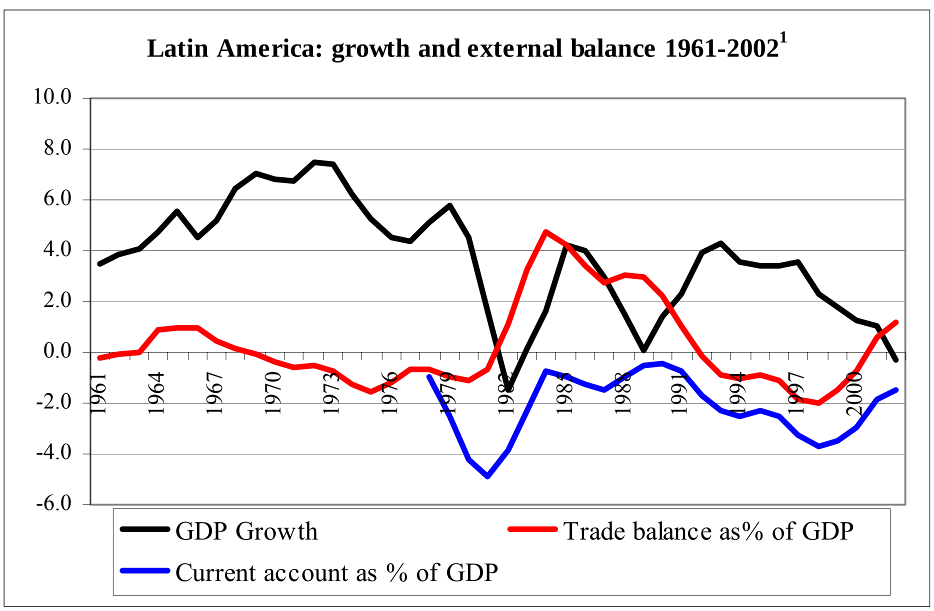
biasing productive investment to short term goals and 'working capital'
delaying projects aimed at meeting environmental regulation
biasing environmentally-innovative projects to EOP and to incremental improvements in energy efficiency
reducing the probability of carrying projects that involve CTs
reducing the probability of engaging in intramural R&D and reducing investment in broad technological capabilities

Macro structural factors gravitate heavily upon the cost of capital, influencing significantly scrapping-decommissioning criteria and the rate of capital turnover. Energy infrastructure investments are big, 'lumpy,' and risky. Many times they involve coordination among complementary investment projects. Ceteris paribus, a lower cost of capital equipment enhances the likelihood of an industry modernizing its plants with new equipment. At the same time, it increases the likelihood of making anticipated plant-scrapping decisions. On the contrary, high costs of capital induce decision makers to postpone major investment decisions, and at the same time reinforce technological search efforts aimed at extending the life cycle of specific pieces of equipment. These stretching efforts are of course efficient in the short run, but at the cost of paralyzing technological development. By inhibiting investment in fixed capital they reduce the possibilities of optimizing the existing technological regime. And in the longer term, it blocks out investment in riskier, more uncertain and less profitable niche alternatives. In this way, the technological structure and investment behavior reinforce each other.

The relationship between public finance and the fossil fuel regimes is especially worrying in oil producer countries. With the exception of Petrobras, dependency on oil revenues has tied the fiscal regimes of oil companies to the financing of government expenditure, blocking investment flows for maintenance, technological upgrading and R&D.

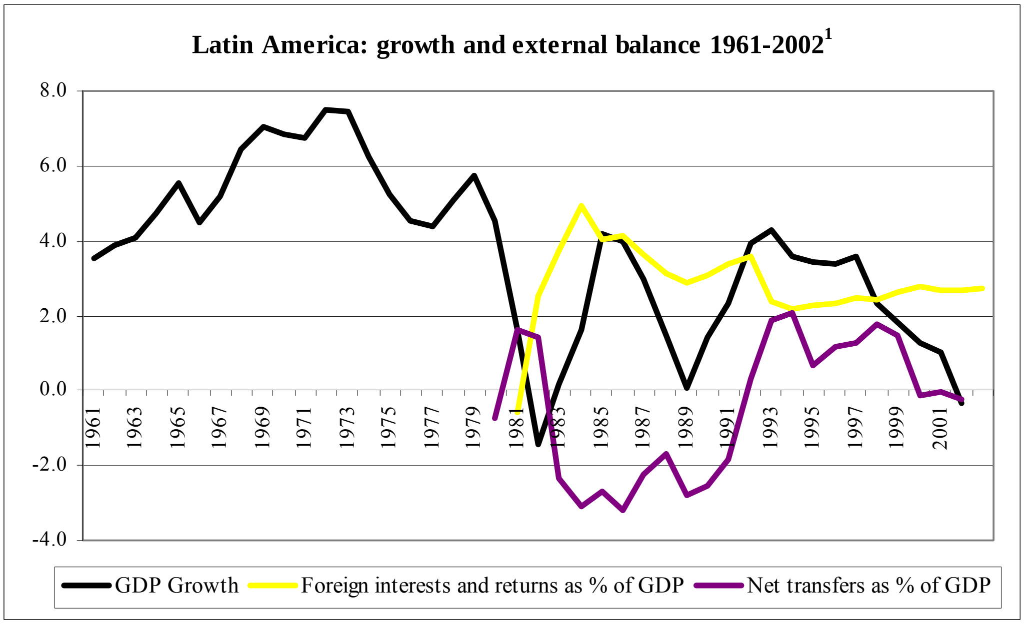
Income concentration and low income levels reduce diffusion rates conduces both from the demand as from the supply side, to slower diffusion rates and to a reduction in the number, variety, and speed of development of potential strategic niches for innovation. Adoption costs can hardly be shared with final users (being them industrial firms or households) with low-income levels, especially during the first phases of transition when new technologies involve higher costs.

GRAPH 3



Notes: [1] Three year moving averages. Includes Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru and Venezuela. Source: World Bank National Accounts Database; International Monetary Fund, Balance of Payments Statistics.

GRAPH 4



Notes: [1] Three year moving averages. Includes Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru and Venezuela. Source: World Bank National Accounts Database; International Monetary Fund, Balance of Payments Statistics.

Finally, but not least importantly, financial pressures on Latin American states seriously hinder their capability of gradually increasing and sustaining government expenditure dedicated to increasing technological capabilities: education services and infrastructure, basic R&D, R&D in general-purpose and other strategic technologies, horizontal and specialized science and technology services and venture capital. The involvement of state expenditure in R&D will be especially important to attract complementary private flows and reduce uncertainty in the first stages of technology development (see Kim, 1997 for the case of Korea).

The next 30 or 40 years present already enormous challenges for financing energy systems in the region. Capital costs are going to be crucial, not only for finding ways to invest in future alternatives, but simply for sustaining the current technological regimes in oil, gas and electricity. According to the IEA, Latin America will need to invest 1.5% of its GDP every year from 2001 to 2030 only to cover its basic energy requirements (around $1,337 billion dollars in the whole period). Of this total, 25% will go to oil and 18.5% to gas. Only exploration and development in fossil fuels will account for 28% for the total energy investment.

SECTION 3
SELECTION ENVIRONMENTS
THE COMPOSITION OF INVESTMENT: FROM FLOWS TO STOCKS AND BACKWARDS

In this last section we construct a simple heuristic framework to exemplify the influence of structural factors on investment flows. By comparing ad hoc examples under stylized conditions we exemplify how rigidities will impact alternative transition paths.

As we argued above, rigidities in a technological regime progressively hinder technological changes of higher order of complexity, biasing technology developments to the easier changes. Clearly, transition out of hydrocarbons implies the generalized adoption of CTs; optimizing trends within the hydrocarbons regime (through diffusion of EOP and increases in energy efficiency), offer in turn a temporary response to emission abatement requirements. Energy efficiency can come both from incremental innovation within the dominant regime of hydrocarbons (EEI) as from incremental and radical innovations in process technologies in end users (EER). Radical improvements in energy efficiency in industrial users can be considered, in turn, as a transition in their respective technological regimes.[51]

[51] CT solutions are clearly preferred to EOP solutions from both environmental and technological criteria. First, EOP technologies are perceived as an increase in cost production, even when these costs are clearly offset by environmental gains. Cleaner pro-

Suppose these possibilities for technological investment are assessed as constituting an investment portfolio. Firms or decision makers evaluate investment decisions comparing expected returns to adoption costs. Suppose that the investment options are: acquiring new equipment on a 'business as usual' basis (BAU), projects involving adoption of EOP, increasing energy efficiency through EEI, or introducing EER or CT. All this options are graded according to the correspondent technological effort or technological 'familiarity distance.' Suppose, finally, that these investment options are compared to a risk-less asset (like bonds or other financial instrument) constituting a financial 'hurdle' rate. A rule of investment will look like:

$(p-r) = \alpha + \beta(TE)$

where *p* are expected returns to the project; *r* the interest rate and *TE* the technological effort.

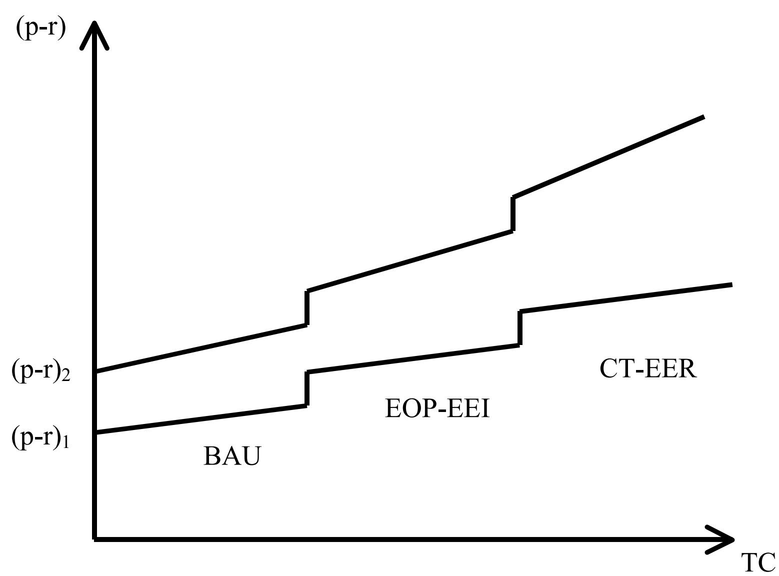
If we graph the possible distributions of investment flows into EOP, EEI, EER and CT according to their expected returns and the requirements on local technological capabilities to carry them on, alternative scenarios would look like Graph 3 (below).

Uncertainty associated with distance in technological familiarity increases along the axis line; but additional 'hurdles' arise from discontinuities in the nature of projects (schematically drawn like jumps in the investment distribution line). Parameter α captures 'system hurdles' derived from sunken costs up-stream the energy chain or associated equipment; parameter β will be affected by the 'sensitivity' to the technological effort or opportunity of appropriating technological gains (the higher the opportunity, the lower the slope of the line).

The model should be appraised not in a deterministic, but in a probabilistic way. In principle, no investment option is excluded. Some risky projects located above the portfolio investment line may be selected. But most selected projects will match the rule. The point of a model like this is to assess how different environments would affect the probability distribution of selecting different technology projects. The static conclusions of this simple exercise seem straightforward. The higher the technological effort of the project (or the less 'familiar' the technology to the organization), the higher the 'hurdle' impact of sunken costs, and the lower the perceived gains, the higher the floor of the expected return demanded to invest in it.

The higher the level of the rule, the more projects are 'screened-out.'

GRAPH 5



duction methods, on the contrary, involve most of the time superior performance, but at higher adoption costs and risk. Second, EOP technologies simply shift the flow of materials creating additional costs of energy, transport and storage. Clean production eliminates (or reduces substantially) the emission of materials and reduces energy intensity by substituting inputs and incorporating more efficient forms of energy use.

Low interest rates, local technological environments conducive to a high perception of technological opportunities and accumulated experience in technical change would increase the probability of having a more distributed profile of technology investments (more 'hits' along the whole range of options). Still, niche nurturing will be necessary to extend the distribution to the upper-right area of the graph. On the contrary, fragile financial systems and stringent access to financial resources, slow market growth, incomplete technological systems and high adoption costs, will bias the distribution of projects to the origin, screening out first CT and EER projects, then incremental advances, and eventually all equipment investment.

Within a technological regime, investment decisions of independent investors will collide and affect each other. The aggregated distribution of investments at a point in time will configure an investment pattern reflecting the 'momentum' of a regime, its drive for optimization and the strength of transition drivers. Structural macro and meso-economic conditions influence the parameters of technology selection, which by allocating investment flows reinforce or weaken the nested persistence of technological configurations.

More interestingly is how different scenarios would *evolve* through iterative investment rounds. As we stated above, there exists a feedback process between capability accumulation and resource allocation to technology projects: 1) local capabilities are a critical component in investment decisions: they illuminate promising areas of technological development, assess risk and opportunities, and reduce transfer and development costs; 2) investment decisions feed capability accumulation: capability is embedded in processes that use and consume resources. This means that the position of the curves (the distribution of technological projects), would depend on previous investment patterns, generating complex, non-linear dynamics and path-dependent trajectories. Developing a formal model is part of our current research.

For the moment we can infer that the technology profile of a country's capabilities would follow closely the aggregated technology investment profile in a clear circular causation relationship. Sunken costs and capital costs are evaluated by agents through parameters defined both at the macroeconomic level (interest rates, demand growth, credit availability) and at the meso-economic level (input prices, and the base of technological capabilities). In this way, signals from the entire economic system are translated into selection pressures that foster or hinder adaptive responses or shifts in technological regimes.

SELECTION ENVIRONMENTS: MEXICO AND THE LATIN AMERICAN CONTEXT

Changing the profile of technology investments in a country will depend at a good extent on the interplay between financial constraints and the capacity of local systems and organizations to unveil technological opportunities. In this last section we examine *grosso modo* the magnitude this two forces in Latin American countries.

Table 5 provides an estimate about the cost of credit in the Latin American region. Average interest rates in Latin America were 3.6 times as big as the U.S. prime rate during the nineties. This difference diminished after the 1994 Mexican crisis but started growing again since the year 2000. Financial liberalization and reform has been unable in bringing down credit prices and, most important, in increasing financial penetration into these economies. Credit scarcity combines critically with the lack of a solid institutional platform providing long-term credit and venture capital.

Table 1

Latin America: Interest Rate Differentials (local rate/US prime rate)*

	1993	1994	1995	1996	1997	1998	1999	2000	2001	1993-1997	1998-2001
Latin America[1]	**8.4**	**4.5**	**2.5**	**2.6**	**2.5**	**2.8**	**3.4**	**2.3**	**3.5**	**4.1**	**3.0**
ARGENTINA	1.0	1.2	2.3	1.9	1.4	1.4	2.1	2.1	6.0	1.6	2.9
BRASIL	69.6	26.6	1.7	5.2	6.2	7.5	8.5	5.1	7.3	21.9	7.1
CHILE	2.7	1.4	1.3	1.5	1.3	2.7	1.4	1.6	1.9	1.6	1.9
COLOMBIA	3.6	3.1	2.9	3.3	2.2	3.0	3.0	1.7	3.4	3.0	2.8
MEXICO	3.7	2.7	3.2	0.3	0.5	1.6	1.4	1.4	1.9	2.1	1.6
PARAGUAY	3.5	2.7	3.0	3.8	3.2	2.5	3.8	2.8	4.7	3.2	3.4
PERU	10.0	5.4	3.8	3.4	3.3	3.5	5.2	4.2	5.5	5.2	4.6

* Real interest rates (deflated by the consumer price index).

[1] Regional average; includes Bolivia, Costa Rica, El Salvador, Ecuador Guatemala, Honduras, Jamaica, Nicaragua, Uruguay, and the above listed countries.

Source: Economic Commission for Latin American Countries and International Monetary Found; U.S Department of Treasury and U.S. Department of Labor Statistics.

These estimates should be accounted as the credit cost baseline due to unregistered operational costs which could easily level up the differential to the reference rate. Even in countries like Chile and Mexico, where strong inflation control has lowered interest rates credit is still almost twice as high. Higher credit costs and market uncertainty constitute enormous financial barriers for long-term investment, especially for small and medium firms. According to the Bank of Mexico's Credit Market Surveys, only 18% of small and medium firms borrow from national commercial banks; 2% borrow from international banks and 2% from development banks.

The impact of high interest rates must add to the fact that capital-intensive investment in developing countries is commonly assessed as less profitable and more risky (IEA, 2003). Conventional technology regimes may very likely face trouble in finding suitable financial sourcing under this conditions, leaving new energy sources and clean technologies in an even weaker competitive position.

Research and development resources in Latin America are scarce. Table 6 shows a set of selected indicators of R&D activities in the region. Total expenditure is small in absolute terms as well as relative to GDP (accounting for purchasing parity power differentials). Per capita expenditure on R&D is 20 and 35 times smaller than that of Canada and the U.S. respectively. Total human resources devoted to R&D are also much smaller than in North America and asymmetries diminish in order of magnitude only for a handful of countries (Cuba, Argentina, Brazil).

This scarcity of resources creates an adverse environment for the private appropriability of technological development, which reflects in the lower level of business enterprise share in R&D expenditure and the minuscule percentage of local patenting. Given the volume of resources, the relatively bigger percentage of R&D allocated to environmental and energy R&D in Latin America is probably insignificant.

Table 2

Latin America: Selected Research and Development (R&D) indicators[1]

country	R&D expenditure					R&D personnel		Patents
	Total (million PPP$)	As percentage of GDP	Per capita (PPP$)	Business enterprise share	Environmental and energy share of R&D	Researchers per million inhabitants	Total S&T personnel per million inhabitants	Invention coefficient[3]
Argentina	908	0.39	25	22.5	7.1	949	1,438	3.0
Brazil	13,564	1.04	80	38.2	2.3	200	1,470	5.2
Colombia	275	0.10	6	46.9		169	299	0.2
Cuba	190	0.62	17	35.0	22.4	538	6,531	1.3
Chile	767	0.57	52	24.9	3.2	429	915	2.8
Mexico	3,321	0.39	34	29.8	23.2	261	446	0.4
Paraguay	21	0.10	4	0.0	3.7	127	438	0.2
Peru	140	0.10	5	10.7	0.0	229		0.2
Venezuela[2]	463	0.38	18	20.9		222		0.4
Latin America	**19,649**	**0.41**	**27**	**25.4**	**8.8**	**347**	**1,648**	**1.51**
Canada	17,869	1.88	569	45.3		3,333	5,073	17.9
United States	276,434	2.64	960	64.6	2.2	7,125	8,545	58.6

Notes:

1 2002 data, excepting Brazil (2000), Chile (2001), and Mexico (2001)

2 Total Science and Technology expenditure

3 Patents applied by residents per 100 000 population

Source: Interamerican Network of Science and Technology Indicators (RICYT).

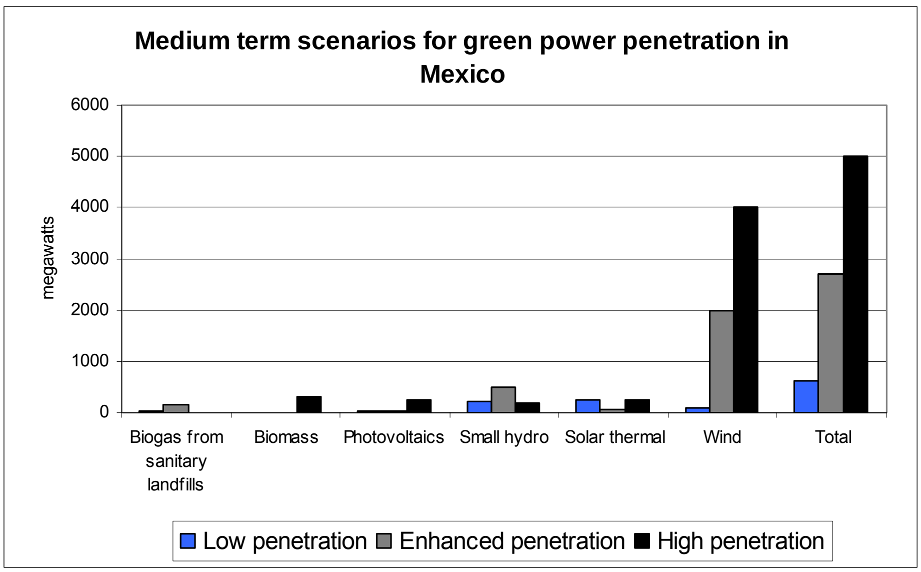
Small investment in specialized technological resources and skills diminishes the capability of transferring, adapting and developing substitute technologies. It also makes more difficult the development of new capabilities and setting up a technologically dynamic environment. This, in combination with a financial environment adverse to capital turnover exemplifies the rigid situation depicted in the heuristic model described above.

How does this relate to the development of new technological capabilities? Take the example of electric power in Mexico. This country has a relatively small use of renewable sources for electricity production due to high endowments of fossil fuels, small energy markets, and direct and indirect subsidies to oil use. Nevertheless, the perceived higher costs of renewables could be reduced by enhancing a number of complementary technological and institutional developments. Between 2004 and 2013, Mexico will need to expand the capacity of its national electric system in around 25,000MW. Technology for 73% of the new capacity has already been chosen: 52% of new electricity will be produced by combined cycle power stations, 7% by other fossil fuel stations, and 12.7% by large hydropower plants (SENER, 2004). Wind energy will contribute with 405MW. Mexico's energy dependence on hydrocarbons will this way emerge unaltered after ten years, unless new renewable sources are assigned for the remaining 6,700MW.

Estimates show, however, that renewable energy resources could in fact cover a much broader share of electric power. According to Huacuz (forthcoming), around 5,000MW could be now economically produced from wind (see Graph 6 below) and another 10,000MW may be detected through further exploration. Next to small hydropower (3,550MW), biomass (36MW) and biogas (150MW), new renewables could be delivering three times the amount of energy which technology choices have already left out.

A concert of technological and organization efforts could reduce the perceived cost of new renewables: augmenting the 'hardware' stock through pilot plants; increasing the availability of 'software' (technical norms and procedures, best practice manuals for project replication, development guidelines); achieving institutional changes at all government levels; and investing in specialized human resources.

Graph 6



Source: Huacuz (forthcoming).

CONCLUSIONS

The energy transition demanded from environmental concerns and limited availability of resources is fundamentally a technological transition. Sunken costs, high capital intensity, laid distribution networks, nested engineering practices and knowledge, as well as the relative inefficiency of alternative technologies and a strong institutional power, are all factors built in hydrocarbon-energy systems that constitute a front of selective pressures hindering energetic transition. Macroeconomic and structural features acting on investment decisions can amplify the selective pressure from built-in barriers to innovative diffusion and replacement in energy systems and energy intensive industries. In the case of Latin American countries, this will likely be the case under present trends.

Three aspects of the 'technological regime transition' are important to highlight. First, its implicit systemic view: technologies are viewed as a hierarchical structure of interrelated, specialized components, production methods and patterns of technological design. Second, the nature of such a system as a 'regime'; regimes are not the product of a master design (even when a design may be at its core, e.g. the combustion engine); rather they are the product of a historic process of interlocking decisions, commitments and interests; regimes are societal products, and as such traversed not only with conflict and power relations, but also with a significant degree of indeterminacy. Finally, the concept already incorporates a theory of cumulative, gradual change with radical discontinuities, highlighting critical moments and necessary phases of development.

Economic environments that punish long term investment and investment in specialized equipment and specialized skills will tend to reinforce the existent technological regime, sinking capital into it and blocking resources to the development of niches for substitutes. Perceived costs of untapped substitute technologies will remain high due to the absence of ancillary investments and supporting technologies. Lagging behind in developing a more flexible capability base will increase the economic costs of adoption and reinforce historical patterns of passive technological transfer, creating stronger rigidities to industrial growth and adaptability, and increasing GHG concentration and environmental impact.

The stability of regimes is, nevertheless relative. They are subject to selection pressures exerted by established competitive regimes and by new configurations in niches, but also by policy coordination and regulation. The reliance of adoption of EST on the local base of capabilities calls clearly for active education, industrial and technology policies. In turn, a perspective on energy transitions based on the concept of technological regimes can offer insights for gearing those policies with energy policy. On the contrary, an economic environment that punishes long term investment, specialized equipment, and specialized skills is the worst possible in a transition scenario, because it will tend to reinforce the existent technological regime sinking capital into it, blocking at the same time resources to the development of niches for substitutes. Lagging behind will increase the economic costs of adoption, reinforce historical patterns of passive technological transfer, creating stronger rigidities to industrial growth and adaptability, and increasing GHG concentration and environmental impact.

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Voluntary initiatives of Japan's Steel Industry against global warming

T.Okazaki[52],M.Nakamura[53], K.Kotani[54]

INTRODUCTION

Steel industry in Japan has placed great importance on environmentally conscious efforts designed to lessen the environmental burden at every stage of its industrial activities, ranging from the procurement of raw materials, production, technological developments to delivery, use and disposal of finished products as well as recycling, with fully aware of impact exerting on the environment.

Our efforts are not only implementing environmental action in-house, which is a steel industry's conventional boundary, but also contributing to the other sectors, including other industries, household and transport sectors, through steel products, by-products, environmental and energy-related solutions, utilization of infrastructure and so on.

With respect to the issues of global warming, we have a voluntary action program with a target of 10% reduction in in-house energy consumption, leading to CO_2 reduction as well, between the year of 1990 and 2010. Our voluntary initiatives include contributions of CO_2 reduction outside of a steel industry's conventional boundary.
Effectiveness and validity of the voluntary initiatives have been demonstrated and verified with actual evidences, including an extensive CO_2 reduction, i.e. 14 million ton-CO_2 reduction in-house between the year of 1990 and 2002, equivalent to approximately 1% reduction on Japan's national basis and another 12 million ton-CO_2 reduction outside of steel industry's conventional boundary.

A lot of environmental measures have been implemented in a timely and voluntary manner with social responsibility and environmental awareness. This type of voluntary initiatives will play increasingly an important role in establishing long-term and global solutions against climate change.

An example of steel industry's case is introduced in the present paper.

Voluntary Initiatives of Japan's Steel Industry against global warming
2a. Industry's Voluntary Initiatives as a National Policy
Keidanren's voluntary initiatives against global warming, including 35 industrial sectors, such as steel, power, paper, cement, chemical and so on, has been specified as one of Japanese national policy pillars.
JISF (Japan Iron and Steel Federation) launched its voluntary action program in 1996. Since then we have improved its transparency and reliability through an execution of PDCA[55] by ourselves, an official following-up by national government and a verification by the third party committee in Keidanren with a thorough publication. In these processes, effectiveness of it has been also proved and recognized both nationally and internationally.

2b. Five pillars
Steel industry's voluntary action program is made up of five pillars in the followings.

- i) Energy saving in the production processes by 10% (2010 vs. 1990)
- ii) Utilization of waste plastics in coke oven and blast furnace under the condition of establishing classification and collecting scheme by local government. Annual amount of utilization will be one million ton which is equivalent to 1.5% energy saving.
- iii) Contribution to energy saving in the society through 'Eco-products'[56] and by-products.
- iv) Further utilization of waste energy in the local communities
- v) International contribution through technology transfer.

It is a so-called commitment to the society to achieve a target of the action plan, driving us to make all efforts for compliance. This pledge and review scheme, which is officially recognized by national government, has demonstrated to work well. Moreover, it is a universal proposition to improve efficiency of natural resources and energy use, which leads to a stronger in competitiveness.

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[55] PDCA denotes 'plan, do, check and act'.

[56] Steel products with world-lowest environmental impact：energy saving, recycability, longer life, less chemical substances etc.

2c. Overview of current achievement
Steel industry has potentiality to provide solutions of energy saving both inside of own processes, achieving approximately 14 million ton-CO_2 reduction between 1990 and 2002, and outside of its conventional boundary as well, achieving approximately 12 million ton-CO_2 reduction so far, showing in Fig.1.
It is an important task for policy makers to bring out this potentiality from industry sectors.

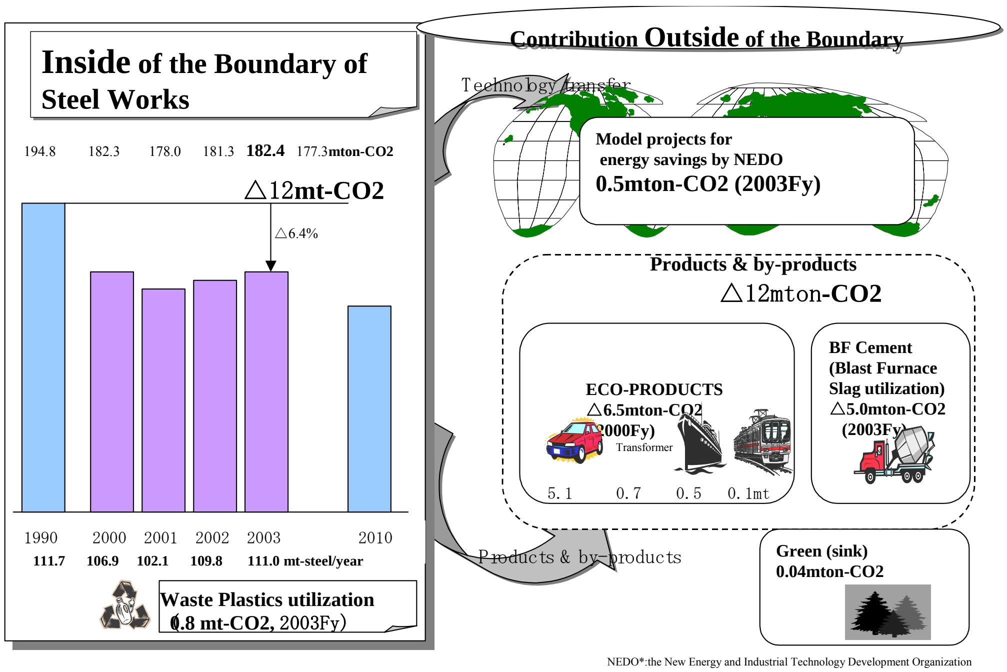
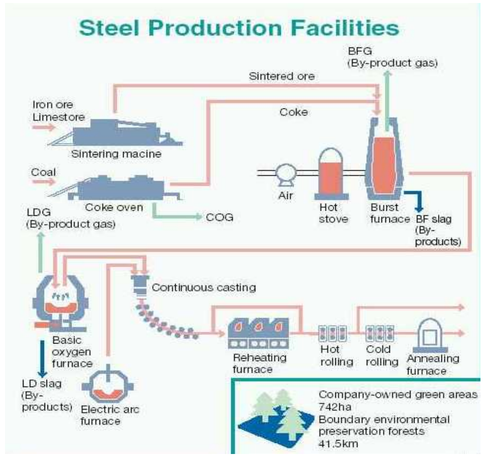


Figure 1: Overview of current achievement of steel's voluntary initiatives

LEANER CO_2 TECHNOLOGY IN THE STEEL PRODUCTION PROCESSES

3a. Overview of efficient use of natural resource and energy in processes
Overall energy efficiency of steelworks is approximately 60% and 98% of the total amount of by-products is utilized as resources, as are described in Fig.2 for Nippon Steel's actual annual data in 2003. The definition of by-products here covers blast furnace slag, steel-making slag, dust, sludge, coal ash and waste furnace refractory, weighing approximately 18.9 million tons as a whole.

Especially the steel flow and stock in Japan as a whole can be found in Figure 3.



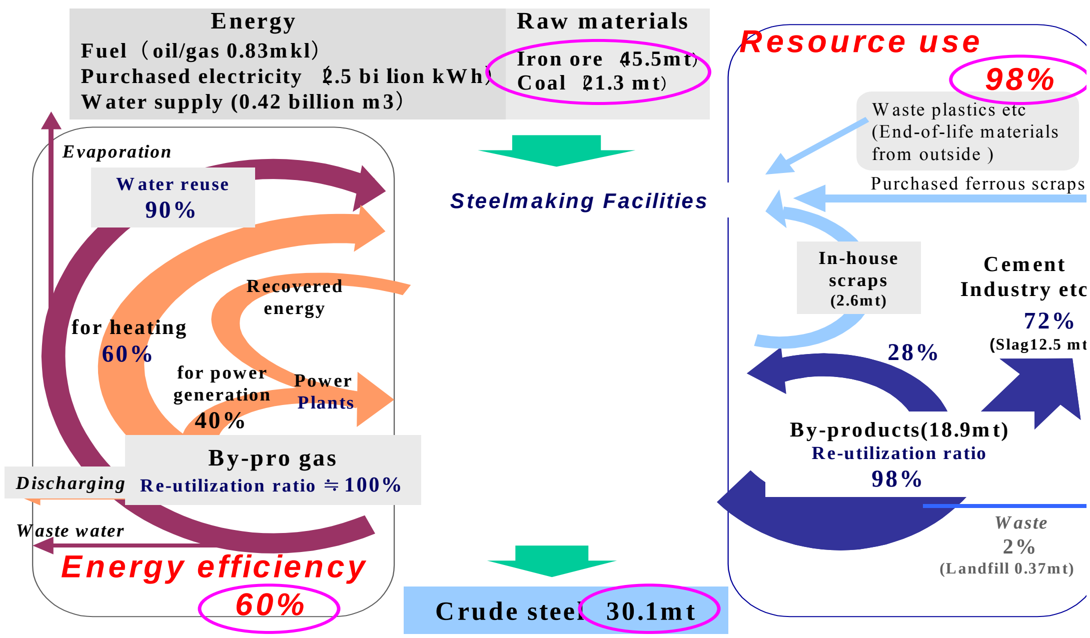


Figure 2: Efficient use of resources and energy in Nippon Steel

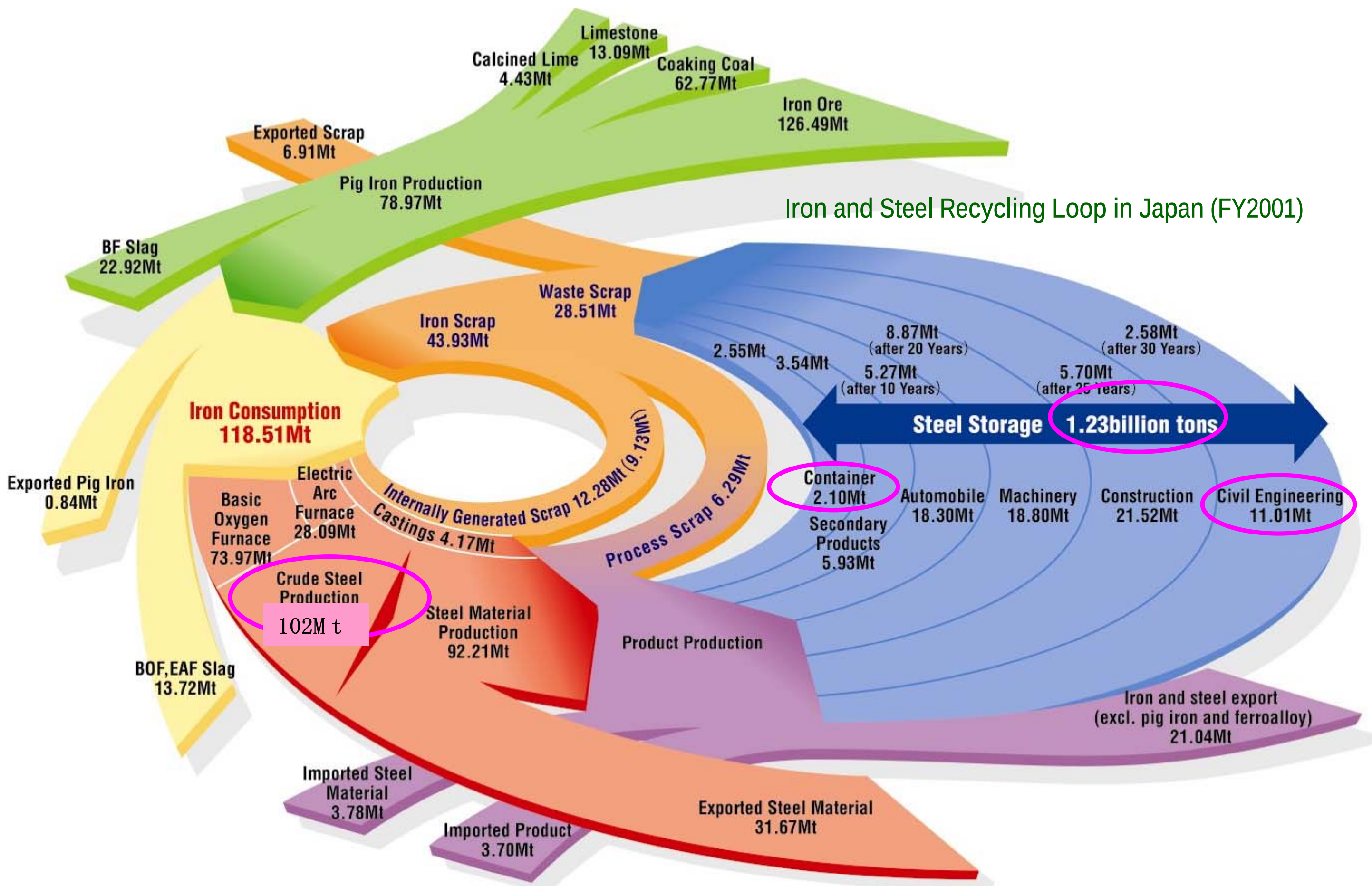


Figure 3: Stock and flow of Steel in Japan

3b. Energy-saving

After the first oil crisis in 1973, steel industry took positive steps toward increasing continuous production processes, improving the efficiency of facilities and increasing the recovery of waste energy to achieve substantial energy saving in excess of 20% by 1990. In the present voluntary action program, we are challenging a further 10% reduction in energy consumption (please refer to Fig.4 and 5).

Measures for improving energy efficiency are implementation of state-of-the-art energy saving technologies, such as CDQ (Coke Dry Quenching), TRT (Top Pressure Recovery Turbine) etc., SCOPE21(Super Coke Oven for Productivity and Environmental enhancement toward the 21st century) and so on. Newly developed technologies can have a chance for application in the case of rebuild of existing processes due to decrepit.

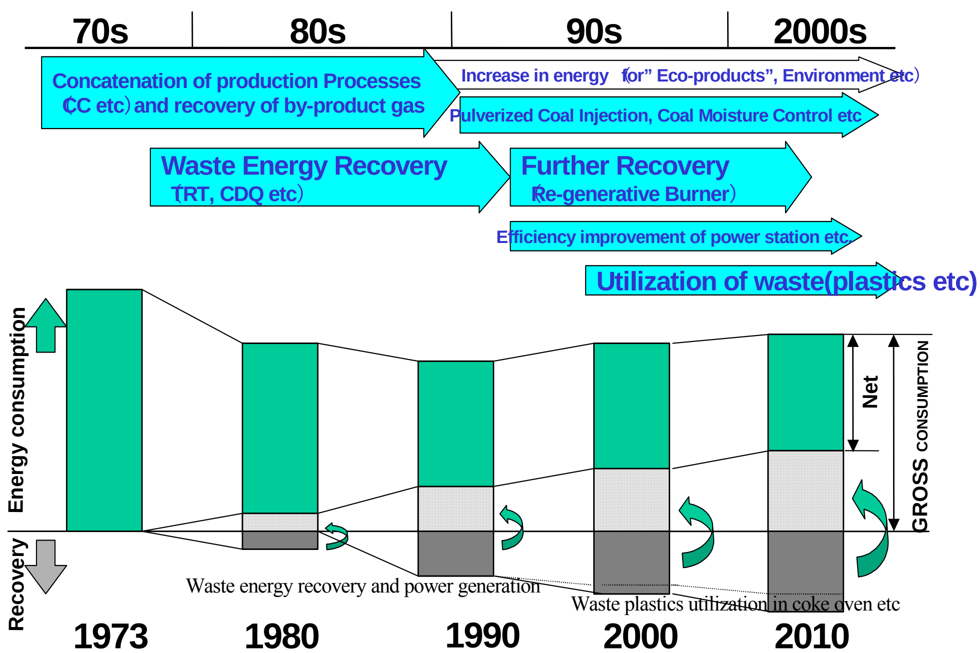
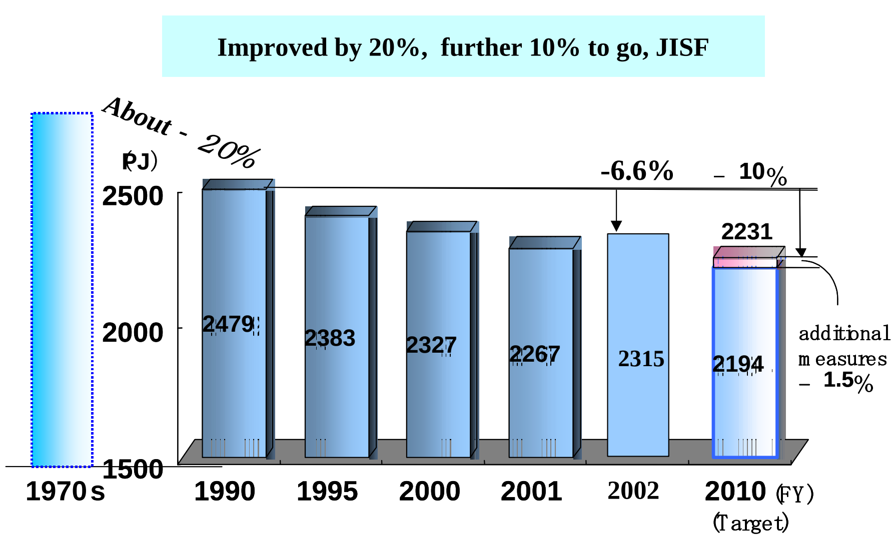


Figure 4: Energy saving since oil-crisis in Japan's Steel Industry



Note PJ: Petajoule (10^{15} joules); 1 cal.: 4.18605J; 1 PJ: About 25,800 kiloliters in crude oil equivalent

Source: The Follow-up of the Japanese Steelmaker's Voluntary Action Program for Environmental Protection by the Japan Iron and Steel Federation (JISF).

Figure 5: Actual and target of energy consumption of Japan's Steel Industry (unit :PJ=10^{15}Joule)

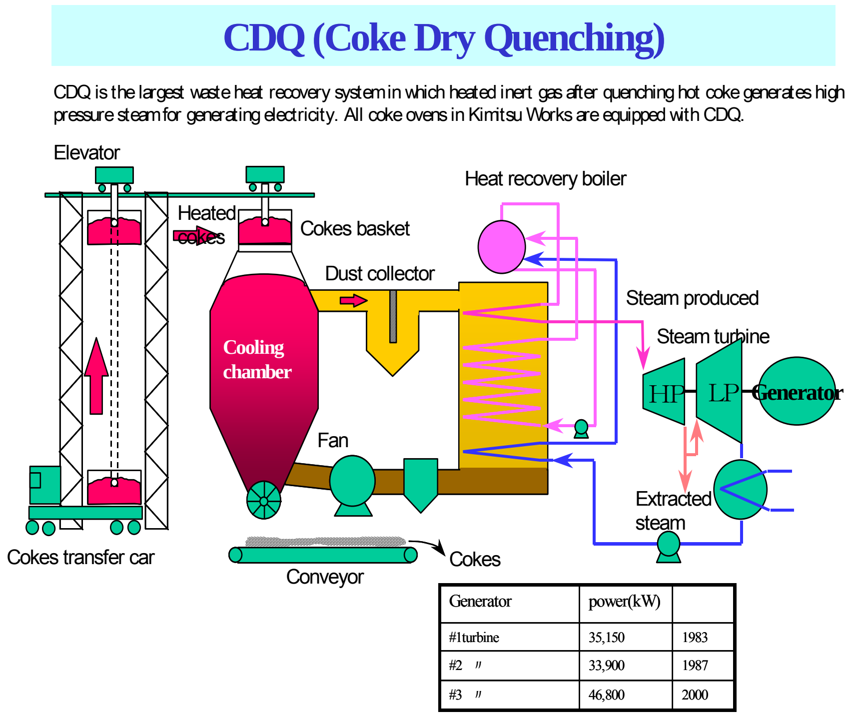
Photo 1 CDQ Plant

CDQ installed in Kimitsu works is shown in Fig.6. Red-hot coke produced in coke oven should be cooled down before carried to blast furnace. In the conventional process, water is used for cooling and there is no recovery of thermal energy. On the other hand, nitrogen gas is used for cooling hot coke in CDQ. By heat-exchanging, heated up nitrogen gas produces steam which generates electricity. In the example in Fig.6, a total amount of power produced is approximately 120,000kW without consuming any fuel.

Diffusion of CDQ is approximately 90% in Japan.

3c. Utilization of waste plastics etc.
Utilization of waste plastics in steel-making processes achieves resource saving and energy saving, contributing to structure a recycling-based society and to mitigate global warming.

As is described in Fig.7, pretreated waste plastics are put into coke oven. In the pretreatment process, iron, aluminum, glass shards, sand and gravel and other foreign matter are removed from waste plastics transported from local governments, then they are crushed and reduced in volume so that they are suitable for charging into coke oven.



Generator	power(kW)	
#1turbine	35,150	1983
#2 〃	33,900	1987
#3 〃	46,800	2000

Figure 6: Coke Dry Quenching

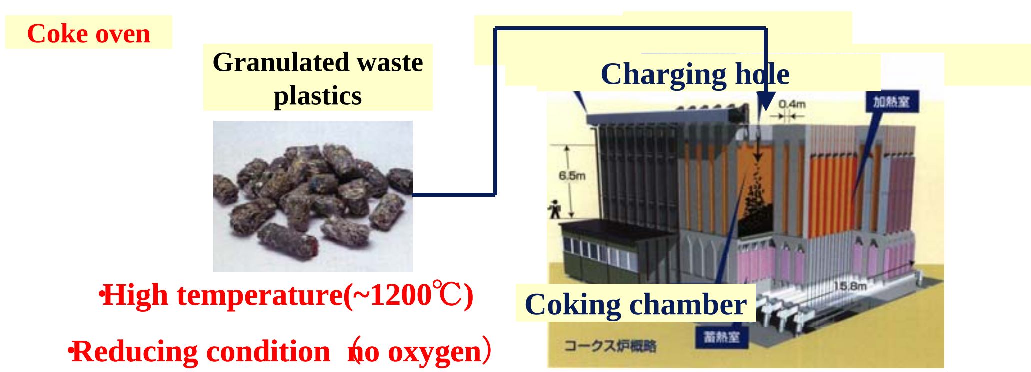


Figure 7: Coke oven chemical materials process

Of the waste plastics processed by the coke oven, 40% is reused as hydrocarbon oil, 20% as coke and 40% as coke oven gas respectively (Fig.8).

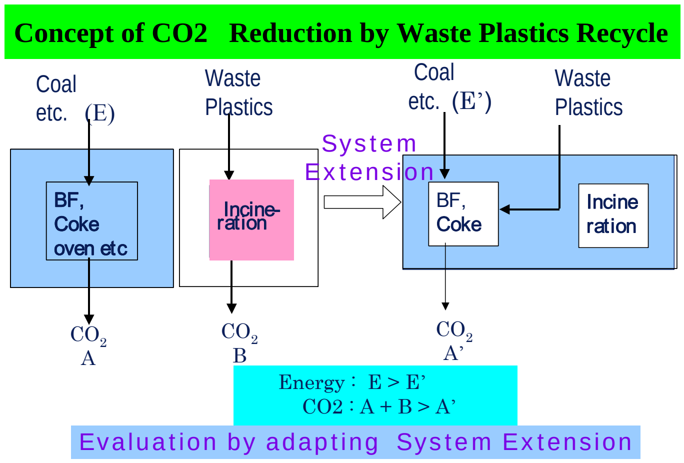


Figure 8: Evaluation of CO_2 reduction

In 2002, annual use of waste plastics was approximately 240,000 ton that is approximately one quarter of final target value as shown in Fig.9. This is evaluated equivalent to 0.6 million ton-CO_2 reduction.

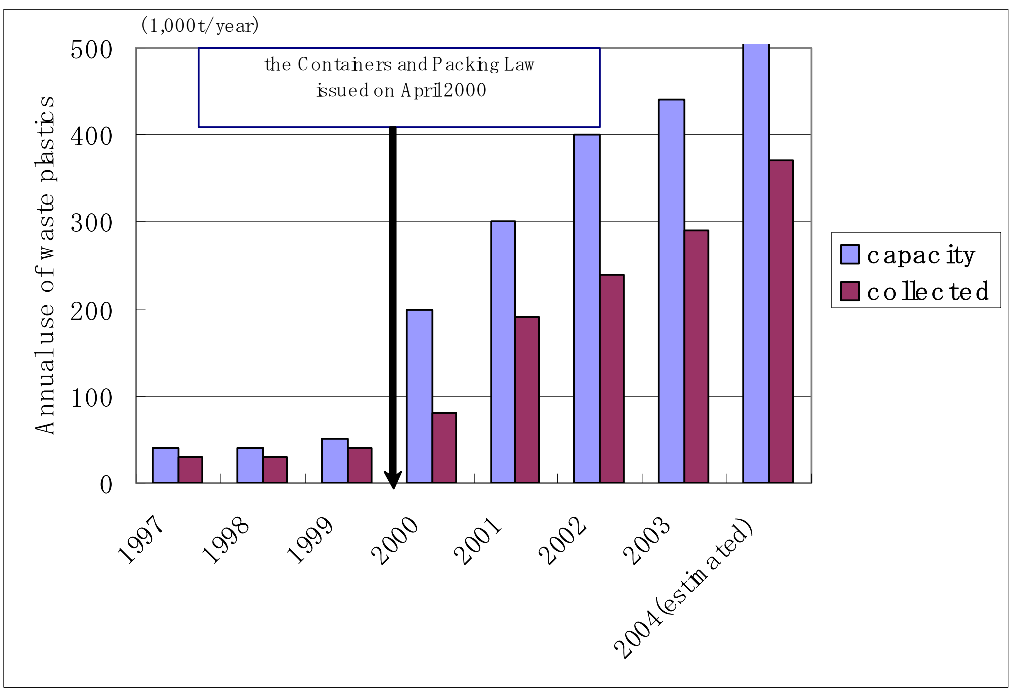


Figure 9: Annual use of waste plastics in Steel Industry

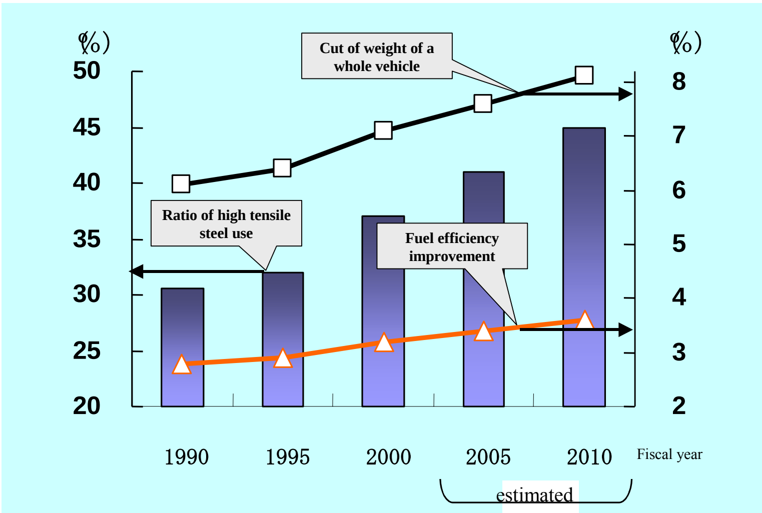
4. CROSS-SECTOR APPROACH, CONTRIBUTION THROUGH PRODUCTS AND BY-PRODUCTS

4a. Products

Steel products, such as high-tensile steel for improvement in fuel efficiency by reduction of weight of automobile and electrical steel sheet for high-efficiency transformer etc., contribute to energy saving in society.

High-tensile steel sheets are excellent in strength, toughness, workability and weld-ability. With the thickness reduction, the material contributes greatly to the reduction of vehicle weight.

Experts of steel, automobile, ship-building and so on worked together to evaluate the quantitative contribution of steel to energy saving and CO_2 reduction during service of final products, such as car, ship and so on. High tensile steel for automobile is a typical example. A quantitative evaluation of CO_2 reduction has been done by experts in the automobile industry, steel industry and other scientists. Fig.10 shows basic data for evaluation, including relations among ratio of high tensile steel use, cut of weight of a whole vehicle and fuel efficiency improvement



Estimation of CO2 reduction by high tensile steel contributed to fuel efficiency of car

1. Representing car : 1.1 ton

2. Fuel efficiency is improved by 4.5% with reduction of vehicle weight by 10%

3. Production of car is **8.36 million.** **(production of high tensile steel =630000ton)**

Figure 10: Effect of high-tensile steel on fuel efficiency of automobile. Methodology for evaluation and results are summarized in

Estimation of CO2 reduction by high tensile steel contributed to fuel efficiency of car

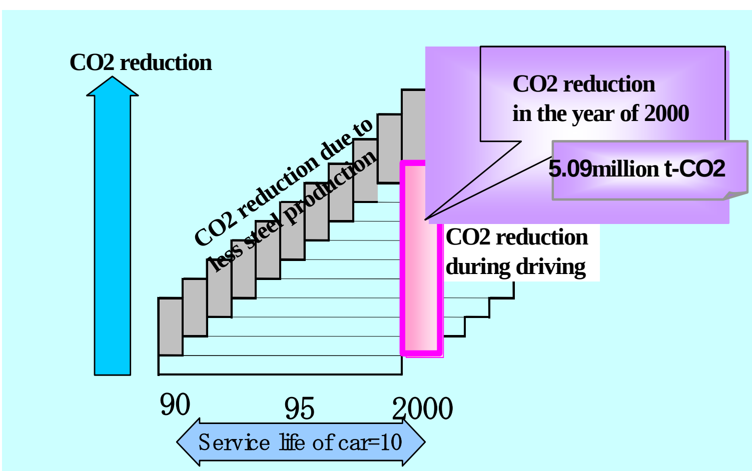


Figure 11: Assuming a service life of vehicle is 10 years, all vehicles produced, during 10 years prior to the year of 2000, contributes energy saving in the year of 2000. In this calculating methodology, contribution is evaluated approximately 5.1 million tons of CO_2 reduction by high tensile steel. Annual contribution of steel is 6.5 million ton-CO_2 reduction, including automobile's case above.

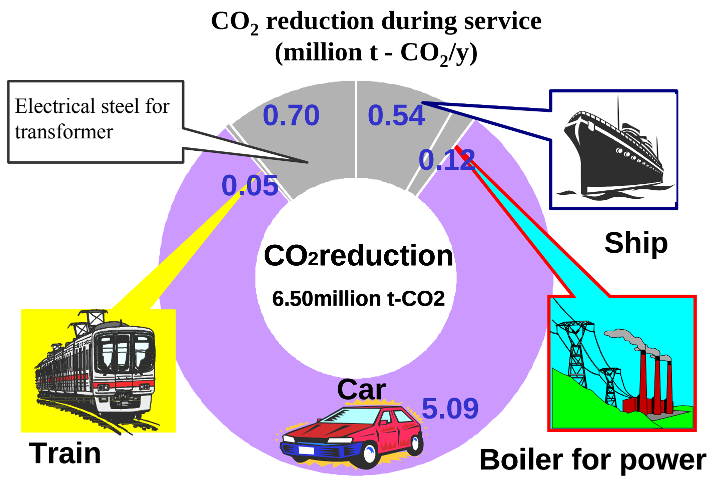


Figure 11: Methodology of evaluation and summary of results (2000)

4b. By-products

Granulated slag with hydraulicity is obtained by quenching molten blast furnace slag with water. This water-granulated slag becomes blast furnace cement when pulverized and mixed with Portland cement. Blast furnace cement is produced by substituting about 45% of Portland cement, thus contributing to the reduction in the amount of limestone as a raw material. This also can reduce energy used in cement manufacture and CO_2 emissions by approximately 40% respectively, as is described in Fig.12.

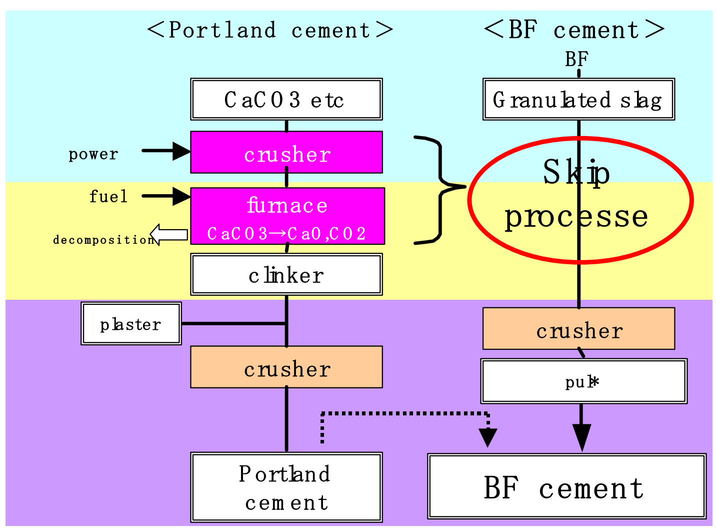


Figure 12: BF cement reduces 40% reduction in CO_2 emissions.

4c. Eco-complex

Other than the forth pillar of voluntary action program has demonstrated remarkable progress as are already explained. The forth pillar is further utilization of waste energy in the local communities. Including this concept, the collaborations among industries and communities have a potential to bring fruitful results in resource and energy efficiencies(Fig.13).

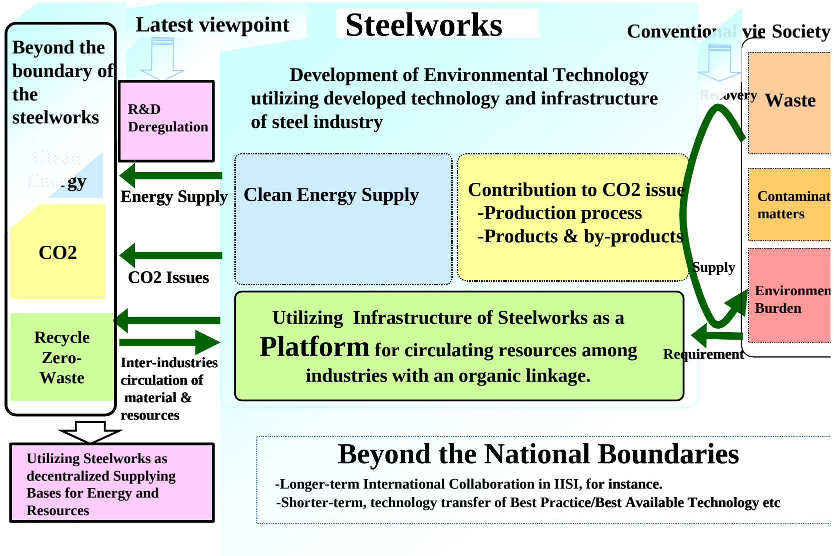


Figure 13: Innovative linkage between steelworks and society

In this case, steelworks have advantages, such as wide range of operating conditions and so on, to provide a platform for the collaborations (Fig.14).

Characteristics of steel industry

① All three phases included

② Wide range of Temperature
From high (BOF : 1700℃、BF : 1550～2300℃)
to low (liquid N2 production : -196℃)

③ Wide range of Pressure
From high (BF : 5kg/cm²) to low (degassing 1×10E-4 kg/cm²)

④ Both reducing/oxidizing conditions

⑤ Huge mass-flow is fully controlled with established infra-structure (resources and energy system is established as is described in the previous figure)

Figure 14: Advantage of steelworks for a platform

CROSS-NATIONAL BOARDER APPROACH, SECTOR-WISE INTERNATIONAL COLLABORATION

5a. International collaboration among steel industry

World-wide steel industry's collaboration has a huge potential of CO_2 reduction on the global basis. In the shorter-term, it is technology transfer and in the longer-term, it is breakthrough technology development as are described in Fig.15.

Global and Long-term Approach

Science and Technology

- ○ **World-wide Collaboration**
  - **Efficient use of Energy & Natural Resources**
  - **De-coupling of Energy (GDP) and CO2**
- ○ **For example,**
  - **World-wide benchmarking of the specific energy consumption and diffusion level of energy-saving technologies, Best Practice and Best Available Techniques, for each sector.**
  - **Technology Transfer, e.g. Kyoto Mechanisms.**
  - **World-wide Long-term R&D for CO2 mitigation .**
  - **IISI Breakthrough Program.**

Figure 15: Steel Industry's collaborations on the global basis.

5b. Contribution through technology transfer

Energy saving technology transfer has also a potentiality of reducing CO_2 emissions. Crude steel production, with less efficient in energy use (Fig.17), in China is growing rapidly, as described in Fig.16, and this growth rate corresponds to Nippon Steel's crude steel production capacity of each year.

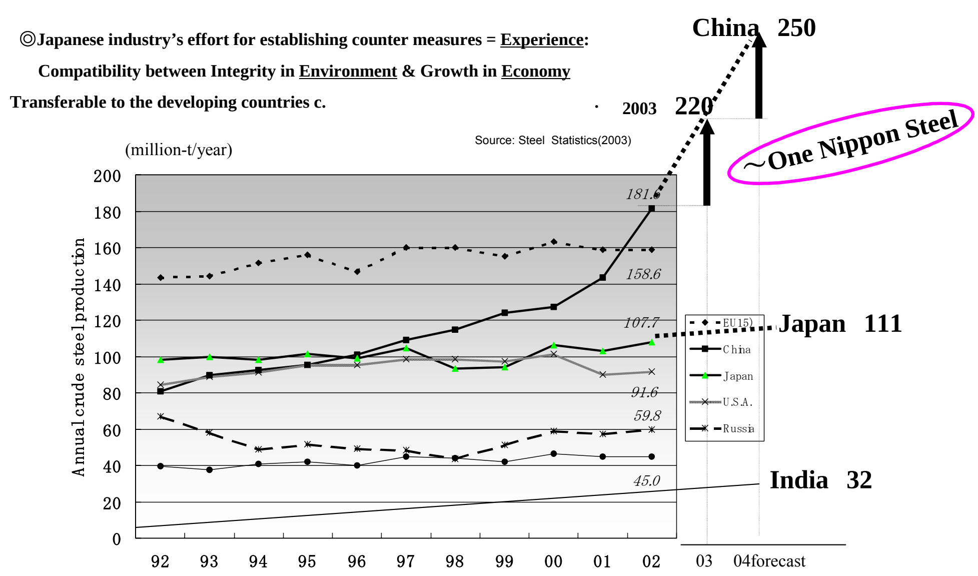


Figure 16: Rapid increase in crude steel production in China

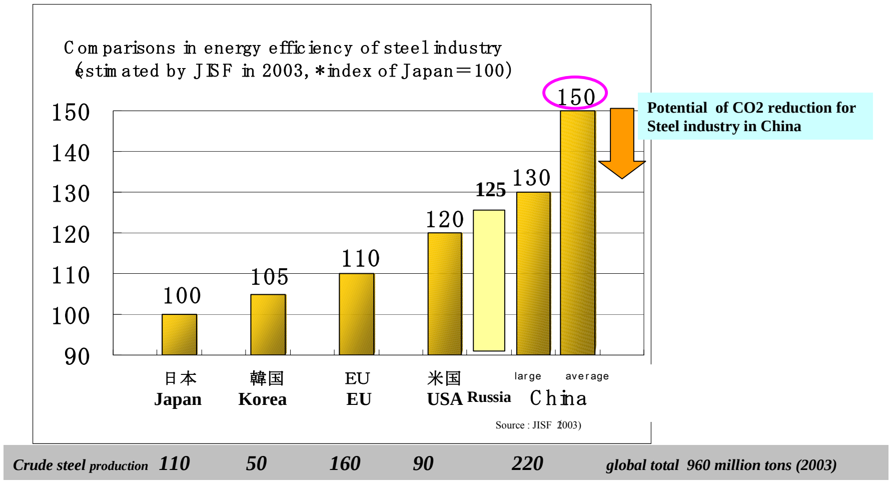


Figure 17: International comparisons in energy efficiency in steel industry

Number of smaller blast furnaces, such as less than 1000m^3 in volume, is increasing (Fig.18).

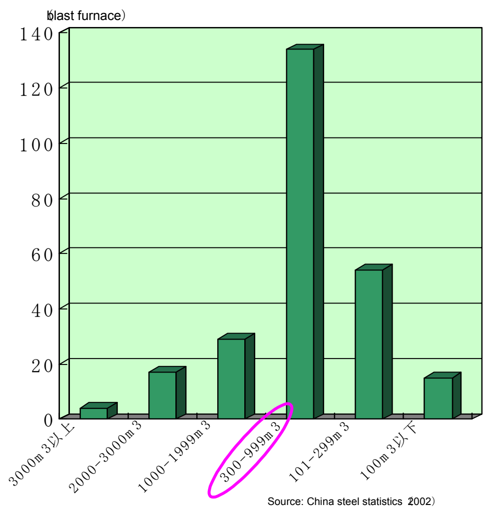


Figure 18: Volume of blast furnaces in China.

Steel industry has had a lot of experience in technology transfer to China, through the scheme of NEDO's model projects, as is described in Table 1.

Table 1 NEDO[57] Energy saving model project participated by steel companies

57 NEDO : New Energy and Industrial Technology Development Organization

	Energy saving technology	Host country	Participant	finished f. year	CO_2 reduction (t-CO_2/y)
	Heat recovery of Hot Stove	China	Nippon Steel	1995	29800
	Coal Moisture Control	China	Nippon Steel	1995	18600
	Heat recovery of Sintering	China	Sumitomo	1997	38000
	TRT	China	Kawasaki	1998	3.936
AIJ	Regenerative burner for Furnace	Thail.	Kobe	2000	4500
AIJ	CDQ	China	Nippon Steel	2000	68000
AIJ	Energy saving EAF	China	NKK	2000	29000
	Gas recovery of BOF	China	Nippon Steel	2001	40000
	Heat recovery of Furnace	China	Nippon Steel	2001	18000
AIJ	Heat utilization of incineration	Thail.	NKK	2001	63000
	Efficient combustion of by-pro gas	China	Sumitomo	2002	7800
	Heat recovery of sludge incinaretion	Malai	NKK	2002	102000
	Heat recovery of Hot Stove	India	Nippon Steel	2003	22000
	CO_2 reduction				480000

Note: (AIJ: Activity Implemented Jointly)

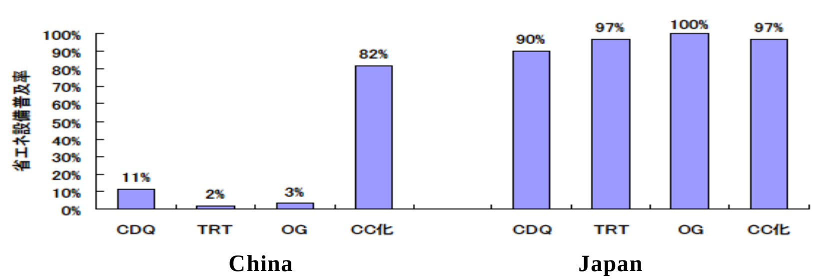
China's case shows a huge chance for a decrease of CO_2 emissions through technology transfer. Barriers are financial resources and incentives in host countries.

As is shown in Fig.19, China has a national plan to introduce CDQ and TRT 60% and 100% respectively for larger cases. Major energy saving technologies are currently low in diffusion rate in China. A solution for it is, for example, CO_2 credit of CDM (Clean Development Mechanism) in the short-term. It is necessary to implement a further incentive schemes for a longer-term.

Promotion of major energy saving technologies for steel industry

- CDQ (**Coke Dry Quenching**) : **diffusion rate 60% or more(for major steelworks)**
- TRT(**Top Pressure Recovery Turbine**) : **diffusion rate 100% (for BF 1000m3 or larger)**
- CC (**continuous casting**) :**95% until 2005**

Current diffusion rate



Source: JISF)

Figure 19: National 5 year plan related to steel industry in China

5c. CO_2 Breakthrough Program in IISI[58]
The primary measures for achieving target are dissemination of technology.

58 IISI : International Iron and Steel Institute.

The R&D for breakthrough technologies will provide an essential solution in the long-term.

IISI launched the CO_2 Breakthrough Program supported by steel industries on a global basis. Figure 20 shows a press release after the IISI annual conference in October 2003 with IISI's position paper on climate change, details at homepage (http://www.worldsteel.org). Current projects among Japan's steel industry are Hydrogen production from coke oven gas, CO_2 separation and sequestration and so on.

In this program, collaborations among many industry's sectors will be required.

FOR IMMEDIATE RELEASE – 6 OCTOBER 2003

International Iron and Steel Institute

Steel News - Press Release

IISI-37 ANNUAL CONFERENCE

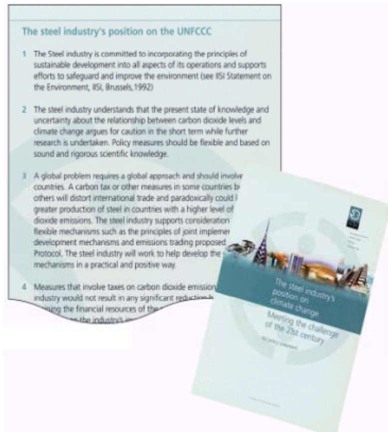
Steel industry launches global initiative to explore opportunities to radically reduce CO_2 emissions.

Chicago, October 6, 2003 – **Adopting an innovative approach to research, IISI has commissioned a programme of activities to explore the opportunities, strategies and goals available globally to radically reduce CO_2 emissions.**

Steel companies around the world have been undertaking projects to look at ways of further reducing CO_2 emissions. Different approaches have been taken on both regional and national levels. However, these projects were independent and unconnected, mainly due to different strategies in terms of goals, timeframe, targeted technologies and funding arrangements. There was unanimous agreement by the IISI membership for international collaboration to address the issues and set a challenging goal for lower emissions. By adopting a proactive methodology, the world steel industry is anxious to demonstrate to all stakeholders its commitment towards the reduction of greenhouse gas emissions.

To provide an international framework for the reduction of CO_2 emissions, IISI has launched a global initiative called the **CO_2 Breakthrough Programme**. The programme takes a multiphase approach to radically reduce CO_2 emissions from the steel industry. Phase 1 of the initiative will take 18 months to 2 years. Phases 2 and 3 may follow and continue over several years. Depending upon the outcome of Phase 1, pilot projects on selected technologies may be implemented during Phase 2 and major demonstration projects during Phase 3. At the IISI Annual Conference, the Board of Directors will discuss the project and will announce a Project Director to coordinate the programme.

Figure 20: IISI CO_2 Breakthrough Program


The steel industry's position on the UNFCCC

1 The Steel industry is committed to incorporating the principles of sustainable development into all aspects of its operations and supports efforts to safeguard and improve the environment (see IISI Statement on the Environment, IISI, Brussels, 1992)

2 The steel industry understands that the present state of knowledge and uncertainty about the relationship between carbon dioxide levels and climate change argues for caution in the short term while further research is undertaken. Policy measures should be flexible and based on sound and rigorous scientific knowledge.

3 A global problem requires a global approach and should involve countries. A carbon tax or other measures in some countries b others will distort international trade and paradoxically could greater production of steel in countries with a higher level of dioxide emissions. The steel industry supports consideration flexible mechanisms such as the principles of joint impleme development mechanisms and emissions trading proposed Protocol. The steel industry will work to help develop the mechanisms in a practical and positive way.

4 Measures that involve taxes on carbon dioxide emission industry would not result in any significant reduction

CONCLUSIONS

Energy saving efforts both in-house (inside of conventional boundary) and outside is important.
Steel industry's example shows quantitative potentiality for other sectors, including other industries, household and transport sectors. Steelworks can provide a platform for collaborations due to a wide range of operating conditions in processes and useful infrastructure. Transparency, reliability, effectiveness and validity of the voluntary initiatives have been demonstrated. Worldwide collaborations among industry sector will play an important role in mitigation of global warming.

As is shown in Fig.21, Nippon Steel has recently issued a long-term vision for global warming and approaches to medium- and long-term environmental strategies.

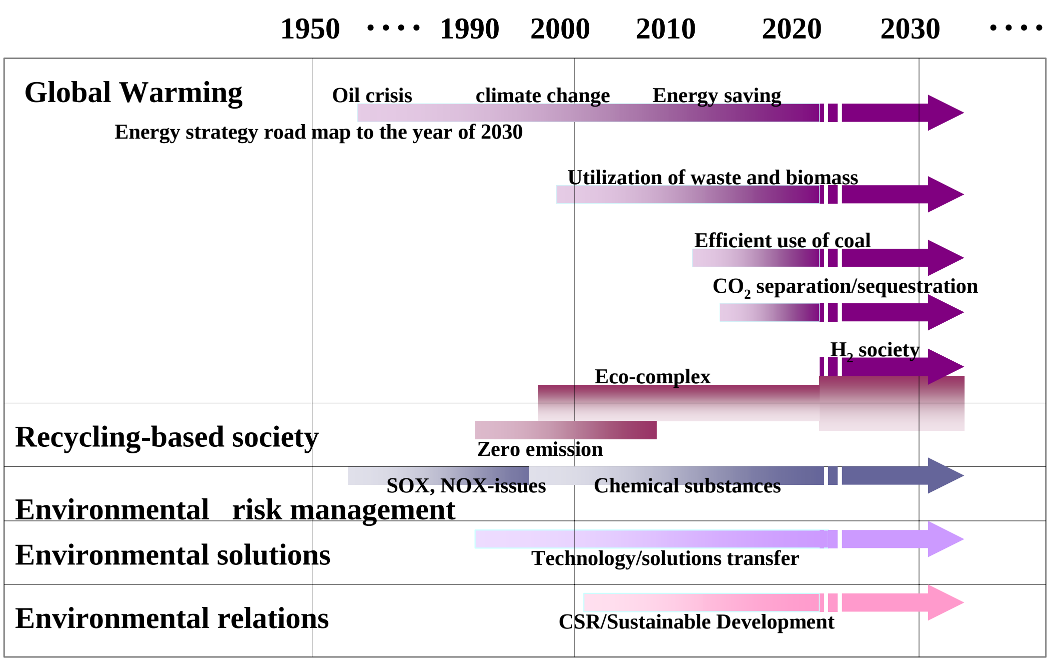


Figure 21: Longer-term vision in energy and environment.

Nippon Steel formulated a Basic Environmental Policy in 1972, shortly after the foundation of the corporation. Since then, environmental conservation has been a priority issue and has contributed to the core of the company's management. As such, environmental measures have been carried out in a comprehensive manner. In 2002, a revised version of the Basic Policy was completed. This covers 'contribution to the creation of society committed to environmental preservation', 'reducing environmental impacts at every stage of operations' and ' international contribution through involvement in environmental conservation initiatives on a global scale'.

Nippon Steel is addressing global warming through a medium- and long-term energy vision that stretches all the way to 2030. The road map toward 2030 was mapped out with 2010 serving as an important milestone. IISI's CO_2 Breakthrough Program is also one of our activities.

With long-term perspectives and visions, it is important to make efforts today.

REFERENCES

For figures in the paper ' Voluntary initiatives of Japan's Steel Industry against global warming', refer to the figure number in the http://www.jisf.or.jp/energy/index.htm or other sources described in the table below.

Figures in the paper.	Corresponding figure number in the http://www.jisf.or.jp/energy/index.htm or other sources.
Fig.1, on the right hand side.	Fig.8
Fig.1 on the left hand side.	Fig.31
Fig.2, Fig.3	Sustainability Report 2004, Nippon Steel Corporation
Fig.4	Fig.13
Fig.5	Fig.7
Fig.6, Fig.7	Sustainability Report 2004, Nippon Steel Corporation
Fig.8	Original in this paper
Fig.9	Fig.21
Fig.10	Fig.23
Fig.11 upper half.	Fig.25
Fig.11 lower half.	Fig.26
Fig.12	Fig.27
Fig.13, Fig14, Fig.15	Original in this paper.
Fig.16	Fig.6
Fig.17	Fig.14
Fig.18	China steel statistics 2002
Fig.19	Original in this paper.
Fig.20, Fig.21	Sustainability Report 2004, Nippon Steel Corporation

Technology Transfer and Mitigation of Climate Change: the Fertilizer Industry Perspective

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EXECUTIVE SUMMARY

Drivers of Technology Development and Diffusion in the Fertilizer Industry and Factors Affecting Success

Although the fertilizer industry as a whole is more than 150 years old, it was not until the early years of the 20th century that processes were developed for capturing atmospheric nitrogen. By enabling the development of greater quantities of nitrogenous fertilizers (and with a higher nitrogen content), these processes led the way for an explosion of agricultural production during the past fifty years.

Fertilizers provide the numerous macronutrients, secondary nutrients and micronutrients required for balanced crop nutrition. Nonetheless, ammonia production accounts for more than 90 per cent of the energy used by the fertilizer industry. Almost all ammonia produced is applied directly as a fertilizer or serves as an intermediary for the production of other nitrogenous fertilizers. Therefore, an examination of the energy use and greenhouse gas emissions from the ammonia sector can be considered indicative for the entire industry.

The nitrogen fertilizer industry is an energy-intensive industry, currently accounting for about one to two per cent of total global energy consumption. As a rule of thumb, about nine-tenths of the energy used to produce ammonia is considered to be from sources that emit greenhouse gases.

The industry has already come a long way towards reducing energy use and related emissions. Ammonia factories built in 2000 have been designed to use some 30 per cent less energy per tonne of nitrogen produced than those designed around 1970. Greenhouse gas emissions in fertilizer production have been reduced by at least 20 per cent.

A number of factors have fostered the geographical restructuring of the fertilizer industry in recent decades. The result is that the industry is moving away from developed countries that are 'mature' markets for fertilizers toward developing countries that are endowed with plentiful and affordable raw materials and often growing markets for fertilizer consumption.

However, many of the engineering firms with expertise in constructing state-of-the-art production facilities are still based in the developed countries. This necessitates a transfer of technology and know-how. Drivers for constructing or revamping a fertilizer plant are listed below as are the factors that influence the success of the project in the short term and the optimalization of its efficient and environmentally friendly operation in the longer run.

Drivers for the constructing of a fertilizer plant
Reducing costs of energy use
National food security strategies
National economic development strategies
Corporate-level business plans
Environmental legislation/license to operate

Factors influencing the successful transfer of fertilizer production technology and know-how
Appropriateness of technology package for local conditions
Economic considerations
Synergy with other modifications (i.e. capacity expansion)
Qualifications of project teams and plant operators
The number and integration of engineering teams, their familiarity with one another, physical distance, language barriers and cultural differences
Compatibility of information technology and other equipment
Centralized data files/streamlined processes to avoid 'mutational' errors
Capital development and staff training
Developing the capacity of in-house engineers to solve problems experienced in running units
Developing the competency of engineering companies in the country receiving the transfer.

INTRODUCTION

Fertilizer production accounts for approximately 1.2 per cent of world energy consumption and is responsible for the same share of total global greenhouse gas emissions (GHG). Increased focus on energy issues during the last 25-30 years has already pushed both numbers down significantly. Ammonia factories built in 2000 have been designed to use some 30 per cent less energy per tonne of nitrogen produced than those designed around 1970. Greenhouse gas emissions in fertilizer production have been reduced by at least 20 per cent. The actual decrease was probably much greater; just as Best Available Technique (BAT)-level performance is not universal today, it probably was not achieved in every case three decades ago. So the historical real energy consumption and emissions levels were likely to be significantly higher than what is listed in Table 1.

Table 1 illustrates these figures in detail. The CO_2-eq. data of ammonia production 30 years ago are a rough estimate applying a straight proportion to production figures from that time. Technical innovation has changed the relative importance of fuel and feed gas, thus modifying the amount of greenhouse gas emissions per tonne of ammonia produced. Nonetheless, this calculation provides an approximation of the reductions made to date.

Table 1: Evolution of energy consumption and greenhouse gas emissions in ammonia production

For 134 mill. t $N+P_2O_5+K_2O$	GJ p/year	Energy use as a % of today	CO_2-eq. per year	GHG emissions as a % of today
Best Available Technique (BAT) 30 years ago	4953	114	338	122
World today	4327	100	277	100
BAT today	2711	63	116	42

Source: Jenssen and Kongshaug.

Theoretically, universal application of the best production techniques currently available could further reduce the fertilizer industry's GHG emissions by 60 per cent and energy use by some 40 per cent. (Annex 1).

That being said, life-cycle analyses indicate that the energy and CO_2 balances for fertilizers are already extremely positive. Experiments on wheat production with and without fertilizer use have shown that fertilizers bring a net gain of energy six times greater than the total energy used for the production, transport and spreading of the fertilizers. The same calculations showed that the extra CO_2 captured in increased biomass is more than five times the volume of CO_2-equivalents emitted when producing, transporting and applying fertilizers. (EFMA, 2002).

This paper looks at how the global fertilizer industry has reduced its energy consumption and greenhouse gas emissions through technology development, diffusion and transfer; what can be done to further reduce that number; and what lessons can be drawn from experiences to date.

A BRIEF HISTORY OF TECHNOLOGY DEVELOPMENT IN THE GLOBAL FERTILIZER INDUSTRY

Development of the industry's basic technologies

The fertilizer industry was born from a conjuncture of circumstances in north-western Europe in the late 18th and early 19th centuries. These include:

a growing understanding of the biological role of chemical elements in crop nutrition;

the industrial revolution;

growing population density and urbanization; and

increasing demand for food and fibre that drove intensification of laborious manure spreading and cultivation to the point at which both approached economic and physical limits.

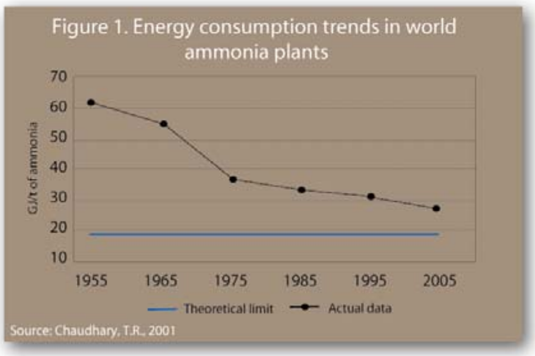
In the early years of the 20th century, processes were discovered for capturing atmospheric nitrogen, most notably the synthesis of ammonia developed by German scientists Fritz Haber and Carl Bosch. The Haber-Bosch process was a remarkable breakthrough for humanity because it opened the door to a virtually endless supply of essential nitrogen, thus laying to rest Malthusian fears. This discovery was considered important enough to merit not one but two Nobel prizes.

It is estimated that some 40 per cent of the protein consumed by humans today depends on the Haber-Bosch process. Today ammonia production is the only available option for industrial fixation of nitrogen. More than 99 per cent of all nitrogen fertilizers are derived from ammonia, which is both an intermediate and a final product. The vast majority of the energy consumed by the fertilizer industry is used for ammonia synthesis (some 94%), which will therefore be the focus of the discussions in this paper.

The evolution of ammonia production technology

A comprehensive survey of the history of ammonia production technology reveals that the process flow sheet established about four decades ago has remained virtually unchanged. Nonetheless, there have been dramatic advances in fertilizer technology over the years, resulting in phenomenal reductions in energy consumption per tonne of ammonia. Driven by cost considerations, energy saving has always been a measure for assessing technological developments/upgrades.

Higher levels of energy efficiency and process reliability can be attributed to:
Better understanding of the reaction kinetics and applications of catalysts;
Superior metallurgy for process equipment and machinery;
An energy efficient decarbonation process with a variety of improved activators with synergistic effect and corrosion inhibitors; and
Systematic and rigorous application of thermodynamic principles to maximize economic recovery of process waste heat and heat from flue gases and steam.



Due to technological innovations, the design energy consumption per tonne of ammonia produced dropped from over 60 GJ in the 1960s to 28.4GJ (LHV) for modern natural gas-based plants constructed recently. Figure 1 shows the energy consumption trends of ammonia plants in the world.

In the recently concluded 'Energy Efficiency and CO_2 Emissions Benchmarking of IFA Ammonia Plants (2002-2003 Operating Period)', the average net energy efficiency for the 66 participating production facilities was 36.8 GJ/ t NH3, with a range from 28.0 to 53.0 GJ/ t NH3. In general, younger plants scored better, but even the group of plants dating from 30-40 years ago included facilities ranging from 28.0 to 29.3 GJ/ t NH3. Higher capacity plants also tend to be more efficient, though, again, the best plants even in the category with a capacity of less than 1000 mtpd have net energy efficiencies ranging from 28.0 to 28.6 GJ/ t NH_3.

In the period preceding the mid-1960s, significant developments took place in each of the ammonia process steps. Some of these innovations were:
The shift from multi-train units to single-stream units with the introduction of steam reformers with feedstocks such as gas and naphtha;
Increasing the pressure in the synthesis gas preparation from atmospheric pressure to high pressure (30-40 bar for the reformation route and 60 bar for partial oxidation reactors);
Dramatic gains in capacity (from 100 metric tonnes per day (MTPD) to the first large single unit at 600 MTPD);
Reducing energy use from above 60 GJ per tonne of ammonia in coke-based plants to 42-50 GJ/t in the natural gas-based plants. (In modern plants, this number has been further reduced significantly.);
Production of steam at increasing pressure;
Recovery of heat in the synthesis loop by steam production or by preheating the high pressure boiler feed water;
Substitution of centrifugal compressors for reciprocating compressors.

These developments prepared the way for the large-capacity, single-stream ammonia plants that emerged in the early 1960s. The period 1963 to 1975 witnessed a construction spurt of single-stream ammonia plants, and the installed capacity of ammonia plants almost tripled.
Because of constraints on the supply of naphtha and fuel oil coupled with a growing natural gas supply, most new ammonia plants from the mid-1960s onward were built to use natural gas. Today, almost 80 per cent of global ammonia capacity is based on gas. Gas is used both as fuel for the process and as feedstock.

The drive for increased energy efficiency in ammonia gained momentum during the first oil crisis in the early 1970s. Efforts towards energy efficiency have been quite successful and mainly related to utilisation of fuel. In fact, the use of natural gas as feed increased for the most optimised process. Nonetheless, overall energy consumption has further declined from about 42 GJ/t of ammonia in the early large-capacity, single-train unit to about 28-29 GJ/t ammonia in modern plants. The major improvements or modifications which have been introduced in individual process steps and other developments are:

Feedstock purification: During desulphurisation, adsorption of hydrogen sulphide on hot zinc oxide has replaced adsorption on activated carbon. This concept paved the way for processes based on reforming under severe conditions, including naphtha reformers.
Reforming: In the reforming section, which is the most critical section of the synthesis gas preparation, the most important developments have been the increase of operating pressure; the decrease of steam addition; the use of more sophisticated alloys for reformer tubes with higher heat flux; increasing preheat temperature for feed, process air and combustion air; and use of catalysts with improved activity and resistance to poisoning and coking.
Shift Conversion: Development of low temperature and more efficient shift catalysts to obtain high conversion of CO to CO_2.
CO_2 Removal Section: Efficient CO_2 removal systems using monoethanolamine (MEA) or hot potassium carbonate as the absorbent. The efficiency of these processes has been gradually improved; processes based on physical or both physical and chemical absorption have been developed.
Final Purification: With the advent of low temperature shift, it became possible to do final purification by methanation, which has since become the preferred method.
Ammonia Synthesis: In ammonia synthesis, improved reactor design, increased converter volume and improved catalysts have resulted in conversion efficiency improvements. With the introduction of radial and axial radial concepts of the converters and replacement of quench cooling with indirect cooling between catalyst beds, single-line capacity was dramatically increased. Recovery of ammonia and hydrogen from purge gas helped improve performance and energy efficiency.
Steam and power system: Better compressors and turbine technology have led to significant energy savings due to improved polytropic efficiency.
Instrumentation and Control: Developments in instrumentation and computer science have led first to the usage of DCS and subsequently to increased use of advanced control systems and optimization of plant operations.
Catalysts: In the 1950s, ammonia plants used only two catalysts, while modern, energy-efficient plants use as many as ten. The development of better catalysts has contributed significantly to energy savings, pollution control and improved plant efficiency.
Feedstock: Feedstock has a substantial impact on energy efficiency. The ammonia plant cost and specific energy consumption depends on the type of feedstock. The relative cost for an ammonia plant and energy consumption per tonne ammonia based on feedstock are shown in Table 2.

Table 2: Relative cost and energy consumption for various feedstocks (per tonne NH_3)

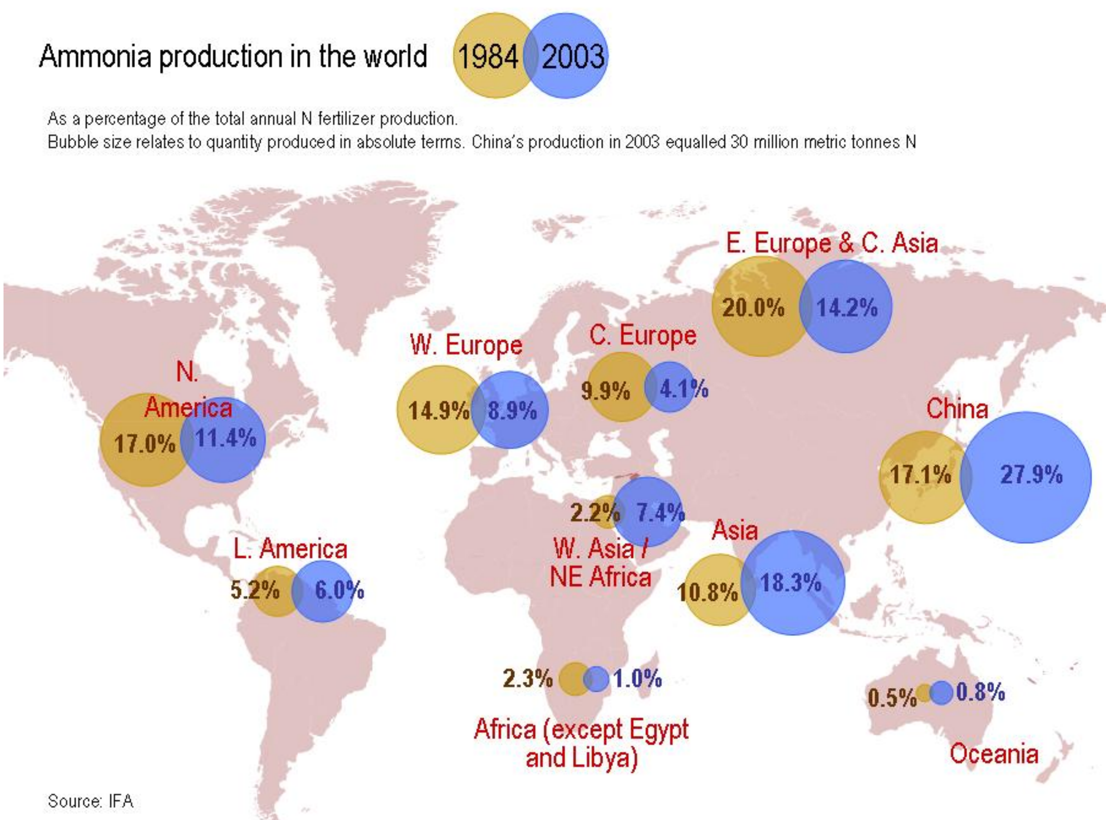
Feedstock	Relative Cost of Ammonia Plant (for large plants of at least 1000 t/day)	Energy Consumption
Natural Gas	1	1
Naphtha	1.15	1.1
Fuel Oil	1.5	1.15
Coal	1.8	1.45

Source: Swaminathan and Goswami, 2002.

Over the years individual process steps, as well as plant layout have been optimized with the integration of overall energy systems. Various improvements have taken place in catalysts; equipment and piping; metallurgy; compression systems; waste heat recovery by integration of process units with steam/power systems; operating pressures; low heat CO_2 removal systems; and others, which have resulted in further energy savings.

Typical energy saving measures that have been adopted by most of the recent greenfield and expansion plants are:
Improved thermal efficiency of the reformer through
Higher reforming pressure (up to 40 ata from the earlier level of 30-35 ata);

Use of micro-alloys in reformer tubes (e.g. Manurite);
Reduction of the steam/carbon ratio in the primary reformer;
Use of adiabatic pre-reformer;
Low NO_x burners;
Installation of efficient burners;
Operation of the synthesis loop at lower pressure;
Use of molecular sieves to remove H_2O and CO_2 from gas;
Reducing system pressure through optimum layout;
Optimizing equipment size;
Optimizing piping engineering;
Recovery of waste heat to the maximum extent by raising steam at different pressure levels and using it to heat boiler feed water, process gas, etc.;
Using super-active catalysts to improve conversion efficiency;
Using process condensate stripping technology that works at medium pressure;
Using gas turbine-driven air compressor for process air compressors and use of exhaust gases as combustion air in reformer;
Using physico–chemical CO_2 removal processes like methyldiethanolamine (MDEA) and use of dual activators in scrubbing solutions;
Using more efficient tower packing;
Integrating the overall power and steam system of the complex. Efficient design of the steam network system to improve thermodynamic efficiency of the plant;
Installation of purge gas recovery units; and
Advanced instrumentation and control.
Technology transfer through structural changes



In the 1970s and 1980s, the geographical balance of the industry shifted strongly towards the former centrally planned economies and developing countries. This was based in part on efforts by these countries to increase local food production and to diversify their economies from primary resources to value-added products. Fertilizer production has been a primary means of economic development for a number of countries endowed with abundant sources of natural gas, phosphate rock or potash.

An additional factor has been the growth of agriculture in developing regions, pushing demand up in these parts of the world, just as fertilizer consumption has reached a plateau in most industrialized countries.

Fertilizers are bulky materials that are costly to transport. Therefore manufacturing fertilizers near both sources of raw materials and major growth markets makes economic sense.

Sharp increases in fuel costs during the oil crises also hit inefficient and therefore uncompetitive producers in developed countries. Concurrently, stricter regulations concerning pollution and other matters put further pressure on uncompetitive producers, triggering significant changes, first in Europe and then in North America.
This historical sequence means that some of the best fertilizer production technology in the world can be found at recently constructed facilities in developing countries. However, the situation is very diverse and individual sites should be judged by their own performance. With regard to energy efficiency, the European industry's consumption is some 15 per cent lower than the global average, no doubt due to the elimination of inefficient producers during the restructuring of the regional industry. (Jenssen and Kongshaug, 2003)

This restructuring trend continues. Persistent high and volatile natural gas prices in North America in recent years have exacerbated the situation there. During 2003, the effect of the severe increase in the price of natural gas led several US producers to idle capacity, curtail production and rely on imports as a competitive source of ammonia. The situation in North America is particularly difficult due to numerous competing domestic demands for natural gas.

At the same time, production has been growing in gas-rich countries (Figure 3). In 2003, Eastern Europe and Central Asia (EECA), South-east Asia, Trinidad and West Asia were all major sources of ammonia exports.

IMPLEMENTING NEW TECHNOLOGY IN THE FERTILIZER INDUSTRY

The nitrogen fertilizer industry suffers from an endemic excess of capacity. As mentioned earlier, this is partly due to economic development strategies of countries endowed with plentiful and affordable sources of natural gas on one hand and by food security strategies of countries with exploding food demand on the other. However, many producers still feel that the benefits of constructing a new facility or increasing capacity outweigh the risks. Because basic production methods have evolved within steps rather than undergoing a complete transformation, there is little perceived risk of facility obsolescence. The same can be said for nitrogen fertilizer products themselves: more resources are directed toward fostering greater efficiency of nitrogen fertilizer use than developing new products. (Higgs, 1999)

This section, which draws heavily on references 5, 6, and 18, outlines the steps in the uptake of fertilizer production technology, which is by and large available off the shelf. Many of these phases overlap.

Analysis and decision-making
The first element of the project is a conceptual study to give a rough idea of the viability of the project. For an existing company this involves a review of the products already manufactured by the company and existing capacities. Synergies arising from integration of new and old production facilities are highlighted. For example, urea facilities are always located together with ammonia plants because ammonia synthesis produces CO_2, a necessary input for urea. This significantly reduces the net greenhouse gas emissions of the nitrogen fertilizer industry.[59] When ammonia is used downstream for products that do not require CO_2 as an input, the fertilizer industry's share of CO_2 emissions can still be reduced by selling the gas to other sectors, such as methanol producers or the food industry. Some 12 mill. t CO_2 are disposed of in this way each year.

As a general principle, large plants offer superior economies of scale, assuming market demand allows the facility to function at or near capacity. However, determining the capacity of a new plant depends, in part, on the size of the largest similar plant built to date. Major jumps in capacity could create previously unknown technical prob-

[59] While this is true, the overall life-cycle analysis is significantly more complex. The CO_2 used to produce urea is released as soon as the product is applied. Nonetheless, the overall balance for fertilizer use captures far more CO_2 through increased biomass than is emitted during production, transport and application combined.

lems. If the technology has not already been employed successfully by similar-sized plants, it may be discarded as too risky. Documentation on the track record of novel technology and sound advice from experts, are therefore vital to foster the uptake of technological innovation, as they help the client evaluate the engineering proposal.

Economic issues are also considered. The order of magnitude of the plant cost and offsite requirements are estimated, as is the expected utilities consumption. Such costs are weighed against the factors likely to affect profits, such as competition and price trends for both raw materials and finished product in the foreseeable future. The latter evaluations require a good knowledge of other industries that may be competitors for energy, bulk transport or other key inputs and services. Based on this analysis, best- and worst-case scenarios can be constructed to guide the decision-making process.

The feasibility study considers the technology and the project viability in more detail, with input from potential technology suppliers and contractors, who can initially be identified through simple channels such as trade journals, directories or the internet. The feasibility study includes an analysis of likely and possible environmental impacts and alleviation measures. This is relevant for regulatory and bureaucratic formalities as well as for the economic assessment.

ENABLING FACTORS

A predictable regulatory framework facilitates the evaluation of the impacts of environmental rules on the project. This also influences the permitting stage, which may be overburdened by bureaucracy. Uncertainty about the cost of future environmental regulations may discourage the project from proceeding. Furthermore, excessively long permitting processes can lead to a situation where the background conditions taken into account in the conceptual and feasibility studies no longer apply, causing the technology transfer to be abandoned.
Not surprisingly, securing financing is also a make-or-break element of project development. Four major factors are usually taken into account: profitability, benefit to the local economy, technical and environmental acceptance and the relative weight of rewards versus risks.

EXECUTION

Once the decision has been made to proceed, firm bids are obtained from competent technology suppliers and contractors. Each supplier is judged according to a number of criteria: process features, references, process description, consumption of raw materials and public utilities, the capital cost for the plant and offsite requirements.

Execution normally consists of six activities: project management, basic engineering, detail engineering, procurement, construction and commissioning. The two engineering phases are the most relevant for this paper.

Basic engineering is effectively the technology transfer package put into a form that can be implemented by the detail engineering contractor. It is generally furnished by the technology provider or an experienced contractor.

The basic engineering team has a responsibility to explain the implications of a given technical option to the client, to ensure that the buyer can make an informed choice. Once this has been agreed, the decision should be stated contractually. Once the engineering firm has offered an honest evaluation of the available options, the buyer should stand by the decision taken, understanding that subsequent modifications could have important implications for costs or delays.

Especially in the case of revamps or expansions, the compatibility of equipment is crucial. On the client's side, open lines of communication between negotiators and plant operators are important to ensure that the final purchase can be implemented optimally.

There is a growing trend for project engineering to be carried out at multiple sites, a practice greatly facilitated by the evolution of information and communication technologies.
This has several advantages. Cost reductions are possible by including qualified professionals in countries where labour costs may be lower than the country where the technology package originated. However, this salary difference may not be a permanent feature of the industry's economic structure. Teams in multiple sites also allow for longer project working days as a result of time zones.

The major risks are misunderstandings or other snags due to the looser hierarchical structure. For this reason it is vital that expectations about relative roles are clear, that all software is fully compatible and that working styles are explicitly explained to the remote partners. Clearly written contracts should help establish shared understandings. Although taken as a sign of mistrust in certain cultures, this practice can help prevent conflicts based on differing perceptions of what was agreed.

Competent project management is vital. Continuity is also important. If the person in charge of the project on either side changes frequently, time and key information could be lost as a result. Smaller engineering firms may have an advantage in maintaining such continuity simply because of the size of their teams. On the other hand, a larger firm may be able to dedicate a permanent project manager.

FOLLOW-UP

Very few technology transfer discussions address what happens after the new technology is in place. However, this is a key point; almost everyone can think of projects that were unsuccessful in the long run because poor upkeep allowed the technical performance to deteriorate. Good maintenance may include an initially higher investment, but is likely to reduce costs in the end, both by optimizing the performance of new technology and by avoiding costly stoppages.

Follow-up is sometimes victim to tough negotiation. Beyond a certain margin, cost reductions necessarily come at the expense of service provision. When follow-up visits are cut as part of the bargain, the buyer may actually make a false economy. A few well-timed and relatively inexpensive technical visits could prevent a costly maintenance shutdown.

Most technology companies suffer from a lack of feedback from their completed projects. In some cases, technologists do not do the necessary follow-up, or clients do not inform the technology supplier about the problems they encounter. This prevents the supplier from correcting the problem in the design or application in subsequent projects.

Another vital point is often overlooked: people count. No matter how good the technology, if it is poorly operated or maintained, performance will be suboptimal. Therefore employees must be trained in these areas as well as engaged in achieving the company's overall goals, such as reducing a facility's environmental footprint. IFA's Director General returned from a site visit to one IFA member company amazed that everyone down to the site's truck drivers have had the concept of sustainable development engrained in them so completely that they constantly look for ways to contribute to it in their daily operations. Such company cultures are rare.

REVAMPS

‘In general, it can be concluded that all large single-train ammonia plants can be improved, at reasonable cost, to an energy consumption level approaching newly designed plants.’ (Verduijn and de Wit, 2001)

The feed gas consumption rate per tonne of ammonia is basically the same in all ammonia plant designs. As such, there is very little scope for saving feed gas in ammonia plants. Therefore, economizing fuel gas has been the focus of every successful energy efficiency revamp. Fuel gas is consumed in the burners of the primary reformer, in gas turbines and for steam super heater burners or auxiliary boiler burners.

As well as reducing energy use, one choice to reduce emissions is complementing an ammonia plant with urea production, as the CO_2 emitted from ammonia production can be fed into the urea process. However, this CO_2 is released when the urea is applied to the crop. As well as creating opportunities for channelling emissions into other processes, integration allows ammonia to be delivered in a low-pressure gaseous form, which requires less energy to maintain. (Verduijn and de Wit, 2001)

The major constraints in retrofitting a facility to achieve greater energy efficiency and to reduce greenhouse gas emissions arise from the initial choice of technology. There are two developments, applicable to every ammonia plant, that have had a particularly major impact on improving energy efficiency in ammonia plants: the development of rotation equipment with much higher compression and expansion efficiency and improved techniques in the CO_2 removal section.

All other revamps depend on the actual design of the plant. Because the burners of the primary reformers are by far the largest consumers of fuel gas, many redesigns focus on reducing this requirement. Some of the major modifications to achieve better energy efficiency and higher production capacities at a conventionally designed

30-year-old ammonia plant are:
Using latest materials stabilized with micro alloys for reformer tubes;
Use of more efficient refractory in the reformer furnace;
Modifications to operate reformer with low steam/carbon ratio;
Utilisation of superior active catalysts;
Installation of pre-reformer;
Pre heat process air to 750°C to reduce methane slip from secondary reformer or use excess air and subsequently remove nitrogen with a cryogenic purifier;
Preheat combustion air to reduce fuel gas flow to burners;
Utilisation of latest and active high temperature and low temperature shift catalysts for shift conversion and use of axial radial concept to reduce pressure drops and increase conversion efficiency. Addition of a third shift reactor with inter cooler;
Utilisation of efficient CO_2 removal process;
Installation of radial flow and axial radial flow converters with active catalysts in the synthesis gas conversion. Addition of third synthesis bed to reduce synloop pressure;
Installation of purge gas recovery systems and ammonia recovery systems;
Installation of DCS Control systems and process optimisers;
Improving the efficiency of compressors. For example, modifying internals, installation of chiller unit in the synthesis section to reduce compression power;
Replacement of single-stage turbines with high-efficiency, multistage turbines;
Installation of waste heat recovery systems;
Installation of Variable Speed Drives for electrical motors; and
Replacement of mechanical compression refrigeration system with vapour absorption refrigeration system to use surplus low-pressure steam.

LESSONS LEARNED

Drivers for technological improvement and transfer

Although compliance with environmental legislation has provided further impetus, reducing energy costs has been the primary imperative for reducing emissions in pre-existing fertilizer facilities. Engineers are practically the only players that can help reduce energy costs in a predictable way. (Verduijn and de Wit, 2001)
With regard to building or expanding plants, driving forces include national food security strategies (the public sector is still involved in fertilizer production in a number of developing countries), national economic development strategies and corporate-level business plans. Moves to increase production capacity or to diversify production may provide an opportunity to improve environmental performance with a lower marginal cost, the flipside of a point made in the next section.

The success of the technology transfer from the supplier to the purchaser can only be measured after the completion of the project. This entails assessing how problems have been solved and the level of improved performance.

Factors affecting technology transfer

The appropriateness of a technology package for local conditions is one of the most basic determinants of whether a transfer will be successful. This will include access to natural resources, the qualifications of operational teams and the cost/benefit ratio. Technology is important, but people are even more so as technology only provides potential that must be realized through daily operation and management. That being said, the energy savings that could be attained by the proper implementation of technology are of the order of 85-90 per cent, whereas those from improved management and control with no technological improvements are only about ten per cent in this sector.

Let us consider the example of poorer developing countries that rely on loans from international institutions, have chronic foreign exchange deficits, non-convertible or soft currency and cheap labour. For such countries, low/moderate investment cost and low foreign exchange requirements are of greater importance ultimately than fuel efficiency, workforce economics or high levels of pollution abatement, even if indigenous cheap natural gas is available in soft currency.

Economic considerations cannot be divorced from decisions about implementing better performing technology. In Europe, where economic and regulatory considerations have driven the industry to superior energy efficiency, the definition of ‘Best Available Techniques’, set out in European Integrated Pollution Prevention and Control (IPPC) Directive, explicitly recognizes the importance of economic feasibility (Annex 2).

In established sectors, such as the fertilizer industry, it is very important to consider the cost/benefit ratio of installing abatement technology. (Rees, 2002) However, the payback period of an energy efficiency revamp can often be improved by increasing capacity at the same time (Verduijn and de Wit, 2001).

The qualification of local professionals will determine the long-term effectiveness of transferred technology. An expatriate team can come into the country to build a new facility, but at the end of the day, overall performance is also vitally dependent on the operation and upkeep of the plant. The professional level of workers is therefore both a precondition and an outcome of a successful technology transfer that is just as important as capital development.

During the project itself, the number and integration of engineering teams will affect the outcome. Physical distance, language barriers and diverse working and national cultures all increase the importance of spelling out expectations and relative responsibilities carefully. An explicitly clear design basis, agreed during the contract negotiations, is an essential element in setting the ground rules. A history of cooperation can greatly speed up the process and help avoid errors.

Similarly, the compatibility of equipment, especially information and communications technology can help prevent glitches from conversion errors. Streamlined processes can also contribute to a positive outcome: repeating instructions or data rather than referring to central files increases the chance that the information will ‘mutate’ as with repeated genetic replications.

CONCLUSIONS

The modern fertilizer industry, based on energy-intensive ammonia synthesis, is a significant consumer of energy. Tied to this energy use are greenhouse gas emissions that account for about 1.2 per cent of the global total. Driven largely by cost considerations, the industry has greatly improved its energy efficiency over the past three decades.

At the same time, the industry has undergone a dramatic geographic restructuring, arising from the interplay of national governments' strategies for food security and economic development; the distribution of raw materials; transport costs; and shifts in global demand for fertilizers. The result is a truly global industry that is now preponderantly based in developing countries. This shift has been instrumental in the transfer of fertilizer production technology from developed to developing countries.

A growing cadre of highly qualified engineers in developing countries has been an important byproduct of this process. These young professionals are vital to the economic development of their countries and enable further technology transfers to be implemented successfully.

Although the process has already significantly improved the fertilizer industry's environmental performance, the universal adoption of best available techniques at all sites, could further reduce its energy consumption and greenhouse gas emissions by 40 and 60 per cent respectively.

However, a number of factors must combine in order for these advanced technologies to be adopted and operated optimally. Finally, technology is a tool, not a silver bullet. Without appropriate human management, efficiency gains will remain limited.

ANNEX 1
World energy consumption and greenhouse gas emissions from fertilizer production

Based on fertilizer consumption figures for 1996/97.

Building block	World consumption	Specific energy (LHV) World	Specific energy (LHV) 'Best'	Total energy cons. World	Total energy cons. 'Best'	Total CO_2-eq. emissions World	Total CO_2-eq. emissions 'Best'
	mill. t N	GJ/t N (*GJ/t NH_3*)		mill. GJ/yr		mill. t CO_2-eq./yr	
NH_3+ NH_4	12.6	44.5 (*36.6*)	34.5 (*28.4*)	5613	435	34	26
Urea	38.1	54.0	41.7	2057	1589	66	35
AN	14.2	46.6	30.5	659	433	101	43
AS	6.5	37.6	13.8	244	90	13	4
CN	0.6	59.9	31.6	36	19	7	2
KN	0.04	90.8	68.7	4	3	1	0.3
MAP/DAP/AP	7.0	44.5	34.5	312	242	19	14
Liquid UAN	4.1	50.3	36.1	206	148	20	10
Total N / Average N	*83.1*	*47.4*	*35.7*	*4079*	*2957*	*261*	*134*
	mill. t P_2O_5	GJ/t P_2O_5		mill. GJ/yr		mill. t CO_2-eq./yr	
Phosphate rock	0.3	1.9	0.3	1	0	0.6	0.1
MAP/DAP/AP	17.2	4.3	-14.1	74	-242	4.9	-16.2
Nitro	2.0	8.4	4.9	17	10	1.1	0.7
TSP	4.5	7.0	-6.1	32	-28	2.1	-1.9
SSP	7.0	3.2	-3.8	22	-27	1.5	-1.8
Total P_2O_5 / Average P_2O_5	*31.0*	*4.7*	*-9.2*	*146*	*-287*	*10*	*-19*
	mill. t K_2O	GJ/t K_2O		mill. GJ/yr		mill. t CO_2-eq./yr	
MOP	18.8	5.9	2.5	110	47	7.4	3.2
SOP	2.0	3.4	-1.3	7	-3	0.5	-0.2
Total K_2O / Average K_2O	*20.8*	*5.6*	*2.1*	*117*	*44*	*8*	*3*
Total N+ P_2O_5+ K_2O / Average N+ P_2O_5+ K_2O	**135**	**31**	**20**	**4342**	**2714**	**279**	**118**

Source: IFADATA and Jenssen and Kongshaug, 2003

ANNEX 2
DEFINITIONS FROM THE EUROPEAN UNION IPPC DIRECTIVE 96/61/EC

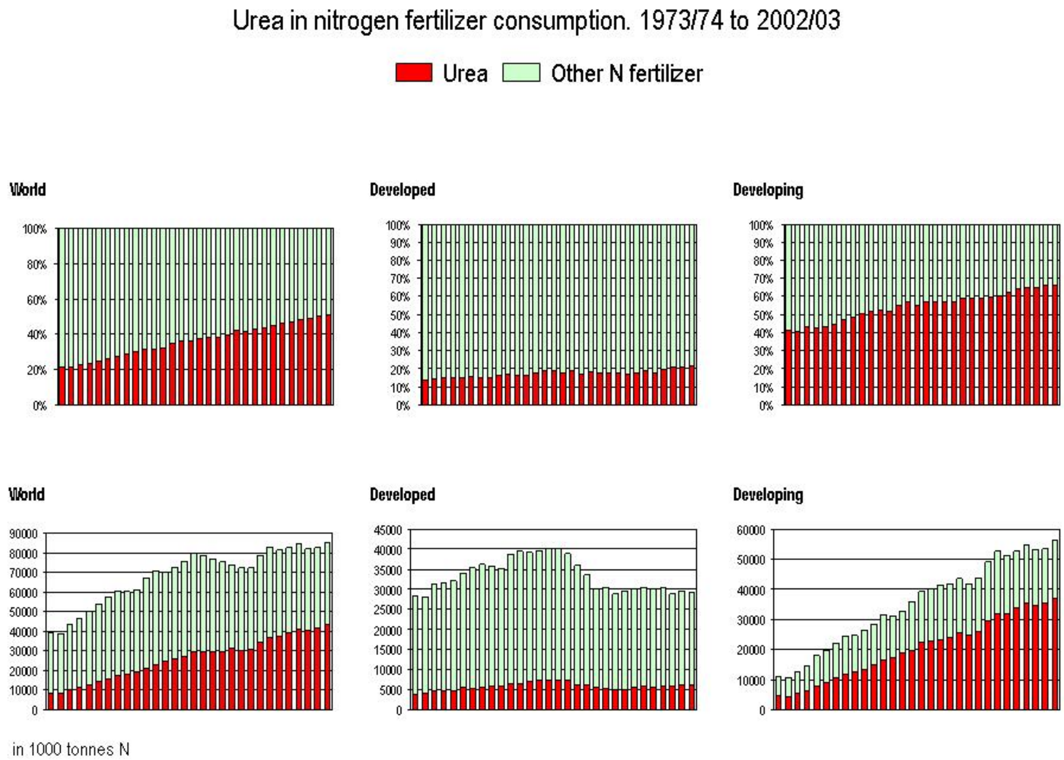
Emphasis added.

Best	The most effective in achieving a high general level of protection to the environment as a whole.
Available	Developed on a scale to allow implementation within a sector *under economically and technically viable conditions*.
Techniques	Both the technology used and the way it is designed, built, maintained, operated and decommissioned.

ANNEX 3
RESPONSES TO SELECTED REVIEWER QUESTIONS

Because not all reviewer comments were integrated into the revised version of this paper, this annex provides the authors' responses as appropriate.

- **It would improve the paper to present the different groups of energy efficiency measures more clearly in a table and show when these technologies became part of the design of ammonia plants.**
  As the focus of this paper is discussing what has driven and facilitated the technical innovations relevant to increasing energy efficiency and decreasing GHG emissions and not the nature of the innovations themselves, the authors feel that presentation of different group of energy efficiency measures in table format and time lines would be too cumbersome and time consuming. The individual energy saving measures in the group of energy efficiency measures have come up at different times and are far too many (Reference 2). Hence only broad time period cited in the literature has been included (Reference 2). For a more detailed discussion of these improvements, we refer the reader to the cited documentation.
- **What is the importance of ammonia production in terms of energy use?**
  As listed in the Executive Summary, the Introduction and the Conclusion, fertilizer production accounts for about 1.2 per cent of global energy consumption. The importance of ammonia production in terms of the sector's energy use is given in Page 4, last paragraph under 'Development of the industry's basic technologies' where we state that it accounts for some 94%. Basic math therefore makes it clear that ammonia production accounts for 1.1% of global energy consumption.
- **What is the basis of the estimates of energy intensities?**
  The basis of estimates of energy intensity is feedstock consumption both as feed and fuel which constitute around 94% of the energy consumed for ammonia production. The exhaustive technical details were not considered appropriate for a case study focusing on technology transfer. Those interested in more complete information should consult Reference 11. Information on feedstock distribution can be found on pp. 160-164 of Reference 10.
- **For technology transfer, it is also important to understand that there are only a few key suppliers of the technology to build ammonia plants. What is the role of this concentration of suppliers?**
  There are only a few suppliers of technology to build ammonia plant namely; Haldor Topsoe, Uhde, KBR, ICI and Linde. The role of these technology suppliers in technology transfer is very limited as the implementation is usually carried out by engineering firms. These firms assist the fertilizer producer in identifying the most appropriate technology package for the site and to adapt it to local specificities. The recently concluded 'Energy Efficiency and CO_2 Emissions Benchmarking of IFA Ammonia Plants (2002-2003 Operating Period)' revealed that some 20 different technologies were employed in the 66 participating production facilities. The plant management can carry out only superficial/small and non-proprietary modifications. For any major change or changes involving higher level of intricacies, the plants have to go back to the technology suppliers.
- **While urea is still the major N-fertilizer in developing countries, this is not the case in industrialized countries. Could this change also occur in developing countries?**
  This comment refers to a non-existent trend. The graphs below (derived from the statistics compiled by IFA over the last 30 years) show clearly that urea has gained in importance in developed countries over the last thirty years as a share of all N fertilizers. In terms of the amount of product used in a given year, this amount has also increased, although there was a slight downturn in the early 1990s when the break-up of the Soviet Union led to the collapse of the agricultural market structures in the formerly planned economies of that region. With the advent of increasingly strict limitations on ammonium nitrate (AN) use, urea's share of N fertilizer consumption may actually increase in developed countries, although we expect at least some of the diverted demand to shift to urea ammonium nitrate (UAN), a fluid fertilizer that does not pose the same security concerns as AN.



Furthermore, urea is likely to remain important in developing country agriculture for a number of reasons:

i) Urea has a relatively high critical humidity (75.2 percent compared to 59.4 percent for ammonium nitrate), which is important for maintaining the physical integrity of the product in the hot, humid conditions found in many developing countries;

ii) Urea does not pose the security concerns of AN;

iii) Urea is natural supplement to ammonia production, making it one of the lowest cost nitrogen sources;

iv) Urea contains the highest percentage of plant food (46.6% N) for any solid N sources, thus optimizing transport and application efficiencies;

v) Urea performs well in environmental terms under the agroclimatic conditions found in many developing countries.

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Estimating technical change and potential diffusion of methane abatement technologies for the coal-mining, natural gas, and landfill sectors

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Modeling the cost and diffusion of methane abatement technologies over time is crucial to demonstrate an economy's ability to reduce greenhouse gases cost-effectively. The U.S. Environmental Protection Agency (EPA) has developed marginal abatement cost curves that reflect the cost of mitigating methane emissions from major anthropogenic sources for countries and regions worldwide [1-3]. This analysis goes beyond previous studies to incorporate estimated increases in efficiency of methane abatement technologies over time, the reduction in the cost of each methane abatement technology over time, and the increase in the use of cheaper domestic labor and capital over time in developing countries. From this analysis, diffusion curves can be estimated. The resulting diffusion curves illustrate potential adoption of methane abatement technologies over time by region and by sector. Sensitivity analysis shows that the diffusion curves are most sensitive to the rate of growth in the share of domestic inputs. This conclusion may provide insights into how to encourage adoption of emission reduction technologies outside of developed countries. Increased adoption of domestically produced mitigation technologies, which are operated and maintained by lower-cost domestic labor, produce larger shifts in the marginal abatement cost curve. Lower project and maintenance costs lead to more profitable projects, allowing for more cost-effective or no-regret actions overall.

1. INTRODUCTION

Traditionally, economic analysis of greenhouse gas (GHG) mitigation has focused on carbon dioxide (CO_2) from utilities. Because of the linkage between energy production and CO_2 emissions, reduction of CO_2 has proven to be costly, affecting economic performance across industries, particularly in the short to medium run. In light of this, increasing attention has focused on the benefits of reducing emissions of non-CO_2 GHGs, particularly methane. Methane, as well as other non-CO_2 GHGs, can be reduced cost-effectively. Changes in production processes can also result in cost savings and increased efficiency of the production process, or capturing and selling fugitive emissions of these gases can result in revenues for the firm. The inclusion of these relatively cheap GHG reduction options lowers the overall cost of a climate change policy [4-7].

Recent climate economic studies, such as the Energy Modeling Forum 21 (EMF21) multigas study, have used static marginal abatement curves (MACs) for non-CO_2 GHGs [8]. The data used in the EMF21 study are country- or region-specific marginal abatement cost curves based on country- or region-specific labor rates, energy system infrastructure, energy prices, policy structure, and the latest emissions data. However, this analysis has limitations. The first is the static approach to the abatement cost assessment. The analysis does not account for technological change over time, which would reduce the cost of abatement and increase the efficiency of the abatement options. Second, the study used only limited regional data. Although the original analytical framework is flexible enough to incorporate regional differences in the characteristics and applicability of various abatement options at the time of the study, limited data are available to make use of this flexibility.

The objective of this study is to improve on many of the limitations of the EMF 21 analysis, in particular to incorporate more firm-level data and estimate reductions in costs of mitigation technologies over time. This analysis constructs a new framework that accounts for technological changes in mitigation options, the reduction of mitigation costs over time, and the inclusion of country-specific, firm-level data. The results presented are a set of MACs by 10-year interval, by country, and by sector. The sectors covered in this analysis include coal, natural gas, and solid waste.

The resulting diffusion curves illustrate the rate at which mitigation options become cost-effective (representing the maximum adoption potential) as technology improvements and information transfer drive down costs and increase efficiency. However, the curves do not reflect sector- or region-specific adoption rates over time. Expected rates of adoption due to a current or potential policy structure are compared to the diffusion curves based on the MAC analysis. A sensitivity analysis is conducted on the MAC assumptions and the resulting diffusion curves are estimated.

2. MARGINAL ABATEMENT CURVES AND SHIFTS OVER TIME

We generate MACs by calculating the ‘breakeven’ carbon price where the revenues from the project equal the costs of the project (i.e., the price at which the net present value [NPV] calculation equals 0) [3]. After the abatement potential and breakeven price are computed, we construct the MAC by ordering, from least expensive (lowest breakeven price) to most expensive (highest breakeven price), all of the technology options across all entities. The MAC approaches the total technically feasible abatement potential asymptotically as the carbon price becomes extremely large (i.e., as the options become very expensive).

Below is the NPV calculation used in the marginal abatement calculations [1-3]. Costs are scaled by region based on labor rates [9] and equipment costs [10-12]. Tax benefits and costs are based on a corporate tax rate of 40 percent. Revenue is generated from the sale of natural gas or generation and sale of electricity based on regional energy prices [9]. The discount rate is sector specific and is based on industry input [1].

The equation is solved for P, which is the breakeven price or the price at which the costs of the project equal the benefits of the project.
PV (Benefits) = PV (Costs) or more specifically,

$$\sum_{t=1}^{T}\left[\frac{(PxER)+R+TB}{(1+DR)^{t}}\right]=CC+\sum_{t=1}^{T}\left[\frac{(O\,\&\,M)}{(1+DR)^{t}}\right]$$

where
P is the breakeven price of the option in $/ton of carbon equivalent (TCE)
ER is the emissions reduction achieved by the technology
R is the revenue generated from energy production
T is the option lifetime
DR is the sector-specific discount rate
CC is the capital cost of the option
O&M is the operation and maintenance costs of the option
TB is the tax benefit equal to CC/T * TR
TR is the tax rate

Previous analyses used average costs per methane project and applied the emission reduction percentages to the total country baseline. Unlike previous international analyses, this analysis incorporates entity-level data where available. Costs and emission reduction estimates are therefore based on the characteristics of the industry in each country. To build up the MACs, each entity selects the technologies that are economically viable based on their individual characteristics (i.e., their unique cost of installing and maintaining the technology and the amount of methane recovered for reuse) and the carbon price. This calculation changes over time as developing countries switch from foreign-produced technologies to domestically produced technologies. The total quantity abated is then obtained by summing across all entities to obtain metric tons of carbon equivalents (TCEs) for a given carbon price.

This analysis also explicitly models changes in input costs, productivity, and reduction efficiency of abatement options over time. As shown in Figure 1, one-time capital costs and operation and maintenance (O&M) costs are broken into their factor inputs (capital, materials, labor, and energy) so that individual technology trends (changes in prices and productivity) can be applied (see Table 1 [b]). Changes in these input factors are expressed in terms of the annual percentage change in price and productivity. Price trends reflect changes in production/input costs in the United States, and productivity trends reflect advances in technologies and processes in the United States that make constant levels of production possible with fewer inputs. The trends are adjusted for other countries based on business cost index [12]. The price and productivity trends over time are then used to adjust one-time capital costs and O&M costs, which in turn affects the economic viability of the option (i.e., the breakeven price) [10-12].

Figure 1 Approach for Integrating Technical Change into MACs

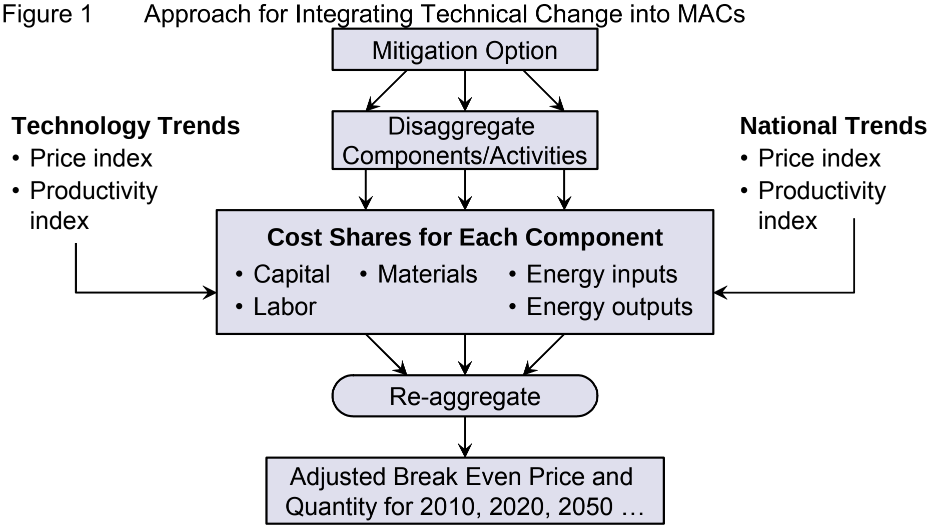

Table 1. Summary of Key Inputs and Trend Parameters

Economic Trends [10-11]	Capital	Labor	Materials	Natural Gas	Electricity
(a) Factor Input Shares by Technology Sector					
Coal Mitigation Options	50%	30%	11%	*N/A	9%
Natural Gas Mitigation Options	52%	34%	10%	*N/A	4%
Landfill Mitigation Options	77%	8%	5%	*N/A	11%
(b) Annual Technology Trends on Factor Inputs [13-18]					
Productivity	–1%	–2%	–1%	N/A	–1%
Real Price	–2%	2%	–2%	2%	–1%
(c) Share of Domestic Inputs in 2000 [19]					
Coal Mitigation Options					
Emerging Countries**	0%	75%	50%	100%	100%
Developed Countries***	50%	80%	75%	100%	100%
Natural Gas Mitigation Options					
Emerging Countries	40%	75%	50%	100%	100%
Developed Countries	50%	80%	75%	100%	100%
Landfill Mitigation Options					
Emerging Countries	0%	75%	50%	100%	100%
Developed Countries	50%	80%	75%	100%	100%

*N/A: Not applicable
** Emerging countries include China, Mexico, South Africa, and Venezuela.
*** Developed countries include Russia, Ukraine, and Poland.

In addition to trends in prices and productivity, changes in the share of domestic versus foreign inputs used to support mitigation options for factor inputs vary by country and over time in this analysis. Because the domestic prices for labor and some capital and materials inputs are typically less expensive in developing countries, input prices used to calculate the breakeven price for abatement options in these countries are adjusted based on regional shares of domestic verses foreign inputs and regional price indices in 2000. Based on interviews with industry experts [19], the share of domestic inputs in 2000 is between 0 and 50 percent for capital, 75 to 80 percent for labor, and 50 to 75 percent for materials (see Table 1 [c]). This is projected to grow to approximately 90 to 100 percent by 2030. For gas, electric, labor, and materials, international price factors were obtained from EPA's International Marginal Abatement Curve (IMAC) Model [3]. For capital, import shares [20] were used to weight international capital price factors [21]. For example, skilled labor in the natural gas sector may be in short supply in developing countries, requiring the use of imported labor services. However, through knowledge transfer, the share of imported labor used to support mitigation options will likely decrease over time. Similarly, high tech abatement capital currently being imported from developed countries may be supplied domestically in the future in developing countries.

3. SECTORS AND COUNTRIES INCLUDED IN THE ANALYSIS

Three major methane-emitting sectors are modeled: coal mining, natural gas, and solid waste. For each sector, we selected up to five countries to be included in the analysis based on the magnitude of their current and future emissions. Table 2 lists the countries modeled for each sector and the cumulative share of methane emissions within the sector for these countries. For each sector and country, we applied the general methodology presented below to estimate the shift in MACs over time. However, data availability greatly influenced the underlying details of each sector analysis.

Table 2. Sectors and Countries Included in the Analysis

	Coal Mining	Natural Gas	Solid Waste
Countries Included	United States, China, Russia, Poland	United States, Russia, China, Ukraine, Venezuela	United States, China, Ukraine, South Africa, Mexico
Share of Global Methane Emissions in 2000 [3]	63%	99%	43%
Projected Emissions in 2030 [3]	65%	75%	48%

3.1 Coal Mining Sector

The analysis includes three coal mine abatement options: (1) degasification (degas), where holes are drilled and methane is captured (not vented) before mining operations begin; (2) enhanced degas, where advanced drilling technologies are used and captured low-grade gas is purified; and (3) ventilation abatement methane (VAM), where low concentrations of methane ventilation air exhaust flows are oxidized to generate heat for process use [11]. Engineering costs for each abatement option were calculated based on individual mine characteristics, such as annual mine production, gassiness of the coal deposits, and methane concentration in ventilation flows. Information was available on 56 underground U.S. coal mines for 2000 [11]. We used EPA's Coal Mining Abatement Cost Model to estimate the one-time investment costs, annual O&M costs, and benefits from using the captured methane for each of the 56 mines. The model also disaggregated costs into capital, labor, materials, and energy.

In addition to costs, several additional factors change over time as a result of enhancements to existing technologies or introduction of new processes and procedures. For example, in the United States, advances in surface mining are projected to decrease underground mining activities, reducing the technical potential for methane abatement. Also, VAM technology is projected to improve over the next 20 years, decreasing the technical applicability concentration level below 0.15 percent methane [19]. The information on coal production and methane liberated for individual mines for China, Russia, and Poland was extracted from several international methane reports provided by EPA [22-24].

Detailed engineering cost information was not available for non-U.S. underground coal mines. Thus, we estimated costs as a function of mine production and liberated methane. We used regression analysis to estimate cost relationships based on the known costs for the given 56 U.S. mines as a function of coal production and/or methane liberated. Individual regressions were run for each cost component/factor (e.g., annual drilling costs, one-time compressor costs), and separate sets of regressions were run for each of the three abatement options. We then applied the coefficients to the known value of coal production and methane liberated for non-U.S. mines [22-24] to generate cost components for each abatement technology [11].

3.2 Natural Gas Sector

EPA's economic cost model of the natural gas sector reports emission factors at the facility or equipment level [25]. Abatement options for the natural gas sector are associated with five general segments of the natural gas system (production, processing, transmission, storage, and distribution) and are typically applied to a facility (e.g., central wells, gathering facilities, gas plants, transmission pipeline networks, storage tanks) or specific piece of equipment in the natural gas system (e.g., wellheads, compressors, heaters) [25]. Also included in the economic cost model is an estimate of the total population for each type of equipment and facility. The model includes 118 different abatement options applied across the five segments of the natural gas sector. Options range from inspection and detection techniques to upgrading compressors and pipes contained in the system. The natural gas economic cost model does not provide information on capital, materials, labor, and energy costs. To obtain this information we used documentation from EPA's *Lessons Learned* [26] and interviews with industry experts to develop the distribution rules for input factor costs.

Although EPA's natural gas economic cost model provided a highly detailed characterization of the United States' natural gas infrastructure, significantly less information is available on natural gas systems for other countries, such as Russia, China, Ukraine, and Venezuela [27-30]. As a result, we characterized the natural gas infrastructure for foreign countries using available data from the United States in combination with international production and consumption values reported in the Foreign Country Briefs published by the Energy Information Administration [31-34]. We estimated the size of the infrastructure related to production, processing, and transmission activities as a function of a country's natural gas production and the size of the infrastructure related to storage and distribution as a function of a country's natural gas consumption. From this estimation process, we estimated the population of facilities, equipment (e.g., compressors, dehydrators), and miles of pipe. In addition, there are differences in the age and level of maintenance of the natural gas infrastructure in each country. This was accounted for by creating country-specific emission factors that adjusted the level of 'leakiness' of natural gas systems. Based on a report published by the IPCC [35], we developed emission factors for several regions for production and processing and for transportation and distribution.

3.3 Landfill Sector

We used EPA's Landfill Population Model to generate a set of landfills for which abatement options might be applied. The U.S. federal government currently requires all large landfills to have a method for abating methane in place [36]. Thus, for the United States, we filtered the landfill population dataset used for MAC analysis to remove all landfills with a design capacity greater than 3.5 million megagrams (or 3.9 million short tons) to attempt to adequately capture all landfills that are not subject to regulation. The MAC model models the investment decision relating to abatement technologies only for those landfills that have a choice.

Abatement options for the landfill sector include a landfill gas collection system, flare, direct-use pumping system, or some mechanism such as a turbine for generating energy through the combustion of landfill methane gas. Equipment required includes wells, wellheads and gathering pipeline, compressors, dehydrator unit, and pipelines to direct-use sites. EPA's engineering cost model reports total estimated methane generation, one-time capital costs, annual O&M fees, and the annual electricity produced or the quantity of gas sold for process heat through the direct-use option. EPA's Landfill Inventory Database provided detailed information that characterized the U.S. landfill population. However, significantly less information is available for landfills in other countries, such as China, South Africa, Mexico, and Ukraine. As a result, all countries' landfill population distribution is based on U.S. landfill characteristics and then scaled up to meet EPA's estimates for landfill emissions in these countries.

4. RECALCULATED MACS

Applying the trends described above, shifts in the MACs for each country–sector listed in Table 2 were developed for 10-year intervals from 2000 to 2030. We discuss two of the MACs below to illustrate differences from previously developed EMF 21 data and highlight factors underlying the shifts in the curves over time. Figure 2 and Figure 3 show the MACs for 2000, 2010, 2020, and 2030 for the U.S. coal mining and the Mexico landfill sectors. The magnitude of the shifts reflects both changes in costs and benefits of abatement technologies and technical changes, such as increased reduction efficiency and trends in production. For example, after 2020, the shift in the U.S. MACs slows because underground mine production is projected to decrease slightly. However, technology improvements continue, driving down costs. In contrast, the MACs for landfills in Mexico shift out and downward steadily, reflecting the decreasing technology costs and the projected growth in landfills. It should also be noted that the results reflect a financial analysis and do not capture all the factors influencing the adoption of mitigation technologies. If unobservable transition costs or institutional or informational barriers to adoption were included, we would not expect the no-regret options to increase so dramatically over time.

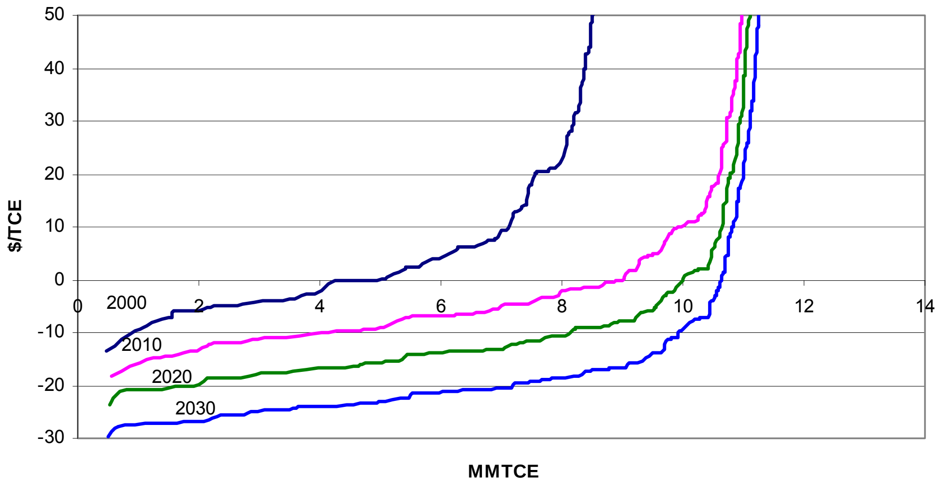

Figure 2: Shift in the United States' MAC for the Coal Mining Sector Over 30 Years

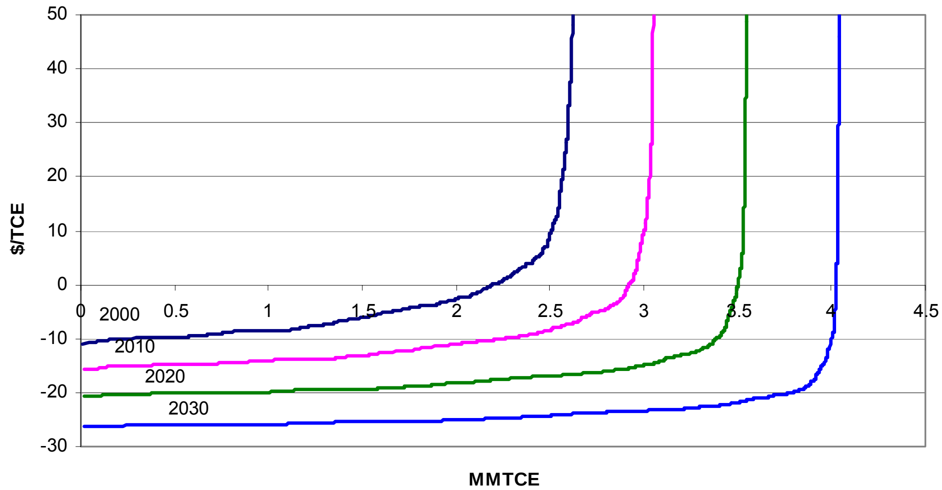

Figure 3: Shift in Mexico's MAC for Landfill Sector Over 30 Years

Individual country methane MACs for 2020 are provided in Table 3. The percentages in Table 3 indicate the share of abatement for a given breakeven price. Abatement for breakeven prices less than or equal to zero are referred to as no-regret options. The large number of no-regret options reflect adoption factors not included in our financial breakeven analysis. This may include missing information barriers, transaction costs, or geopolitical constraints affecting the timing of adoption of mitigation options. Table 4 summarize the factors driving the shifts in the MACs for the coal mining, natural gas, and solid waste sectors, in terms of percentage changes from 2000 to 2020. As shown in the tables, over time, the cost of abatement options decreases while their reduction efficiency increases. These factors combine to increase economic viability of the mitigation options, hence lowering their breakeven price and shifting downward. As shown in these tables, the change in reduction efficiency is technology specific and thus constant across countries, increasing on average between 11 and 14 percent by 2002. However, changes in costs vary greatly across each country because of the changing shares of domestic versus foreign inputs over time.

Table 3: 2020 MACs for Countries Included in the Analysis

Sector	Breakeven Prices ($/TCE)							
	–$20	–$10	$0	$10	$20	$30	$40	$50
Coal Mining								
United States	11.7%	47.8%	58.0%	61.9%	62.6%	63.5%	63.9%	64.4%
China	0.0%	35.8%	72.3%	81.8%	85.5%	86.7%	88.9%	89.8%
Russia	0.0%	0.0%	8.0%	8.4%	8.4%	8.4%	8.4%	8.4%
Poland	3.0%	3.2%	3.2%	3.2%	3.2%	3.2%	3.2%	3.2%
Natural Gas								
United States	8.4%	9.3%	9.4%	10.6%	11.9%	12.1%	12.3%	12.4%
China	0.0%	11.1%	12.6%	12.7%	12.7%	12.8%	12.8%	12.9%
Russia	0.0%	9.6%	14.4%	14.6%	14.7%	14.7%	14.7%	14.7%
Ukraine	11.4%	11.9%	11.9%	12.0%	12.0%	12.0%	12.0%	12.0%
Venezuela	8.9%	11.2%	11.8%	12.2%	12.4%	12.4%	12.5%	12.5%
Solid Waste								
United States	28.2%	54.1%	61.7%	65.1%	67.1%	67.5%	68.3%	68.6%
China	0.0%	62.9%	64.2%	64.4%	64.5%	64.5%	64.5%	64.5%
Ukraine	61.3%	64.4%	64.5%	64.5%	64.5%	64.5%	64.5%	64.5%
Mexico	13.6%	54.1%	55.9%	56.4%	56.5%	56.6%	56.6%	56.7%
South Africa	50.1%	51.7%	52.3%	52.6%	52.6%	52.7%	52.8%	52.8%

Table 4: Percentage Reduction by 2020 in Factors Driving the Shifts in the MACs

Sector	Change in One-Time Costs	Change in Annual Costs	Change in Reduction Efficiency
Coal Mining			
United States	37%	9%	10.0%
China	69%	60%	10.0%
Russia	72%	36%	10.0%
Poland	74%	27%	10.0%
Natural Gas			
United States	18%	17%	9.6%
China	68%	58%	9.6%
Russia	64%	41%	9.6%
Ukraine	68%	41%	9.6%
Venezuela	57%	45%	9.6%
Solid Waste			
United States	18%	27%	7.8%
China	68%	46%	7.8%
South Africa	38%	34%	7.8%
Ukraine	68%	68%	7.8%
Mexico	53%	39%	7.8%

Table 4 shows the percentage changes for the coal mining sector that result from the trends implemented in our analysis. U.S. one-time costs and annual costs decrease by 37 percent and 9 percent, respectively, as a result of applying price and productivity trends. The difference in the rate of change between one-time and annual costs is due to their relative level of capital versus labor intensity. Because the real wage rate is projected to increase, offsetting labor productivity, labor-intensive activities are not projected to have as large a decrease in costs as capital-intensive activities. And, for all the coal mining abatement options, one-time costs are capital intensive, and annual costs are labor intensive.

China, Russia, and Poland have greater decreases in costs because this analysis assumes that they are currently importing most inputs, but they are projected to increase the use of significantly lower-cost domestic capital, labor, and materials over time. This results in greater downward shifts in these countries' curves over time relative to the United States. The changes in costs are also a function of each country's relative prices. For example, the percentage change in annual costs is not as great in Russia and Poland, compared to China, because China has lower wages than these countries and, thus, experiences a greater decrease in annual costs when switching to domestic labor. The results are similar for the natural gas and solid waste sectors.

4.1 Comparison to EMF 21 MACs

The effect of the above approach can be illustrated by comparing the curves in this paper (referred to as 'enhanced' curves) with the MACs produced for the EMF 21 multigas study [3]. Table 5 shows the percentage methane abatement in 2020 at different carbon prices for both the EMF 21 and enhanced projections. The comparison between the EMF projections and the enhanced curves in 2020 reflects differences in building the baseline MACs using entity-level data and the influence of shifting the curves over time to account for technical change. For U.S. coal mining, the comparison indicates that the enhanced approach leads to more abatement at lower breakeven prices. For example, the EMF 21 estimates no abatement at –$10, whereas the enhanced approach estimates 48 percent abatement. However at higher breakeven prices, the EMF 21 estimates project a larger abatement percentage, 86 percent at $50, compared to 66 percent at $50 for the enhanced approach. This is because the enhanced approach incorporates different assumptions about technical applicability or potential market penetration. For example, the enhanced MACs use mine-level data to determine if VAM is technically applicable for each mine in 2020, instead of assuming all mines are eligible.

Table 5: Comparison with EMF 21 MACs

	Breakeven Prices ($/TCE)							
Sector	**–$20**	**–$10**	**$0**	**$10**	**$20**	**$30**	**$40**	**$50**
Coal								
United States								
EMF 21	0.0%	0.0%	49.2%	49.2%	66.5%	86.0%	86.0%	86.0%
Enhanced	11.7%	47.8%	58.0%	61.9%	62.6%	63.5%	63.9%	64.4%
China								
EMF 21	0.0%	0.0%	0.0%	0.8%	49.7%	84.5%	84.5%	84.5%
Enhanced	0.0%	35.8%	72.3%	81.8%	85.5%	86.7%	88.9%	89.8%
Natural Gas								
United States								
EMF 21	1.9%	5.6%	14.5%	14.5%	18.9%	18.9%	19.2%	19.2%
Enhanced	8.4%	9.3%	9.4%	10.6%	11.9%	12.1%	12.3%	12.4%
Russia								
EMF 21	0.0%	0.0%	3.8%	9.2%	25.0%	26.6%	26.6%	26.9%
Enhanced	0.0%	9.6%	14.4%	14.6%	14.7%	14.7%	14.7%	14.7%
Landfill								
United States								
EMF 21	0.0%	0.0%	10.0%	10.0%	31.4%	31.4%	42.1%	42.1%
Enhanced	28.2%	54.1%	61.7%	65.1%	67.1%	67.5%	68.3%	68.6%
Mexico								
EMF 21	0.0%	0.0%	10.0%	20.7%	31.4%	42.1%	42.1%	42.1%
Enhanced	13.6%	54.1%	55.9%	56.4%	56.5%	56.6%	56.6%	56.7%

Similar trends are seen in the natural gas and landfill sectors. The enhanced approach estimates more abatement potential at lower breakeven points when entity-level data are used and technical change reduces costs and increases reduction efficiency. No-regret abatement is approximately 15 percent for natural gas and approximately 60 percent for landfills using the enhanced approach in 2020. As in the coal mining sector, at higher breakeven prices, differences in assumptions regarding technical potential lead to differences in the maximum abatement potential (i.e., the vertical asymptote for the MACs) for the natural gas and landfill sectors. At higher breakeven prices, the enhanced approach yields less abatement compared to the EMF 21 estimates for natural gas. The difference is due to more conservative assumptions being used for technical applicability of natural gas mitigation options in the enhanced approach. In contrast, for landfills, the enhanced approach yields a higher maximum potential, reflecting increases in reduction efficiency by 2020.

5. CALCULATING THE MAXIMUM POTENTIAL ADOPTION OVER TIME USING THE MAC ANALYSIS

The result of technical change is that the MACs shift outward over time, leading to greater potential of cost-effective emissions reductions for any given carbon price. What is not represented in the curves shown in Figures 2 and 3 is the rate of expected adoption over time. The maximum potential adoption is expected to take on an S-shaped curve where diffusion of a new technology is slow in the beginning, speeds up as it becomes cost-effective for more firms and finally slows down as the last few high-cost options become economically viable.

The maximum potential adoption curve for a particular methane mitigation technology or for methane mitigation in a particular sector can then be estimated as shown in Figure 4. For a technology-specific curve, the MAC analysis would be constrained to show adoption of one type of technology (e.g., degasification in coal mining) by each representative firm in a region. For a sector-specific potential diffusion curve, the sector-specific MAC is used. As shown in the example below, each point where the MAC intersects with the $0/TCE line determines a point on the diffusion curve. This resulting diffusion curve is the **maximum** potential adoption of mitigation technologies, shown in terms of million metric tons of carbon equivalent (MMTCE) captured or reduced, for a given $0/TCE carbon price. The maximum potential could only be realized in the absence of all policy, institutional, and informational barriers to firms.

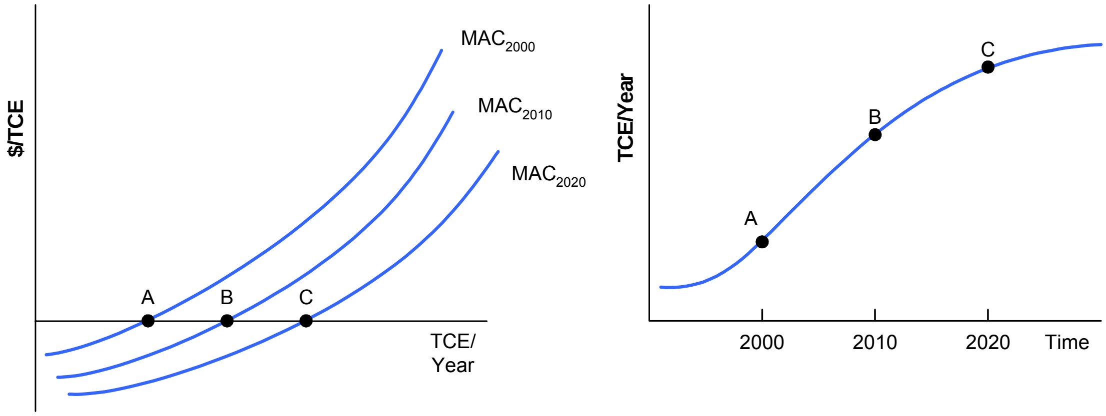

Figure 4: Illustrative Determination of Technology Change and the Identification of the Diffusion Path

The maximum potential diffusion curve can also be calculated for changing energy- or policy-induced changes in the carbon price over time. For changing energy prices, the $0/TCE line shifts upward with energy prices as the revenue from methane mitigation increases relative to the cost. As the price of carbon increases, the diffusion curve can be estimated by the intersection of the carbon price and the MAC. At this point, the carbon price plus the energy revenue is equal to the cost of the project. As the amount of cost-effective options increases with the energy or carbon price over time, the corresponding point on the diffusion curve increases (see Figure 5). The result is, as the price increases or as additional policy measures are implemented, the diffusion curve becomes steeper. The above MAC analysis includes changing gas prices over time but does not include climate-related policies.

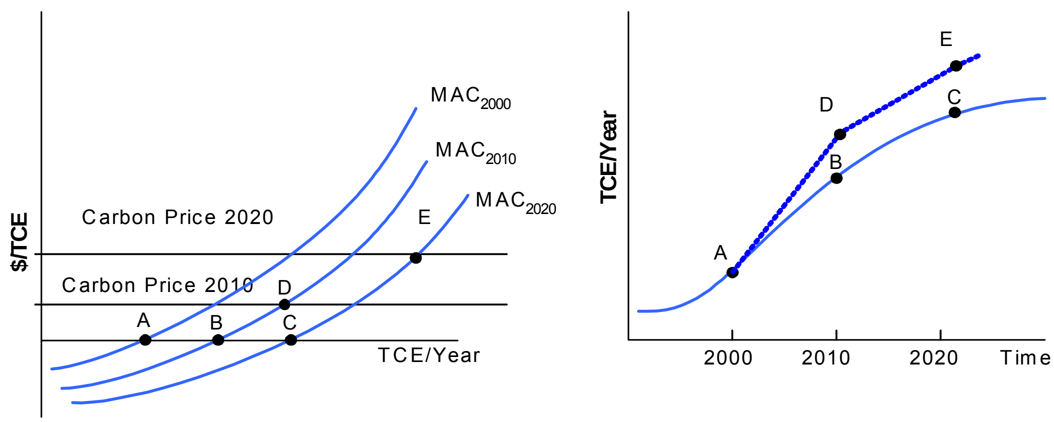

Figure 5: Change in Diffusion Curve with Change in Gas Price or Carbon Price over Time

5.1 Maximum Potential Diffusion Estimates Under an Assumption of Technical Change

From the above MAC analysis, we can generate diffusion curves over time. Figures 6a and 6b illustrate two examples of this for the landfill sector in the United States and in China. In each figure, the above MAC analysis (or the enhanced MAC analysis) is compared with the previous EMF 21 MAC analysis. As shown in both graphs, technical change shifts the maximum potential diffusion curve upward significantly over time as well as changes the slope of the curve or the rate of diffusion over time. As more mitigation options become more efficient and cost-effective, more adoption of mitigation options is possible sooner. The enhanced MAC analysis shows the maximum estimated diffusion potential assuming the continued implementation of current regulations, no further regulation, and no transaction costs or institutional barriers to implementation.

The estimated maximum potential diffusion curve follows the predicted S-shape in the examples below. In the United States, a large percentage of landfill already flare landfill gas due to the Landfill Rule, which requires mitigation of methane and other volatile organic compounds (VOCs) at large landfills for odor and safety reasons. The inclusion of the Landfill Rule in the U.S. business-as-usual (BAU) baseline has the effect of flattening out of the diffusion curves in the United States (see Figure 6a). The implementation of the Landfill Rule is projected to increase mitigation of methane, reducing BAU projections for the United States. The BAU projections flatten out over time as more landfills fall under this rule. The above MAC analysis only captures the cost of the landfills that do not fall under the landfill rule. As fewer and fewer landfills fall under this designation, the potential for diffusion of technology beyond or in addition to what is implemented under the current policies and measures is reduced. Because of the Landfill Rule, the United States is at the top of the S-curve for diffusion of cost-effective options. Only a significant increase in energy prices or an additional policy signal could 'unflatten' the curve.

In China, only a small number of landfill gas projects have been undertaken to date. China is at the beginning of a steep slope upwards on the S-shaped maximum potential diffusion curve. The enhanced MAC analysis has a steeper slope due not only to technical change estimates but also to estimates of domestically produced equipment in the analysis. In the EMF 21 analysis, all capital is assumed to be produced in the United States or Europe. The enhanced MAC analysis assumes that over time a larger percentage of capital and materials will be produced domestically. This conversion to domestically produced capital and materials means the same abatement option is significantly cheaper to install in China than in the United States because domestically produced goods and services are cheaper. This further increases the slope of the diffusion curve relative to the EMF 21 analysis.

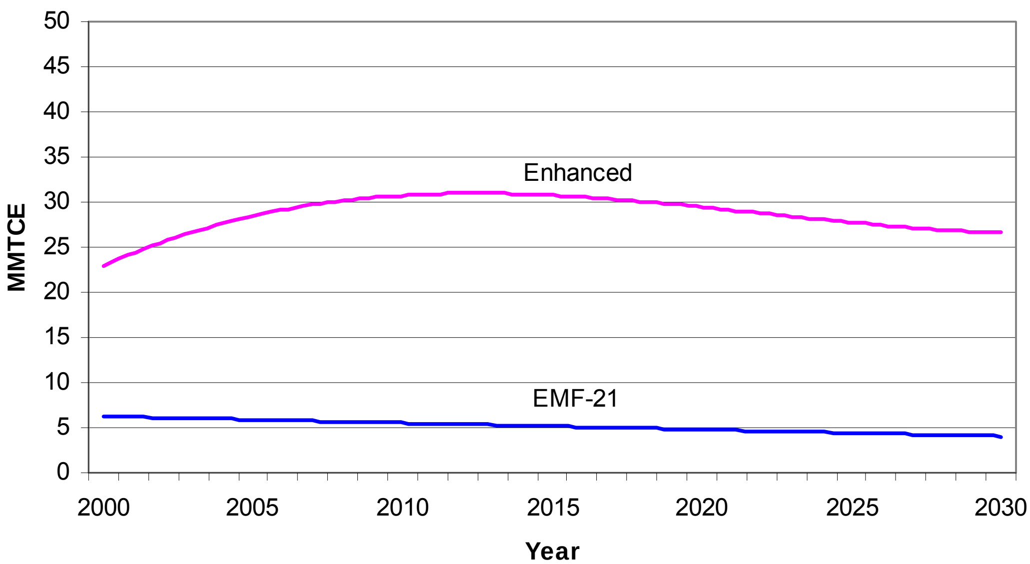

Figure 6a: Diffusion Curve—Landfills: United States

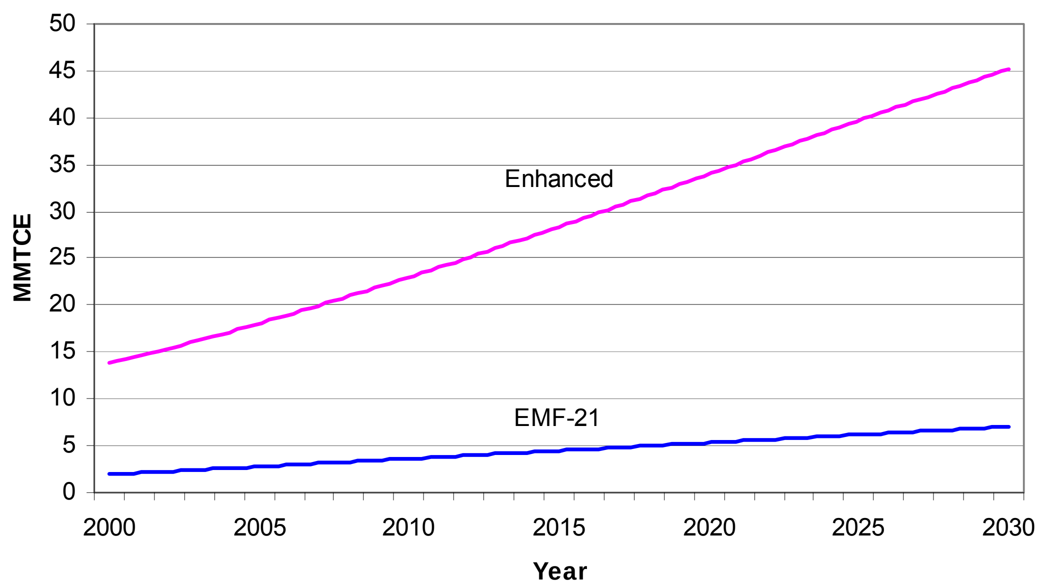

Figure 6b: Diffusion Curve-Landfills: China

5.2 Diffusion Estimates Under an Assumption of Future Policy and Measures

Transaction costs, opportunity costs, institutional barriers, and informational barriers are responsible for the underutilization of cost-effective methane mitigation projects, represented by the no-regret options below the $0/TCE axis. The MAC analysis illustrates the number of cost-effective projects and amount of reductions not yet realized. Over time, however, these projects will be implemented as many of the barriers are reduced. Each country has its own set of policies and barriers that affect adoption of methane mitigation. To reflect these differences, this analysis looks at the policy goals and targets of a particular country or region and compares these reductions to the maximum potential estimates in this analysis. These policies are intended to break down the barriers that hinder adoption of methane mitigation projects.

The above cost analysis determines the amount of cost-effective reductions that are available under a no climate policy scenario. However, coal mining, solid waste management and natural gas production, processing, and transmissions/distribution fall under a variety of climate policies and nonclimate regulations. For example, many countries regulate VOCs, including methane, at landfills for odor and safety reasons. Under these types of nonclimate-related regulations, methane is mitigated. Reductions due to these types of regulations are normally reflected in the BAU projections. In addition, many countries encourage methane capture-and-use projects through voluntary programs, technical assistance, and tax credits/subsidies. These policies are expected to increase the adoption of cost-effective mitigation technologies over time, but this adoption is not reflected in the BAU baselines or the MAC analysis presented above. By recalculating the MAC curves over time with a baseline that includes all policy and measures, a new diffusion curve can be estimated.

In the case of the United States, these regulations and voluntary reduction programs for the above sectors include the Natural Gas Star Program, which promotes efficiency in the natural gas sector to reduce fugitive methane releases; the Coalbed Methane Outreach Program, which promotes the capture and use of methane emissions from coal mining operations; and the Landfill Methane Outreach Program, which promotes emission reductions through the use of landfill gas. In addition to these federal programs, state programs also affect methane mitigation in the United States. For example, many states require a percentage of electricity to be produced by ‘renewable resources.’ These programs include landfill gas capture and use as a renewable source.

EPA estimates that the above voluntary federal programs will reduce methane emissions from these sectors by 24 MMTCE and 40 MMTCE in 2010 and 2020, respectively [37]. Using the reduced baseline for the MAC analysis, new diffusion curves can be estimated. Figures 7a and Figure 7b show the example of the landfill sector in the United States. Over time, the Landfill Methane Outreach Program is expected to reduce methane emissions by approximately 15 MMTCE and 19 MMTCE in 2010 and 2020, respectively. Figure 7a shows the MAC analysis for 2010 with and without the inclusion of these programs, which shifts the horizontal intercept from 30 MMTCE to 15 MMTCE. Similarly, Figure 7c shows the shift from approximately 29 MMTCE to 10 MMTCE with the inclusion of programs.

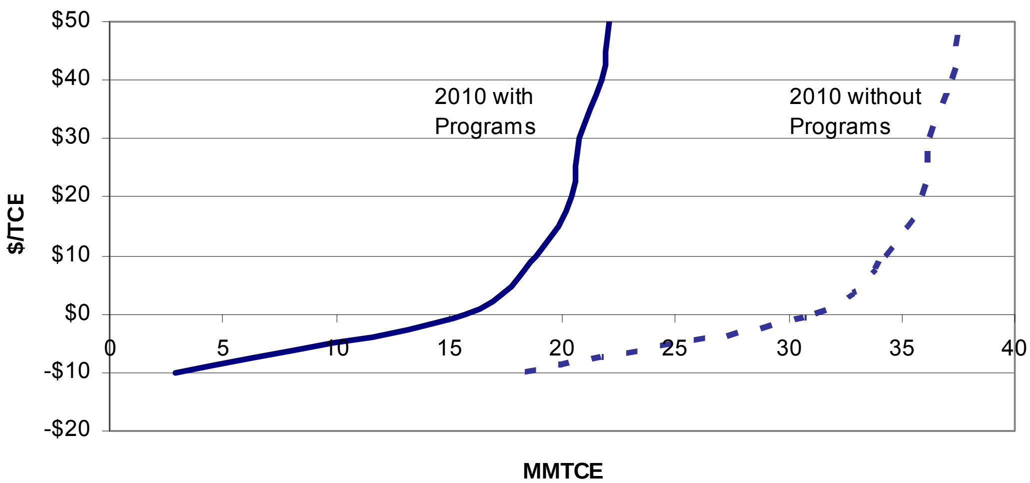

Figure 7a: U.S. Landfill Example—MAC Analysis With and Without Reduction Programs: 2010

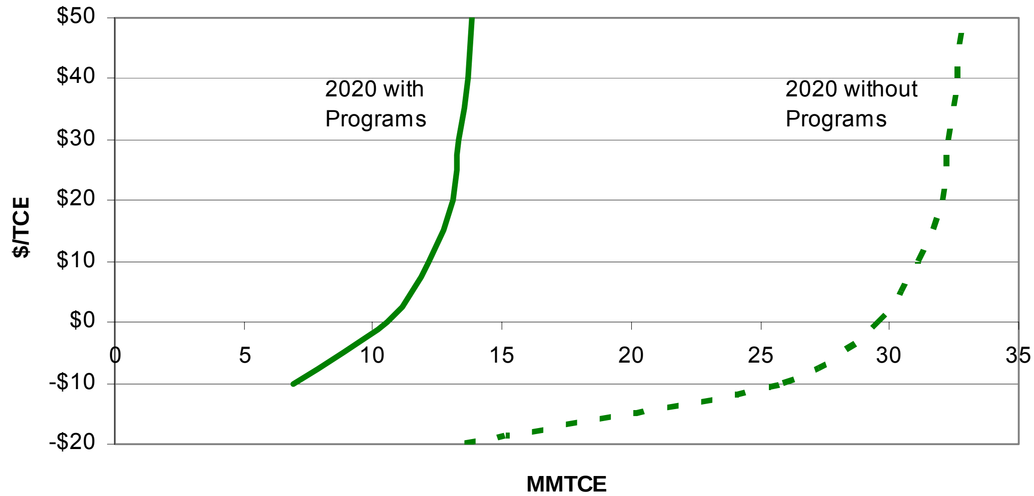

Figure 7b: U.S. Landfill Example—MAC Analysis With and Without Reduction Programs: 2020

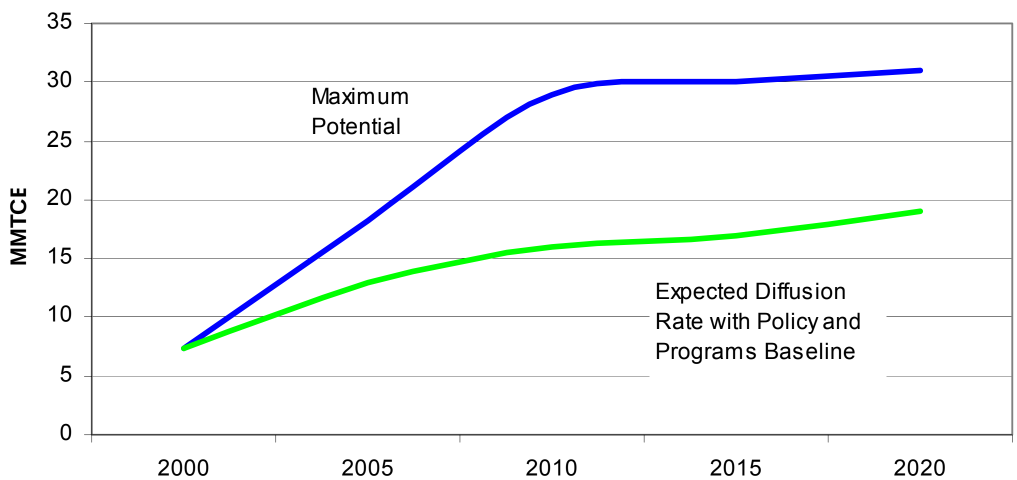

Figure 7c: Resulting Diffusion Curves for Landfills in the United States under Current Policy Regime

In this example, the expected diffusion rate under current policies is approximately half of the maximum potential as calculated by the previous MAC analysis (see Figure 7c). The gap between the estimated maximum potential and the expected diffusion due to current policies and measures is the result of continued institutional and policy barriers, such as perceived risks of new technologies by financial institutions, and no net metering policy for electricity generated. Barriers such as the ones listed present an ongoing challenge to further development of the mitigation projects in the sector. These barriers can be addressed through a variety of means including additional future energy policy and new methane initiatives.

5.3 Sensitivity to Changes in the MAC Assumptions on the Diffusion Curve Estimates

The MAC curves presented in Figure 2 and Figure 3 are the result of simultaneously applying several technology feasibility, efficiency, and import trends. Each contributes to lowering the cost and/or increasing the benefits associated with abatement technologies and hence shifts the MACs. We conducted sensitivity analysis to investigate which trends have the most significant impact on the MACs over time and therefore on the diffusion curve estimates.

Table 6 presents a sensitivity analysis for the share of domestic inputs used in abatement options for Chinese coal mines. By varying domestic labor estimates from 85 to 100 percent; domestic capital estimates by 40 to 100 percent and domestic materials by 69 to 100 percent, an upper and a lower bound are estimated as shown in Figure 8. In this example, the range of variation is due to the abundant availability of low-wage labor in China resulting in a large decrease in the cost as more domestic labor is used in mitigation projects.

Table 6: Trends Affecting MACs for Chinese Coal Mines

		2030		
	2000	Lower Bound	Original Projection	Upper Bound
Domestic share of labor	75%	85%	100%	100%
Domestic share of capital	0%	40%	80%	100%
Domestic share of materials	50%	69%	88%	100%

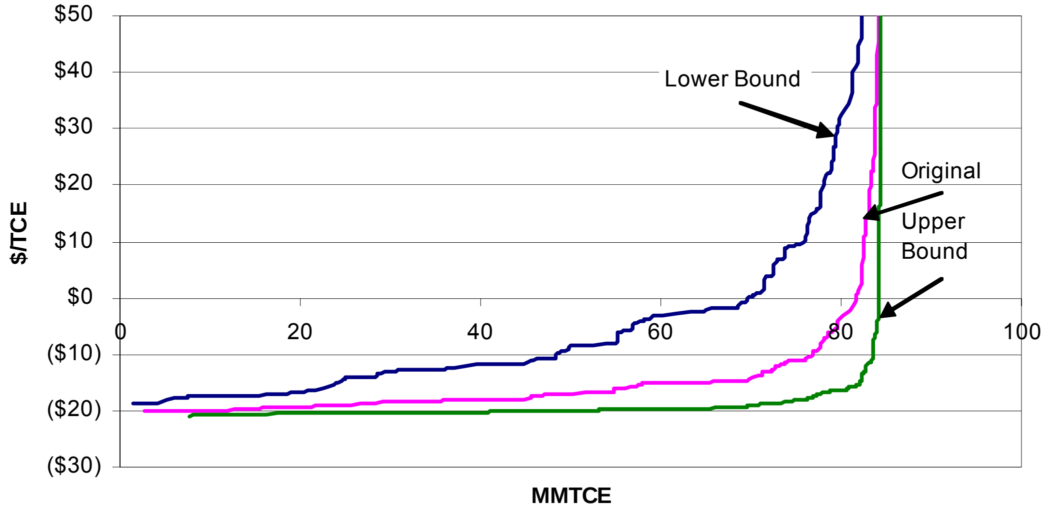

Figure 8: Sensitivity Analysis for China Coal Mining 2030

From the sensitivity analysis, diffusion curves for each case can be estimated. Figure 9 shows estimates of the diffusion curves for the ‘high estimate,’ where domestic capital and labor dominate; the original estimate; and the ‘low estimate,’ where foreign capital and labor dominate. As noted above, the increased use of domestic capital and labor allows for more cost-effective mitigation options. This in turn means greater and quicker adoption over time.

As Figure 9 shows, the sensitivity analysis implies that the growth of domestic inputs has a significant effect on the diffusion estimates. This conclusion may provide insights into how to encourage adoption of emission reduction technology outside of developing countries. Technical assistance and information transfer programs may yield greater emission reductions compared to direct foreign aid. Technical assistance would allow developing countries to accelerate the adoption of lower-cost, domestically produced mitigation technologies that are operated and maintained by lower-cost domestic labor. Lower project and maintenance costs lead to more profitable projects, allowing for more cost-effective or no-regret actions overall.

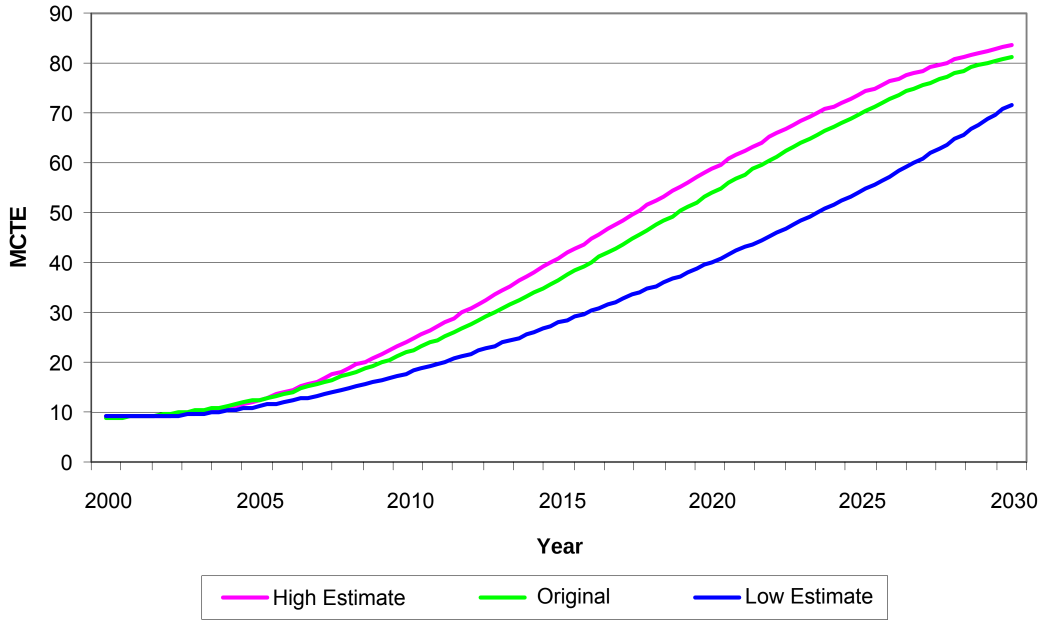

Figure 9: Resulting Diffusion Curves from Sensitivity Analysis

6. LIMITATIONS OF THE OVERALL ANALYSIS

The major objective of this analysis is to evaluate the international potential and costs of methane abatement. Although the results provide analysts with a standardized approach across major emitting regions, we briefly discuss two limitations below.

6.1 Transaction Costs, Institutional Barriers and Other, Nonquantifiable Barriers

Costs not included in mitigation project development may include identifying potential partners, identifying project options, conducting a technical and economic feasibility study, arranging financing, and obtaining permits/licenses. Currently, little data are available on transaction costs and other costs in these sectors. As these costs become better understood, they can be added to the NPV calculation as upfront costs (e.g., finding a partner, obtaining financing) or as costs over the lifetime of the project (e.g., renewal of permits, monitoring and verification). Including these costs can change the slope of the diffusion curve.

6.2 Demand for Mitigation

This analysis is a partial equilibrium analysis and as such does not address issues of welfare, feedbacks with the energy sector, crowding out of competing investment opportunities, or other greater sectoral issues. Changes in welfare, energy prices, and energy supply will greatly affect the behavior of a given firm over time. The focus of this analysis has been on the effects of technology transfer, changes in costs, and increased efficiency over time. However, the inclusion of this analysis in a broader energy sector, computable general equilibrium (CGE) models, or integrated assessment (IA) models would allow for further analysis of the effects.

6.3 Domestic Technologies, Firm Representation, and Adaptation of Technologies

The analytical framework used in this study is flexible enough to incorporate regional differences in all the characteristics and costs of abatement options. Although this analysis differentiates costs using a probability distribution within each country or region, the analysis is not based on specific firm information with the exception of the coal industry in the United States. Comparable firm-level data across regions are not available to the authors.

Limited country-specific data led to a reliance on expert judgment, which was obtained from source-level technical experts in government and industry with knowledge of United States and European Union (EU) project-level technologies, costs, and specific regional conditions. Applicability of abatement options, for example, relies on expert judgment, because the make-up of the current infrastructure in a given country in a given sector is uncertain. A much greater use of data on the cost of domestic technologies, adaptation of U.S. technologies for domestic use, etc., is recommended for the follow-up research in countries outside the United States and EU. Cheaper domestic technologies will make the slope of the diffusion curve steeper.

7. CONCLUSIONS AND NEXT STEPS

The methodology outlined above presents a bottom-up, engineering-economic analysis approach for developing regional and sector-specific MACs. Compared to previous analyses, the current analysis improves estimates by incorporating better sector- or firm-level data. Instead of modeling abatement costs using average firm costs and applying the average cost to one representative firm in each country or region, this methodology applies specific costs to a distribution of representative firms or, in the case of natural gas, an estimated natural gas infrastructure in each country or region. The current analysis also moves away from the static estimates generated in the previous studies. In this analysis, energy prices change over time, engineering efficiencies of the abatement technologies improve over time, and the cost of abatement technologies decreases over time. In addition, the percentage of domestic inputs, both labor and capital, used in the abatement option increases over time for developing countries.

An important use for MACs is to show how financial incentives can stimulate adoption of abatement options in support of policy analysis. However, existing MACs commonly have two short-comings: 1) financial cost effectiveness analysis may omit less tangible transaction costs, opportunity costs, and institutional barriers, and 2) BAU projects do not always include future policy scenarios that will influence the available or 'additional' mitigation quantities applicable for future policy scenarios.

Adoption or diffusion curves can be calculated from the MACs based on the amount of reductions that can be made cost-effectively. However, historical data show that not all cost-effective mitigation actions are taken because of information barriers and other transaction costs. The diffusion curves show maximum cost-effective potential while actual adoption rates may be significantly lower, depending on the policy structure within the country. Expected rates of diffusion can be calculated based on country-level policy data where available.

The MAC analysis shows that almost all regions could potentially have cost-effective methane emissions reductions. Even in developed countries, expected adoption rates under the current policy regime do not meet the maximum potential adoption calculated using the MACs. This illustrates the need for a better understanding of the barriers to these projects and associated costs and policy options to address these final barriers.

The MAC analysis also shows that resulting MAC estimates are most sensitive to the rate of growth in the share of domestic inputs used in the mitigation options, more so than the improved efficiency of the technology. This conclusion may provide insights into how to encourage adoption of emission reduction technology outside of developed countries. Technical assistance and information transfer programs may yield greater emission reductions compared to research and development expenditures in developed countries or direct foreign aid for developing countries. Cost data on current technologies produced outside of the EU and the United States, as well as the domestic market penetration of these technologies, are limited. A better understanding of the current mix and potential future trends of domestic versus imported technology use and labor division is needed.

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Consideration of CO_2 from Alternative Fuels in the Cement Industry

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ABSTRACT

In the cement industry, the use of alternative fuels in an environmentally responsible manner preserves natural resources and significantly contributes to the reduction of global CO_2 emissions. At the same time, it makes an important contribution to the recycling-based society and offers an efficient means through which communities can manage waste.

A considerable reduction in CO_2 emissions from cement manufacturing can be realized by using both biomass-originated and fossil-originated alternative fuels. Although CO_2 emissions reduction from the recycling and use of fossil-originated alternative fuels has not generally been recognized in Japan, the industry believes that co-processing wastes in cement manufacture instead of disposal by incineration or landfill is a key measure to achieve a reduction of CO_2 emissions. The efforts of the industry to develop further recycling technologies while maintaining quality and to transfer such technology to developing countries should be encouraged.

In this paper, the effect of alternative fuels and raw materials utilization by, and CO_2 emissions from, the cement industry are discussed and it is proposed that it is necessary to integrate waste management and waste co-processing policies in order to meet the goals of CO_2 emissions reduction and the establishment of resource recycling societies.

1. INTRODUCTION

The Japanese cement industry has made intensive investment throughout the nation's rapid economic growth period which has been characterized by production increases and subsequent two oil crises. The world's most advanced energy-efficient cement production facilities have been built and, in consequence, steps have been taken to address its effect on global warming, setting a benchmark for the world's cement industry.

Furthermore, the establishment of a recycling based society is one of the nation's main waste management policies. This has led the cement industry to use wastes as fuel in place of fossil fuels. As a result, total CO_2 emissions are reduced, fossil fuel resources are preserved and the life of landfill sites is extended.

The technology to utilize wastes as alternative fuels in an environmentally responsible manner is important for the sustainable development of not only Japan, but also the world in the future. It is not practical to separate waste management, often regarded as a regional environmental issue, from the environmental problem of global warming. The harmonization of waste management policies and global warming issues is necessary.

2. WHAT THE JAPANESE CEMENT INDUSTRY HAS DONE

2.1 Energy efficiency

State-of-the-art cement production facilities were introduced in the 1980's and, in 1990 the average specific heat consumption was 2,700MJ/t-cem, the most efficient level in the world, as shown in Fig.1. Japanese cement production also attained a low electricity consumption level per unit of production, registering 95kWh/t-cem. in 1994.

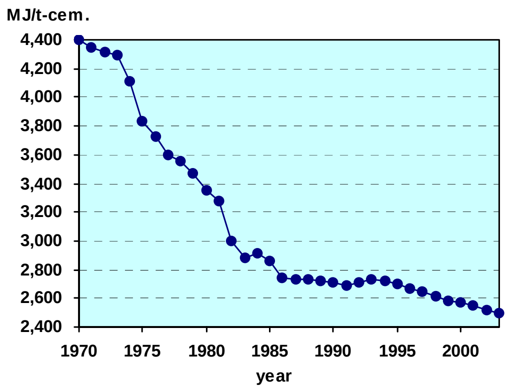

Figure 1: Change in Specific Heat Consumption (alternative fuel excluded) For Cement manufacturing
Source:Japan Cement Association [1]

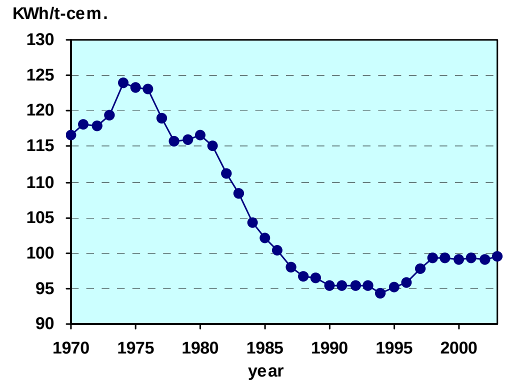

Figure 2: Change in Specific Electric Power Consumption For Cement manufacturing
Source: Japan Cement Association [2]

Having achieved the above, the industry had little opportunity for further energy efficiency investment. Accordingly, it has promoted the utilization of wastes and by-products as alternative fuel and raw materials (AFR). However, the electric energy consumption per unit of production is presently on the increase because of the pretreatment required for their utilization, as wastes are hauled directly from source to cement plant in Japan (See Fig.2).

2.2 Cement production and waste disposal

Every year Japan generates 450 million tons of wastes, of which 400 million tons are industrial wastes and 50 million tons, municipal wastes[3]. Landfill sites receive as much as 53 million tons for landfill disposal after recovering reusable wastes or incineration of combustible wastes[4]. Reflecting such situation, Japan has the problem in securing landfill sites for the future and is already beginning to run out of capacity. It is a great concern and challenge to prolong their remaining useful service lives.

On the other hand, the cement industry consumes wastes and by-products, reaching 28 million tons annually in 2003 (See Table 1), corresponding to 6% of the total quantity generated in Japan[5].

Its usage is made possible by the four main cement compositions of CaO, SiO_2, Al_2O_3 and Fe_2O_3 generally contained in the wastes and by-products, which the industry usually obtains from natural raw materials such as limestone and clay. Since cement raw materials are calcined and sintered in a rotary kiln where the temperature reaches 1450℃, it can safely produce cement of specified quality and in a large quantity, while recycling wastes and byproducts.

Table 1: Waste Materials & By-products used in Cement Industry (unit: thousand tons)

Item	1999	2000	2001	2002	2003
Blast furnace slag	11,449	12,162	11,915	10,474	10,173
Coal ashes	4,551	5,145	5,822	6,320	6,429
By-product gypsum	2,567	2,463	2,568	2,556	2,530
Waste tires	286	323	284	253	230
Waste oil	250	239	204	252	238
Waste plastics	58	102	171	211	255
Wood chips	0	2	20	149	271
Others	6,423	6,923	7,077	7,023	7,438
Total	25,584	27,359	28,061	27,238	27,564

Source:'Cement Handbook 2004 (in Japanese)' Japan Cement Association
Note: 'Others' include Steel manufacturing slag, Nonferrous slag, Coal tailings, Dirt, Sludge and so on.

2.3 CO_2 Reduction with AFR

CO_2 emissions from the cement industry are mainly attributable to the calcination of limestone and fossil fuel burning as shown in Fig.3.

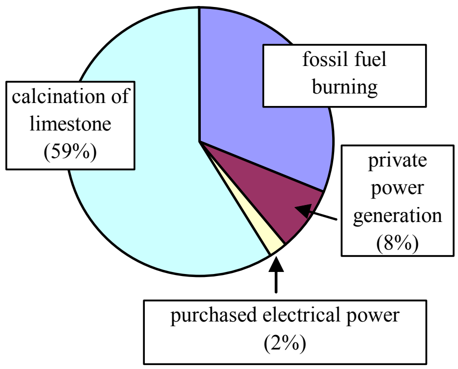

Figure 3: CO_2 emissions by source
Source:Japan Cement Association [1]

The cement industry's efforts to reduce CO_2 are divided into the following activities.
Reducing CO_2 emissions from fossil fuel and limestone by increasing the use of AFR.
Reducing fuel and electricity consumption by installation of energy efficient facilities.
Lowering the clinker factor in cement by addition of cementitious materials.

As for the use of AFR, it contributes to the reduction of CO_2 in society when emissions from both the combustion of fuels in cement production and waste disposal by landfill/ incineration are considered.

3. DIFFICULTIES IN EXPANDING AFR UTILIZATION IN THE CEMENT INDUSTRY

3.1 FAF utilization possibility

As shown in Figure4, the cement industry is utilizing a significant amount of fossil-originated alternative fuels (FAF) such as waste tires, oils and plastics[5].

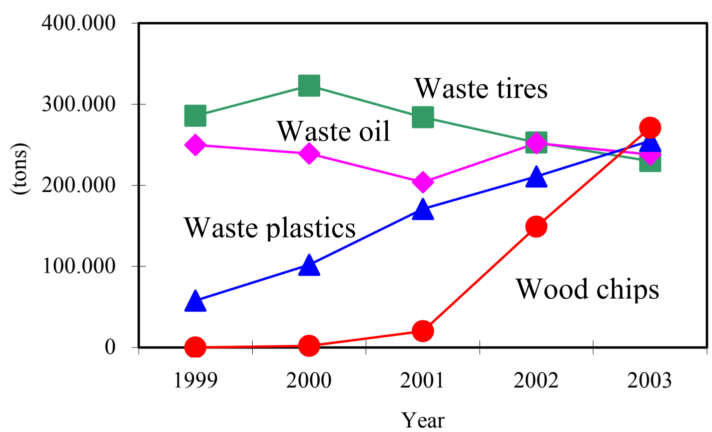

Figure 4: FAF utilization by the Japanese cement industry

To increase FAF utilization further however, it is necessary to promote government policies that encourage thermal recycling through co-processing. The amount of waste plastics generated in Japan is 10 million tons every year and 50% of it disposed by incineration and landfill.

Meanwhile, the 'Container Packaging Recycling Law' was enforced from April 2000[6]. The recycling methods accepted by this law are only material and chemical recycling. Thermal recycling is excluded. The chlorine content (represented by PVC) of waste plastics in many cases is one of the factors that make recycling difficult. Chlorine poses a problem for the cement manufacturing process. However, many technical approaches, such as the development of the chlorine bypass system and relaxation of product content, will increase the use of waste plastics[7].

3.2 Accountability for CO_2 emissions from FAF

While CO_2 emissions from waste incineration are classified as an emission by the waste sector under international guidelines, they are classified as an emission by the energy sector, including the cement industry[8], if used as energy. It is a simple transfer between the sectors. But the actual CO_2 emission for society as a whole will be reduced when the wastes are used as heat energy at a cement plant as opposed to being simply burnt for disposal. (Fig.5)

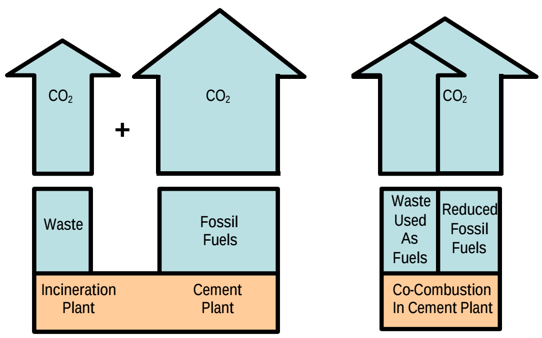

Figure 5: CO_2 Impacts of AFR Use
Source: CEMBUREAU, 1997 [9]

According to the 'National GHG Inventory of Japan submitted in 2004'[10], CO_2 emissions from waste incineration are 24 million tons. Therefore, the potential for global CO_2 reduction could be enormous if all FAF is co-processed in cement manufacture.

However, if the cement industry is held accountable for the CO_2 emissions originating from wastes, promotion of FAF utilization and its technology development would be discouraged.

3.3 Contradictory issues

The use of wastes and by-products in the cement plant is considered to be an effective environmental practice in many countries. It not only helps reduce greenhouse gas emissions, but also provides a better means to control environmental impacts than presently prevalent disposal means such as landfill or the combination of incineration and landfills.

Particularly in a country like Japan where limited landfill capacity remains, the use of wastes as AFR for cement production is an essential element in building a recycling-based society. It not only preserves the remaining service life of landfill sites, but ensures high economic utilization of existing cement manufacturing facilities and the need for new incineration facility investment diminishes.

The cement industry has a high potential to use AFR and thereby reduce global CO_2 emissions. If these CO_2 emissions are considered as emissions from the cement industry alone, an important opportunity to reduce global CO_2 emissions would be lost. In order to establish a sustainable society it is necessary to look at the whole picture, not just parts in isolation.

4. LCA EVALUATION OF WASTE PLASTICS

As a typical example of utilization of FAF in the cement industry, the environmental impact of utilizing containers and packaging plastics (CPP) was analyzed (Sano et al.,2002) [7].

Waste plastics were pre-treated (de-chlorination) as shown in Fig.6, and used as an alternative fuel through the main burner, partially substituting pet-coke. The results of this field test (Table 2), where the amount of CO_2 reduction is estimated by the difference of H/C ratio between waste plastics and pet-coke, showed the reduction of CO_2 emission by 6% when 35% of pet-coke was replaced, and increases of other air pollutants (SO_x, NO_x, HCl, dioxins) were not observed. A recent study conducted by SINTEF on behalf of the WBCSD Cement Sustainability Initiative has also confirmed that modern, dry cement kilns could normally meet a very low dioxins emission levels and that the type of fuel used (including wastes) is not the cause of dioxins emissions[11]. Based on the field test data, the amount of CO_2 emitted was compared with other recycling procedures using LCA methods, and it was found that utilizing CPP in cement production has a remarkable effect compared with several types of liquefaction recycling procedures (Fig.7).

This encourages confidence in the great potential of using FAF in cement manufacture to reduce CO_2 emissions. Furthermore, greater CO_2 emission reductions (more than 30%) can be estimated if the following potential benefits of FAF are also included:
If not used by the cement industry, FAF would eventually be decomposed to CO_2 or CH_4 in landfill or by incineration.
If such wastes are landfilled, cement or chemicals often have to be used to prevent elution of hazardous or toxic components. These materials themselves require considerable energy for their production.
In providing landfill sites, large areas of land, often forested, have to be cleared thereby reducing natural CO_2 absorption by plants.

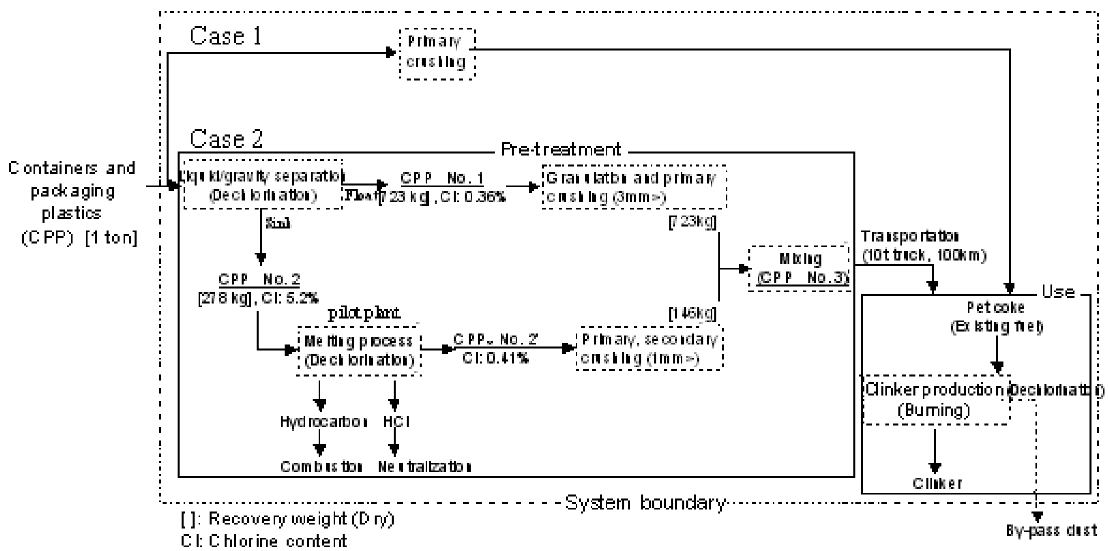

Figure 6: Process flow of the treatment and use of waste plastics.
Source: Sano et al.,2002[7]

Table 2: Results of burning test and CO_2 emission from use of CPP

	Used (t)		Production of clinker (t)	Energy (GJ)**		CO_2 emissions (kg)		
	Plastics	Pet-coke		Plastics	Natural energy: Pet-coke***	Plastics	Pet-coke	Total
Blank	0	2.463	51.6	0	90.8	0	8,360	8,360
Field test	1.0 (0.869)*	1.577	51.6	31.86	58.1	2,085	5,351	7,436
Difference	□	-0.887	□	□	-32.7	2,085	-3,010	-924

( )*:as CPP No.3
**:Lower caloric value
***:Includes refining energy etc.

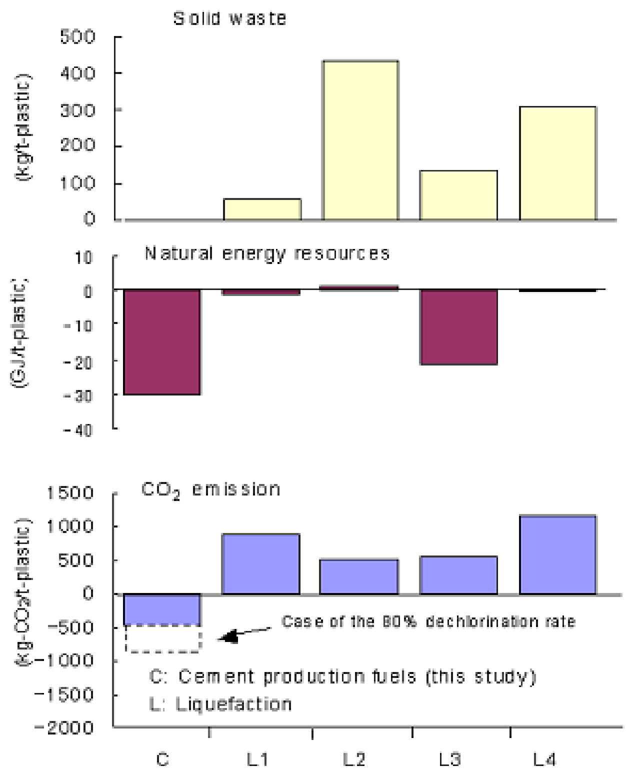

*Figure 7: Environmental impact of each recycling method.**
Source: Sano et al.,2002[7]

5. OUR CONCERNS

The net environmental impact is reduced if the wastes that are incinerated or dumped in landfills can instead be used by the cement industry as AFR. To ensure that this opportunity to reduce net environmental impact is not missed, some kind of incentive for the CO_2 reductions (as illustrated in Fig.5) achieved by the cement industry should be granted. For instance, the WBCSD Cement CO_2 Protocol [12] shows the concept of 'gross emissions' and 'net emissions'.

If the cement industry remains accountable for CO_2 emissions from AFR, this not only conflicts with Japanese environmental policy aimed at realizing a recycling based society, but will discourage waste recycling and reduction of greenhouse gas emissions. It will also seriously discourage technical development by the cement industry.

6. CONCLUSION

The use of wastes and by-products in the cement industry has excellent applicability.
The Japanese cement industry can contribute technically to waste utilization internationally.
Existing cement production facilities can utilize wastes and by-products as resources and furnish an effective means to mitigate global warming and facilitate waste management globally.
Integration of waste management and industrial processes will be one of the key issues that lead to the establishment of a sustainable society.
The effort of the cement industry to develop, implement and transfer internationally, AFR technologies should be encouraged.

* L1-L4 in Fig.7 denote data for four different cases in Japan, all processing waste plastics for manufacturing light oil for use as fuel.

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ENERGY INTENSIVE CONSUMER GOODS BREAKOUT GROUP

Potential Carbon Dioxide Reduction Through the Use of Hybrid Buses in Brazil

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ABSTRACT

Carrying more than 55 million passengers per day, buses are the main mode of transportation in Brazil. Most of these vehicles are diesel-fuelled, causing dependence on oil, extensive greenhouse gas emissions and increasingly severe air pollution in urban areas. In order to improve this situation the options open to Brazilian cities include the use of alternative fuels and new propulsion technologies, such as hybrid vehicles. Field tests carried out by the authors indicate that fuel consumption improvement through the use of hybrid buses would certainly exceed 20%, resulting in lower fuel costs and reduced carbon dioxide (CO_2) emissions. However, the acquisition costs of heavy hybrid vehicles average out at 30% higher than regular vehicles. Consequently, the introduction and acquisition of this new technology depends on a strategy that can reconcile these advantages with the constraints imposed on urban bus operators.

This paper proposes an evaluation procedure that analyzes market opportunities for introducing and disseminating a new technology, based on five aspects that that are closely aligned with the needs of the urban bus operator. The main issues addressed are: perception of advantages; simplicity of application; ease of understanding; product credibility; and reversibility of use. By analyzing and surmounting the barriers generated by any new technology through these five aspects, the hybrid bus technology might well post gains of scale with lower costs. The procedure covered by this paper compares hybrid buses to their conventional diesel-fuelled counterparts.

1. INTRODUCTION

In the main State Capitals of Brazil, buses carry more than 550 million passengers a month; with a fleet of around 55,000 vehicles that covers some 250 million kilometers a month (NTU, 2003). In order to service this market, Brazil is today the world's second-largest bus manufacturer, with an output of around 15,000 vehicles a year (FABUS, 2002).

This means that 72% of Brazil's diesel oil consumption is absorbed by the road transportation segment, with urban passengers accounting for a significant portion, contributing to high greenhouse gases emission rates as well as local air pollution.

In order to deal with this situation, some proposals have been presented, outstanding among which is the use of alternative fuels, such as compressed natural gas and, more recently, the use of dual-fuel buses running on Brazilian technology, in order to develop vehicles that are quieter, more economic and less pollutive.

Reconciling the two propulsion systems in question – the conventional option based on the internal combustion engine, and the electrical option, used many years ago by trolleybuses – hybrid technology is today largely mastered, requiring no major investments in capacity-building for the labor-force. However, initial costs are still some 30% higher than conventional technology, meaning that some type of government incentive is required, particularly for the developing countries that are still heavily dependent on the bus as a means of mass transportation.

Nevertheless, the introduction and dissemination of these new technologies on the market depend on a strategy that can reconcile their advantages and constraints with customer requirements. This paper proposes the preparation of a procedure for assessing opportunities to introduce and disseminate a new technology on the market, based on five aspects that focus on customer requirements: perception of advantages; simplicity of application; ease of understanding; product credibility; and reversibility of use (Edosomwan, 1989; Ettlie, 2003). This procedure is applied to hybrid buses, comparing them with conventional buses fuelled by diesel oil.

2. USE OF THE HYBRID BUS IN BRAZIL

As shown in Figure 2.1, 29% of the commutes in Brazil during 2000 used public transportation, of which 94% were urban buses (Figure 2.2) (Vasconcellos, 2003).

This involves a fleet of around 55,000 vehicles covering more than 250 million kilometers a month in the major cities of Brazil, consuming sixty to seventy million liters of diesel oil a year (NTU, 2003).

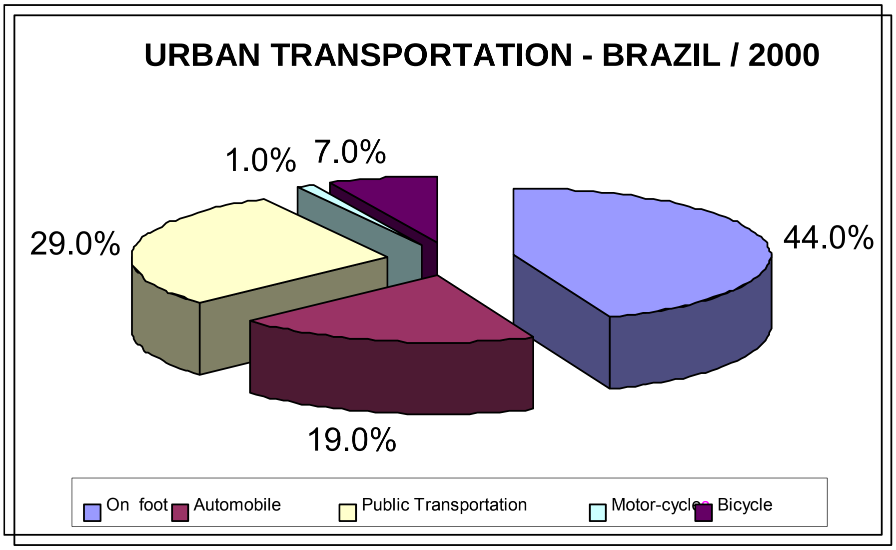

Figure 2.1 – Commute Distribution in Brazil

The implementation of mechanisms designed to reduce diesel oil consumption, particularly in sectors – such as road transportation – that post more significant figures, is both necessary and desirable. A long-term view indicates the need for heavy investment, underwriting the implementation of higher-capacity modes of transportation, such as trains and subways driven by electricity. However, developing countries such as Brazil do not always have the resources required for these high-cost mass transportation alternatives.

Within this context, the best short-term alternative for reducing diesel oil consumption and air pollutant emissions in Brazil due to the ongoing use of urban buses, is the replacement of diesel oil by compressed natural gas (CNG) or renewable fuels (ethanol, biogas and biodiesel), or even the introduction of new propulsion technologies, such as hybrid-drive vehicles (IEA/OECD, 2002).

Brazil has developed hybrid drives for buses. The models shown in Table 2.1 are already in operation (ELETRA, 2002). From the options listed in Table 2.1, the Padron model meets the specifications established during the 80's by the Ministry of Transportation, as best adapted to urban passenger transportation. The Padron model consists of large, high-capacity buses with a rationalized internal layout that streamlines passenger boarding and alighting procedures and offers better onboard seating, equipped with two or three double doors and a weight/capacity ratio that is optimized for urban traffic (GEIPOT/EBTU, 1983).

Table 2.1 Brazilian Hybrid-Drive Bus Specifications

Name	Arrangement	External Dimensions				Capacity		Performance		
		L [m]	W [m]	H [m]	Tare [kg]	Seated	Standing	S_{max} [km/h]	Pot_n. [kW]	Pot_{MG} [hp]
Articulated	Series	18.15	2.60	3.40	18,000	57	113	60	360	150
Padron	Series	12.00	2.60	3.40	12,000	36	64	60	240	80
Microbus	Series	8.00	2.20	2.70	7,000	25	-	80	150	50

Notes - L: length; W: width; H: height; S_{max}: maximum speed, Pot_n.: rated power of electric motor; Pot_{MG}: rated power of motor generator group. Source: ELETRA, 2002.

Some 16% of the urban bus fleet in 27 Brazilian State Capitals already consists of Padron vehicles. However, this specification is applicable to the operation of some of the remainder of this fleet, which today consists of smaller, lower capacity buses (75 passengers) known as Conventional Urban Buses (CUB) (ANTP, 2000).

Due to the size, capacity and performance of the Padron bus when compared to CUB models, these vehicles are particularly suitable for operations in Bus Rapid Transit (BRT) Systems, defined as high-quality, customer-oriented transit facilities that deliver fast, comfortable and low-cost urban mobility (IEA/OECD, 2002). BRT is an evolution of the bus-lane and bus-way concepts, which propose to upgrade the performance of bus transportation systems through assigning priority to bus traffic by physically separating bus lanes from regular traffic and considering the use of specially designed buses. Becoming widespread in Latin America, this type of operation is already operating successfully in some Brazilian cities (IEA/OECD, 2002; ANTP, 2000) where heavy constraints on investments in mass transportation systems leads to the use of buses as an important alternative to rail systems for providing rapid transit.

The BRT concept also involves the use of environmentally-friendly vehicles (IEA/OECD, 2002), which makes the hybrid-drive Padron bus – called Padron H from now on – an appropriate choice, as it can meet these demands with no loss of flexibility, in contrast to the articulated or bi-articulated models.

A set of historical data on the operational costs of the hybrid-drive buses is not available but an estimate of them can be obtained from the manufacturer's experience, as presented in Table 2.2. The multiplication factors consider as base the operational costs of Padron model buses and an average mileage of 7.500 km/month. The costs not considered in the Table 2.2 are independent of the propulsion system.

Table 2.2.Factors to estimate operational costs of hybrid-drive buses

Costs	Multiplication factor
Fuel	0,8
Lubricant oil	0,5
Tires	0,6
Brake lining	0,3
Engine reform	0,5
Batteries	4,0

2.1. Pilot Experience – Sao Paulo

A pilot project introducing Padron H type buses is underway in the São Mateus – Jabaquara – Ferrazópolis Metropolitan Corridor in the São Paulo Metropolitan Region (SPMR).

This is a Metropolitan Corridor for trolleybuses servicing five Municipal Districts (São Paulo, Diadema, Sao Bernardo do Campo, Santo Andre and Maua) in Sao Paulo State, with three integration terminals, one of which links into the subway system. This corridor is 33 kilometers long, of which only 22 kilometers are electrified, with the non-electrified leg (11 kilometers) serviced by conventional diesel-fuelled buses, making hybrid traction vehicles a natural alternative.

The current operating fleet consists of 46 trolleybuses, 120 Padron-type buses (Padron C) and 23 articulated buses that travel some 75,000 km/year at a commercial speed of 22 km/hour.

From January 2003 onwards, three Padron H buses were added to this fleet operating in the Metropolitan Corridor. These vehicles are slightly different from the vehicles tested by COPPE/UFRJ, as noted in Item 3 of this Paper, as they are fitted with air conditioning. This imposes even more stringent operating conditions, while reducing energy efficiency [km/l], and this type of bus is consequently appropriate for a long-duration trial.

These vehicles operated throughout the whole of 2003, building up an average of 80,000 kilometers each, with no extraordinary problems noted in the hybrid traction system, rating them as satisfactory for the durability and reliability trials.

2.2. Potential for Disseminating Technology

As shown, the findings of these long-duration trials of the hybrid traction buses in the Sao Mateus - Jabaquara - Ferrazopolis Metropolitan Corridor are satisfactory so far. Under the same operating conditions, tests were carried out by COPPE/UFRJ demonstrating the potential fuel economy reduction through the use of the Padron H bus, as shown below. Based on these affirmations, it appears that the hybrid traction technology for buses may be more widely used in transportation corridors, where these advantages are already being proven.

Although transportation corridors are not common in Brazilian cities, Campinas has the Amoreira Corridor, some five kilometers long and with exclusive bus lanes running alongside the divider and covering only part of the section between Downtown (Centro) and the Ouro Verde Terminal, which is one of the most important hubs in this town.

There is only one kilometer of separate lane in Uberlândia and some 4.4 kilometers of exclusive lanes, but a slightly better situation is found in Goiânia, with 19.4 kilometers of exclusive lanes in the Anhangüera and North-South Corridors. Due to poor conservation and lax oversight, these lanes were improperly used for several years. Recently, the Anhangüera Corridor was rebuilt. Only the Curitiba Metropolitan Region has a properly-integrated system with an extensive network of exclusive lanes, covering approximately sixty kilometers of roads, and the network of exclusive bus lanes in Porto Alegre is relatively well developed, with a length of 28.1 kilometers.

In these cities, the Padron C bus accounts for some 46% of the fleet, with articulated and bi-articulated buses reaching around 5%. In other towns and cities in Brazil, conventional buses account for 92% of the fleet, with the Padron C representing 6.8%.

In an initial approach, the potential for using Padron H buses appears in the urban transportation corridors of São Paulo, Campinas, Uberlândia, Goiânia, Curitiba and Porto Alegre. This could be implemented through acquiring the Padron H bus when renewing and expanding the fleets in these cities. However, the acquisition cost of the Padron H bus is around 30% higher than its Padron C counterpart, which may hamper this process.

3. PERFORMANCE ASSESSMENT OF HYBRID BUSES

As hybrid buses offer operating advantages over conventional diesel buses, including smoother and quicker acceleration, more efficient braking, improved fuel savings and reduced emissions (NAVC, 2000; IEA/OECD, 2002; Jefferson & Barnard, 2002), a series of trials were run by the research team of the Transportation Engineering Program at the Rio de Janeiro Federal University, in order to ascertain the potential for reducing diesel oil consumption and CO_2 emissions through the use of Brazilian-made hybrid buses.

The fuel savings trial was carried out on the Sao Bernardo – Ferrazopolis stretch of Sao Mateus - Jabaquara Metropolitan Corridor. The bus-way used for this trial was mapped using a GPS device. It has a flat surface paved with concrete blocks in flawless condition throughout its entire length. The road configuration consists of lanes traveling in the same direction with traffic lights at the crossroads. They are separated longitudinally from oncoming traffic and constitute a 7.25-km closed circuit. There are seven stops both ways for passenger boarding and alighting.

For each vehicle loading condition (loaded and unloaded) the circuit was run at least five times. In order to measure fuel consumption, a properly calibrated flow-meter was fitted to the vehicle engine fuel-feed system. Fuel consumption and time were noted at each stop in order to obtain a mass of fuel consumption data based on the trial duration, which could be rated to the distance covered as average speed.

The fuel consumption data surveys for the Padron H and Padron C buses (the latter used as a benchmark) were carried out simultaneously, with each vehicle accompanying its counterpart as leader and follower. This was intended to minimize differences in the traffic conditions. At the end of each cycle, the vehicles switched positions, taking it in turns to drive as the lead vehicle.

Figure 3.1 illustrates the results obtained in fuel savings trials for the loaded condition. The analysis of the findings indicates that, the Padron H vehicle was at least 23.33% more fuel-efficient than its Padron C counterpart for the operating conditions established in the trials. This occurred for average speeds ranging from 20 to 24.9 km/h with a loaded vehicle.

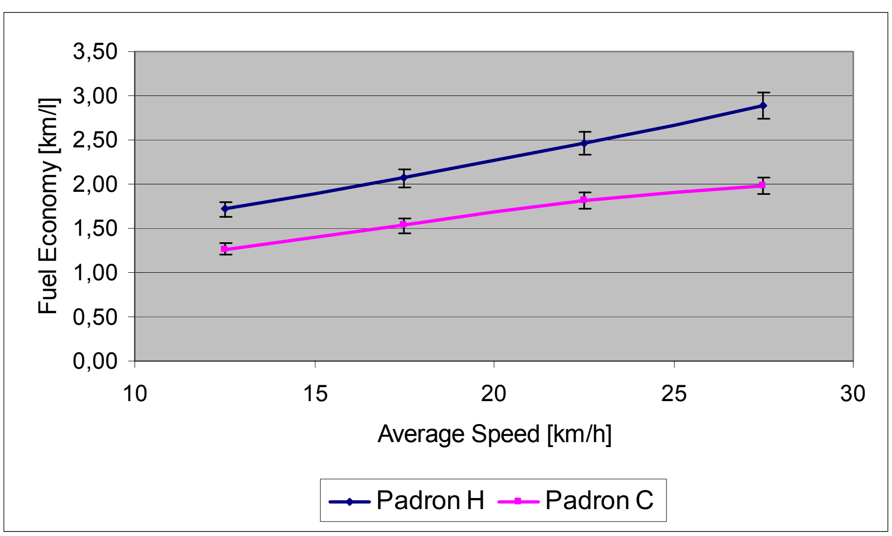

Figure 3.1 –Padron H x Padron C Comparison – Loaded Vehicles.

Table 3.1 presents an approximate relationship between traffic conditions and average speed intervals. It considers that average speed models stopping frequency and idling time (GEIPOT, 1986). This allows to take advantage of the results on Figure 3.1 to extend the fuel savings estimates when using of hybrid drive buses to different traffic conditions.

Table 3.1. Estimated relationship between traffic condition and average speed

Traffic flow	Average speed[km/h]
Common lane	5 to 15
Buslane	15 to 25
Busway	Over 25

Independent of the fuel economy estimated from the use of Figure 3.1 and Table 3.1, in real operation of the hybrid drive buses it will depend on the possibility to use the regenerative brake system, what presupposes soft braking and engine off when idling, maximising fuel economy in bus stops.

To take maximum advantage of the regenerative brake system, the traffic condition on common lane is not necessarily the most appropriate, because it imposes abrupt and fickle braking, what hinders the conversion of kinetic energy into electricity. Thus, the best fuel economies occur for average speed into 15 to 25 km/h interval (bus lanes). However, for the best results in fuel economy the ideal would be to design the hybrid drive vehicle to specific traffic conditions.

The reduction in diesel oil consumption resulted in a proportional drop in carbon dioxide (CO_2) emissions, meaning that each liter of diesel oil saved avoids the emission of some 2.6 kg of CO_2 (taking the specific mass of diesel oil as 0.83 kg/l and the CO_2 emission factor as 3,188 g/kg).

The total emissions reduction will depend on the distance traveled by the vehicles and their average speed over each section, being calculated specifically for each application.

4. INTRODUCTION AND DISSEMINATION OF NEW TECHNOLOGY

A procedure may be drawn up to assess the opportunities for introducing and disseminating a new technology on the market, based on five aspects that meet customer requirements (Bright & Baker, 1999): perception of advantages; simplicity of application; ease of understanding; product credibility; and reversibility of use. Each of these aspects is presented below, applied to the Padron H vehicle case study.

Perception of Advantages:
The Padron H bus consumes some 20% less fuel and emits proportionally less atmospheric pollutants and noise, which are two undoubted benefits. The first advantage is economic, as fuel accounts for 15% to 25% of the operating costs of a bus company. The second advantage is social and environmental, due to lower external effects inherent to the operation of urban passenger transportation facilities.

As additional advantages, the Padron H buses tested in 2003 in the São Mateus – Jabaquara – Ferrazópolis Metropolitan Corridor also posted lower maintenance costs, through gentler acceleration and braking processes, with less wear and tear on mechanical parts and tires, which is the second-highest variable cost in bus transportation.

Consideration should also be given to the main disadvantage: the need for an initial investment some 30% higher than required for the Padron C bus. This is more than offset by fuel savings during the useful life of the vehicle.

Simplicity of Application:
The Padron H bus is apparently identical to its Padron C counterpart, with the same operating flexibility and running on the same fuel. The difference lies in how the chemical energy of the fuel is put to work, resulting in higher savings. No changes are required in the operating structure, and no toxic or hazardous products are handled. Everything is very similar to the transportation system to which the operators and users are become accustomed.

Ease of Understanding:
The hybrid drive technology fitted to the Padron H bus combines two other well-known technologies in an innovative manner: (1) the internal combustion engine, which has been in use for more than a hundred years, and (2) electrical traction, which is perhaps even older. Its functional effectiveness lies in blending these two propulsion systems in a harmonious way, leading to a technological solution that can meet urban passenger transportation operating needs with the advantages already presented.

Moreover, as this Project combines two well-known technologies, the introduction of Padron H buses and their dissemination needs no elaborate and expensive capacity-building programs that are usually required for other alternatives.

Product Credibility:
The conceptual design of the Padron H bus uses parts and technologies based on well-known technology, while companies already established on the market ensure its credibility. The mechanical components (internal combustion engine, drive shaft, chassis and frame) are the same as those used by Brazil's auto-assembly industry. The electric drive system (electric engines, batteries, controllers) are the same as those used in trolleybuses, also based on well-known technology.

Reversibility of Use:
The manufacturer of the Padron H bus is well able to service the Brazilian and international markets, offering more than four bus models that service all transportation segments in Brazil.

Component maintenance can be handled directly through the original suppliers, whose networks cover the entire Brazilian market, regardless of where the vehicle plant is established, meaning that the resale segment offers no problem. Another advantage is the fact that diesel oil is the fuel used, with a nationwide supply infrastructure already well established.

5. CONCLUSIONS

As Brazil depends heavily on buses for urban transportation, the use of hybrid-drive models may well offer an attractive opportunity to introduce a new technology that can lower operating costs through reducing fuel consumption, with less wear and tear on the mechanical components in the internal combustion engine, brakes and tires. Additionally, reductions are expected in the emission of local and global atmospheric pollutants (CO_2), as well as noise.

Although some 30% more expensive, the application of this procedure opens us fresh opportunities for introducing and disseminating a new technology on the market, providing a feasible alternative and responding positively to the five aspects under analysis. Additionally, this procedure fosters a better understanding of how to reconcile the activities of the public and private sectors, fostering technology transfers and dissemination.

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Technology Diffusion in Industry

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ABSTRACT

Studies have shown that GHG mitigation and associated costs are sensitive to the development and diffusion of technologies. Among models used to assess emissions mitigation and its costs, many assume technological progress to be non-economic and subject to exogenously defined parameters. However, evidence suggests that there are economic and endogenous drivers to technology development and diffusion. To analyse technological progress and diffusion, we have developed and utilised for many policy analyses a model that represents technologies explicitly and evolves these technologies endogenously in simulations that reflect a realistic portrayal of technology choice behaviour, couched in a general macro-economic equilibrium framework.

The behavioural parameters in our technology-explicit model, called CIMS, are obtained from existing literature and from a set of empirical studies using Discrete Choice Surveys of technology preferences, both revealed and stated. The model is considered a hybrid in that it integrates 'top-down' behavioural and macro-economic criteria with highly detailed technology descriptions in over 10 process-focused industry models as well as other sectors of the economy (residential, commercial and transportation), detail typical of a 'bottom-up' model. CIMS incorporates learning-by-doing curves (experience curves), discount rates, market variability and contingent valuation techniques to help define both technologies and choices for technologies. Its macro-economic component assesses the impact of change in technology stock on costs of production using an empirical estimation of macro-economic structural response (service demand and trade) to changes in costs. This modelling technique is applied to all sectors of the economy on both the supply and demand side. The model is integrated, providing a general equilibrium outcome by simulating energy supply and demand and macro-economic feedbacks simultaneously.

INTRODUCTION

Scientific investigation affirms that the recent accumulation of greenhouse gases (GHG) in the earth's atmosphere is related to society's use of resources to meet its needs. The type of technologies used to convert resources into the products and services we use defines the character and scale of this, and other, environmental impacts. If we believe that GHG accumulation alters climate, it makes sense that policy-makers focus on affecting the types of technologies in use by society as one approach to help define a solution to the problem. We seek to replace current technologies with those better able to provide the product or service, lessening this impact; we seek technological change.

Researchers focused on policies to ameliorate the GHG impacts see such change as positive but technology evolution is not driven by this criterion alone. While we note that automobiles are becoming more efficient, we also see them getting larger. Stand-by power for 'instant on' convenience counteracts efficiency improvements in certain household appliances. Patio heaters and increasing numbers of water coolers in homes and offices add energy loads not seen a decade ago.

It appears then that the challenge of policy makers confronting an environmental problem like climate change is to influence both the rate and direction of technological change. They can utilise a spectrum of policies and programs to influence the manner in which members of society choose between technologies to meet their needs. On the one hand, one can initiate non-compulsory programs that provide information or focus on moral suasion to move in certain technology directions. On the other, compulsory regulations can force compliance to technology standards or technical requirements. In between these two lie a number of financial and other (dis)incentives, some more creative than others, that move technology choice, and, indeed, research and development, in specific directions or towards certain goals. Each type of policy will have a different influence on people's choices and will cause different economic impacts. How does one begin to evaluate these various approaches? One can always look to what others have done, learning from someone else's successes and mistakes. But, for an ex ante estimation of policy effects, pol-

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icy makers often turn to models of the energy-economy.

Reliance on modelling techniques has spurred the generation of many different energy-economy models over the last 30 years. These can generally be classified as top-down models, which describe the energy system in terms of aggregate relationships derived empirically from historical data, or bottom-up models, which determine the financially cheapest way to achieve a given target based on the best available technologies and processes. Because of their different structures and definitions of costs, the two types of models tend to predict very different policy outcomes (Grubb et al., 1993; IPCC, 1996, Jaccard et al., 2003). Top-down models, often used to model the global economy, tend to predict that the cost of meeting an environmental goal will be high and the attaining of targets difficult, while bottom-up models tend to predict the opposite. This divergence in modelling results is confusing to policy makers, and although interesting academically, ultimately decreases the practical value of such models in real-world policy analysis. The structure and assumptions of both of the traditional types of models predispose them to these biases in cost predictions.

Over a decade ago, Grubb (1991) referred to 'the missing models' in arguing for the development of a new generation of models that would better inform policy-makers of the critical issues in estimating GHG reduction costs. Returning to the issue a decade later, the same author and co-authors (Grubb, Kohler and Anderson, 2002) noted some significant developments, especially in terms of assessing the relationship between policies that induce technical change and the long-run cost dynamics of GHG reduction. At the same time, these researchers and others (Tol, 1999) noted that cost estimates still diverge widely, in part because of different assumptions about technical change (which is perhaps inevitable) but also because of how costs are defined and depicted in models that estimate the costs of GHG reduction. While we have made great advances in understanding the causes of cost differences, models can go further in helping decision-makers sort out the factors that cause these divergent cost estimates. To the extent that the definition of cost is a significant factor, decision-makers can then test their own definition for its effect on cost estimates.

In this paper we wish to address the need for an appropriate representation of technological change in modelling routines. In the next section, we briefly review how these two classes of models view technological change and how recent modelling innovations, a mix or 'hybrid' of the top-down and bottom-up, may better characterise uncertainties about long-run technical change. We follow this with a section on the design and parameter estimation of a hybrid model that combines key elements of the alternative modelling approaches. We elaborate on this using CIMS, a model developed by researchers of the Energy and Materials Research Group at the School of Resource and Environmental Management at Simon Fraser University. In the conclusion, we summarise and point to research and analyses that have made this modelling approach useful to decision-makers, especially with respect to the depiction of long-run uncertainties about technological diffusion, technological change and consumer preferences.

The Major Model Types

Bottom up

Bottom-up analysis, applied frequently by engineers, physicists and environmental advocates, estimates how changes in energy efficiency, fuel, emission control equipment, infrastructure and land-use practices might lead to different levels of GHG emissions. Technologies that provide the same energy service (space heating, lighting, industrial motive force, personal mobility) are generally assumed to be perfect substitutes except for differences in their anticipated financial costs and emissions of GHGs and other pollutants. When their financial costs (capital and operating) in different time periods are converted into present value using a social discount rate, many emerging technologies available for reducing GHG emissions appear to be profitable or slightly more expensive relative to existing equipment. Bottom-up analyses often show, therefore, that substantial GHG abatement can be profitable or low cost if these low-emission technologies were to achieve market dominance (Lovins and Lovins, 1991; Brown et al., 1998).

Many economists criticize this approach for its assumption that a single, anticipated estimate of financial cost (using the social discount rate) indicates the full social cost of technological change (Jaffe and Stavins, 1994; Sutherland, 1996, Stavins, 1999).

Households and firms might not see competing technologies as perfect substitutes for several reasons.

New technologies may pose greater risks of failure or unforeseen operating problems, meaning

that realized financial costs could exceed anticipated financial costs.
Technologies with longer payback periods (relatively higher up-front costs) are riskier if the cumulative probability of failure or accident increases over time.
Two technologies may appear to provide the same service to a designer but not to a consumer, who would pay more for one technology because of some perceived qualitative advantage.
The financial costs facing consumers and firms often differ from one location to another, meaning that a comparison of single-point estimates of financial costs may under- or over-estimate the true market potential for a low-GHG technology.

The first two differences contribute to what economists call option value: the expected gain from delaying or avoiding an investment (Pindyck, 1991). For example, in the metal smelting industry, where pyrometallurgical techniques are well understood, investing in the new hydrometallurgical processes increase the perceived risks of process failure for some managers. Also, this more energy efficient process is currently not fully tested and may have higher up-front costs, which increases the risk of not realising the payback on this extra investment. The third difference refers to what economists call consumers' surplus: the extra value that consumers realise above the financial cost of a particular technology. In this case, it may simply be a matter of the health and other uncertainties of using the chemicals required in the hydrometallurgical process. In another example from the transportation sector, public transit usually costs far less than personal vehicles, but many consumers are willing to pay extra for privacy, convenience, time-saving and status. The fourth difference can lead to a downward bias in bottom-up cost estimates if analysts focus on best-case conditions. Managers of smelters located near mines isolated from transmission or distribution networks are likely to face higher costs or fewer fuel choice alternatives than sites near urban areas.

When consumers are induced or forced to switch away from a technology they would otherwise choose, economists say that the social cost of this switch is the difference in financial costs plus any less-tangible costs related to option value, consumers' surplus and market heterogeneity.[61] By ignoring these latter values, bottom-up analysts may overestimate the benefits to consumers and businesses from GHG abatement and thus underestimate the social cost. Politicians seem to be instinctively aware of these other values, and often question claims that GHG abatement has little or no cost. In providing only part of the cost picture, the bottom-up approach is less helpful to policy-makers and those who wish to understand technology diffusion than it could be. Ironically, with their portrayal of consumers as one-dimensional, financial cost minimizers, bottom-up modellers may be more susceptible than economists to the critique of applying a simplistic, rational-economic-man view of the world.

Top down
The alternative, top-down analysis, applied by economists, usually relies on real-world market data to estimate aggregate relationships between the relative costs and the relative market shares of energy and other inputs to the economy, and links these to sectoral and total economic output in a broader equilibrium framework – full equilibrium models are referred to as computable general equilibrium models. Elasticities of substitution (ESUB) indicate the substitutability between any two pairs of aggregate inputs (capital, labor, energy, materials) and between primary energy (coal, oil, natural gas, renewables) or secondary energy (electricity, processed natural gas, gasoline, diesel, methanol, ethanol, hydrogen) within the energy aggregate, as their relative prices change. Another key parameter in top-down models, the autonomous energy efficiency index (AEEI), indicates the rate at which price-independent technological evolution improves energy productivity. High parameter values for energy-related ESUB (which imply a high degree of substitutability between energy and capital, and between GHG-intensive and non-GHG-intensive forms of energy) equate to a relatively low cost of GHG abatement and vice-versa. Because this parameter is estimated from real market behaviour, as energy prices and consumption have changed historically, it is assumed to reveal the actual preferences of consumers and businesses – and therefore implicitly incorporate losses or gains in option value and consumers' surplus as well as reflecting market heterogeneity. With AEEI and ESUB estimated, economists simulate the economy's response to a financial signal (a GHG tax, tradable GHG permits) that increases the relative cost of GHG-intensive activities. The magnitude of the financial signal necessary to achieve a given GHG reduction target provides the implicit marginal cost of that target. Since

61 Externality costs, such as pollution damages, should also be included in social cost estimates unless options are being compared in terms of their relative cost-effectiveness in achieving a particular externality reduction target. In the case of GHG abatement, therefore, estimated changes in GHG damages would not be included in social costs, but other externality benefits, such as reducing local air pollution, should be.

movement away from current technologies includes losses of these intangible values, top-down analysis usually generates higher cost estimates of GHG abatement (Weyant and Hill, 1999).

The top-down approach is, however, also vulnerable to the criticism of being unhelpful to policy-makers and those who seek help in understanding technology diffusion. The substantial GHG abatement required to stabilise global atmospheric concentrations implies the need for profound technological change over a period of several decades at least. Policy-makers want to know the extent to which their policies might influence the characteristics and financial costs of future technologies, and the willingness of consumers and businesses to adopt these in future. If the critical top-down parameters for portraying technological change – ESUB and AEEI – are estimated from aggregate, historical data, there is no guarantee that these parameter values will remain valid into the future under different GHG abatement policies (Peters et al., 1999; Grubb et al., 2002; DeCanio, 2003). Until recently, there was little incentive to design and commercialise low-GHG technologies. Today, such technologies are under development worldwide as research, development and commercialisation intensifies and the resulting economies-of-scale and economies-of-learning reduce financial costs (Azar and Dowlatabadi, 1999; Grubler et al., 1999).[62] A similar logic applies to historically-based estimates of consumers' surplus losses. If policies can help new technologies reach market penetration levels where expanding public awareness and adoption precipitates a feedback cycle of product improvement, intensified marketing and increased acceptance, the long-run costs of GHG abatement may decline as consumer preferences change (Norton et al., 1998; DeCanio, 2003). The ESUB value for interfuel substitution in personal vehicles is likely to be higher in future when consumers have a realistic opportunity to switch from gasoline to ethanol, electricity, methanol, bio-diesel, natural gas or hydrogen than when their choice was primarily limited to conventional gasoline and diesel. The average consumer's receptivity to hybrid gasoline-electric vehicles, for example, is likely to increase once several friends and neighbours have adopted this technology and fuel type.

Increasingly concerned with this problem, some top-down modellers are exploring ways of treating technological change endogenously. Several analysts (Loschel, 2002; Carraro et al., 2003; Weyant and Olavson, 1999) have surveyed new approaches for top-down models to portray how policies might influence the technical characteristics, costs and adoption rates of new technologies – and thus the long-run costs of GHG abatement. The most common mechanisms for endogenous technological change in top-down models are via investment in R&D in response to market conditions, spillover from R&D, and economies-of-learning. While these developments improve the potential usefulness of top-down models, there is as yet little empirical basis for their parameters of endogenous technological change (Loschel, 2002). Few researchers have grappled with the challenge of linking real-world empirical research into technological potential and consumer preference dynamics with the estimation of the aggregate parameters of technological change in these models.

Another difficulty is that the constraints of policy development processes often push policy-makers towards technology- and building-specific policies in the form of tax credits, subsidies, regulations and information programs.[63] Because top-down models represent technological change as an abstract, aggregate phenomenon – characterised by ESUB and AEEI parameter values – this approach only helps policy-makers assess economy-wide policy instruments such as taxes and tradable permits. A model may be more useful if it can assess the combined effect of these economy-wide, price-based policies with the technology-focused policies, but this requires the explicit representation of individual technologies that top-down models lack.

In summary, the top-down and bottom-up approaches offer competing cost definitions, both of which have their failings in terms of usefulness to policy-makers and those focused on technology diffusion. These different representations of technological change and diffusion can confuse policy makers, who are left unable to distinguish between definitional issues and different views on key long-run uncertainties as factors causing divergent estimates of GHG abatement costs. They also are left without any means of assessing how policies might affect these technological change and preferences so that costs of GHG abatement might be reduced in the long-run.

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[62] Economies-of-learning can be depicted by an experience curve, indicating how financial costs fall rapidly with the initial expansion of production and early operating experiences, but eventually more slowly toward as a technology matures (Gritsevskyi and Nakicenovic, 2000).

[63] An obvious reason is that GHG taxes and permit prices may need to be substantial if they are to have a significant effect on GHG emissions. Such a prospect leads policy-makers to apply a mix of more focused policies in order to minimize the public reaction that significant energy price increases might trigger.

Hybrid Models
As a consequence, several policy modellers have concluded that a more useful modelling approach would be a hybrid of top-down and bottom-up. An energy-economy model for costing long-run GHG abatement policy should be both technologically explicit and behaviourally realistic (incorporating preferences) while also capturing macro-economic feedbacks between energy supply-demand adjustments and the output and structural performance of the economy as a whole. This research is still at an early stage, but portrayals of hybrid modelling of some kind include Jaccard et al. (1996), Bohringer (1998), Jacobsen (1998), Koopmans and te Velde (2001), Morris, Goldstein and Fthenakis (2002), Frei et al. (2003) and Jaccard et al. (2003). In Figure 1, we characterise policy models in terms of these three key attributes: technological explicitness, preference incorporation and equilibrium feedback.[64]

Conventional bottom-up models do well in terms of technological explicitness, but not in terms of the other two attributes. However, some types of bottom-up models perform fairly well in terms of equilibrium feedback by integrating energy supply and demand, and in a few cases by including interactions between this integrated energy system and the economy as a whole (Nystrom and Wene, 1999). Conventional top-down models, such as energy-economy, computable general equilibrium models, perform well in terms of preference incorporation and equilibrium feedback, but not in terms of technological explicitness – nor in terms of portraying the potential dynamics of technological innovation, cost reduction and preference shifting (Peters, Ackerman and Bernow, 1999).

A hybrid model would perform well in terms of technology and preferences, and should also include substantial energy-economy feedback. Figure 1 situates CIMS, the hybrid that we describe and apply below. CIMS is technologically explicit like bottom-up and seeks behavioural realism, like top-down models. Its behavioural parameters are based on empirical research into firm and household decision-making. Because this type of hybrid model can portray decision making in different ways – including or excluding option value and consumers' surplus losses – it can help policy-makers understand the contribution of differences in cost definitions to differences in cost estimates.

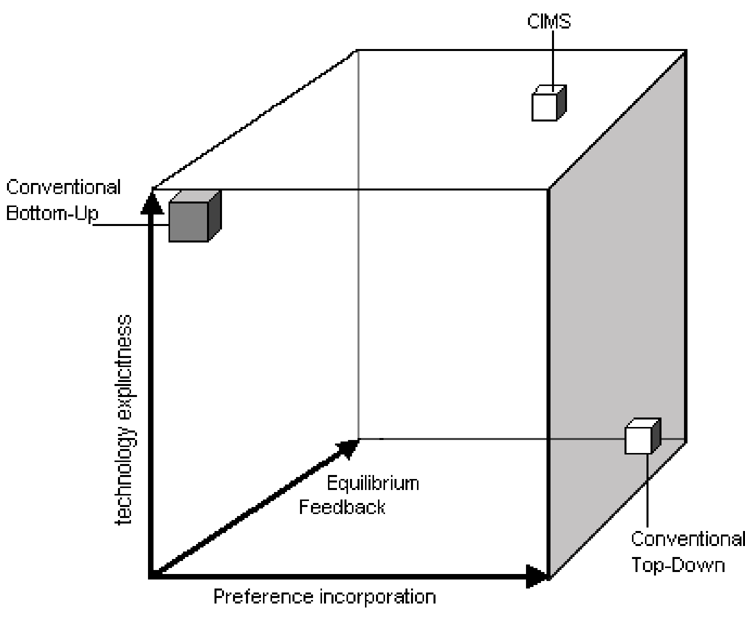

Figure 1. Characterisation of Energy-Economy Models

CIMS, a Hybrid Model
CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macro-economic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate government budgets and the markets for employment and invest-

[64] A new generation of integrated models takes a more ambitious definition of equilibrium feedback that includes the relationship between the energy-economy system and the climate (Kolstad, 1998).

ment.[65] Also, its representation of the economy's inputs and outputs is strongly skewed toward the energy supply and energy intensive demand sectors. As a technology vintage model, CIMS tracks the evolution of technology stocks over time through retirements, retrofits, and new purchases, with consumers and producers making sequential decisions with limited foresight. Figure 2 depicts the model's structure; it is modular in design containing nodes that represent energy supply, energy demand and the macroeconomic component of an energy-economy. Both supply and demand modules contain sub-models of their component parts. For example, the Energy Demand module has at least 10 sub-models that include residences, commercial enterprises, transportation and a set of major industries (pulp and paper, iron and steel, non-ferrous metal, non-metallic minerals, etc.) while the Energy Supply module contains at least another 5 (electricity supply, oil and gas extraction, oil refining, coal mining). A model simulation iterates between energy supply, energy demand and the macroeconomic module until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent five-year period of a complete run, which usually extends at least 30-35 years. Service demands grow or decline depending on an initial exogenous forecast of economic output, and then the subsequent interplay of energy supply and demand with the macroeconomic module.

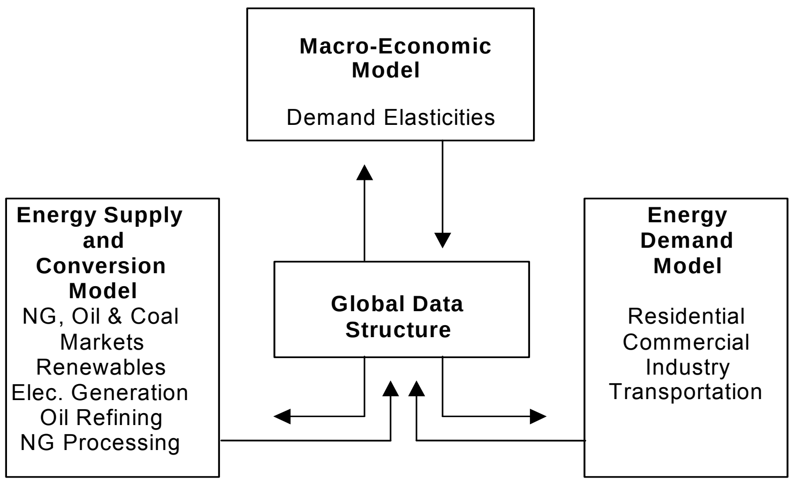

Figure 2. Characterisation of CIMS structure

Method

CIMS begins its simulations with a base-case macroeconomic forecast. If the forecast outputs are in monetary units, these must be translated into forecasts of physical product and energy services over the modelling period (typically 35 years at 5 year intervals). These forecasts, of course, can reflect different views of the future.

In each time period, some portion of existing capital stock is retired according to stock lifespan data. Retirement is time-dependent, but sectoral decline can also trigger retirement of some stocks before the end of their natural lifespans. One can also designate premature retirement of technologies as the result of regulation, for example. The outputs of the remaining capital stocks are subtracted from the forecast energy service or product demand to determine the demand for new stocks in each time period.

Prospective technologies compete for new capital stock requirements based on financial considerations (e.g., capital cost, operating cost), technological considerations (e.g., fuel consumption, lifespan), and consumer preferences (e.g., perception of risk, status, comfort, etc.), as revealed by behavioural-preference research. Market shares are a probabilistic consequence of these various attributes. The competition algorithm is described in more detail in the next section.

A competition also occurs to determine whether technologies will be retrofitted or prematurely retired. This is based on the same type of considerations as the competition for new technologies and actually occurs after retired stocks are tabulated and before new ones are obtained.

The model iterates between the macro-economy, energy supply and energy demand modules in

[65] One of our current projects is to use CIMS to produce ESUB and AEEI parameter values for a computable general equilibrium model, showing how these vary depending on the set of policies applied to induce long-run technological change.

each time period until equilibrium is attained, meaning that energy prices, energy demand and product demands are no longer adjusting to changes in each other. Once the final stocks are determined, the model sums energy use, changes in costs, emissions, capital stocks and other relevant outputs.

Technology Choice

The key market share competition in CIMS can be modified by various features depending on the evidence about factors that influence technology choices. Technologies can be included or excluded at different time periods. Minimum and maximum market shares can be set. The financial costs of new technologies can decline as a function of market penetration, reflecting economies of learning and economies of scale. Intangible factors in consumer preferences for new technologies can change to reflect growing familiarity and lower risks as a function of market penetration. Output levels of technologies can be linked to reflect complementarities.

Typically CIMS calculates energy costs (and GHG production) at each service demand node in the economy (e.g., there is a node for heated commercial floor space, one for person-kilometers-travelled and one for tonnes of pulp, cement or steel) by simulating choices of energy-using technologies by consumers and firms at each node.
Market shares of technologies competing to meet new stock requirements are simulated using the following formula:

$$MS_j = \frac{\left[CC_j * \frac{r}{1-(1+r)^{-n}} + MC_j + EC_j + i_j \right]^{-v}}{\sum_{k=1}^{K} \left\{ \left[CC_k * \frac{r}{1-(1+r)^{-n}} + MC_k + EC_k + i_k \right]^{-v} \right\}} \qquad (1)$$

where MS_j is the market share of technology j, CC_j is the capital cost, MC_j is the non-energy maintenance and operation cost, EC_j is the energy cost, i_j is the intangible cost (monetized value reflecting non-monetary decision factors such as option value and consumers' surplus), r is the private discount rate, v is a measure of market heterogeneity and n is the technology's lifespan. The main part of the formula (the part inside the square brackets) is the levelized life cycle cost (LCC) of each technology as seen by consumers and firms.

This inverse power function, with v as a key parameter, acts to distribute the penetration of a particular technology j relative to all other technologies k at the node. A high value of v means that the technology with the lowest LCC captures almost the entire market for new stocks. A low value distributes shares fairly evenly, even if LCCs differ significantly.

The Parameters

The model captures consumer and firm behavior primarily via v, the private discount rate, r, and the intangible cost factor for each technology i_j. Historically, we have estimated these behavioral parameters through a combination of literature review, judgment, and meta-analysis (Nyboer, 1997; Murphy, 2000). However, the literature we have used often estimates the parameters separately, sometimes using just the discount rate to account for time preference, attitudes to risk, and technology-specific qualities. This restricts the ability of this type of hybrid model to evaluate the policy options for influencing technological change and diffusion rates.

More recently, we conduct discrete choice surveys to generate empirical estimates of these parameters based on decision-specific consumer and business preferences (revealed and stated) with respect to time horizon, type of decision and technology attributes (Washbrook 2001, Horne 2003, Rivers 2003, Sadler 2003). Integrating this realistic description of the behavior of economic actors at a microeconomic level into a technology explicit model addresses many of the concerns that arise from using a strictly top-down or bottom-up modelling approach, and should provide more useful information to policy makers about the likely effects of alternative, energy-related GHG abatement policies intended to induce technological change and diffusion rates of technologies.

The three main behavioural parameters are key to simulating technology competition for new capital stocks, but other functions and constraints are important.

A *service flow model* links service demands in a hierarchy in which demand for lower level services are a linear function of the demand for higher services. The choice of motor drive is nested within the choice for auxiliary units (fans, pumps, conveyers, etc.), which is, in turn, nested within the choice between the sets of primary technologies that provide a service (the digestion of pulp, the calcining of cement, the smelting of steel).
A *market share constraint* can be used to set a maximum or minimum market share for any technology in any time period. A maximum market share for natural gas fired boilers can ensure that this technology does not penetrate faster than the physical ability to extend the natural gas transmission system.
A *declining capital cost function*, if activated, links a technology's financial cost in future periods to its cumulative production, reflecting economies-of-learning (and perhaps economies-of-scale depending on the technology), as in equation 2. In this formulation, *C(t)* is the financial cost of a technology at time *t*, *N(t)* is the cumulative production of a technology at time *t*, and *PR* is the progress ratio, defined as the percentage reduction in cost associated with a doubling in cumulative production of a technology. Researchers have found empirical evidence of this relationship, with *PR* values typically ranging from 75% to 95% depending on characteristics of the technology (scale, modularity, thermodynamic limits, special material requirements) and maturity of the technology (McDonald and Schrattenholzer, 2001; Argot and Epple, 1990; Neij, 1997).

$$C(t) = C(0)\left(\frac{N(t)}{N(0)}\right)^{\log_2(PR)} \qquad (2)$$

A declining intangible cost function, if activated, links the intangible costs of a technology in a given period with the market share of that technology in the previous period, reflecting improved availability of information and decreased perceptions of risk as new technologies become increasingly integrated into the wider economy. Attraction to a new technology can increase as its market share increases and information about its performance becomes more available (Banerjee, 1992; Arthur, 1989).[66] We currently estimate the shape of this function from the literature, but are conducting discrete choice surveys to estimate how changes in key attributes (range, fuel availability) might affect its evolution over time. Intangible costs for technologies decline according to equation 3, where i(t) is the intangible cost of a technology at time t, MS_{t-1} is the market share of the technology at time t-1, and A and k are estimated parameters reflecting the rate of decline of the intangible cost in response to increases in the market share of the technology.

$$i(t) = \frac{i(0)}{1 + Ae^{k*MS_{t-1}}} \qquad (3)$$

The declining cost functions are especially important when we consider the long-run character of the GHG abatement challenge and the types of policies that policy makers are likely to want to assess in their effort to influence long-run technological change. Vehicles illustrate this point. They already account for a significant share of GHG emissions in developed countries (15 – 25%), and are projected to play a similar role soon in developing countries as the global number of vehicles doubles from 600 million today to a projected 1.2 billion in 2030 and perhaps 2 – 3 billion by 2050. There are new and emerging technological options for substantially reducing per-vehicle GHG emissions (Odgen et al., 2004), but their market penetration depends on the delicate interplay of technology attributes, financial costs, and consumer preferences. Policy makers want to know what long-run GHG abatement from vehicle use might cost. They also want to know what policies have the best chance, in a politically acceptable way, of pushing new technologies to commercialization levels where their financial costs fall enough to test the potential for wide-spread public adoption. More recent versions of bottom-up models apply declining cost functions (Grubler et al., 1999), but still in a manner that portrays consumer choice as fixated on deterministic financial cost minimization to the exclusion of all else. A hybrid model, with a declining cost function that includes a dynamic portrayal of consumer preferences, seems to be appropriate for meeting this policy evaluation need.

Macroeconomic analysis
Policies, changes in fuel price, world price for input commodities or other economic events are

[66] This application of CIMS has some similarities to what is referred to as *agent-based modelling* in that it establishes a basic set of assumptions about initial behavior and then simulates behavioral dynamics as key conditions change (financial cost of low-GHG vehicles, proportion of neighbors, family and friends who have acquired the newer technology).

likely to change the cost of producing final goods and services and, consequently, will change demand for them, causing structural change in the economy. The more aggressive the economic event, and the more responsive demand for a good or service to a change in costs, the larger this structural effect is likely to be. Top-down models normally include this dynamic, while bottom-up models do not. Due to its modular design, CIMS may be linked to an existing macroeconomic model or use its own system of structural change feedbacks, a mixture of CGE and macro-econometric methods. In CIMS, demand for internationally traded goods is adjusted using a system of empirically estimated substitution elasticities following the Armington specification, whereby demand is met from a mixture of domestic and foreign production. Demand for non-traded goods, such as residential and commercial floor space and freight transportation, is linked to manufacturing activity using econometrically estimated equations and parameters, while a travel elasticity is used to adjust personal transportation demand. CIMS' macroeconomic module includes methods for calculating standard macroeconomic indices, such as changes in sector value-added (GDP), capital investment and labour expenditure.

Once CIMS has iterated between demand and supply to come to a supply / demand equilibrium specified by the analyst, the model estimates the change in costs for the major goods and services and informs the macroeconomic model of these changes. If demand changes surpass a user-defined threshold, the whole model (demand and supply as well as macroeconomic modules) iterates to find a new equilibrium. Once equilibrium between demand, supply and structural change is found, the model advances to the next simulation year.

Conclusion and Applications

Analysts agree that changes in technologies used to provide goods and services offer an important component in humankind's efforts to reduce GHG emissions. Researchers have recognised for some time now that models currently used to analyse policy impacts on GHG emissions do not represent technology change very well. Those using top-down models, including many of the global models currently used to analyse overall GHG emissions reduction, have difficulty defining parameters related to technology change and diffusion, and conclude that reducing GHG emissions will be both difficult and expensive. Those using bottom-up models, on the other hand, generally fail to incorporate important decision-making criteria related to risk, option value and consumers' surplus and, consequently, model outcomes suggest that attaining reduction targets will be relatively easy and inexpensive.

Hybrid models try to capture the best of the top-down and bottom-up approaches and, in some cases, recognise that there are economic and endogenous drivers to technology development and diffusion. To analyse technological progress and diffusion, we have developed and utilised for many policy analyses CIMS, a model that represents technologies explicitly and evolves these technologies endogenously in simulations that reflect a realistic portrayal of technology choice behaviour, couched in a general macro-economic equilibrium framework. Such a modelling framework can provide more reasoned estimates of the technology change parameters used by top-down models and can offer insight to actions found in bottom-up models.

The modelling team at the Energy and Materials Research Group of the School of Resource and Environmental Management at Simon Fraser University has applied this model to a number of analyses reflecting the Canadian situation. In 1999, the team completed a study related to the costs of GHG reduction in Canada. The project was twice expanded to include other aspects of analysis not initially considered. Details of these analyses are available (see particularly Laurin et al., 2001 and Jaccard et al., 2003) and were published in a book, The Cost of Climate Policy (Jaccard, Nyboer and Sadownik, 2002). Analysis have been made on behalf of specific industry associations to help them understand not only the costs they might face but also any changes in demand for their product (Murphy et al., 2004a). The model has been used to estimate the impacts of applying various ecological fiscal reform policies (Sadownik et al., 2004), the impacts of permit allocation on demand side management projects (Rivers et al., 2004), the potential for combined heat and power in Canada (Laurin, 2004) and conservation potentials of various programs for utilities (Murphy, 2004b).

An Application: Canada and Kyoto

Recently, EMRG researchers sought to contribute to Canada's GHG policy deliberations by first presenting the special challenges facing policy-making for an environmental risk such as human-induced climate change (see Jaccard, et al. 2004). An understanding of these challenges provides an important basis for comparing alternative policy approaches. They developed a standard set of policy evaluation criteria and applied these to both conventional and newly emerging policy options for GHG emission reduction. Turning to Canada's current GHG reduction policies, they suggested reasons why these are unlikely to perform well according to the policy criteria. So, they devised their own policy package (see figure 3).

Figure 3. Proposed policy package

Name of Policy	Type of Policy	Sectors Affected	Actions Induced
Large Industry Emission Cap and Tradable Permit	Market-oriented regulation	Industry, Electricity Generation	Switching to lower GHG fuels and more efficient equipment Reduced demand for electricity
Renewable Portfolio Standard	Sector-specific Market-oriented Regulation	Electricity Generation	Switching to renewable sources of electricity generation
Vehicle Emissions Standard	Sector-specific Market-oriented Regulation	Personal Transportation	Switching to lower emissions vehicles
Carbon Sequestration Requirement	Sector-specific Market-oriented Regulation	Upstream Oil and Gas	Geological sequestration of carbon from fossil fuel use
Building and Equipment Standards	Command-and-control regulations	Residential and Commercial	Switching to high efficiency appliances, equipment and buildings

The researchers used CIMS to assess the performance of the policy package with respect to their policy evaluation criteria. The simulations showed that the policy package could achieve a significant reduction in GHG emissions in the Kyoto timeframe and, more importantly, stimulate substantial technological innovation and commercialization that will ensure continuing emission reductions in the post Kyoto period, a period during which the international community expects to negotiate further commitments on global emission reduction. This could be achieved without significant short-term economic disruption, either in terms of domestic energy prices or the international competitiveness of Canadian industry. While the policy package fell short of achieving domestically all of Canada's Kyoto commitment by the deadline of 2010, it was consistent with the federal government's own climate change plans, in which a recognized shortfall in domestic reductions is compensated for by the purchase of emission credits from countries whose GHG reductions exceed their Kyoto commitments, or by actions in other countries that offset Canada's emissions.[67] Most parties recognize that the timeframe is simply too short for Canada to achieve all of its ambitious Kyoto commitment through domestic reductions alone at an acceptable cost.

The package shown in figure 3 was not intended to be comprehensive but rather to demonstrate clearly an alternative to Canada's current policy approach. Each of the various alternatives was chosen with the objective of roughly equating the incremental costs of GHG emission reductions between sectors. More and less aggressive versions of each policy assessed.

We are not able in this space to fully elaborate on the outcomes of the simulations but provide, in figure 4, a summary of the results for more and less aggressive versions of this policy package.[68] It shows that while substantial GHG abatement is available from a fairly modest policy signal, the more aggressive policy has less incremental effect – suggesting that the cost of GHG abatement rises quickly, at least in the Kyoto timeframe. Some of the analyses, especially on the upstream oil and gas sector, were completed outside of the model framework.
Figure 5 shows the simulations for the evolution of GHG emissions in Canada under business-as-

[67] Under the Kyoto Protocol, developed countries are allowed to make use of three *flexibility mechanisms* designed to reduce the costs of implementation over domestic action alone – international carbon credit trading, joint implementation, and clean development mechanisms. These latter two mostly involve GHG reducing projects in developing countries.

[68] For a full description of the analyses and outcomes, please see Jaccard, et al. (2004) *The Morning After: Optimal Greenhouse Gas Policies for Canada's Kyoto Obligation and Beyond*, available on the ERMG web site at www.emrg.sfu.ca.

usual and our proposed policy package.[69] Although neither the less nor the more aggressive policy packages achieves all emission reductions required under Kyoto, both generate significant technological change that stabilizes GHG emissions over the longer-term, even as economic output and population grow. The more aggressive package goes even further by decoupling GHG emissions from economic output (which continues to rise throughout the forecast) – portending a future, decarbonated Canadian energy system supplied by large hydro, small-scale renewables, zero- and low-emission transformation of fossil fuels, and perhaps nuclear – if this latter can be politically acceptable and economically efficient.

69 In the interests of brevity, we have only presented the detailed results of our policy simulation for 2010. Results for later years are available from the authors.

Figure 4 - Expected results of our proposed policy packages in 2010

Policy Name	Less Aggressive			More Aggressive		
	Requirements	Reductions	Financial Effect	Requirements	Reductions	Financial Effect
Industry Carbon Trading System[70]	\$10/t CO_2e permit price	12.1 Mt	- Cost to industry of \$100M in 2010 - Non-energy commodity production costs increase by much less than 1% - Retail price of gasoline increases by 3%, natural gas by 4%	\$50/t CO_2e permit price	15.4 Mt	- Cost to industry of \$380M in 2010 - Non-energy commodity production costs increase by 1-2% - Retail price of gasoline increases by 15%, natural gas by 20%
Electricity Carbon Trading System	\$10/t CO_2e permit price	45.4 Mt	- Increase average retail electricity price by 2%	\$50/t CO_2e permit price	71.9 Mt	- Increase average retail electricity price by 8%
Renewable Portfolio Standard[71]	6% total generation from renewable sources	6.2 Mt	- Increase average retail electricity price by 1%	10% total generation from renewable sources	14.4 Mt	- Increase average retail electricity price by 2%
Vehicle Emissions Standard	3% ZEV 15% ULEV 22% LEV	14.8 Mt	- Increase average vehicle cost by 8% - Decrease average fuel consumption by 12%	6% ZEV 25% ULEV 33% LEV	29.2 Mt	- Increase average vehicle cost by 14% - Decrease average fuel consumption by 19%
Sequestration Requirement	6.5 Mt geological sequestration requirement	6.5 Mt	- Increase retail natural gas price by 0.3% - Increase retail gasoline price by 0.3%	12.5 Mt sequestration requirement	12.5 Mt	- Increase retail natural gas price by 0.9% - Increase retail gasoline price by 0.5%
Building and Equipment Standards[72]	Phase out sales of least efficient 10% of new equipment and buildings	6.0 Mt	-	Phase out sales of least efficient 30% of new equipment and buildings	9.2 Mt	-
Total		**91.0 Mt**		**Total**	**152.6 Mt**	

70 The GHG reductions from the industrial ECTP are in addition to the sequestration requirement. In the absence of the sequestration requirement, the reductions from the ECTP would be 21.4 and 30.7 Mt for the less and more aggressive policies, respectively.

71 The GHG reductions from the renewable portfolio standard are in addition to the development of renewables that is assumed to occur under business as usual and the development of renewables encouraged by the electricity sector carbon trading system – 2.4 Mt at both the \$10/t and \$50/t CO_2e price.

72 If the equipment standards are applied in the absence of any policies in the electricity sector, the reductions are 10.0 and 19.1 Mt respectively, for the less and more aggressive policies.

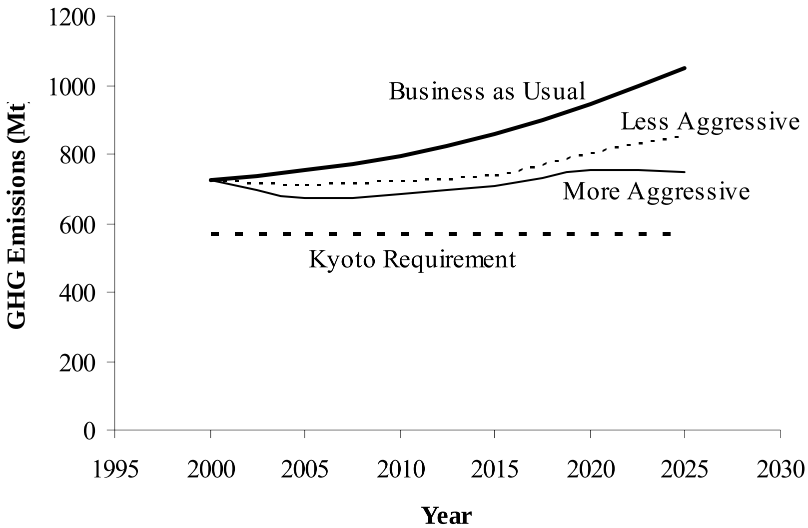

Figure 10: Long-term evolution of GHG emissions in Canada

Finally, in this longer timeframe there may be some concern that a low-emission, low-cost energy source like natural gas will become expensive at consumption levels higher than today's, or in the near future as currently producing gas fields are exhausted. In CIMS, the researchers assumed that the long-run supply cost for natural gas (conventional or synthetically produced from coal bed methane, coal gasification, and other sources) was likely to rise only slightly in North America, even though prices may fluctuate dramatically because of cyclical market imbalances. If this proves to be incorrect, and instead North America is on the verge of exhausting all means of producing natural gas-like products at or close to current production costs, then the policy scenario could cause higher energy prices. Still, this will only occur if most other means of reducing GHG emissions, such as energy efficiency, renewable energy, coal gasification with carbon sequestration, and nuclear power, prove to be very expensive in the long-run no matter how intensive our efforts to reduce their costs.

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Driving Factors and Limiting Barriers of Technology Transfer in the Energy Sector in Macedonia

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ABSTRACT

The paper comprises a comprehensive assessment of the prospects for transfer and diffusion of improved technologies in the energy sector in Macedonia. Sixteen mitigation options divided in three sub-sectors (energy–intensive consumer goods, electricity production and renewables, energy-intensive industry) are evaluated, along with the country-specific barriers and opportunities for their transfer and diffusion. In particular, the options belonging to the sub-sector of energy–intensive consumer goods are chosen as an example upon which, the economic and environmental effectiveness of the technologies in Macedonian conditions are thoroughly elaborated.

The evaluation is performed using GACMO costing model, which compares each mitigation option with the baseline and determines its economic and environmental effectiveness. The resulting marginal cost curve indicates a total achievable reduction of about 20% with respect to baseline emissions.

The finding that almost half of the considered options are of ‘no regret’ type represents the main driving factor for the technology transfer, although, reducing the baseline emissions for less then 3%, these options have relatively low environmental effectiveness. On the other hand, options with largest mitigation potential are most difficult for implementation, mainly due to the lack of domestic financing and low prospects for attracting foreign investments. Furthermore, there is not enough awareness for the need to incorporate energy efficient and environmentally favorable technologies into private and public decision-making, which is additionally impaired by the uncertainty related to the energy and economic savings expected from those technologies. Also, the country lacks necessary infrastructure in terms of institutions, legislative framework and economic incentives, as well as personnel capable to deliver the required technical, managerial and financial services.

INTRODUCTION: BRIEF DESCRIPTION OF THE ENERGY SECTOR

Since 1991 entering the transition towards market economy, Macedonia has been facing a significant decline in industrial activities currently operating at 50 % of its former capacity. Hence, the revival of the industrial sector is an important factor in the country’s economic prospects. Energy demand is expected to rise over the next few years in correlation with GDP growth. In the regional context, until 2001 Macedonia exported 3-5% of its electricity production during the summer months and imported nearly the same amount from other countries in the region during the winter, while nowadays, Macedonia has to import almost 20% of the total electricity consumption throughout the whole year. The primary energy supply along with the electricity production in the country in the year 2000 is shown in Table 1.1.

Table 1.1. Primary energy supply and electricity production in the year 2000

1. Electricity	(GWh)	(10^3 TJ)
a) Production	6,329	22.78
- Hydro Power Plants	1,170	4.21
- Thermal Power plants	5,159	18.57
b) Imports	291	1.05
c) Exports	179	0.64
d) Consumption (a+b-c)	6,441	23.19
2. Coal	(kt)	(10^3 TJ)
a) Production	6,430	48.46
b) Imports	80	0.61
c) Exports	-	-
d) Consumption (a+b-c)	6,513	49.07
3. Coal coke	(kt)	(10^3 TJ)
a) Production	-	-
b) Imports	80	2.34
c) Exports	-	-
d) Consumption (a+b-c)	80	2.34
4. Petroleum products	(kt)	(10^3 TJ)
a) Production	804	35.34
b) Imports	217	9.54
c) Exports	114	5.01
d) Consumption (a+b-c)	907	39.87
5. Natural gas	(10^6 m^3)	(10^3 TJ)
a) Production	-	-
b) Imports	54	1.81
c) Exports	-	-
d) Consumption (a+b-c)	54	1.81
6. Wood	(10^3 m^3)	(10^3 TJ)
a) Production	650	7.08
b) Imports	-	-
c) Exports	-	-
d) Consumption (a+b-c)	650	7.08
7. Geothermal energy	(10^3 TJ)	(10^3 TJ)
a) Consumption	0.60	0.60
TOTAL (10^3 TJ)		123.96
a) Indigenous production (%)		56.7
b) Imports (%)		43.3

Macedonia's national power utility 'Elektrostopanstvo na Makedonija' (ESM) is operating under direct supervision of the Ministry of Economy. ESM's available electricity generating capacity is 1,432 megawatts (MW), of which 1010 MW thermal power plants (Bitola, Oslomej and Negotino) and 422 MW hydropower plants. In addition, approximately 3 MW of hydropower capacity belongs to independent irrigation organisations. For over three years, the government has been discussing the restructuring of the power sector with divestiture of ESM and subsequent partial privatization. by the end of 2005.

The energy sector in Macedonia is highly polluting and in critical need for modernisation. According to the National GHG Inventory, prepared for the purpose of the First National Communication under UNFCCC [1], the contribution of the energy sector is about three-quarters of the total emissions, the rest being shared nearly equally by industrial processes, agriculture and waste. Within the energy sector itself, the GHG emissions appear to be mostly due to electricity generation (73%), followed by heat generation (17%) and transport (10%). The required GHG emissions reduction, as well as the ongoing transition process towards a market economy, has created the need for more effective and energy-efficient technologies.

MITIGATION OPTIONS

From a climate change perspective, mitigation analyses entail identification and evaluation of technologies, practices and reforms that might be implemented in different sectors of a country to reduce GHG emissions and climate vulnerability. These technologies and practices are well-suited to the needs of development in its broadest sense, since many of them, being developed in response to the needs of mitigation, especially renewable energy and energy efficiency, are now proving to be economically important sources of supplying and utilizing energy efficiently. Therefore, technology transfer is of high importance not only in context of the UNFCCC, but also from the country developmental perspective.

When selecting country-specific mitigation options in the energy sector for economic and environmental evaluation, two criteria were taken into account:
Prospects for implementation in national conditions
Existence and availability of relevant studies and other materials providing input data for the evaluation.

Sixteen mitigation options divided in three sub-sectors (energy–intensive consumer goods, electricity production and renewables, energy-intensive industry) are evaluated [2], along with the emerging barriers and ways for their removal. In Table 2.1 the selected mitigation technologies are listed, with indication on the corresponding base units.

Table 2.1. Selected country-specific mitigation technologies

No.	Technology	Base unit
	Energy–intensive consumer goods	
1	Efficient lighting	1000 bulbs
2	Efficient refrigerators	1 unit
3	Air conditioning	1 unit
4	Replacement of bus diesel motors	1 bus
	Electricity production and renewables	
5	Introduction of liquid fuel in power generation	1 plant
6	New hydro power at Boskov Most	70 MW plant
7	Mini hydro power (4 plants of 1 MW)	4 MW plant
8	Wind power plants	1 MW
9	Landfill gas power plant	1 plant
10	Geothermal heating for greenhouses and hotels	1 plant
11	Biogas from small agricultural industries	1 plant
12	Grid-connected solar PVs	1 kW
13	Solar heater for hot water in individual houses	1 unit
14	Large solar heaters for hot water in hotels, hospitals, public buildings	1 unit
	Energy-intensive industry	
15	Efficient motors	1 kW
16	Efficient boilers	1 boiler

For each mitigation option the data sources and all necessary input data were identified. In addition, information on the fuel prices, electricity generation fuel mix and emission factors was collected, providing the key-parameters for the evaluation and enabling the underlying assumptions to be made.

Economic and Environmental Evaluation

Practically, the economic and environmental evaluation of the selected country-specific mitigation options was performed through direct use of the software tool GACMO (GHG costing model), developed at the UNEP Risø Centre [3]. Namely, the GACMO tool which is used to evaluate the costs and benefits of a wide range of mitigation options, calculates the GHG emissions reduction, as well as the average mitigation costs expressed in US$ per ton of CO_2-eq. It is able to combine the options in a form of emission reduction cost curve, displaying the marginal cost of the GHG emissions reduction for a number of different alternatives.

The basis for a mitigation analysis is a baseline or reference scenario for GHG emissions from the base year to the target year, which is 2010, as a midyear of the first commitment period under the Kyoto Protocol. The baseline comprises knowledge of the energy services supplied within different energy consuming sectors i.e. the number of energy consuming units and the annual energy consumption by each unit. This information is needed to do a good mitigation study for a country. The Macedonian baseline scenario is described in the GHG Abatement Analyses within the First National Communication under the UNFCCC [4], according to which the total GHG emissions in 2010 amount to 18 Mt CO_2-eq.

The mitigation scenario combines the emissions from the reference scenario with the changes (reductions) in emissions introduced by the various mitigation options being evaluated. For each mitigation option, the technologies that deliver energy services in the reference option are changed. A unit measure for the new technology has to be defined, along with the penetration rate of the mitigation option in the country. It is assumed that the level of service demand does not change when the new technology is introduced.

In the national GHG abatement analyses [4], two mitigation scenarios are considered, quantifying only mitigation options in the sub-sector of electricity production. The first mitigation scenario comprises mitigation option No 5 (see Table 2.1) and the second mitigation scenario comprises options No 5 and No 6. In the heat production, the two mitigation scenarios are translated in terms of fuel consumption without addressing specific measures. The main link between the electricity production sector and the heat production according to the two mitigation scenarios is the consumption of natural gas, which is limited by the capacity of the pipeline.

Herein, the analyses are extended by additional mitigation options in the sector of electricity production and renewables, as well as, by consideration of options from another two sub-sectors: energy–intensive consumer goods and energy-intensive industry. In particular, the options belonging to the sub-sector of energy–intensive consumer goods are chosen as an example upon which, the economic and environmental effectiveness of the technologies in Macedonian conditions, as well as the country-specific barriers and opportunities for their transfer and diffusion are thoroughly elaborated.

Efficient lighting

The replacement of the conventional, incandescent lamps by new energy saving lamps (fluorescent etc) is one of the most popular measures for energy conservation. In the Macedonian case, where the share of solid fuels in the power generation mix is significant, the electricity saving measures are even more effective from the environmental point of view. Two options are compared: use of compact fluorescent lamps (mitigation option) versus use of incandescent lamps (reference option). For the mitigation option, it is assumed that compact fluorescent lamps of 15 W will be used for 4 hours a day at 1,000 locations which yields to 21.9 MWh annual electricity consumption. The price of these lamps is 12 $/lamp and the O&M costs are estimated to 0.15$/lamp change. The reference option (use of incandescent lamps) supplies the same amount of light but with a capacity of 75 W at 1,000 locations, so that 109.5 MWh electricity are required annually. The price of these lamps is 0.7 $/lamp while the O&M costs are the same as for the mitigation option. The lamp lifetime for the mitigation option is 12,000 hours (they last 8.2 years at 4-hour daily usage), while in the reference option the lamp lifetime is 2,500 hours, so they have to be replaced 4.8 times on average or every 625 days. Accordingly, the costs for 1,000 lamps are discounted every 625 days, leading to bigger discount rate (10.27%) then the one of the mitigation option (6%). In both cases, it is assumed that the lamps will be used 75% of the time in the low tariff period, so that the average electricity price is 0.036 $/kWh. The emission factor for the whole power system is 1 t CO_2-eq/MWh.The summarised information on this mitigation option is presented in Table 2.1.1.1, in a form prescribed within the GACMO methodology.

Table 2.1.1.1. Economic and environmental evaluation of the efficient lighting

General inputs:	Discount rate: 6%	
Fraction of time using low tariff	75%	
Fraction of time using high tariff	25%	
Average electricity price	0.036	US$/kWh
CO_2-eq emission coefficient	1.000	t CO_2-eq/MWh
Mitigation option: Compact fluorescent lamps		
O&M	0.15	US$/lamp change
Activity	1,000	Locations
Cost of efficient lamp	12.00	US$
Lamp lifetime	12,000	Hours
Lamp wattage	15	W
Daily usage	4	Hours
Annual electricity used	21.9	MWh
Reference option: Incandescent lamps		
O&M	0.15	US$/lamp change
Activity	1,000	Locations
Cost of incandescent lamp	0.70	US$
Lamp lifetime 1	2,500	Hours
Lamp lifetime 2	625	Days
Required lamp replacements	4.8	Times
Lamp discount rate	10.27%	
Lamp wattage	75	W
Daily usage	4	Hours
Annual electricity used	109.5	MWh

Costs in US$	Reduction Option	Reference Option	Increase (Red.-Ref.)
Total investment	12,000	4,077	
Project life	8.2	8.2	
Lev. investment	1,892	643	1249
Annual O&M	24	284	-260
Annual electricity cost	794	3,972	-3177
Total annual cost	2,710	4,899	-2,188.51
Annual emissions	Tons	Tons	Reduction
Total CO_2-eq emission	21.9	109.5	87.60
US$/t CO_2-eq			-24.98

Under the assumptions made, a decrease of 2,188.51 US$ in total annual costs is associated with the mitigation option, while the reduction of GHG emissions is 87.6 t/year. Accordingly, the specific costs (costs for reduction of 1 t CO_2-eq) amount to -24.98 US$/t CO_2-eq.

Efficient refrigerators

Application of two types of refrigerators - efficient (with wattage of 100 W and annual electricity consumption of 584 kWh) and inefficient (with wattage of 200 W and annual electricity consumption of 1,168 kWh) are considered as mitigation and reference option respectively. It is assumed that in average Macedonian household, 16 hours per day the refrigerator would be in operating mode, half of which in the low tariff period, and the rest of the day it switches to stand-by mode, consuming a negligible amount of energy.

The costs of the refrigerators are assumed as being 450 and 300 US$ respectively, while the GHG emissions are calculated with the equivalent emission coefficient for the whole power system. The summarised information on this mitigation option is presented in Table 2.1.2.1.

Table 2.1.2.1. Economic and environmental evaluation of the efficient refrigerators

General inputs:	Discount rate: 6%	
Fraction of time using low tariff	50%	
Fraction of time using high tariff	50%	
Average electricity price	0.044	US$/kWh
CO_2-eq. emission coefficient	1.000	t CO_2-eq/MWh
Mitigation option: Efficient refrigerator		
O&M	0.00	US$
Activity	1	Refrigerator
Lifetime	10	Years
Cost of eff. refrigerator	450	US$
Refrigerator wattage	100	W
Daily usage	16	Hours
Annual electricity used	0.584	MWh
Reference option: Non-efficient refrigerator		
O&M	0.00	US$
Activity	1	Refrigerator
Cost of old refrigerator	300	US$
Refrigerator wattage	200	W
Daily usage	16	Hours
Annual electricity used	1,168	MWh

Costs in US$	Reduction Option	Reference Option	Increase (Red.-Ref.)
Total investment	450	300	
Project life	10.0	10.0	
Lev. investment	61	41	20
Annual O&M	0	0	0
Annual electricity cost	25	51	-25
Total annual cost	87	92	-5
Annual emissions	Tons	Tons	Reduction
Total CO_2-eq emission	0.58	1.17	0.58
US$/t CO_2-eq			-8.63

Under the assumptions made, a decrease of 5 US$ in total annual costs is associated with the mitigation option, while the reduction of GHG emissions is 0.58t/year. Accordingly, the specific costs amount to –8.63 US$/t CO_2-eq.

Air conditioning

Air conditioners of 3 kW cooling capacity with different coefficients of performance (COP) and costs are compared. The efficient one has COP of 3.3 and costs 100 US$ more than the reference one with COP of 2.5. They will be operating for 90 days/year and 6 hours/day with 50% of the time in the low tariff period. The summarised information on this mitigation option is presented in Table 2.1.3.1.

Table 2.1.3.1. Economic and environmental evaluation of the air conditioners

General inputs:	Discount rate: 6%	
Fraction of time using low tariff	50%	
Fraction of time using high tariff	50%	
Average electricity price	0.044	US$/kWh
CO_2-eq emission coefficient	1.000	ton CO_2-eq/MWh
Mitigation option: Efficient air conditioner		
O&M	0.00	US$
Activity	1	Air conditioner
Lifetime	7	Years
Extra cost for eff. air conditioner	33.3	US$/kW cooling capacity
Cooling capacity	3	kW
COP	3.3	
Annual usage	540	Hours
Annual electricity used	0.491	MWh
Reference option: Old window air conditioner		
O&M	0.00	US$
Activity	1	Air conditioner
Cooling capacity	3	kW
COP	2.5	
Daily usage	6	Hours
Days used	90	Days
Annual usage	540	Hours
Annual electricity used	0.648	MWh

Costs in US$	Reduction Option	Reference Option	Increase (Red.-Ref.)
Total investment	100		
Project life	7.0	7.0	
Lev. investment	18	0	18
Annual O&M	0	0	0
Annual electricity cost	21	28	-7
Total annual cost	39	28	11
Annual emissions	Tons	Tons	Reduction
Fuel CO_2-eq emission	0.49	0.65	0.16
Total CO_2-eq emission	0.49	0.65	0.16
US$/t CO_2-eq			70.51

Under the assumptions made, the mitigation option could achieve 0.16 t/year reduction of GHG emissions and has11 US$ higher total annual costs then the reference option. Accordingly, the specific costs are positive and amount to 70.51 US$/t CO_2-eq.

Replacement of bus diesel motors

Energy efficiency improvements in buses are introduced by replacing the old diesel engine with a new one, which reduces the specific energy consumption for the same performance of the vehicle. The buses we are taking into consideration are relatively small with low engine power and maximum 50 seats. The assumptions concerning the specific consumption are confirmed by the local public transportation utilities. It is assumed that the new engine costs 10,000 US$ and decreases the specific fuel consumption from 25 l/100 km (4 km/l) to 16.7 l/100 km (6 km/l).

In the calculations, the local diesel price, as well as IPCC default data [5] for diesel calorific value and emission factors have been taken. The summarised information on this mitigation option is presented in Table 2.1.4.1.

Table 2.1.4.1. Economic and environmental evaluation of the replacement of bus diesel motors

General inputs:	Discount rate: 6%	
Mitigation option: New bus		
Activity	1	Bus
Investment	10,000	US$
Diesel price	17.2	US$/GJ
Specific fuel consumption:	6	km/l
Annual distance	102,400	km
Density of diesel	0.84	t/m^3
Diesel calorific value	42.7	GJ/t
Annual fuel use	612.1	GJ/year
CO_2-eq emission coefficient	0.074	t CO_2-eq/GJ
Reference option: Existing bus		
Number of units:	1	Bus
Specific fuel consumption:	4	km/l
Annual distance	102,400	km
Total fuel use	918.2	GJ/year

Costs in US$	Reduction Option	Reference Option	Increase (Red.-Ref.)
Total investment	10,000		
Project life	10		
Lev. investment	1,359		1,359
Annual fuel cost	10,519	15,778	-5,259
Total annual cost	11,877	15,778	-3,901
Annual emissions	Tons	Tons	Reduction
Fuel CO_2-eq emission	45.49	68.24	22.75
US$/t CO_2-eq			-171.49

Under the assumptions made, a decrease of 3,901 US$ in total annual costs is associated with the mitigation option, while the reduction of GHG emissions is 22.75 t/year. Accordingly, the specific costs amount to –171.49 US$/t CO_2-eq.

Specific Costs and Achievable Reduction

The results of the economic and environmental evaluation of all sixteen country-specific mitigation options (including the above elaborated four consumer goods options) are presented in the Table 2.2.1. Besides the calculated specific costs and emission reduction, for each option the assumed penetration rate in 2010 is indicated.

The most cost effective option appears to be the application of geothermal energy in greenhouses and hotels followed by the replacement of old bus engines with more efficient ones, having high negative costs as a result of the very poor performances of the old engines. On the other hand, PVs connected to electric grid is by far the most expensive option due to the high initial investments. Concerning abatement potential, as expected, the application of efficient industrial boilers (annual reduction of 1.48 Mt CO_2-eq) and the introduction of liquid fuel in electricity production (annual reduction of 1.24 Mt CO_2-eq) are the greatest contributors to the overall emission reduction. In total, these two options reduce about 2.72 Mt CO_2-eq annually, while the cumulative reduction of all other options amounts to 0.83 Mt CO_2-eq. Consequently, the total achievable reduction (if all considered options are implemented) in 2010 is estimated to be 3.55 Mt CO_2-eq, which is 19.74% of the baseline emissions.

Table 2.2.1. Economic and environmental effectiveness of the of the mitigation options

Mitigation option	Specific costs US$/t CO_2-eq	Unit type	Emission reduction t CO_2-eq /unit	Units penetrating in 2010	Emission reduction in 2010		
					Per option Mt/year	Cumulative	
						Mt/year	Percentage of baseline emissions in 2010
Geotherm. heat. for greenhouses, hotels	-187.15	1 unit	2,269.34	1	0.0023	0.0023	0.01%
Replacement of bus diesel motors	-171.49	1 bus	22.75	2,000	0.0455	0.0478	0.27%
Efficient lighting	-24.98	1000 bulbs	87.60	200	0.0175	0.0653	0.36%
Efficient refrigerators	-8.63	1 refrigerator	0.58	150,000	0.0876	0.1529	0.85%
Hydro power (Boskov Most)	-4.09	1 plant	202,195.87	1	0.2022	0.3551	1.97%
Efficient motors	-3.22	1 kW	0.78	25,000	0.0194	0.3745	2.08%
Landfill gas power	-2.85	1 plant	112,232.58	1	0.1122	0.4868	2.70%
Wind turbines	4.16	1 MW	2,872.98	50	0.1436	0.6304	3.50%
Minihydro power	7.21	4 MW plant	12,423.71	1	0.0124	0.6428	3.57%
Large solar heater	11.70	1unit	62.16	200	0.0124	0.6553	3.64%
Residential solar water heating	19.35	1 unit	1.32	100,000	0.1320	0.7873	4.37%
Liquid fuel in power generation	22.71	1 plant	1,238,139.75	1	1.2381	2.0254	11.25%
Biogas from agro-ind. sewage water	43.21	1 digester	11,699.89	3	0.0351	2.0605	11.45%
Efficient industrial boil-ers	63.93	2 tones steam	29,652.40	50	1.4826	3.5431	19.68%
Air conditioning (residential)	70.51	1 air condit.	0.16	60,000	0.0094	3.5525	19.74%
PVs connected to elec-tric grid	398.22	1 kW	1.10	500	0.0006	3.5531	19.74%

The combined representation of reduction/cost indicators is a curve called marginal cost abatement curve (Figure 2.2.1), with the achievable reduction in 2010 (kt CO_2-eq) in the horizontal axis and the specific cost of the mitigation options (US$/t CO_2-eq) in the vertical axis. The options are introduced according to their cost-effectiveness (the options with smallest specific costs are introduced first in the left side of the curve). It must be emphasised that it is only an approximating curve as all the measures are introduced additively. The synergies and interactions among the measures are not taken into account. For example if the measures in the electricity production sub-sector are implemented then the electricity production mix will be changed and a new emission factor must be calculated and applied in the subsequent measures related to electricity. Nevertheless, although this curve is an approximation, it serves well as an illustrative tool for recognising priorities in GHG abatement policy.

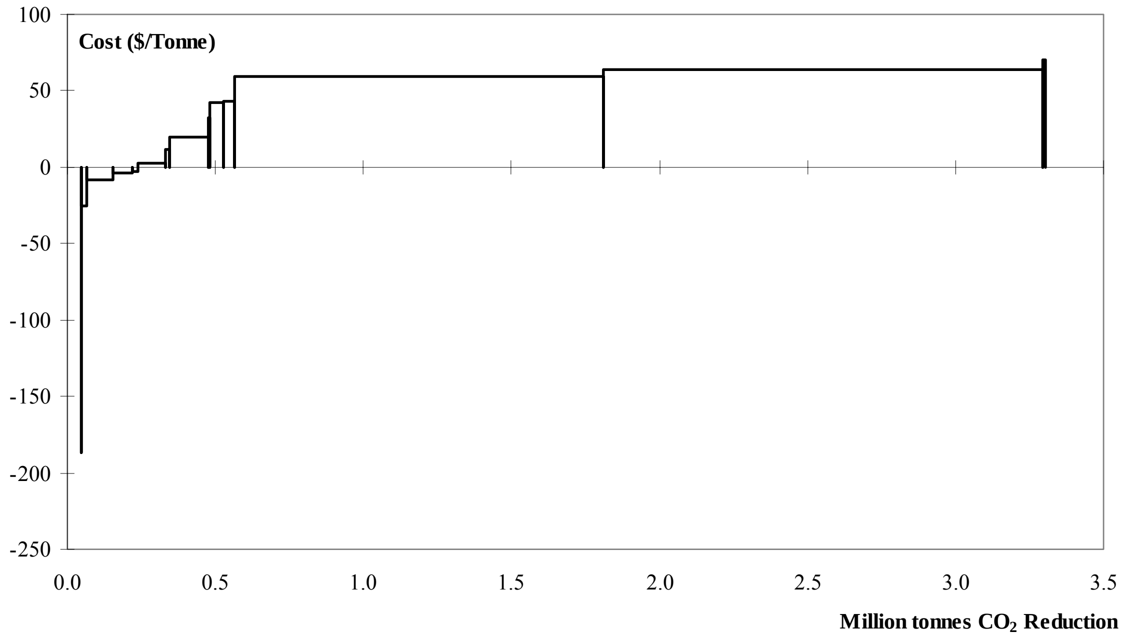

Figure 2.2.1. Marginal cost abatement curve for the year 2010

The mitigation options belonging to the sub-sector of energy–intensive consumer goods exhibit high favourableness from the economic standpoint. Three out of four examined measures in this sub-sector have negative specific costs which could be explained by the outsized use of obsolete technologies in the country, additionally impaired by the unfavourable practices of the consumers when using those technologies.

However, the environmental effectiveness of these options is relatively low, being assessed to 0.89% from the baseline emissions in 2010. Namely, if by 2010 the motors of 2,000 buses are replaced by more efficient ones, 200,000 efficient lamps are installed, 150,000 efficient refrigerators are put into operation and 60,000 households instead of outdated window air conditioners buy air conditioners with greater coefficient of performance, the total baseline emissions will be reduced by 0.16 Mt CO_2-eq.

PROSPECTS FOR TRANSFER AND DIFFUSION OF TECHNOLOGIES

Driving Factors

'No Regret' Implementation

Calculations have shown that almost half of the examined options have negative specific costs or are 'no regret' or 'win-win' options in the long run, meaning that they are beneficial even from a financial point of view. This could be explained by the high-energy intensity in the present national economy, providing thus much room for improvements. Expressed in numbers, achievable reduction in 2010 by 'no regret' options (Geothermal heating, Replacement of bus diesel motors, Efficient lighting, Efficient refrigerators, Hydro power plant Boskov Most, Efficient motors and Landfill gas power plant) amounts to 0.49 Mt CO_2-eq, which is 2.7% of the total baseline emissions in 2010.

This particularly holds true for the options belonging to energy-intensive consumer goods subsector, since in Macedonian conditions most of them appear to be with negative costs. Even if climate change is not an issue, there will be still a strong case for implementing these options on the grounds of their economic benefits alone.

Limiting Barriers

Financing

The largest constrain to technology transfer in Macedonia, as a country with economy in transition facing significant economic and social problems, is the lack of financing. Even in the case of 'no regret' technologies, it is very difficult to find national sources for the initial investment. In addition, the potential for attracting foreign investments is quite low, as a result of the high degree of uncertain political circumstances, bad economic situation and unfavourable business climate in the country.

Particularly important for the financial aspect of the transfer and diffusion of new technologies in the sub-sector of energy intensive consumer goods is the rationalization of energy prices in the country. To encourage self-investing in the new technologies, the energy prices must reflect the actual costs, providing thus, the consumers with economic motivation to use energy efficient and energy saving technologies. Moreover, economic incentives, such as import duties and tax deduction, must be put forward, and that will make more general economic advantages for the country in terms of creation of new markets, as well as new services and production sectors.

Strongly related to the financing of technology transfer, is the main recommendation in the recently prepared national strategy for energy efficiency [6], where the creation of an Energy Efficiency Fund and Agency is indicated as the most important activity to be undertaken in the country. The Energy Efficiency Agency will be assigned responsibility for the design of surveys, and the collection, collation and analysis of data related to energy supply and demand. These data will be reviewed and evaluated for their social, economic and environmental impacts. Additionally, the Energy Efficiency Agency will be responsible for promoting policies and activities that encourage the broad development and participation of the non-governmental sector in the implementation of energy efficiency programs. The real barrier to the creation of the Energy Efficiency Fund and Agency appears to be the commitment of financial and staff resources from an already constrained national budget. However, there are possibilities to use funding (grants and favourable loans) from international financing institutions, such as World Bank, GEF, etc. and donations of the governments of some developed countries as main Energy Efficiency Fund revenues. Certainly, the decisive factor for attracting this kind of international funding is the co-ordinated and collaborative acting of the Ministry of Economy and the Ministry of Environment and Physical Planning.

Private and Public Decision-making

In addition to financial barriers, another major obstacle is the lack of actual awareness of the situation and of possibilities for environmentally and economically beneficial interventions in the energy sector, among which is the transfer and diffusion of new technologies. In many cases the main constraints concern the inertness and reluctance to new technologies along with the low level of interest even for the application in resolving vital energy related problems.

Furthermore, the criteria for selection of the technology to be bought or installed, particularly in the sub-sector of energy-intensive consumer goods, are not always appropriately established. Hence, for homeowners replacing their own fridge, the energy use is usually not a top consideration. Size, color and convenience tend to predominate. And even if the consumers do take energy use into account, they often demand that any extra investment pays itself back within a year or less, far less than the threshold of what would bring about all the cost-effective energy savings. The choice of refrigerator is especially important because it determines the amount of energy the fridge will use, far more than how the consumer makes use of it. Also, opening the refrigerator door accounts for just 2% of the appliance's energy use and cleaning the coils in the back has no statistically noticeable effect on energy consumption. What does matter is the decision of what model to buy.

In some cases, different interests of the stakeholders are serious constraints, since very large number of independent decision-makers are present and their objectives are very difficult to harmonise. A starting point then, could be the implantation of the new technologies to public buildings like hospitals, schools, universities, where the decision is made on a centralised level. The benefit of such action is doubled - from one side it is in favour of the technology transfer in the country, and from another, it is a good example for replication not only in public, but also in the residential sector.

Still, the fact that in the countries with economy in transition, such as Macedonia, the economic criterion is the leading one in the decision-making, is the main rationale behind the low level of interest for investment in new technologies. For this reason, uncertainties related to expected energy and economic savings in such circumstances obtain more influential role in the decision-making and become more pronounced barriers to the process of technology transfer.

Required Infrastructure

In general, the effectiveness of the transfer and diffusion of technologies in the energy sector strongly depends on the established infrastructure - institutional arrangements, legislative and administrative tools, and engagement of stakeholders, whose list by function ideally includes:

- Government departments with responsibility for:
    - relevant areas of policy - energy, environment and development
    - regulation of energy sector
    - promotion and development of industry and international trade
    - finance.
- Industries and/or public sector bodies responsible for provision of energy services
- Companies, industry and financial institutions involved in the manufacture, import and sale of energy technologies
- Households, small businesses and farmers using the technologies and practices in question
- NGOs involved with the promotion of environmental and social objectives
- Institutions that provide technical and scientific support to both government and industry (academic organizations, industry research and development centers, consultants, forums)
- Labour unions
- Consumer groups
- International organizations and donors.

Macedonia lacks the required infrastructure in terms of institutions, legislative framework and economic incentives, as well as personnel capable to deliver the required technical, managerial and financial services. There are no specialized institutions for promotion and support of technology transfer in the country. In many cases the inter-ministerial communication is missing or insufficient, which holds true for almost all other stakeholders. Moreover, the national legislation fails to address necessary commitments to contemporary technologies, having the situation further impaired by the complex and inefficient administration. The available human capacity is not enough and needs further empowerment in terms of skills, knowledge and awareness.

The transfer and diffusion of technology in the country could not be realised without all stakeholders' support, including substantial 'buy in' from the private sector. Therefore, development of specialized national private companies that would assume the financing and execution of technological breakthrough is strongly recommendable and deserves serious consideration.

CONCLUDING REMARKS

The economic and environmental evaluation of the selected country-specific mitigation options, along with the analyses of the emerging barriers and possibilities for their overcoming, leads to the following concluding remarks:
'No regret' options, in spite of their relatively low environmental effectiveness, are good starting point for promotion and reinforcement of technology transfer in the energy sector. The rationale behind this is the full compliance of these options with the leading role of the economic criteria in the decision-making. However, the problem of finding financial sources for the initial investments remains to be resolved.

Present status of technologies used in the energy and industry sectors is far of being satisfactory. The prolonged transition period has caused delay in accepting contemporary and environmentally favourable technologies. The situation is even worse since the harmful effects of the outdated technologies, as well as of the poor, inadequate or even neglected maintenance of the equipment have not reached their real size due to the substantial reduction in the industrial and similar activities during the ongoing transition period.

The need for quick and almost general replacement of the existing technologies with contemporary ones, characterized by lower energy consumption, improved productivity, lower emission of pollutants, closed loop cycles is evident. The main constraint against is the lack of domestic capital to be invested and the absence of foreign investors. The later is caused by foreigners' lack of willingness to invest in a region with unfavourable business climate and conditions. In any case, the present growth rate of economic activity in the country is insufficient.

Macedonia lacks supportive infrastructure for successful technology transfer. This problem becomes more severe in going from personal to institutional and finally, to systemic level. At the personal level, the available human resources are not enough and there is a need for training and other types of improving the existing skills and knowledge. Appropriate awareness rising activities should be undertaken in order to modify the behaviour of the stakeholders, their attitudes towards the new technologies, as well as the criteria according to which their energy-related decisions are adopted. The stimulation of demand of energy services when more efficient technologies are applied is not an issue, since in countries like Macedonia, the energy prices are considered as social categories. Institutional and systemic capacity building will create possibility to establish supportive institutions and to design, implement and enforce policies for technology transfer, as well as to monitor their results. It is particularly important to incorporate the technology transfer as a parameter in all policies considered of primary priority in the country.

Efficient transfer and diffusion of technologies will be presumably realized with considerable participation of the private sector by establishing and strengthening national companies that will finance and conduct the introduction of new technologies in the energy sector.

Finally, worth mentioning is the fact that, the obtained results of this case study have wider scope. Given the similarities in the national circumstances, the findings of the conducted assessments and analyses, derived conclusions and recommendations and lessons learned, all being related to transfer and diffusion of technologies in the Macedonian energy sector, could be more or less relevant also for the other countries with economy in transition.

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Driving Technology In The Motor Vehicle Industry

George Hansen
General Motors Corporation

'Transportation Emissions Are All About Technology'
Jae Edmonds

INTRODUCTION

Technological innovation is at the core of both the success of the 20th Century and the promise of the 21st. It is easy to exaggerate its importance in the short run, but difficult to over estimate it in the long run. Harnessing the full potential of technology is the surest way to decouple CO_2 emissions from economic growth, creating a world where more people have access to the opportunities of economic growth while reducing CO_2 emissions and other negative externalities.

Personal mobility is the source of great private and social benefits, as well as significant costs. Mobility is essential to economic growth and improved living standards in nations around the world. Personal mobility increases access to essential medical, emergency, community, religious and educational services, as well as to vastly wider employment, cultural and personal opportunities. Mobility is freedom – the freedom to choose where to live, shop, worship and work. The greater access to a wider selection of goods that consumers enjoy with increased mobility forces sellers to offer more competitive quality and lower prices. Greater freight mobility provides consumers with a broader range of products from which to choose and producers with wider markets for distributing their goods. This geographic expansion permits the specialization of production and enables manufacturers to realize economies of scale that significantly lower costs. With all these greater choices comes higher productivity and wages, increased competition, lower costs, and improved quality, reliability and service.

With today's technology, mobility also brings significant unwanted social effects ('negative externalities') including pollution, emissions of greenhouse gases, traffic deaths and injuries, congestion and noise. Technologies are already being employed in most developed and some developing economies to ameliorate and even eliminate some of these effects, but the cost of theses technologies in many cases is more than individual consumers are willing or can afford to bear. And while these costs are substantial, a number of studies estimate that aggregate private and societal benefits from transportation far exceed the sum of private and social costs.[1]

The development, commercialization and global diffusion of new transportation technology can play a major role in providing increased mobility and the benefits it brings to people throughout the world over the next fifty years – both in developing and developed countries. It can play an equally important role in mitigating the adverse environmental, safety and social impacts that accompany increased mobility.

Accelerating the development, commercialization and global diffusion of technology to meet both the demands for personal mobility and to reduce unwanted social impacts requires the coordinated and collaborative efforts of the private and public sectors. Neither can accomplish these dual objectives independently. Technology in the 21st Century requires sustained long-term efforts by both sectors – as well as by other key stakeholders such as consumers and NGOs. By its nature, it is long-term, costly, risky, multi-sector and interdisciplinary.

The public sector plays an essential role in encouraging and facilitating the development and commercialization of new technology. It supports much of the basic and pre-competitive research and scientific advancement upon which technology increasingly relies. It provides incentives for the research, development and adoption of technologies for which market demand is initially limited. It provides necessary codes and standards; intellectual property protection; and the legal, economic and physical infrastructures that support advanced technology. In terms of stimulating the development of technologies to reduce CO_2 emissions, it may be that there is an enhanced role for governments to play. For example, migration to a hydrogen-based economy requires coordinated research, development and technology implementation and uptake across the entire system from fuel production through distribution through tech-

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1 See M. Cameron, Efficiency and Fairness on the Roads, Environmental Defense Fund, 1994; and M. DeLuchi, Total Cost of Motor Vehicle Use, Access, Spring, 1996, p.9

nologies that operate on the new fuels. This systems-based technological revolution is far beyond the scope of any one company to undertake in terms of scope, scale and time for economic return. Accordingly, governments have a greater role in encouraging all elements of the system to take responsibility for that which is within their direct purview and for ensuring that the economic signals encourage the investments and behaviors required to migrate the world to a lower CO_2 production profile.

The successful development, commercialization and global diffusion of technology, however, ultimately rest with the private sector that funds and performs the majority of R&D, and assumes the risks and reaps the rewards or suffers the losses. The share of total, non-defense R&D funded by the private sector in the U.S., for example, has been steadily increasing while government funding for energy-related R&D has been falling throughout the OECD countries, save Japan.[2] In 2002, the private sector funded about two-thirds of research and development in the U.S. and Germany, and about three-fourths of R&D in Japan and South Korea.[3] Overall, industry funded about 55% of R&D in the European Union in 2002.[4]

Realizing the full potential of technology also requires recognizing that technology is not developed and commercialized in a social vacuum. It is essential to understand that technology is an integral part of a nation's social system, and can only be successfully developed, commercialized and disseminated within this context. A country's economic, political, social and cultural institutions are as important to the successful development and commercialization of new technology as its scientific knowledge and technical skills. Different societies will respond differently to technological change. Some countries will embrace technological change; some will not. Some societies will quickly adapt social behavior and life styles; others will resist. Some will lead the introduction of new technology; others will lag.

The next section of the paper describes the motor vehicle industry's global footprint, and how its size and shape might change over the coming thirty to fifty years. The following three sections discuss the market, social and regulatory factors driving technology in the motor vehicle industry. The penultimate section describes the pursuit of technology in the motor vehicle industry to address concerns about global climate change. The final section summarizes the paper, and highlights several fundamental conclusions about the role of technology in the motor vehicle industry.

THE GLOBAL MOTOR VEHICLE INDUSTRY

The motor vehicle industry is the world's largest industry measured by employment and value added. Yet, only 12% of the world's population is on wheels, excluding bicycles and two and three-wheel motorized vehicles so prominent in many developing countries.[5]

There were 700 million light duty vehicles, automobiles, light trucks, SUVs and minivans, on roadways around the globe in 2000. These numbers are projected to increase to 1.3 billion by 2030, and to over 2 billion vehicles by 2050, with most of the increase coming in developing countries.[6]

The U.S. motor vehicle industry, accounting for 4% of GDP and 11% of manufacturing shipments, illustrates the economic significance of the industry.[7] It employs 450,000 Americans directly.[8] Outside the U.S., the industry accounts for 6% of total manufacturing employment in Western Europe, 7% in Japan, and for nearly 7% of total national employment in South Korea.[9]
Automakers purchased nearly $200 billion in parts in the U.S. in 2002, and are major purchasers of raw materials

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2 Battelle, Global Energy Technology Strategy , Global Energy Technology Strategy Program, p5.

3 OECD, Main Science and Technology Indicators, 2003

4 Ibid.

5 Based on 700 million vehicles and a world population of 6 billion people.

6 World Business Council for Sustainable Development, Mobility 2030, Overview 2004, The Sustainable Mobility Project, July 2004, p. 11

7 Estimated by General Motors

8 Automotive Trade Policy Council, The Contribution of the U.S. Auto Industry to the American Economy, 2002

9 Estimated by General Motors

such as rubber, aluminum, iron and steel.[10] They invested over $200 billion in the U.S. between 1980 and 2002, and spend over $16 billion on research and development annually – more than any other industry and 20% of all manufacturing R&D.[4]

Although the auto assembly industry is not an energy-intensive industry, with power costs representing only a small portion of the cost structure for vehicle assemblers, given the scale of the industry, it is generally one of the largest consumers of power in countries where the industry has a significant presence. GM's power costs, for example, total more than $1 billion per year globally.[12] In the highly competitive global automotive industry, the opportunity to reduce power consumed represents an important opportunity for cost savings. Given that in most auto-producing nations, a significant portion of the power is fossil fuel based, this impetus to reduce energy consumption translates into significant CO_2 emission reductions. GM for example, has reduced CO_2 emissions from its operations in North America by 12% since 2000 while increasing output, and GM is well on its way to meeting its global energy consumption reduction goal of 10% between 2000 and 2005, again even as output is increasing.[4]

It is clear that if the price signals are correct, each step of the value chain will have a direct incentive to reduce the energy consumed and CO_2 produced resulting from the activities of that element of the chain. In terms of the road transportation sector, assemblers such as GM are engaging suppliers to share knowledge and encouraging them to improve their energy efficiency, both to reduce environmental impacts as well as to improve the cost structure. While vehicle makers such as GM are taking the lead in developing more fuel efficient vehicle technologies, it is equally important that consumers be engaged to make the right choices in terms of vehicle selection, maintenance and usage. The price of fuel, urban planning and even cultural norms all play critical roles in this regard.

FUTURE GROWTH

The demand for personal and freight mobility is driven more by growth in household disposable income, income after taxes, than by any other factor. Income growth increases vehicle ownership, leads to more and longer trips, and increases the volume of commercial activity and traffic.

Real income per capita is expected to grow rapidly over the next several decades, especially in a number of key developing countries. Average total annual economic growth is estimated at 3% globally out to 2030.[14] Growth in OECD countries is estimated at 2% while growth in developing countries is estimated at 4.1%, with China at 4.8% and India at 4.6% annual rates of economic growth.[4]

This rapid economic growth will spur the demand for personal mobility, especially in developing countries. The demand for personal transport (passenger kilometers traveled) is estimated to grow at 1.6% per year out to 2030.[16] The fastest demand growth is for air transport, 3.5%, followed by passenger rail, 2.4%, two and three-wheelers, 1.9%, and 1.7% for light duty vehicles, the largest component of personal transport demand by far.[4]

Global vehicle sales are estimated to increase 2-2.5% a year over the next ten years, surpassing 75 million annually early in the next decade.[18] Sales in developed markets will grow less than .5% a year while sales in developing markets will increase by over 6% a year, accounting for 80% of the growth in global vehicle demand over this period.[4] By 2012-15, developing countries will account for 40% of global vehicle sales.[20] Sales in China could double from about 5 to 10 million vehicles, making it the second largest vehicle market in the world behind the U.S. Vehicle ownership rates in China in 2050 could approach those in European OECD countries today.

Economic growth, industrialization, urbanization and motorization will drive demands for energy over the next fifty years. The global demand for energy in the International Energy Agency's reference scenario increases 1.7% a

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10 Automotive Trade Policy Council, The Contribution of the U.S. Auto Industry to the American Economy

12 General Motors Corporation, 2004 Corporate Responsibility Report, www.gmresponsibility.com

14 World Business Council for Sustainable Development, Mobility 2030, Full Report, The Sustainable Mobility Project, 2004, p.29

16 Ibid., p.31

18 Estimated by General Motors

20 Ibid.

year, reaching 15.3 billion tons of oil equivalent by 2030 – an increase equal to two-thirds of current demand.[21] Over 60% of this increased demand will come from developing countries, especially in Asia.[22] Their share of total world energy demand will increase from 30% to 43% between 2000 and 2030.[4]

Fossil fuels will meet more than 90% of this increase in demand, accounting for 87% of energy supplies in 2030 compared with 85% today, with some shifting from coal to natural gas.[24] Much of the increased demand for oil and gas will be met by the Middle East and former Soviet Union, which have significant hydrocarbon resources.[25]

Global demand for oil will rise 1.6% a year from 75mb/d in 2000 to 120mb/d in 2030.[24]
Almost three-quarters of the increase in oil demand will come from the transport sector.[4]
Transport demand, almost entirely for oil, will grow the fastest of all end-use sectors at 2.1% per year, overtaking industry in the 2020s as the largest final-use sector.[22] As a consequence, baseline GHG emissions from the transportation sector are projected to double from 2000 to 2050.[29] Emissions will remain relatively flat in developed countries, but increase much faster in developing countries.

MARKET FACTORS DRIVING TECHNOLOGY

Competition is a key driver of technological change in the motor vehicle industry. Motor vehicle manufacturers around the world must meet today's consumer demands for larger, safer, more powerful, more functional and more affordable vehicles to remain viable in an intensely competitive global industry, and to earn the resources needed to invest in the technologies of the future. At the same time, they must be on the leading edge of new technology. New technologies can threaten a company's core business as illustrated by the impacts of mobile phones on long-distance and fixed line service, and digital photography on the traditional film business. As the saying goes – 'if you're not cannibalizing your own business, someone else will.' Trying to catch-up after the new technology is in place often proves too little, too late.

There is little market demand today for propulsion technologies that are more costly than fossil fuels. In a ranking of vehicle attributes demanded by consumers in the U.S., fuel economy ranked 37th out of 56, still well behind cup holders![30] Even with higher diesel and gasoline prices, the European market continues to demand larger and more upmarket models. In fact, as auto manufacturers have introduced more fuel-efficient vehicles into the market, consumers have offset much of these gains by purchasing larger, more powerful vehicles with added safety, convenience and performance features, and by driving them more as the cost per mile declines with improved fuel economy. To illustrate this impact, over the past fifteen years, annual vehicle fuel efficiency improvements have averaged nearly 1% per year, but overall fuel economy has been flat for both cars and light trucks in the U.S.[31]

SOCIAL FACTORS DRIVING TECHNOLOGY

In addition to the market demands for enhanced performance and additional features, a number of important social factors are also driving the pace and direction of technology in the global motor vehicle industry, including concerns about pollution, climate change and greenhouse gas emissions, energy security, roadway safety, recyclability, congestion, and noise, Technology has played a major role in addressing some of these issues, and must play an even greater role in addressing others.

Smog-causing emissions from motor vehicles in the U.S. and Canada have been reduced by as much as 99% from uncontrolled levels.[32] Europe, Japan, Australia, China and Canada have all taken steps to reduce smog-causing emissions dramatically with a combination of advanced vehicle emission technologies and cleaner fuels.

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21 International Energy Agency, World Energy Outlook 2002, Executive Summary, p.26

22 Ibid., p.28

24 Ibid., p.27

25 Ibid., p.29

29 Mobility 2030, Full Report, p.37

30 CNW Marketing Research, Inc., Attributes Considered Important

31 Data from Light-Duty Automotive Technology and Fuel Economy Trends: 1975-2004, EPA 420-S-04-002, April 2004

32 Based on data from J. Calvert, J. Heywood, R. Sawyer and J. Seinfeld, Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions, Science, v. 261, July 2, 1993, p.37 and United States Environmental Protection Agency

While local pollution will continue to decline in developed countries, it could increase in developing countries over several decades with rapid motorization. Concerns for energy security and supply diversity will increase with rising imports and concentrated oil production in the Mideast and former Soviet Union.

While traffic fatalities are at historic lows in most developed countries, road traffic fatalities are likely to grow substantially in developing countries unless steps are taken to attenuate this trend.[33] Congestion and noise will likely increase with motorization and urbanization in most areas, particularly if road infrastructure expansion does not keep pace with increased demands for mobility. GHG emissions will increase with economic growth and increased mobility, again especially in developing countries.

Automakers are investing aggressively in developing and bringing to market technologies that will satisfy consumers and address these critical issues of CO_2 emissions, smog-causing emissions, improved safety, reduced congestion and noise and enhanced recyclability in a balanced way. Unfortunately, trade-offs are often required between these competing priorities – for example, adding safety features increases weight, which reduces fuel economy. While the focus of this paper is on strategies to reduce CO_2 emissions from the road transportation sector, it is important to recognize that this important issue is only one of several where government, the private sector, NGOs and consumers have a responsibility to act.

The transportation sector (including road, rail, air and shipping) in 1998 accounted for 26% of worldwide CO_2 emissions from the combustion of fuels according to the IEA.[34] The largest source of emissions was the production of energy, accounting for 41% of the global total.[4] Manufacturing and construction accounted for 19%, residential for 8%, and commercial and other for 6% of total global CO_2 emissions.[4] Passenger cars in 2001 accounted for 5.5% of global anthropogenic CO_2 emissions and trucks for 6% of the total according to the OECD. [37]

Global energy-related emissions of carbon dioxide are projected to grow 1.8% a year from 2000 to 2030, reaching 38 billion tons by 2030 – 16 billion tons or 70% more than today's emissions.[38] Two-thirds of the increase will come from developing countries.[4] China alone will account for a quarter of the increase in CO_2 emissions. [40]

Most baseline projections show that gasoline and diesel fuel will be the dominant source of energy for motor vehicles through 2050.[41] The result of the increase in mobility and continued reliance on fossil fuels is that global GHG emissions in the transport sector will double between 2000 and 2050 under baseline projections.[42] Emissions will remain relatively flat in the developed regions of the world, but rise much faster in developing countries.

REGULATORY FACTORS DRIVING TECHNOLOGY

Because of limited market pull for improved fuel economy at current and projected fuel prices, it is essential that public policies support the development and commercialization of advanced energy and environmental technologies. Governments can most effectively drive technologies to address climate change by ensuring that any externality is internalized through measures that make the prices of fuels reflect their full social cost. However, these measures are often politically difficult to implement.

Particularly, in the absence of strong fuel price signals, breakthrough advances in technology offer the best opportunity to cost-effectively reduce GHG emissions while enabling continued economic growth in both developing and developed economies. These technological breakthroughs will require a sustained long-term technological effort. The futility of mandating technology before it is developed and without the necessary supporting policies to encourage its uptake by consumers has been amply demonstrated. Imposing arbitrary targets and timetables on technol-

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33 Mobility 2030, Full Report, pp 42-45 &120

34 World Business Council for Sustainable Development, Mobility 2001, Sustainable Mobility Project, 2001, p.1-13

37 OECD, Environmental Outlook, 2001

38 World Energy Outlook 2002, p.30

40 Ibid., p. 31

41 Ibid., p.27 & Mobility 2030, Overview 2004, p.9

42 Mobility 2030, Full Report, p.37

ogy development diverts resources to short-term, often incremental and uneconomic, fixes at the expense of the needed breakthroughs in science and technology that spawn true innovation.

Effective policies to drive technology should begin with reforms of current regulations that often ‘lock-in’ current technologies by increasing risks and costs, and reducing the incentives to innovate. Substituting incentive-based measures for technology-forcing standards; and eliminating antiquated codes and zoning ordinances that penalize energy-efficient technologies would encourage innovation.

Governments can also accelerate the development and commercialization of new technology through the following key measures:
Increasing funding for basic and pre-competitive research
Ensuring that a significant portion of government R & D resources/programs are allocated to research that will assist in addressing greenhouse gas emissions
Providing R&D tax credits in all countries at levels sufficient to share in the risk of research, and making the credit permanent in the U.S.
Support an appropriate level of demonstration projects to facilitate learning of how these technologies perform in real-world environments, identify what regulatory and other barriers exist to widespread commercialization and build consumer enthusiasm for the product, while ensuring that too many resources are not drawn away from technology-enhancing research for the purpose of positive ‘optics’
Providing financial assistance to bridge producers between early stages of production where significant capital investment may be required with limited production and market returns and the longer term, full economic module production
Providing tax incentives to encourage consumers to purchase advanced technology vehicles
Utilizing government procurement to stimulate early market demand to help accelerate the achievement of efficient production levels and economies of scale
Developing needed technical and safety codes and standards
Promoting the development of the infrastructures needed to support advanced technologies such as the low-carbon production of hydrogen, and the availability of convenient and economical refueling on a complementary timetable with the vehicle and other technologies that will require these fuels to operate. (Given the capital intensive nature of today’s fossil fuel production and distribution industry and the need for regular renewal of this infrastructure, the resources required for this transition are not enormous, but some cost-sharing may be required between governments and refuelers, and a staged approach to establishing the infrastructure, particularly in the initial stages before widespread market penetration of the new technologies).

Governments can facilitate the creation of public-private research partnerships that are key instruments for effectively utilizing a nation’s full scientific capabilities, and for accelerating the movement of promising transportation technologies from the laboratories to the marketplace. These partnerships need to be long-term, multi-disciplinary, multi-sector, and global. They need to be responsive to market forces, monitored externally and held accountable for performance.

General Motors, Ford and DaimlerChrysler and the U.S. Department of Energy have entered a public-private partnership – Freedom CAR – to accelerate the development of fuel cell vehicles and the necessary hydrogen infrastructure in the U.S. Similarly, the European Commission is establishing ‘Lighthouse,’ a ten-year program to develop fuel cell technology and infrastructure. GM has signaled its support for this initiative.

GM and other automakers are also working with government partners in Canada to develop fuel cell technology, as well as with individual states in the U.S. such as the California Fuel Cell Partnership and Michigan’s Next Energy Program. GM is also engaged in numerous private research partnerships with companies such as Hydrogenics, General Hydrogen and Quantum, on developing fuel cell technologies; with BP Amoco, and Shell Oil on developing cleaner fuel formulations and hydrogen refueling capability; and with consumers such as Dow Chemical (automotive fuel cells in a stationary application using hydrogen co-product from a Dow plant to generate power for the facility), and FedEx (operating a GM fuel cell vehicle, HydroGen3, several days a week on its regular Tokyo delivery route.)

Governments in other countries are also establishing similar programs. Given the enormity of the challenges, it is important that wherever possible, governments collaborate with each other to develop harmonized approaches. This will enable resources to concentrate on implementing new technologies as quickly as possible, rather than on compliance with a proliferation of similar but often competing regulatory requirements.

Broad government policies can also accelerate the global diffusion of technology in the motor vehicle industry. Reducing excessive controls on the export of technology; eliminating taxation on international, intra-firm transfers of environmental and energy-efficient technologies; reducing tariffs and subsidies; preventing exchange rate manipulation and other protectionist measures; increasing access to foreign markets; opening government procurement practices; and providing adequate protection of intellectual property rights would all increase the global diffusion of technology.

Governments can also facilitate the global diffusion of new technologies by pressing international development financial institutions to provide special focus on energy technologies and supporting infrastructures, and by improving the financial, physical, technical, legal and regulatory infrastructures in developing countries to enable them to assess, implement, and operate advanced technology systems.

TECHNOLOGY STRATEGIES IN THE MOTOR VEHICLE INDUSTRY

Auto manufacturers must meet the specific demands of consumers as well as the broader demands of society to succeed. The larger the gap between the demands of the market and the needs of society, the greater the risk to automakers. Building cars and trucks that satisfy government regulations but fail to sell in the marketplace only increases the retention of older vehicles with adverse consequences for emissions and safety. The only realistic strategy for automakers is to narrow this gap over time by improving conventional technology to meet current demands while simultaneously investing in a portfolio of new technologies for which there is currently little market demand but that ultimately could prove competitive with fossil fuels. This dual strategy exposes corporate decision makers to both great market and regulatory risks.

In addition to these great technical, economic and regulatory uncertainties, diverse consumer transportation demands; varied driving conditions; heterogeneous national and regional markets; varied regulatory regimes; and markedly different fuel prices around the world also make it necessary to develop a broad portfolio of technologies to succeed in the motor vehicle industry.

Technology strategies in the motor vehicle industry must also take cognizance of the fact that advanced technology vehicles will co-exist with conventional gasoline and diesel-powered vehicles for decades to come. With over 200 million Internal Combustion Engine (ICE) vehicles in the U.S. today, and over 700 million worldwide, annual sales of advanced technology vehicles must be in the millions to alter the environmental footprint of the fleet. With the average life of a new vehicle around fifteen years, half of the vehicles sold today will be on the road in 2020. Gasoline, diesel, other alternative fuels, hybrid and fuel cell vehicles will all compete for a share of the market, as did gasoline, steam, and electric vehicles at the turn of the last century.

Each automaker in the global motor vehicle industry is pursuing a number of technology streams to improve fuel economy, reduce CO_2 emissions, and enhance energy security, as well as to address other important issues such as safety, noise, and recyclability. It is important to note that it is not likely that 'one size will fit all' – different technologies will be appropriate in different markets and at different points as technologies develop into the future. In addition, it is also important to recognize that the differing technology strategies being pursued by various automakers results in a natural portfolio approach which moderates risk to society as a whole and increases the probability of appropriate technologies being developed (albeit some firms may prosper where others may suffer based on which technologies prove out).

Government should be very cautious about taking measures which advantage one technology over another – choosing winners and losers. Instead, generally stimulating a range of innovation strategies, combined with facilitating complementary progress on all elements of the system (e.g. vehicle technology plus fuel production and distribution) and stimulating positive consumer behavior will produce the fastest technological progress at the lowest cost.
Across the auto industry, some of the promising technologies to improve the energy efficiency of ICE engines that are being explored by automakers include:
Downsized spark ignition engines
Gasoline direct injection engines
Engine shut-off at idle

Variable valve timing
Displacement on demand
Multispeed transmissions
Turbo charging
Controlled auto ignition
Lean burn engines.

Technologies that may improve the environmental performance of diesel engines include:
Direct injection diesel engines
Downsizing
Turbo charging
Homogeneous charge compression ignition combustion
Diesel particulate filters.

Several non-powertrain technologies could also improve the energy efficiency of conventional vehicles:
Climate control systems – improve system seals and reduce leakage, reduce heating and cooling loads, and reduce the amount of refrigerant needed.
Tires – reduce rolling resistance with sensors that warn of underinflation that increases rolling resistance and tire wear.
Aerodynamic drag – reduce the pressures and frictions on the vehicle as it moves through the air. Drag is determined primarily by the size and shape of the vehicle. Reducing the size of the frontal area, lowering engine hoods, raising the rears, and pulling in the sides and underbody all reduce drag, but often conflict with the vehicle's performance and functionality.
Vehicle weight – vehicles have been getting heavier in recent years because of equipment added and changes made to improve safety, enhance performance and to reduce emissions and noise. Weight reduction comes from design changes and from substituting lighter, more costly, materials.

Technologies to improve fuels and reduce their carbon content are also essential to reducing GHG emissions in the motor vehicle industry:
Low sulphur gasoline and diesel fuel
Compressed natural gas
Liquefied petroleum gas
DME (di-methyl ether)
FT diesel made from natural gas using the Fischer-Tropsch process
Biofuels - Ethanol and Biodiesel
Advanced biofuels (biomass-to-liquid and lignocelluloses material to fuel)
that use a broader range of biomass feedstocks and that require new technologies such as pyrolysis, gasification and digestion
Carbon sequestration associated with fuel production.

In addition to continually improving the performance of the ICE engine and automotive fuels, the industry is pursuing advanced hybrid and fuel cell technologies aggressively. Hybrids combine an internal combustion engine with a generator, battery and one or more electric motors. Hybrids can reduce CO_2 emissions to varying degrees depending on driving cycles and differing technologies. Hybrid cars, pickup trucks and buses are now available in some markets.

Fuel Cell vehicles consist of an electrochemical energy converter in which hydrogen and oxygen react to create electrical energy. Water and heat are the only vehicle emissions. Total emissions depend almost entirely on the methods to produce and distribute the hydrogen. Fuel cell vehicles have the highest energy efficiency and lowest GHG and conventional emissions if the hydrogen is produced from carbon-neutral sources. This requires the hydrogen to be produced from renewable energy (solar, wind, hydro or geothermal) or capture and storage of the CO_2 emissions.

Another advantage of fuel cell vehicles is that hydrogen is available from a wide variety of feedstocks, thus increasing energy diversification, reducing energy delivery vulnerability and increasing energy security. Emissions also remain zero as the vehicle ages, even if not properly maintained by the owner.

The most promising fuel cell technology for vehicles is the Proton Exchange Membrane (PEM) with on-board hydrogen storage. Two major issues to be resolved are:
High cost – cost must be reduced substantially to be commercially viable
On-board storage – a major technical problem. Compression, cryogenic and metal hydride tanks are being explored.

General Motors' Technology Strategy for Reducing Emissions
At GM, our technology strategy can be described as technologies to improve conventional gasoline and diesel engines and alternative fuels in the short term; to develop hybrid vehicles in the mid term; and to develop fuel cell vehicles in the longer term. General Motors' goal is to reduce emissions so that they are no longer a factor in the environmental equation. A new generation of gasoline and diesel engines will continue GM's progress on improved fuel economy, efficiency and emissions performance**.**

GM's mid-term strategy is to apply hybrid technology to high-volume and high fuel-consuming vehicles like trucks, SUVs and mass transit buses to save as many gallons of fuel and to reduce CO_2 emissions as much as possible.

GM has developed three hybrid propulsion systems, all designed to meet customer requirements for acceleration, climbing grades, and towing:
Flywheel Alternator Starter (FAS) System - GM is the first automaker in the world to produce full-size trucks – the Chevrolet Silverado and GMC Sierra – with hybrid powertrains. The hybrid pickups will deliver up to 10 percent improved fuel economy over a regular Sierra or Silverado.
Belt Alternator Starter (BAS) System - GM will introduce this hybrid system, which improves fuel economy up to 12 percent, on high-volume SUVs and cars in the next three years. It will introduce the BAS hybrid system in mid-2006 on the '07 MY Saturn VUE.
Advanced Hybrid System II (AHS II) - GM is developing the AHS II system, based on its Allison hybrid bus technology. GM will introduce the AHS II system in mid-2007 in GM's full-size SUVs, with pickup trucks to follow. The AHS II will be mated with Displacement on Demand for a significant gain in fuel-efficiency.

In addition to providing hybrid systems for passenger cars, trucks, and SUVs, GM is delivering the world's first roadworthy commercial parallel hybrid buses to mass transit fleets across the country. This year alone, GM will deliver more than 270 buses to 10 cities, including 235 to the Seattle/King County, Washington area. These buses can offer up to a 60 percent improvement in fuel economy and reduction in carbon dioxide over a conventional diesel system in a transit bus application.[43]

General Motors' long-term strategy is focused on fuel cells. GM is a leading company in developing fuel cells and is stretching for commercially viable technology by 2010. That would be a fuel cell that is competitive with today's engines on cost, power and durability, assuming high volumes. From that point, how quickly significant volumes of exciting, safe and affordable fuel cell vehicles emerge depends on many factors, including conveniently available hydrogen for customers.

Achieving high volumes of environmental and energy technologies is required to realize the positive environmental impacts of fuel cells. For this to happen, we need to have sufficiently available hydrogen refueling options for our fuel cell vehicle customers. Additionally, appropriate codes and standards must be adopted and in place to enable the practical production, storage, delivery and dispensing of hydrogen fuel. In addition to developing fuel cell technology for vehicle application, GM is working with energy companies, such as Shell Oil, governments around the world, and other involved organizations to ensure the necessary infrastructure is available to realize our fuel cell vehicle introduction goal in the 2010 timeframe.

GM is making tremendous progress in the fuel cell arena. The move to hydrogen vehicles will take decades, but GM has made impressive progress toward reaching a cost target where fuel cell technologies could be commercially viable.

GM's AUTOnomy concept fuel cell vehicle introduced in 2002 was the first vehicle designed from the ground up

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[43] General Motors Corporation, Corporate Responsibility Report, 2004, p.4-6.

around a fuel cell propulsion system, and the first to combine fuel cells with by-wire technology. The vehicle consists of a skateboard-like chassis that contains the fuel cell, electric drive, hydrogen storage system, computer control module, heat exchangers and wheel motors. This flexible chassis accommodates multiple, interchangeable 'snap-on' bodies that can be customized to meet customer needs.

The GM Hy-wire is the world's first drivable fuel cell and by-wire concept vehicle. It was also introduced in 2002 at the Paris Motor Show. All of the propulsion and control systems are contained in an 11-inch thick skateboard-like chassis. There is no engine to see over and no pedals to operate.

The GM/Opel HydroGen3 recently drove through 14 European countries, covering 9,696 kilometers in 5.5 weeks – nearly doubling the previous distance record for fuel cell cars.

SUMMARY AND CONCLUSIONS

Personal mobility brings with it great economic and social benefits as well as some environmental, and safety costs, although we have already made significant progress. The use of energy and fossil fuels in particular is projected to increase substantially over the next fifty years with economic growth, industrialization, and increasing personal mobility. This growth will generate increased GHG emissions and raise additional safety concerns, especially in developing countries where growth is much greater. The development of advanced vehicle technology provides the opportunity to decouple the growth in economic development and personal mobility from GHG emissions and other adverse social impacts.

A number of diverse, often contradictory, market, social and regulatory factors are driving the pace and direction of technology in the motor vehicle industry. The auto companies must meet both the demands of the market and broader societal requirements to succeed. This paper illustrated the industry's efforts to develop the technologies to meet society's demands for reduced GHG emissions from the road transportation sector. It described the most effective public policies for accelerating the development of these technologies.

The best way to accelerate the development of smart vehicles to meet these demands is to start with smart policies. Governments need to implement stable, long-term policies that encourage and support the development of advanced technologies. They need to support basic and pre-competitive research, provide market incentives for the development and commercialization of advanced technology vehicles, and develop needed codes and standards. Governments need to promote the development of the cleaner fuel production and distribution infrastructure needed to support advanced technologies such as hydrogen fuel cell vehicles, and they need to provide necessary technical, legal and financial assistance to developing countries that will enable them to adopt these advanced technologies with minimum lag.

The development, commercialization and global diffusion of advanced technology are essential to reducing CO_2 emissions in the motor vehicle industry. As Jae Edmonds stated: 'Transportation emissions are all about technology.' But, there is no single technological solution to reducing CO_2 emissions in the transport sector. A portfolio of powertrain and fuel technologies will be pursued in the near term. Further, diesels and hybrid ICEs fueled with conventional gasoline and diesel fuel, or even fuel cells fueled with hydrogen derived from natural gas can only slow the growth in transport CO_2 emissions. Changing the basic path of transport-related GHG emissions will eventually require the world to move beyond current technologies to advanced technologies such as fuel cells powered with low-carbon hydrogen.

The current costs of these technologies are too high to compete with today's vehicles and fuels. Thus, one of the most important challenges is to lower these costs so that these technologies can be adopted on a global basis. It is essential that costs be lowered sufficiently and other policies adopted to reduce the lag between the adoption of these advanced technologies in developed and in developing countries where emissions are increasing the fastest.

Finally, actions to reduce GHG emissions in the transportation sector alone cannot come close to stabilizing concentrations in the atmosphere. Seeking very large reductions in GHG emissions from the transportation sector would not be cost effective because transportation represents the highest value use of carbon fuels, and is one of the most costly ($/ton) sectors for reducing GHG emissions. That is why the development and global implementation of new, cost-effective energy technologies in all sectors, such as renewable hydrogen, is the most effective way to improve energy efficiency and reduce greenhouse gas emissions across the economy. Encouraging voluntary initiatives and market-oriented measures, not government mandates, best facilitates this approach.

The Energy Saving Potential in China

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ABSTRACT

This paper quantitatively analyzes China's energy saving potential from two aspects, i.e., potential of technology improvement and potential of economic structure change. Analysis results show that energy saving potential of technology improvement is 26%, and potential of economic structure change is 33%. Statistically, these two potentials add up to 50% of energy saving, or 570 Million tons of oil equivalent, a figure that has important implications for energy consumption, economy development and environment protection.

1. INTRODUCTION*

China is often said to be inefficient in energy consumption because its energy intensity of GDP (energy consumption per GDP) is remarkably high. For example, its energy intensity is ten[73] times as high as Japan. However, this gap of ten times is an overestimated figure.

The high estimation arises when exchange rates are applied to obtain same unit of monetary-based indicator. To avoid it, this paper divides China's energy saving potential into two parts: potential of technology improvement and potential of economic structure change. Measurements of these two parts do not use exchange rates, and the problem of high estimation is overcome.

Japan is considered to be one of the most efficient countries in energy consumption. This paper chooses Japan as China's comparison target.

2. POTENTIAL OF TECHNOLOGY IMPROVEMENT

In this paper, the energy saving potential of technology improvement is measured by comparing physical energy intensity for all sectors between China and Japan. Physical energy intensity comparisons are often carried out for specific sectors, such as iron and steel, hardly any comparisons are conducted systematically for all sectors. The reason is simple; because physical comparison of all sectors demands too much data; and to collect this date is difficult.

Although this paper uses a physical energy intensity comparison, there are limitations with collection of data. In fact, the number of investigated sectors in the comparison is only 14. However, since the total energy consumption of these 14 sectors accounts for 70% of the primary energy consumption, the final conclusion can be drawn reliably.

Analysis procedure hereafter is simply to break down the whole energy consumption by sector and analyze each sector one after another as shown in Figure 1. For convenience, principal data and main conclusions are shown in Figure 1.

In order to make China and Japan comparable, the IEA's sector definition and energy consumption data are adopted.

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73 Unless otherwise specified, all data are for year 2000.

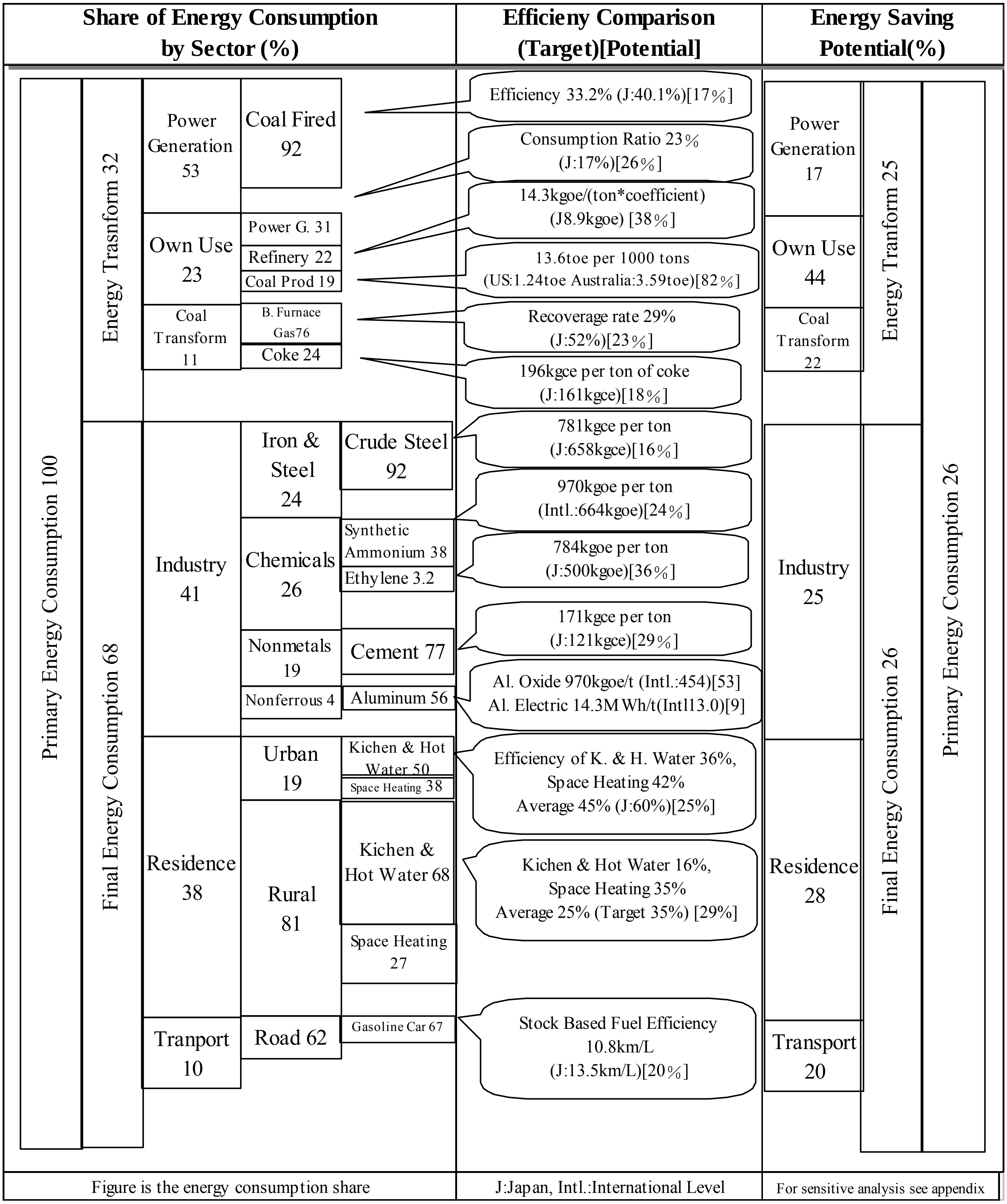

Figure 1 Energy saving potential of technology improvement (Year 2000)

2.1 Energy Transformation Sector

The energy consumption of the energy transformation sector accounts for 32% of the primary energy consumption. The breakdown is 53% for power generation, 23% for own use consumption, 11% for coal transformation, with these three sectors accounting for 87% of the total energy consumption.

2.1.1 Power Generation Sector

Coal-fired power generation accounts for 92% of the energy consumption in the power generation sector. The efficiency of coal-fired power generation in China is 33.2% and for Japan it is 40.1%, the energy saving potential for China is 17%[74].

The main reason for the low efficiency of coal-fired power generation in China is considered to be that the unit capacity of power generation facilities in China is too small. In China, unit capacity of less than 300 MW accounts for 72% of the total 240 GW coal-fired power generation capacity[75]. In Japan the same ratio is 18%.

In order to avoid unnecessary complications and continue our analysis with some minor sectors data not available, the paper assumes an equal energy saving potential for not-investigated sectors as the average of investigated sectors. Because energy consumption of investigated sectors accounts for most of the total consumption, this assumption is considered to be an allowable compromise.

Conclusion of power generation sector: Following the assumption described above, the energy saving potential of non-coal-fired power generation is assumed to be 17%, and by weighting with the coal-fired power generation, the energy saving potential of power generation sector is 17%.

2.1.2 Own Use Sector

The breakdown of own use sector is 31% for power generation, 22% for oil refinery, and 19% for coal production.

The own use ratio of energy consumption in the power generation sector is 8%. This ratio is 6% in Japan. The energy saving potential for China is 25%. Only electricity consumption is accounted, that is, own use ratio is defined as the ratio of electricity consumed by the sector itself with respect to the total electricity it generated.
In the oil refinery sector, one of the indicators to express the energy consumption efficiency is the *process-standardized efficiency* (PSE). The unit of PSE is *kgoe*/(*ton***coefficient*), where *kgoe* is kilogram of oil equivalent, and the *coefficient* is the sum of difficulty coefficient of all refinery processes (the difficulty coefficient of the atmospheric distillation process is 1). This paper adopts PSE to compare the energy consumption efficiency between China and Japan because it reflects the differences of process difficulty and refinery depth between different refinery plants. The PSE in China is 14.3 *kgoe*/(*ton***coefficient*), and in Japan it is 8.9 *kgoe*/(*ton***coefficient*), so the energy saving potential for China is 38%.

In coal production, the energy consumption per tonnage of coal produced is 13.6 toe in China, while the international level for advanced countries is 2.4 toe (here, this is the average of 1.24 toe of the US and 3.59 toe of Australia), and the energy saving potential for China is thus 82%.

Three major energy transformation sectors in China - i.e. power generation, oil refinery, and coal production - have a common weakness. The smallness of the average production scale. As shown in Table 1, the average capacity of coal-fired power generation in China is 52 MW, while it is 409MW in Japan. The average crude oil process capacity of plant in China is 2.38 Mt, while it is 6.84 Mt in Japan. The average coal production capacity of plant is 16 kt, while it is 48.6 kt in Japan (figure of year 1995. It is 367 kt in US in 2000). This factor lowers the energy consumption efficiency of the sector and also increases the own use of energy consumption, since low capacity demands more plants, thus more energy will be consumed.

Conclusion of own use sector: Based on the energy saving potential of three sub-sectors of power generation, oil refinery and coal production, the average energy saving potential of the own use sector is estimated to be 44%.

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[74] Here energy-saving potential is defined as the ratio of saving to energy consumption. That is to say, when the power generation efficiency improves from 33.2% to 40.1%, it means the necessary energy consumption per electricity demand decreases from 1/0.332 to 1/0.401, or 17% when converted into a ratio.

[75] Rather than coal-fired, thermal power data is used here, because coal-fired power generation prevails overwhelmingly in China.

Table 1 Comparison of average production scale in energy transformation sector (Year 2000)

	Unit	China	Japan
Capacity of Coal-fired Power Generation	MW/unit	5.2[*1]	40.9
Crude Oil Processing Capacity of Refinery	Million tons/plant [*2]	2.38	6.84
Capacity of Coal Production	Thousand tons/mine [*3]	16	486[*4]

Note: *1: Figure for 1999 and capacity larger than 6 MW. *2: Figure for 2002. *3: Figure for 1995. *4: 36.7 in the US.

2.1.3 Coal Transformation Sector

Coal transformation includes sectors that produce coke and blast furnace gases. Coke production accounts for 24% and blast furnace gas production for 76% of the total energy consumption respectively. The energy intensity for coke production per tonnage in China is 196 kg coal equivalent, or kgce, while it is 161 kgce in Japan. That is, an 18% energy saving potential in China. Meanwhile, for blast furnace gases, the recovery rate on a calorie basis is 29% in China, while it is 52% in Japan, so that the energy saving potential for China is 23%.

The number of coke ovens that meet international standard (automatic operation and dry quenching) in China is only eight (all are installed at Shanghai Baoshan Steel Co.), and their production capacity accounts for only 8% of total national capacity. The national average production capacity per unit is 350 thousand tons.

Conclusion of coal transformation sector: The energy saving potential of the coal transformation sector is estimated to be 18%.

Conclusion of energy transformation sector: The energy saving potential of the whole energy transformation sector is estimated to be 25%

2.2 Final Consumption Sector

The final consumption sector accounts for 68% of the total energy consumption. Major sectors are industrial 41%, residential 38% and transport 10%, and these three accounts for 89% of the final consumption sector.

2.2.1 Industrial Sector

Major energy consumption sectors in the industrial sector are iron & steel 24%, chemicals (including petrochemicals) 26%, nonmetals 19%, and nonferrous metals 4%, and the total of the four accounts for 73%.

1) Iron & Steel Sector

92% of energy consumption is used for crude steel production in the iron & steel sector. The comparable energy intensity of crude steel production is 784 kgce per tonnage in China [China Steel Industry Association, 2002], while it is 658 kgce in Japan [Japan Steel Statistics Committee, 2001], so the energy saving potential is 16%[76].

Table 2 Comparison of crude steel production between Japan and China (Year 2000)

	Unit	China	Japan
Continuous Casting Rate	%	83.4	97.3
Iron to Steel Ratio	%	1.02	0.72
Ratio of Convertor Furnace and Electric Furnace	%	81.9	100
60% of Production	M.tons	76.1	64.2
Corporation Number of Top 60% of Production	Unit	16	5
Average Production Capacity	M.tons/Unit	4.8	12.8

76 This is the average level for 75 major steel companies. But the author noticed that the energy intensity descended gradually from 997 kgce/ton to 901 kgce/ton during the period from 1990 to 1998, and drastically decreased to 784 kgce/ton. The reason is not clear yet. If the average improvement speed is used, the intensity in 2000 is about 877 kgce/ton. In this case, the energy saving potential is 25%.

The reasons why the energy intensity of crude steel production in China is high are that the production capacity per blast furnace is small, the continuous casting rate is low, and the iron to steel ratio is high (Table 2). For example, when the continuous casting rate goes up by one percentage point, the energy saving effect is about 34 kgce per tonnage of crude steel (average figure is adopted according to reference 31). If the iron to steel ratio is higher, it means that more energy will be consumed to produce the same amount of steel. Thus if the ratio in China can be reduced, energy saving is expected to be achieved.

2) Chemicals Sector

In the chemicals sector, synthetic ammonium account for 38% and five main petrochemical products (ethylene 3.2%, polyester 1.6%, acrylic 0.6%, polypropylene 0.6%, PTA (Pure Terephthalic Acid) 0.5%) account for 7% of energy consumption. The energy intensity for ammonium is 970 kgoe per tonnage, while the international level in advanced countries is 664 kgoe, so the energy saving potential is 24%. Ethylene accounts for half of the energy consumption for the five petrochemical products[77]. The energy intensity of ethylene excluding feedstock is 784 kgoe per tonnage, while it is 500 kgoe in Japan[*7], so that the energy saving potential for China is 36%.

The small production scale is one of the main reasons of the low efficiency in China. For example in ammonium production, 70% of the total amount is produced by small-to-medium sized firms, and China's average production is almost one tenth of the international level, as shown in Table 3.

In the chemical sector, the type of raw material is an important factor affecting energy intensity. In China, averagely 64% of raw material in producing synthetic ammonium is coal. Reducing the ratio of coal can improve the energy intensity. In US ethylene production, natural gas is the raw material and as a result, the ethylene production energy intensity is only 234 kgoe per tonnage. On the other hand, naphtha is mainly used in Japan and China. This means that comparison between Japan and China is possible. However, the naphtha ratio of the raw material in China is about 50%, while it is almost 100% in Japan. This ratio is expected to increase with the progress of the West-to-East natural gas project.

Table 3 Production scales for synthetic ammonium (Year 2000)

	Unit	China	US	Russia
Production	Million Tons	34	17.9	10.6
Plant Number	Unit	785	50	35
Average Production	Thousand Tons/Unit	43	358	303

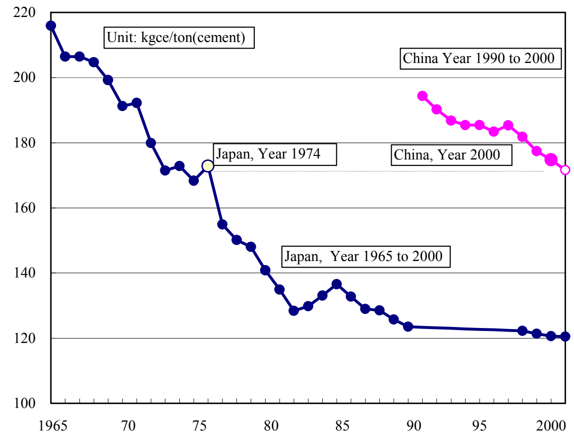
Note: converted in NH_3

3) Non metals Sector

In the non metals sector, 77% of the energy consumption is cement production. The cement production energy intensity in China is 171 kgce per tonnage of cement, while it is 121 kgce in Japan; thus the energy saving potential is 29% for China.

As can be seen from Figure 2, the energy consumption efficiency in the year 2000 in China is the same as in 1974 in Japan.

77 Four types of petrochemical products other than ethylene were unable to be compared with Japan due to a shortage of data.



Source: Data from 1965 to 1999 for Japan is calculated from the production quantity and energy consumption. Data from 1990 for Japan is from *The endeavor of cement industry to cope with the global warming issue*, (Japan Cement Association, 2003). Data for China is from (Zhou 2003).

Figure 2 Energy intensity of cement in Japan and China

There are two main causes for the high energy intensity of cement production in China. One is that international mainstream production technology (dry system with preheating; that is, NSP or SP[78] system) has diffused 100% in Japan, while the diffusion rate in China is only 12%. The other is that the average production scale in China is significantly small (Table 4). The cement production per kiln is 50 thousand tons in China, while it is 13 million tons in Japan, a factor of 260.

Table 4 Comparison of cement production between Japan and China (Year 2000)

	Unit	China	Japan
Diffusion Rate of NSP/SP	%	12	100
Production Capacity	1000 tons per year per plant	50*1	13,000

Note *1 figure in year 1997

In May 1999, China decided to close its small-scale cement plants, and Niu [2002] reported that a total of 3,940 small-scale plants shut down by August 2002. Closing down small-scale plants can contribute to improvements in the energy consumption efficiency of cement production.

4) Nonferrous Metals Sector

The non ferrous metals sector accounts for 4% of industrial energy consumption. In particular, aluminum production accounts for 56% of the energy consumption in the nonferrous metals sector. As shown in Figure 1, the energy saving potential for the production of aluminum oxide from raw ore is 53% [Lynn 2001], and for the production of electrolytic aluminum from aluminum oxide it is 9% [Chinese Academy of Science, 2001]. The ratio of energy consumption between these two processes is approximately 6 to 4, so that the energy saving potential is estimated to be 35% (53%*0.6+9%*0.4=35%).

Production of aluminum oxide is mainly carried out using the Bayer process or the Complex process. The energy consumption efficiency of the Bayer process is more than twice as good as for the Complex process; however the aluminum content in China's domestic ore is too low to apply the Bayer process and so the Bayer process is not widely used in China. China lags behind considerably with international levels in the Complex process. Small-scale production prevails in the aluminum sector. In the year 2000, the number of companies was 116 and aluminum production was 2.86 million tons, so that average production per company was only 25 thousand tons, which is one seventh of the international average of 183 thousand tons. What remains to be done is to improve the energy consumption efficiency by closing down small-scale plants and boosting the average production scale, as well as scaling up electrolysis vessels.

78 NSP is an abbreviation for New Suspension Preheater. And SP stands for Suspension Preheater.

Conclusion of industrial sector: Based on the estimated energy saving potential in the iron and steel, chemical, nonmetals sector, and nonferrous metals sectors, the energy saving potential of the whole industrial sector is estimated to be 25%.

2.2.2 Residential Sector

Residential sector accounts for 38% of the final energy consumption sector. About 70% (200 million toe) of that is noncommercial biomass energy.

In urban areas, 460 million people (36% of the total population) consume 19% of the residential energy. In rural areas, 810 million people (64% of the total population) consume 81% (but commercial energy is only 9% when 72% of noncommercial biomass is excluded). The characteristics of residential energy consumption in urban areas obviously differ from those in rural areas in China, so we will analyze residential energy consumption in these two areas separately.

Kitchen and hot-water supply accounts for 50% of total residential energy consumption in urban areas. The spread of electricity and gas usage has increased energy consumption efficiency to 36%. In rural areas, kitchen and hot-water supply accounts for 68% of the energy consumption, and most rural areas still depend on biomass energy such as firewood, the energy consumption efficiency is as low as 16%. The average energy consumption efficiency for kitchen and hot-water supply use, space heating, and lighting and power is 45% in urban areas and 25% in rural areas. If the target is set at 35% for energy consumption efficiency for rural areas ten percentage points lower than current urban efficiency, the energy saving potential of rural areas is 29%. Meanwhile, when the target energy consumption efficiency of urban areas is set at 60%, the same efficiency as in Japan, the energy saving potential is 25%.

Energy consuming equipment for domestic use includes various electric appliances, lighting equipment, and firewood, coal, and gas-fired appliances. Improving the energy consumption efficiency of the equipment and appliances counts most in the residential sector. In particular, the energy consumption efficiency of firewood-fired kilns used in kitchens in rural areas is approximately 10% . That of coal-fired kilns used for the same purpose is 25%. And for gas-fired kilns, it can reach as high as 60%. There is a great demand for energy for kitchen and hot-water supply use in both urban and rural areas in China, so that improving the efficiency of the appliances or shifting from low-efficiency appliances to high-efficiency ones is considered to contribute significantly to improving the overall energy consumption efficiency.

Meanwhile, space heating accounts for 38% of energy demands in urban areas, and 27% in rural areas, so that it carries a lot of weight in both cases. As space heating systems in rural areas are of the decentralized type and are operated by burning coal, the heating efficiency is only 35%. As the spread of central heating and air-conditioners is anticipated also in rural areas, an improvement in the energy consumption efficiency of heating can be expected. Boosting the insulation performance of housing in urban is also a key factor.

Conclusion of residential sector: By calculating weighted averages for urban and rural areas, the energy saving potential of the residential sector is estimated to be 28%.

2.2.3 Transport Sector

Energy consumption in the transport sector accounts for 10% of final consumption. 62% of that is attributed to road transport, where gasoline-fueled vehicles consume 67%. The average stock-based (all existing vehicles) fuel efficiency of gasoline-fueled vehicles is 10.8 km/L[79] in China, while it is 13.5 km/L in Japan. Thus the energy saving potential in China is 20%.

Improving the energy consumption efficiency in the transport sector, especially in road transport would make a high impact. Energy consumption in the transport sector accounts for 10% of the final consumption. The number of vehicles is increasing quickly with an annual average growth rate of 27% during the period from 1990 through to 2000. Furthermore the growth rate of private-owned passenger cars reached 33% in 2002. The number of vehicles, which is now 16 million, is estimated to increase to around 100 million in the year 2020, increasing the share of energy consumption of the transport sector to 14%.

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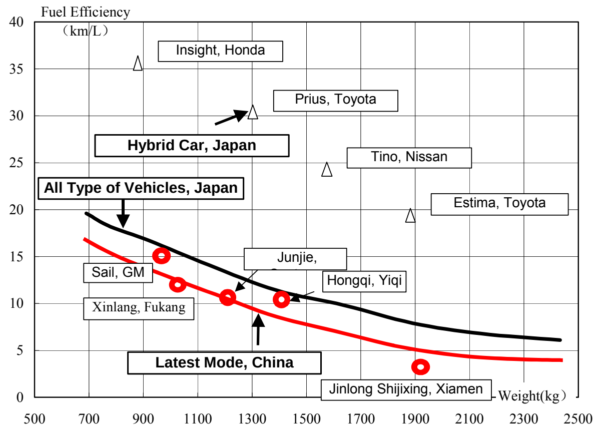
79 Note that the estimation made here was based on the average fuel efficiency of the latest models in China, 11.2 km/L, which was converted to stock average with the ratio of 1: 1.04 (ratio of new mode to stock-base in Japan in the ’80s). This suggests that the average fuel efficiency for all models in China is worse.



Source: Data for China is from China Automotive Technology and Research Center (2001). But they are converted to Japanese 10-15 mode for comparability. Data for Japan is from Ministry of Land, Infrastructure and Transport, Japan (2001).

Figure 3 Comparison of fuel efficiency between Japan and China

The majority of existing cars are old models and their fuel efficiency is currently poor. As shown in Figure 3, the average fuel efficiency of the latest models in China is even worse than that of all models in Japan. There is room for improvement in the fuel efficiency of Chinese vehicles that could be higher than 20%. In Japan, there has recently been a growth in the market penetration of high efficiency hybrid cars such as Toyota Motor Corp's Prius. The spread of such high efficiency cars should be studied strategically in China because motorization is progressing rapidly.

Conclusion of transport sector: The energy saving potential of the whole transport sector is estimated to be 20%.

Conclusion of final consumption sector: Based on the energy saving potential of the industrial, residential, and transport sectors, the energy saving potential of the final energy consumption sector is estimated to be 26%.

Conclusion of primary consumption sector: Based on the energy saving potential of the energy transformation and final consumption sectors, the energy saving potential of primary energy consumption is estimated to be 26%[80].

3. ECONOMIC STRUCTURE CHANGE POTENTIAL

To measure the energy saving potential of economic structure change, we follow the equation below,

$I=E/V=\Sigma(E_i/P)=\Sigma(E_i/P_i)(P_i/P)$,

where I is the average energy intensity of GDP; E is the total energy consumption; P is GDP; i is sector index; E_i is the energy consumption of sector i; P_i is the value added of sector i.

Since P_i /P stands for the economic structure, we replace it by that of Japan and then measure the energy saving potential of economic structure change by comparing the change of energy intensity. The energy intensity of GDP of China is originally 85.3 toe per Million RMB Yuan, and when using the economic structure of Japan, it becomes 57.3 toe per Million RMB Yuan (Table 5). Therefore, the energy saving potential of economic structure change is 33%.

China is a developing country and its economic structure is most characterized by *Gongyehua*, meaning being industrialized. While Japan is an industrialized country with primary, secondary and tertiary industries accounting for 1.4%, 32.1% and 66.5% of total GDP, China's three industries account for 16.4%, 50.2% and 33.4%, respectively. China's heavy reliance on secondary industry is a main structural reason that causes its higher energy intensity of GDP. It is because that the ratios of energy intensity among the three industries are roughly 1:5:1.5.

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80 Strictly speaking, energy conversion losses saved in the final consumption sector will be amplified in primary sector, because energy transformation efficiency is less 1. But it is not considered here.

As shown in Column A in Table 5 sorted in energy consumption share, its first seven sectors (Iron & Steel, Chemicals, Non-metals, Transport & Telecommunication, Mining, Oil & Coal Products and Electric Power, Gas & Water) consume as much as 67.1% of total energy. Because total shares of these sever sectors add up to as much as 25.9% of GDP, a figure much higher than 14.0% in Japan, and the energy intensities of these seven sectors are much higher than the average energy intensity of 85.4 toe per Million RMB Yuan, these sectors inevitably push up much of the energy consumption.

On the contrary, China's tertiary industry is still under development. Because the energy intensity of the tertiary industry is less than one third of the secondary industry, a shift from the secondary to the tertiary sector will contribute much to improving energy consumption efficiency. Although recent economic development shows that China is relying more on heavy industry, the fact that China's tertiary industry's share of GDP is only half of that of Japan reveals that there is large room left for economic structural change.

4. CONCLUSIONS

China's energy saving potential has been measured from two aspects, i.e., potential of technology improvement and potential of economic structure change. Both technology improvement and economic structure change are difficult to achieve during a short period. The fact that there are many companies in the cement and iron and steel industries alone is enough to demonstrate that improvements in energy efficiency cannot be achieved quickly. It would also cause problems of unemployment, social stability, and economic progress.

Analysis results show that energy saving potential of technology improvement is 26%, and that of economic structure change is 33%. Statistically, these two potentials add up to 50% of energy saving, or 570 Million tons of oil equivalent, this quantity of savings would impact highly on China's energy consumption, economy development and environment protection.

Table 5 Energy saving potential of economic structure change (Year 2000)

Sector	Energy Consumption Share		Energy Intensity		Economic Structure		Contribution to Energy Intensity	
	(E_i/E) (%)	Order	(E_i/P_i) (toe/M.Yuan)	Order	China (P_i/P) (%)	Japan (P_i/P) (%)	China (toe/M.Yuan)	Japan (toe/M.Yuan)
	A	B	C	D	E	F	G (=C*E)	H (=C*F)
Iron and Steel	15.1	1	575.9	1	2.2	1.0	12.9	5.7
Chemicals	13.7	2	291.0	5	4.0	1.8	11.7	5.2
Non-metals	9.2	3	407.4	3	1.9	0.7	7.9	3.0
Transport & Telecommunication	8.8	4	124.0	8	6.0	6.4	7.5	7.9
Mining	7.2	5	111.9	11	5.5	0.1	6.1	0.1
Oil and Coal Products	6.6	6	415.0	2	1.4	1.2	5.6	5.2
Electric Power, Gas & Water	6.5	7	115.1	10	4.9	2.8	5.6	3.2
Agricuture	5.3	8	27.7	21	16.4	1.4	4.5	0.4
Other Service	5.2	9	23.3	24	19.2	46.5	4.5	10.8
Non-ferrous	3.3	10	320.0	4	0.9	0.4	2.8	1.3
Food	2.9	11	50.8	17	4.8	2.5	2.4	1.3
Wholesale and Retail Trade	2.7	12	27.7	22	8.2	13.6	2.3	3.8
Textile	2.3	13	89.3	12	2.2	0.2	2.0	0.2
Other Manufacture	1.8	14	140.9	7	1.1	1.1	1.5	1.6
Pulp and Paper	1.7	15	201.6	6	0.7	0.6	1.4	1.3
Construction	1.3	16	17.0	27	6.6	7.4	1.1	1.3
Electric Equipment	1.2	17	18.4	26	5.6	4.2	1.0	0.8
Transport Machinery	1.2	18	43.8	18	2.3	2.2	1.0	1.0
Ordinary Machinery	1.0	19	58.8	15	1.4	2.0	0.9	1.2
Metal Products	1.0	20	79.5	14	1.0	1.1	0.8	0.9
Special Machinery	0.7	21	57.9	16	1.0	0.3	0.6	0.2
Rubber Produtcts	0.5	22	120.1	9	0.4	0.3	0.5	0.3
Garments	0.3	23	22.9	25	1.0	0.4	0.2	0.1
Timber Processing	0.3	24	82.6	13	0.3	0.2	0.2	0.2
Publication and Printing	0.2	25	40.4	19	0.3	1.2	0.1	0.5
Leather Products	0.2	26	24.4	23	0.6	0.1	0.1	0.0
Furniture	0.1	27	40.2	20	0.2	0.2	0.1	0.1
Average Energy Intensity			85.4				85.4	57.3

Note 1: Noncommercial and renewable is excluded.
2: Residential energy consumption is excluded.
3. See context for Symbol meaning.

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ELECTRICITY PRODUCTION AND ENERGY CARRIERS BREAKOUT GROUP

Clean Coal Technologies for Climate Protection: Utilize today's options and develop future potentials

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INTRODUCTION

RWE Power and Vattenfall Europe (VE) are leading utility companies in Germany whose power generation is based on a mix of fossil fuels, nuclear energy and renewables. RWE Power has an installed capacity of 26.300 MW in Germany. VE has 15.700 MW at its disposal. In addition, the RWE and Vattenfall group of companies operate power plants in Finland, Germany, Hungary, Poland, Sweden and the UK. The Production in Germany totals to roughly 230 TWh (figure 1):

RWE Power and Vattenfall Europe: Major Players in the German Power Market (2002/2003 figures)

RWE

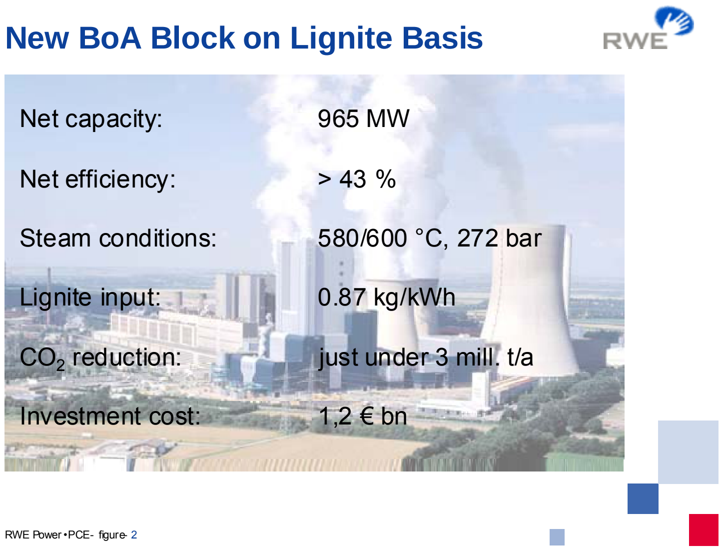
	RWE + VE	Germany
Installed Capacity	42,000 MW	101,000 MW
Production	230 TWh	520 TWh
Production by fuels		
- Coal	69 %	52 %
- Nuclear	21 %	30 %
- Oil/Gas	5.5 %	9 %
- Renewables	3.8 %	9 %
CO_2 emissions	182 mill. t	860 mill. t

RWE Power •PCE- figure- 1

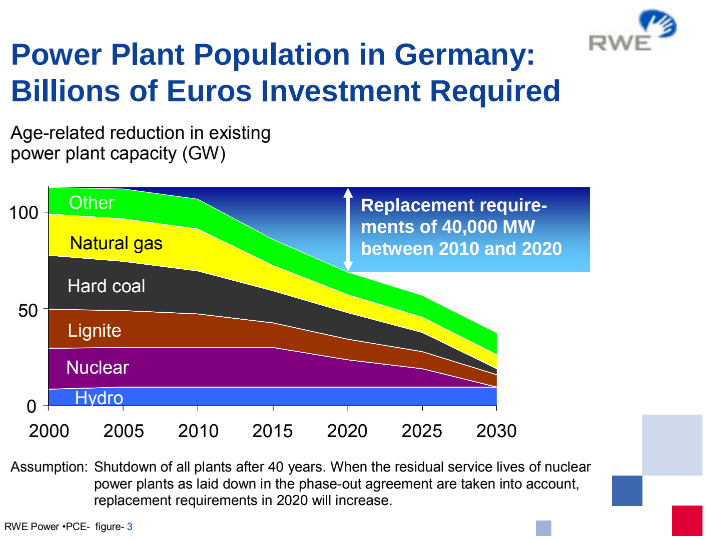
With the competitive domestic lignite extracted in opencast lignite mines and their nuclear power plants, the companies primarily cover base-load power requirements [1]. In the past, oil and natural gas only had a relatively small share in supply because competitiveness in the base load and in much of the intermediate load range, too, has not been given so far.

BOUNDARY CONDITIONS FOR POWER PLANT RENEWAL AND THE ADDITION OF NEW POWER PLANTS

The operation of RWE Power's and VE's power plants result in annual CO_2 emissions of some 182 million tonnes (mill. t) which corresponds to some 21% of German CO_2 emissions totalling approx. 860 mill. t. Thanks to the renewal and retrofit of lignite-fired power plants, both companies have made considerable contributions to cutting greenhouse gas (GHG) emissions in Germany since 1990. With the market introduction of a new generation of lignite-fired power plants in the 900/1,000 MW capacity range (figure 2), the efficiency of new lignite power stations was raised from some 36% so far to more than 43%, although the flue gas desulphurization of the new power plants consumes additional energy. Compared with 1990 levels, GHG emissions in Germany were cut some 19% by the year 2002. Since 1995, a voluntary agreement of German industry and the energy sector with the federal government has been in force on the reduction of GHG emissions until the year 2010. Under the terms of this agreement, emissions are to be reduced by 25% on a 1990 basis.



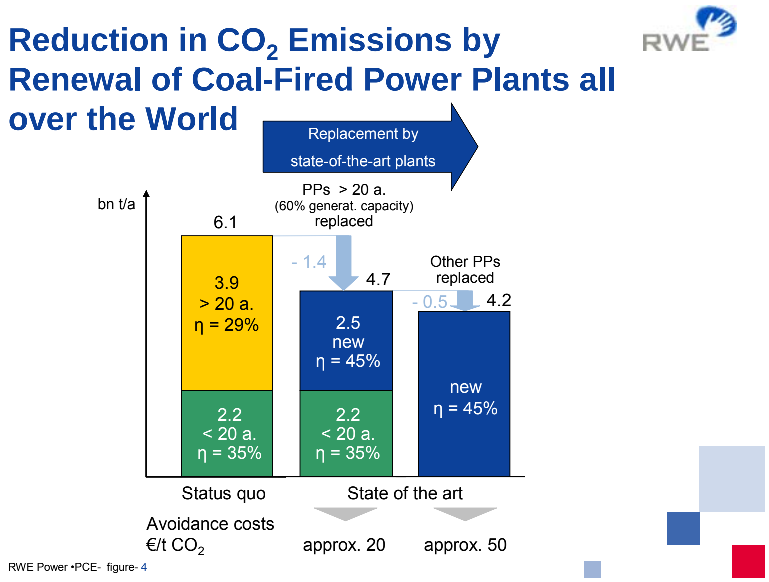
Power plant replacement demand is estimated to be some 40,000 MW in Germany until the year 2020 (figure 3),



and even around 200,000 MW in Europe. This opens up the opportunity to use energy-efficient and, as a result, low CO_2 processes. Besides the renewal of old lignite- and hard coal-fired power plants, companies are also planning to step up the use of natural gas in power generation in future. What must be borne in mind as well in view of the CO_2 balance is that in Germany a political decision was taken to phase out nuclear energy, so that all nuclear power plants will have to be shut down over the next 20 years. It will primarily be fossil fuels that will have to serve as a replacement.

It is a great challenge for privately owned companies of the energy sector to invest large sums in power plant renewal on a liberalized power market--in Germany alone, this investment is estimated to be some €30 billion until 2020--while meeting ambitious CO_2 reduction targets. An indispensable condition is a stable energy policy environment allowing companies to earn a sufficient return on investment geared to the capital market. The second condition is that progressive, but, at the same time sufficiently tested technologies are used in environmental and climate protection measures for the construction of new and replacement power plants, so that the technical/economic risk is manageable [2].

For precautionary climate and environmental protection, it is essential that power plant renewal is implemented as fast as possible. Any delay, also in view of the fact that in several years we will possibly have even more efficient technologies available, is time lost for climate protection. As much as 1.4 billion tonnes (bn t) of CO_2 could be saved worldwide each year if all coal-fired power plants were equipped with state-of-the-art technology (figure 4):



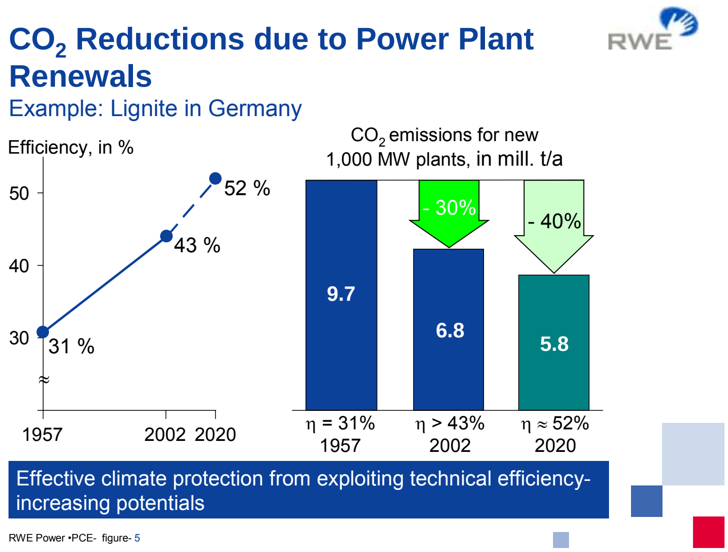
Planning and constructing advanced coal-fired power plants requires a lead time of 6 – 7 years until commissioning. Only technologies that already have a high level of development today and will be available in the next few years--trialled on an industrial scale--can make an important contribution to power generation before 2020. The technical development towards even higher energy efficiency must be stepped up further in parallel with power plant renewal, so that plants that will be planned and built in the next decade can reach an even higher CO_2 reduction.

Developing and testing entirely new power generation systems is very time-consuming and expensive. This applies in particular to the development of a 'zero-CO_2' coal-fired power plant with subsequent CO_2 storage; from an industrial point of view this is still a vision today. To implement this vision, we must reckon with lead times of at least 20 years and development costs of more than €1 billion; this is the lesson learned from the development of pressurized fluidized-bed or IGCC technology over the past decades. For such cost-intensive and high-risk projects, an operating experience of several years gained in industrial-scale demonstration plants is imperative prior to a market launch. For this alone, time requirements of 5 – 10 years will have to be assessed.

EFFICIENCY INCREASE OF COAL-FIRED STEAM POWER PLANTS

Today 38% of the electricity produced worldwide comes from coal-fired power plants. This share will presumably continue to rise until the year 2020, and coal output used for power generation will certainly increase. Therefore, the further development of coal-fired power plant technology to even higher efficiencies is a great challenge that will allow the ambitious CO_2 reduction targets for precautionary protection against the global greenhouse effect to be met [3]. In Germany, experts from science and industry under the auspices of the Federal Ministry of Economics and Labour submitted a 'Research and Development Concept for Zero-Emission Fossil-Fuelled Power Plants' (COORETEC) in 2003 [4]. This report shows the possible lines of development for an efficiency improvement in power plant technology using lignite and hard coal. In addition, it proposes a development strategy for power plants with CO_2 capture and storage.

In the short term, a rise in efficiency of coal-fired power plants beyond the state reached can only be achieved by a further development and optimization of the conventional PF-fired steam power plant. This calls for systematic improvements in the field of fluid mechanics, thermodynamics, materials and the pre-drying of lignite. Raising the process parameters will make efficiencies of ca. 50% possible even for coal-fired power plants in the medium-term, i.e. by ca. 2020 (figure 5):



Various development projects have been launched on a national and European level in order to tap the improvement potentials mentioned. Of central importance to an efficiency increase in steam power plants is the development and testing of high-temperature and anti-corrosive materials. Such materials will be available within the next 10 years, and this puts a steam power plant with process parameters of 700 °C and 375 bar within the range of feasibility. Over the next few years, endurance tests of the new materials and components are planned to be carried out in a component test plant that will be erected at the cost of some €16 million (COMTES 700). Concomitant material qualification is envisaged to be performed by means of practice tests in one lignite- and one hard coal-fired power plant.

For more than 10 years now, pre-drying of lignite has been developed and trialled in Germany, and expectations are that it will bring an efficiency gain of 4-5% points for lignite fired power stations [5]. Within the next few years, RWE Power will spend some €40 million on the construction of an industrial-scale drying plant based on fluidized-bed technology with integrated waste heat utilization (WTA technology) and, in doing so, convert part of an existing lignite-fired power plant to dry-lignite combustion (some 250 MW). So this technology could be available for commercial power plant use by the year 2010.

DEVELOPMENT OF A ‘ZERO-CO_2’ COAL-FIRED POWER PLANT

The time of development and introduction of the ‘zero CO_2’ power plant is expected to be determined by permanent storage of CO_2. Despite many R&D projects started worldwide in recent years, the technology is still in an early stage of research even if some field tests have already been completed successfully. In Germany, sequestration in depleted gas fields, deep salt water aquifers and possibly also in not economically mineable coal seams offer favourable conditions for CO_2 storage, as current findings establish. At present, the costs of CO_2 transport and permanent storage are estimated to be some €10 – 24/t CO_2. Necessary fields of research are listed in the above-mentioned COORETEC concept, and these must be tackled soon in order to qualify and evaluate possible permanent CO_2 storage sites. The research topics range from the detection of suitable geological formations via sealing issues and research into the possible reactions of CO_2 with the site environment all the way to safety and environmental issues. In order to allow a comprehensive evaluation of the overall concept of a ‘zero-CO_2’ coal-fired power plant from an industrial viewpoint, VE and RWE Power participate in a European project on research into CO_2 storage (CO_2 SINK).

Companies, however, are focussing on power plant-related research topics. In principle, for CO_2 capture as well, end-of-pipe technologies, i.e. the separation of CO_2 from the flue gas of conventional fossil-fired steam power plants by means of physical/chemical scrubbing, can be used. However, such process concepts are very expensive and inefficient in energy terms. When CO_2 capture is introduced, we therefore consider it necessary from today's point of view to change to new power generation processes permitting more efficient CO_2 capture. In the opinion of RWE Power and VE, it is in particular the IGCC technology and the O_2/CO_2-fired power plant (oxyfuel) that come into consideration [6]. Compared with the alternatives discussed, CO_2 separation from the fuel gas of an integrated coal gasification combined-cycle power plant (IGCC) promises not only relatively small efficiency losses and low CO_2 avoidance costs. Above all, the IGCC technology has already reached a high development level. Some 20 years ago, the Cool Water Project was the first IGCC power plant operated in California. Since then, various demonstration plants with a capacity of up to 300 MW have been commissioned in Europe and US. Up to now, however, the IGCC technology has not seen a breakthrough of wide market introduction. The complex technology requiring high capital expenditure has so far not allowed sufficient availability and, as a result, has not been economically efficient in a comparison with conventional power generation processes as yet.

RWE Power and VE have great experience in coal gasification technology, especially in the development and operation of lignite gasification processes. In the 80s and 90s, RWE Power operated a demonstration plant for the production of methanol and, in doing so, successfully trialled the high-temperature fluidized-bed coal gasification process (HTW process). New programmes and projects targeting the development of a 'zero-CO_2' power plant with IGCC technology will have to concentrate primarily on the following subjects: The comprehensive planning and operating experience available should be used to reach a robust and competitive plant design. RWE Power and VE are engaged in this process within the framework of the COORETEC development program. The focus of research and development must be on CO_2 capture and the hydrogen turbine. In Germany, corresponding R&D programmes are derived under the COORETEC initiative. Moreover, RWE Power and VE are involved in the European ENCAP project that deals with further aspects of 'zero-CO_2' coal-based power generation.

An alternative to IGCC with CO_2 capture could be the combustion with pure oxygen (oxyfuel). Here, however, research work was only started a few years ago, so that a much longer development time than for IGCC must be assumed, and we must first wait and see what the results of laboratory investigations and studies are before we can better assess its technical an economic feasibility.

In order to reduce the combustion temperature during oxygen combustion, part of the CO_2-rich flue gas produced must be returned to the combustion process. Research must address the following foci and identify technical solutions:
Combustion, fouling and emission behaviour for O_2/CO_2 combustion
Separation of trace elements from flue gas and wastewater

Compared with a conventional, air-fired steam power plant, boiler, flue gas cleanup and condensation of the steam from the flue gas flow are new or essentially modified process steps that--via bench-scale, pilot and demonstration plants--must be developed to the market introduction stage.

Demonstration and market introduction

Today, generators are operating on a liberalized power market in Europe. In order to be able to stand their ground in competition, they must heed a lot of decision-relevant criteria when making investment decisions. Maximum climate protection in the renewal and construction of new power plants with the most efficient, CO_2-saving technology is only possible if, at the same time, other necessary conditions for these decisions, above all of an economic nature, are fulfilled. The market introduction of new technologies, too, must be measured against this catalogue of criteria.

Economic efficiency

As a consequence of keen competition on the European energy markets, the most important criterion for a justifiable entrepreneurial decision to build a new power plant is more than ever the competitiveness of the produced product, i.e. the power generation costs. New technologies for fossil-fuelled power plants can only contribute to meeting environmental policy goals if the investor can earn a return geared to the capital market. Government aids granted for market introduction and/or penalties imposed on CO_2 emissions can influence the economic efficiency comparison of power generation alternatives to a limited extent. However, the drawbacks of such an investment decision must be considered as well: Although, over the long term, penalties on CO_2 emissions can shift the power generation mix in favour of low-CO_2 fuels and technologies, this often also entails a rise in power prices.

If we assume, for example, that the costs for capture and storage of CO_2 from a coal-fired power plant are € 50/t CO_2, this means an increase in power generation costs of some €40/MWh, resulting in an approx. threefold rise of the usual power generation costs of a coal power plant without CO_2 capture today. Decisions in favour of an introduction of such technologies will only be possible to be made in a global context. Otherwise, the result would be serious market distortions that cannot be accepted in the global competition of industrial regions. Moreover, access to power and energy must remain affordable for people or, in many countries, still has to be established at affordable costs.

Security of supply

A secure energy supply is the prerequisite for sustainable development. And secure supplies can only be guaranteed by a broad energy policy approach. An energy mix that includes all available sources of energy ensures supply at internationally competitive prices, reduces dependence on few supply regions and protects against price peaks of individual energy sources over the long term. Only a diverse energy portfolio will also make a solution to the climate problem possible on a global scale and is the prerequisite for boosting research and development of advanced energy technologies with the goals of increasing efficiency and cutting costs for all relevant energy sources and fuels.

Investment certainty

The energy industry, and here the power sector in particular, is characterized by large investment requirements for infrastructure and generation plants. Therefore, plants normally have a useful technical and economic life of a minimum 30 – 40 years to make optimum use of the invested capital. New investment with such a long useful life can only be justified in a liberalized power market if the main cost factors are calculable in the long run and the political boundary conditions are considered stable. New investment requires a protection of legitimate expectation. This means that e.g. penalties on CO_2 emissions, if this is a political goal worldwide, must not devaluate investment already made. Otherwise investment will be stalled and/or concentrated one-sidedly on plants offering short payback times.

Another aspect in risk management of power plant investment is that investment is only made in plants whose technical operating risk is manageable or calculable. The market introduction of new technologies is therefore only possible after comprehensive up-front testing in demonstration plants. Demonstration is part of power plant development which in general calls for government aid.

Research and development
Long-term and sustainable CO_2 reduction is only made possible by technological progress, i.e. in the power sector above all by the development of energy-efficient power plants. New developments of fossil-fired plants are--as already mentioned—very expensive and time-consuming and therefore require long-term and continuous financial backing at a high level. This does not square with the fact that R&D expenditure on fossil power plant technology in Europe has not been stepped up, but, on the contrary, slashed since 1990. Meanwhile, it is true, a change of opinion is noticeable, but this has not been sufficient so far to enable rapid progress. In a liberalized power market, companies are not able to close this gap. In Germany, we hope that the COORETECT initiative will give rise to a new, comprehensive energy technology development programme.

A development strategy for efficiency enhancement and CO_2 capture technologies calls for a clear avowal of the long-term role of coal in the energy mix. This is necessary, on the one hand, to justify development financed by public funds and, on the other, a prerequisite for stronger commitment by private companies.

SUMMARY

A strategy of precautionary climate protection requires close cooperation between the political decision-taking bodies and the sectors and companies of the energy industry that--generating power or producing energy-intensive products--account for a large portion of global CO_2 emissions. A special role is played by power generation from fossil fuels, in particular coal.

Since fossil power generation cannot be dispensed with even in the long term, CO_2 reduction strategies must take account of the sector's specific requirements and its technical and economic possibilities, so that energy remains affordable for people and can be guaranteed without any disruptions. This leads to the following demands:

- Covering the rising power needs worldwide will require the use of coal in power generation for decades to come. In order to reconcile this with the CO_2 reduction requirements of precautionary climate protection, the R&D efforts to develop even more efficient power plants must be redoubled.
- A significant increase in the energy efficiency of coal-fired power plants thanks to continuous technical improvements is also foreseeable for the future; the power plant portfolio must be continuously renewed or extended based on the actual state of the art and irrespective of long-term development goals.
- Developments in energy technology and, above all, industrial-scale testing in demonstration plants are so time-consuming and expensive that they cannot be implemented without public money in a liberalized energy market;
- The 'zero CO_2' coal-fired power plant is a development vision whose implementation should be spurred in the next 20 years with the collaboration of power plant operators.

The energy sector requires heavy investment that can only be made if a return geared to the capital market can be earned; investments once made must not be devaluated by changes in political boundary conditions before the end of their useful technical/ economic life has been reached.

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Life Cycle Assessment on the Liquefied Natural Gas

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1. INTRODUCTION

As global environment issues become more critical, greater attention is being paid to methods for evaluating the extent to which products and corporate activities are friendly to the environment. One of the methods under consideration is the LCA (life cycle assessment) method of evaluating environmental impacts throughout a product's life from raw material acquisition through production, consumption and disposal. This method is of particular interest because of its ability to suggest products and production processes with low global environmental loading over the whole life cycle.

In the energy sector, it is becoming necessary to be able to utilize LCA analysis to suggest urban energy systems and domestic appliances that are friendly to the environment. In order to be able to do this, it is essential to have reliable data on emissions of greenhouse gases over the whole life cycle, from production of the fossil fuels used as fuel to the consumption stage. LNG and city gas are the subject of high expectations as key energy sources that can make a substantial contribution to the effective use of energy resources, the improvement on atmospheric environment and CO_2 mitigation. For this reason, it is important for all countries and all sectors to gain an accurate picture of emissions of greenhouse gases during the production and liquefaction processes for LNG and city gas, in order to be able to implement LCA appropriately and to use the LCA findings as a basis for policymaking.

During the period from 1998 to 2003, the Japan Gas Association and the authors of this paper conducted on-site surveys of gas fields/liquefaction terminals in Southeast Asia, Oceania and the Middle East, the sources of LNG for city gas. The survey teams gathered actual data on CO_2/CH_4 emissions and energy efficiency in the gas fields/liquefaction terminals. The life cycle emissions of greenhouse gases for LNG and city gas were then analyzed[1), 2)] on the basis of the requirements for representative and reliable data from known sources set out in ISO14040 (LCA Principles and Framework).

The findings of this analysis not only demonstrate once more the environmentally friendly nature of LNG, but are significant for providing basic data that is of use in examining the reduction of greenhouse gases by the effective utilization of LNG. In Section 4, consideration is given to the potential for LNG to reduce greenhouse gases, from the perspective of expectations for LNG's role and based on the results of this research. It is well known that when acquiring energy, there are big differences in the levels of CO_2 emissions and other factors according to the conditions applying at the location in question. It was Japan that took the lead in developing and deploying systems for transporting natural gas as LNG, but they are now coming into general use worldwide. Establishing the evaluation methodology for LCA of LNG transportation – a key system – will identify the specific conditions applying to Asia and other regions where LNG demand is expected to grow, contributing to the reliability of CO_2 emissions assessments in these regions, and will also be significant in terms of providing knowledge of use in conducting objective evaluations of similar sorts of systems that are subsequently applied worldwide.

2. LIFE CYCLE CO_2 ANALYSIS METHODOLOGY FOR LNG/CITY GAS

The scope of the assessment covered by the analysis, or in other words, the boundaries of the system, is as shown in Figure 1. For natural gas production/liquefaction, the assessment took into account CO_2 emissions from fuel consumption, CO_2 emissions from flare combustion, CH_4 vent emissions, and CO_2 emissions associated with construction of equipment. Next, for overseas transportation, the CO_2 emissions associated with energy consumption during transportation, and CO_2 emissions associated with construction of ships and other equipment were taken into account. In the analysis for city gas, these considerations were supplemented by taking into account the CO_2 from fuel consumption in gasification and city gas production, and the CO_2 emission associated with the manufacture of equipment. The assessments incorporated CO_2 mitigation through the use of

LNG cryogenic energy, which is possible because LNG is kept at -162°C. Finally, for both LNG and city gas, the assessments include the CO_2 emissions at the stage when the gas is finally combusted. The bottom up approach was adopted as the method of analysis. CO_2/CH_4 emissions were computed from environmental loading and the energy balance at each stage, analyzing CO_2/CH_4 emissions over the whole life cycle. For the calculations, CH_4 was converted to the equivalent amount of CO_2 in terms of its global warming potential (21 times the GW_p of CO_2[3]).

The analysis was conducted as follows.
Surveys were conducted of overseas transportation and of gas fields/liquefaction terminals in the countries from which Japan imports LNG, evaluating the emissions of greenhouse gases due to LNG using up-to-date and reliable CO_2/CH_4 emissions data.

In addition to 1), CO_2 emissions were evaluated for the whole of the city gas (13A) chain, taking into account the use of LNG cryogenic energy as well as LNG vaporization and heating value adjustment at the city gas manufacturing plants of three gas companies (Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd., Toho Gas Co., Ltd.). The three gas companies account for approximately 75% (2002 figures) of the amount of city gas supplied in Japan.[4]

For both 1) and 2), life cycle emissions of greenhouse gases were evaluated, including the CO_2 emissions associated with the manufacture of equipment for natural gas production, liquefaction, transportation, domestic plants, and pipelines.

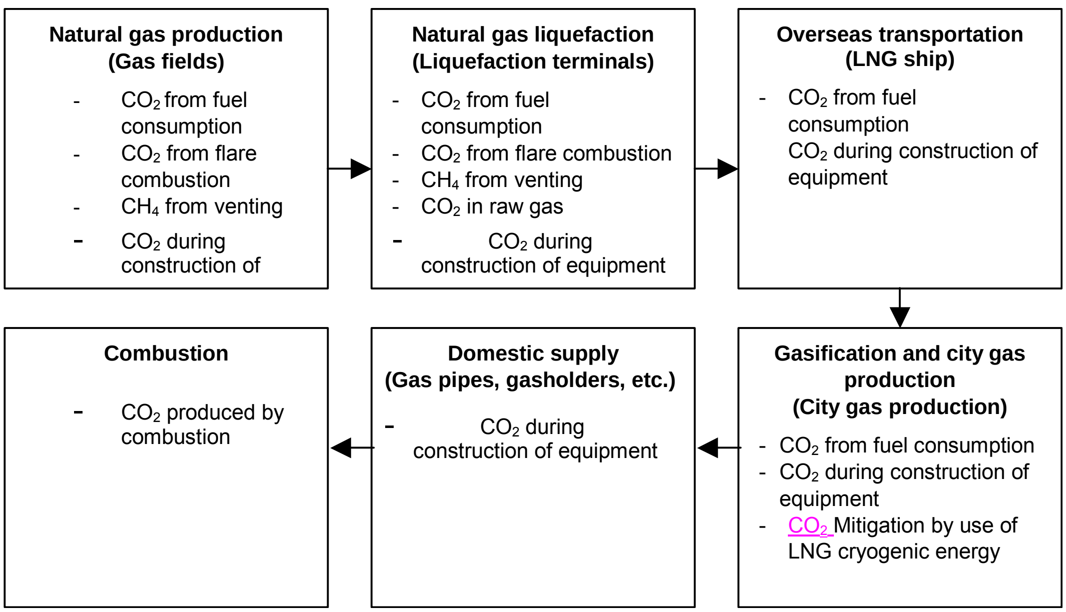

Fig.1 Evaluation scope of LCA in this report

Table 1 shows a record of Japan's total LNG imports for FY2002, broken down on a project basis,[5] together with the results of an informal survey into amounts imported by the three gas companies involved in this study.

Table 1: Total domestic LNG import to Japan and LNG import for three gas companies (2002)

Exporting location	Total LNG import to Japan		LNG import for three gas companies	
	Amount (Mt)	Percentage (%)	Amount (Mt)	Percentage (%)
Indonesia	17.52	31.9	4.77	31.6
Malaysia	10.88	19.8	4.28	28.3
Australia	7.15	13.0	2.26	14.9
Qatar	6.64	12.1	1.97	13.0
Brunei	6.01	10.9	0.84	5.6
Abu Dhabi	4.63	8.4	0.00	0.0
Alaska	1.25	2.3	0.32	2.1
Oman	0.87	1.6	0.68	4.5
Total	54.96	100.0	15.12	100.0

3. LIFE CYCLE CO_2 ANALYSIS FOR LNG/CITY GAS

3.1 Emissions at the natural gas production/liquefaction stage

On-site surveys of gas fields/liquefaction terminals were conducted in the countries from which Japan imports LNG, analyzing the sources of CO_2/CH_4 emissions and the actual amounts of emissions.
The situation regarding CO_2 and CH_4 emissions in natural gas production and liquefaction is set out below.

(1) Natural gas production stage

a) CO_2 from fuel consumption

The power for the compressors used to pump natural gas use electricity generated by gas turbines or similar equipment. Natural gas is used as the fuel for generating this electricity, and CO_2 is exhausted when the natural gas is consumed. The amount involved differs according to the pressure of the gas flowing from the gas field.

b) CO_2 from flare combustion, CH_4 from venting

Purged gas in emergencies and at startup is flared at a flare stack so as to produce fewer greenhouse gas emissions than venting. Some gas fields produce no CO_2 at all from flare combustion under normal operation.

Glycol is used as a solvent to eliminate moisture from the natural gas, and some hydrocarbons, including CH_4, escape when the liquid is flushed to recover the solvent. These hydrocarbons have usually been discharged by venting into the air, but recently measures are being taken to cut greenhouse gas emissions by either combustion of the hydrocarbons for release as CO_2 or by injecting the hydrocarbons back into fuel lines.

(2) Liquefaction stage

a) CO_2 from fuel consumption

Similarly to (1), liquefaction plants are powered by electricity generated by gas turbines or similar means, and consequently CO_2 is produced with the consumption of natural gas as the fuel used to generate the electricity. The amount of fuel consumption at the liquefaction stage differs according to the scale of production at the individual liquefaction terminal and according to factors such as plant efficiency.

b) CO_2 from flare combustion, CH_4 from venting, CO_2 in raw gas

Prior to liquefaction, absorbents such as amines are used to eliminate CO_2 content from the natural gas. At the stage when the absorbents are recovered, small amounts of CH_4 that have been dissolved along with the CO_2 are released to the atmosphere as offgas. Recently, measures are being taken to cut greenhouse gas emissions by either recovering the CH_4 and injecting it back into the fuel line, or by combustion of the CH_4 for release as CO_2.

At the natural gas production and liquefaction stage, LPG and heavier hydrocarbons are also produced at the same time, so based on the sort of allocation method shown in Figure 2, the CO_2 and CH_4 emissions at each stage are allocated to different products in proportion to their heating value. In the production of natural gas stage, the emissions are allocated to heavy hydrocarbons (COND1), and at the liquefaction stage, the emissions are allocated to heavy hydrocarbons (COND2), LPG, and LNG.

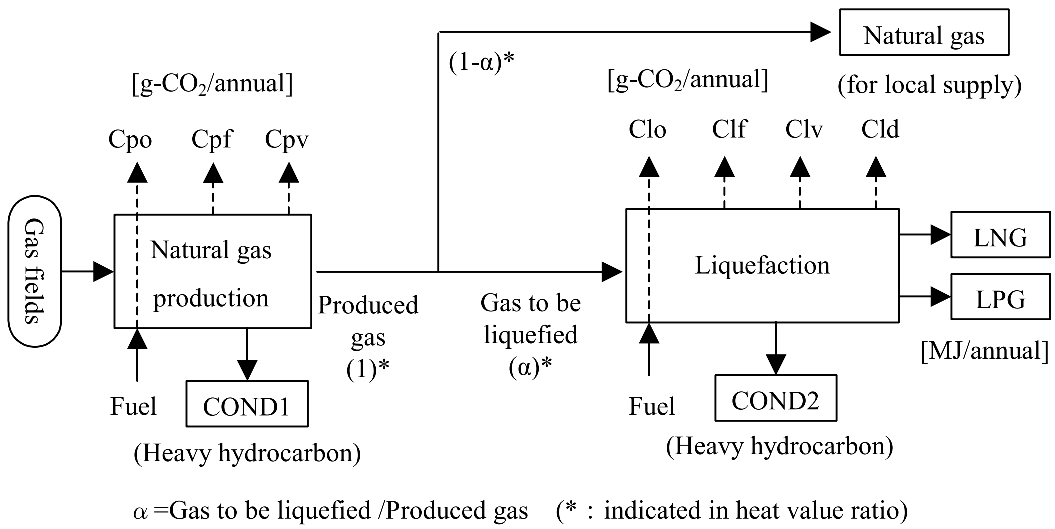

Figure 2: Allocation of CO_2 and CH_4 at the natural gas production and liquefaction stages

Table 2: Proportional allocation of CO_2 and CH_4 at the natural gas production and liquefaction stages

Item		**Allocation formula [g-CO_2/MJ]**
Natural gas production	**CO_2 from fuel consumption**	$\frac{Cpo \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
	CO_2 from flare combustion	$\frac{Cpf \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
	CH_4 from venting	$\frac{Cpv \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
Liquefaction	**CO_2 from fuel consumption**	$\frac{Clo}{COND2 + LPG + LNG}$
	CO_2 from flare combustion	$\frac{Clf}{COND2 + LPG + LNG}$
	CH_4 from venting	$\frac{Clv}{COND2 + LPG + LNG}$
	CO_2 in raw gas	$\frac{Cld}{COND1 \times \alpha + COND2 + LPG + LNG}$

3.2 Emissions at the LNG transportation stage

In order to be able to compute the CO_2 emissions associated with LNG transportation, each project was surveyed to discover the transportation ship BOG consumption, bunker C fuel oil consumption, LNG cargo capacity and transportation distance. Weighted averages were then calculated based on the records of LNG imports for each sea route (using the FY 2002 figures shown in Table 1). By calculating the transportation energy intensity, care was taken to provide means of confirming the benefit of transportation efficiency enhancements.

BOG is an abbreviation for boil-off gas, the gas vaporized by the effect of atmospheric heat on LNG at -162°C.

3.3 Emissions at the gasification and city gas production stage

(1) CO_2 from fuel consumption
Surveys were made of the levels of energy consumption by LNG vaporization and heating value adjustment etc. at the LNG receiving terminals of the three Japanese city gas utilities, Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd. and Toho Gas Co., Ltd. The CO_2 emissions due to this energy consumption were calculated, and the value divided by the annual city gas sendout to calculate the CO_2 emission factor. The average CO_2 emission factor for thermal power in Japan[6)] was used as the CO_2 emission factor for purchased commercial electricity.

(2) Emissions of greenhouse gases related to the use of LPG for heating value adjustment
City gas in Japan is subject to heating value standards. For that reason, city gas is produced from the natural gas obtained by vaporizing LNG by adding LPG to adjust the heating value to the 13A city gas quality standard, which requires the gas to have a standard heating value in the range 41.9 MJ/Nm^3 to 62.8 MJ/Nm^3, and a Wobbe index (WI) in the range 52.7 to 57.8. For the purposes of the current study, the level of greenhouse gases emitted during LPG resource extraction, production, transportation and other processes[7)] was added to the evaluation.

(3) Use of LNG cryogenic energy
At LNG receiving terminals, the -162°C cryogenic energy in the LNG is recovered and used in applications such as cryogenic power generation or air separation. The power generated by cryogenic power generation (generation for in-house consumption) is used to provide the electricity needed for city gas production, cutting the amount of commercial electricity that needs to be purchased. Cryogenic air separation is used in the production of liquid $O_2/N_2/Ar$, or the production of liquid carbon dioxide or dry ice. This use of the cryogenic energy in LNG mitigates energy consumption, so surveys were conducted of each project using LNG cryogenic energy at the LNG terminals in Japan run by the three gas companies to discover the extent of use of LNG cryogenic energy and the electricity usage factor when LNG cryogenic energy is used. Based on the findings of those surveys, the amount of electricity consumption displaced was calculated as the reduction in electricity usage due to the use of the cryogenic energy from LNG. The mitigation of CO_2 emissions associated with the cut in electricity consumption was then calculated utilizing the average CO_2 emission factor[3)] for the thermal power sources used in Japan's generating mix to make adjustments to meet demand variations.

3.4 Emissions at the domestic gas supply stage

City gas 13A is sent out to customers by pipeline from the Japanese LNG terminals. A high gas pressure is produced when the LNG is vaporized, so at the city gas production stage, LNG receiving terminals in Japan regulate the pressure before sending the gas out. For this reason, there is no need for compressors or other means of raising the sendout pressure. Consequently, the CO_2 emissions from fuel consumption at LNG receiving terminals are counted as the CO_2 emissions associated with gas supply.

3.5 Emissions during manufacture of equipment

Surveys of the amounts of materials used in manufacture of equipment were performed for the wellhead equipment in the country of production, the LNG carriers, and the equipment for gasification and city gas production and supply. The figures resulting from those surveys were multiplied by the CO_2 emission factors for the manufacture of the materials to calculate the CO_2 emissions produced when the equipment was manufactured.

3.6 Findings of LNG/city gas life cycle CO_2 analysis

The overall figures for emissions of greenhouse gases in the whole cycle for city gas 13A and the LNG chain are collated in Table 3 based on the figures calculated above. The figures for LNG represent the amount of CO_2 equivalent per unit of LNG calorific value at the receiving stage in Japan, and the figures for city gas 13A represent the amount of CO_2 equivalent per unit of city gas 13A calorific value at the point of demand. The CO_2 emission factors for combustion of LNG and city gas 13A were taken to be 49.40 g-CO_2/MJ, and 51.23 g-CO_2/MJ on higher heating value (HHV) basis, as set out in the Guideline for Calculation Methods on Greenhouse Gas Emissions from Businesses.[8)]

Having determined life cycle CO_2 for LNG and city gas, the next step was to perform a comparison with the life cycle CO_2 of other fuels. The results are shown in Figure 3 and Table 4. Figure 3 and Table 4 confirm that LNG and city gas 13A produce greater CO_2 emissions than other fuels at the production and liquefaction stage overseas, but that they are extremely clean fuels when the life cycle total is considered.

Table 3: LNG and City gas 13A life cycle CO_2 analysis results (g-CO_2/MJ)

Item		LNG	City gas 13A
Natural gas production			
CO_2 from fuel consumption		0.50	0.49
CO_2 from flare combustion		0.15	0.15
CH_4 from venting		0.20	0.20
	Subtotal	0.85	0.84
Liquefaction			
CO_2 from fuel consumption		5.47	5.04
CO_2 from flare combustion		0.43	0.35
CH_4 from venting		0.53	0.45
CO_2 in raw gas		1.94	1.59
	Subtotal	8.37	7.43
Overseas transportation			
CO_2 from fuel consumption		1.97	1.58
	Subtotal	1.97	1.58
Gasification and City gas production			
CO_2 from fuel consumption		-	0.23
Use of LNG cryogenic energy		-	-0.31
LPG for heating value adjustment		-	0.28
	Subtotal	-	0.21
Equipment		0.05	0.39
Combustion		49.40	51.23
Total		60.65	61.64

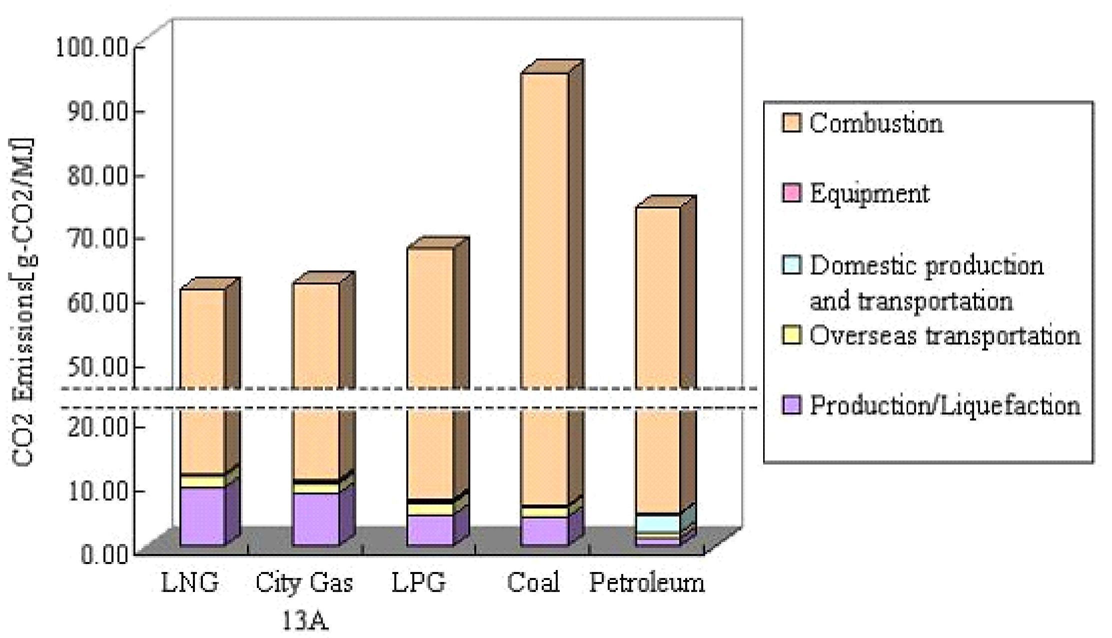

Figure 3: Life cycle CO_2 comparison with other fuels

Table 4: Life cycle CO_2 comparison with other fuels (g-CO_2/MJ, HHV standard)

Item	LNG	City gas 13A	LPG[7]	Coal[7]	Oil[7]
Production/Liquefaction	9.22	8.27	4.94	4.58	1.35
Overseas transportation	1.97	1.58	1.80	1.71	0.79
Domestic production and transportation	0.00	0.21	0.45	0.00	2.94
Equipment	0.05	0.39	0.11	0.11	0.08
Combustion	49.40	51.23	59.84	88.51	68.32
Total	60.65	61.64	67.14	94.92	73.48

4. POSITIVE EXPECTATIONS FOR LNG'S ROLE

The results of the current analysis (Table 4) provide a re-evaluation of the cleanness of LNG as a fuel. This Section discusses methods and issues for more effective use of LNG. It also discusses the further potential for LNG in regions where growth in LNG usage is projected, and methods and issues for making that a reality.

(1) Upstream (natural gas producer country, production and liquefaction stage)
Considering the natural gas production and liquefaction stage, the results of analysis show that CO_2 emissions due to fuel consumption levels at the liquefaction stage are relatively high. In order to save energy in fuel consumption at the liquefaction stage, it is necessary to enhance the efficiency of liquefaction. One conceivable way to raise liquefaction efficiency is to use larger equipment. At terminals where larger equipment is already in use, fuel consumption levels at the liquefaction stage are reduced, producing a cut in CO_2 emissions of about 15% relative to the average for all terminals.
Next, it is clear that there is a large CO_2 content in the raw gas. The CO_2, which takes the form of a solid impurity in LNG, must be separated off during the liquefaction process. If, instead of releasing the recovered CO_2 to the atmosphere, it can be sequestered in the ground or elsewhere, it would be possible to achieve substantial reductions in CO_2 emissions. Sequestering under the ground can be expected to produce additional costs, but approaches such as project implementation under the Clean Development Mechanism (CDM) may be feasible. Technical and economic assistance from advanced nations are likely to be important here.
For flare combustion and methane venting, the most recent LNG terminals are already taking action to achieve zero emissions in these areas.
If these measures are put into action, there appears to be the potential for achieving a cut of approximately 40% in upstream CO_2 emissions (9.22 g-CO_2/MJ) if underground sequestration of the CO_2 in raw gas is included, or approximately 20% if underground sequestration of the CO_2 in raw gas is excluded.
Natural gas is widely distributed around the world, including large resources in Asia, South America, and the Middle East. There is great potential for broad-ranging technology transfer from advanced nations to these developing nations through CDM or other international agreements, making available the many technologies needed to optimize $LCCO_2$ in the liquefaction of natural gas.

(2) Downstream (LNG demand country, city gas production and combustion stage)
As can be seen from Table 3, substantial CO_2 mitigation can be achieved through effective use of the -162°C cryogenic energy in LNG. In developing countries in Asia where new demand is projected and LNG demand is expected to grow, optimum plant design needs to take into consideration intersectoral cooperation such as siting plants to use LNG cryogenic energy adjacent to LNG terminals. Doing this has the potential for achieving new CO_2 mitigation through the use of LNG cryogenic energy. The results of the current analysis show that using the cryogenic energy in LNG enables approximately 0.36 t-CO_2 of CO_2 mitigation per ton of LNG. For example projections for 2020 of demand for LNG in China suggest demand of approximately 15 million tons per year.[9] It is estimated over 32 million t-CO_2 per year of CO_2 mitigation by providing 15 million ton per year of demand with LNG compared with the case where it is assumed that all of the demand is provided with coal as before. If plant design takes the use of this cryogenic energy into consideration right from the start, it would be possible to contribute mitigation amounting to another 5.4 million t-CO_2 per year.

Use of LNG is now under consideration in developing countries, too, particularly in countries such as China and India where substantial energy demand is envisaged. When these countries start using LNG, there is great potential for international cooperation in the transfer of LNG cryogenic energy utilization technologies that have been nurtured in Japan.

Next, looking at energy consumption in developing nations, it can be seen that there is great potential for CO_2 cuts by converting to LNG fuel from fuels such as oil or coal, and it is considered essential to actively encourage this approach. There are strong expectations of benefits from technologies applicable to the use of natural gas, such as cogeneration, which enable the optimum use, cascade-style, of the natural gas. There is good potential for international agreements for the transfer of this sort of advanced technology from advanced nations to developing nations.

The findings of the LCA analysis presented here demonstrate that greenhouse gases can be mitigated by the use of LNG, and that it is possible to quantify the effect in advance. The findings of the current study are also expected to be of broad-ranging use as basic data for quantification.

In general, when evaluating total efficiency or CO_2 emissions of energy systems that require complex conversion processes between the primary energy resource and the final form of demand, the whole energy chain needs to be evaluated, not just the factors at the point of demand. In other words, LCA-style evaluations are essential. Regarding CO_2 emissions in particular, it is essential to clarify the extent of CO_2 emissions and energy losses at each locality or to clearly show how they eventually are affected by various forms for the final demand. It is essential to give a high rating to efficient systems that have low CO_2 emissions in overall and global terms. It is very likely that people will be considering systems that involve new methods of conversion, such as complex energy chains that include CO_2 recovery and sequestration as well as using hydrogen to keep CO_2 emissions down. In that sort of situation, it is extremely important to establish means of evaluating the CO_2 emissions of such systems by utilizing the sort of objective and transparent methods introduced here. In the future, the authors intend to provide useful information in the form of practical example of the application of the sorts of evaluation methods described in this paper to hydrogen systems and systems for conversion of sustainable resources.

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Contribution of nuclear technology to climate change mitigation

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Abstract
To mitigate global climate change, the energy industry is presently offering efficient technologies for power generation. Not only the energy and electricity savings must be encouraged but also greenhouse gas (GHG) neutral or GHG free technologies must enter on the markets thus re-orienting the energy mix in the different regions of the world. Nuclear energy is a quasi CO_2 free technology that already contributes to mitigate the global climate and might do better in the long term. Today, nuclear light water reactors are currently used for power generation either in once-through uranium fuel cycle or with spent fuel reprocessing and recycling of plutonium. But other types of reactors like high and very high temperature reactors can provide both electricity and high value heat. They can produce hydrogen, a promising future energy vector for transportation, without emitting GHG. In a longer term, fast breeder reactors could release the constraint on world fissile resources.

Present world nuclear fleet has good record tracking on technical performances and safety. Nuclear is recognised as profitable despite a high investment cost for new units compared to other technologies and contributes to national energy security. In the near future, to gain more public favour, governments have to demonstrate their commitment to deploy adapted waste management strategies. Non-proliferation aspects have to be addressed on a world basis.

The company AREVA is one of the major nuclear market actors offering different types of reactors (PWR, BWR, HTR). It has feedback experience of transferring technology through long-lasting partnerships. The partnership with the Chinese nuclear industry driven by a true win-win spirit has shown success stories at the Daya Bay, Ling-Ao and Qinshan II nuclear power plants. Technology transfer is an important factor to help developing countries to address their increasing energy demand and to build an active industry network. And transfer of clean technology helps for fighting against climate change.

NEED FOR MITIGATION

According to the International Energy Agency 2002 publication **[1]**, the world emissions of greenhouse gases were about 6.2 Gt of carbon per year in 2000, the power generation emissions representing 40% of the total. Total emissions would rise up to about 7.5 GtC/year in 2010, 8.9 in 2020 and 10.4 in 2030 on a business as usual (BAU) pathway (reference scenario). The BAU trend would go as high as 15 to 16 GtC in 2050.

The CO_2 atmospheric concentration is now about 380 ppm compared with pre-industrial concentration of 280 ppm. Is it possible to stabilise the atmospheric concentration of carbon dioxide by the end of the 21st century at a level avoiding too harsh adaptation effort?

Climate stabilisation will take time all the more that oceanic balances are very slow. According to the IPCC/SRES ad hoc scenarios **[2]**, the carbon emissions per year would have to follow a curve passing by a maximum before the middle of the century and then decreasing in the long term down to around 2 GtC. Most scientific people agree that we are missing the stabilisation target of 450 ppm of CO_2 equivalent in the atmosphere because now on it would imply too much effort of reduction. Total emissions should be limited to about 10 GtC per year by 2050 to comply with the 550 ppm target. That means a division by nearly two at that time compared with the BAU pathway based on 1990's technologies.

Human adaptation systems to climate change will have to be developed but world adaptation capacity to climate damages is limited especially for developing countries. We thus need to implement mitigation policies to avoid unbearable costs for economies.

The Kyoto Protocol requirements for 2008-2012 represent the first step but are not sufficient to curb significantly the emissions. To stabilize at 550 ppm requires avoiding about 6 GtC/year from the current trend by 2050 and even more after. This represents an enormous reduction that should address all economical sectors.

NUCLEAR TECHNOLOGIES CONTRIBUTION TO GHG MITIGATION

First, let us quote S.Pacala and R. Socolow **[3]:**

‘Humanity can solve the carbon and climate problem in the first half of this century simply by scaling up what we already know how to do.’

The global emissions result from the end uses of energy in all sectors. The final consumption is generally spread over three main sectors: industry, transport and residential. The increase in use of more carbon-free electricity in those sectors should be encouraged as well as cogeneration.

In the industry sector, processes that need heat and electricity could heavily benefit from cogeneration which is presently the case but whose installed capacity could be increased in the future. If supplied electricity is de-carbonized, the new industry technologies must favour electric processes and operating devices.

For transportation, besides clean electric vehicles, use of bio fuels and hybrid cars can answer the growing demand. In the far future, transportation may develop from hydrogen either by direct feed for fuel cells or by carbonation of hydrogen and further use as a liquid fuel in conventional engines. But in both cases hydrogen should be produced by a carbon-free source.

For residential sector, solar thermal or geothermal heating for building are clean energy to be enhanced in the future.

So, we see that the main way to fill the gap for energy demand is an increased use of CO_2 free electricity. Several energy technologies can be mobilised to fulfil this specification. Renewable energies such as hydroelectricity, windmills and others should be fostered (biomass which is carbon neutral). However their absolute potential of production remains limited. Much more carbon-free electricity can be generated by nuclear reactors, or by operating carbon capture & sequestration at large fossil power plants (fixed installations). Emerging countries like China and India will continue to use their huge resources of coal because it is rather cheap and because they are facing enormous growing electricity demand. The expected growth in China is about 10% per year in the coming decade. As coal use will constitute a reliable resource for a long time it is very important to develop carbon capture and storage. But it will take some time to industrialise and to operate carbon capture and sequestration plants and we need to better master the long-term carbon storage

Using more nuclear electricity would preserve our limited fossil resources for the other chemical uses in the future. Nuclear energy is presently well adapted to provide massive base load electricity with the currently in-service reactors and the new Generation III+ reactors such as the European Pressurized Reactor (1600 MW_e). Besides, nuclear reactors may have other uses in the future such as providing heat and clean hydrogen with advanced designs of reactors such as the very high temperature reactor. As a consequence, R&D must be favoured for developing the technologies of the future with a special mention on Generation IV nuclear reactors and their associated fuel cycle. **Figure 1** below presents the historical and future evolution of generation types of nuclear reactors.

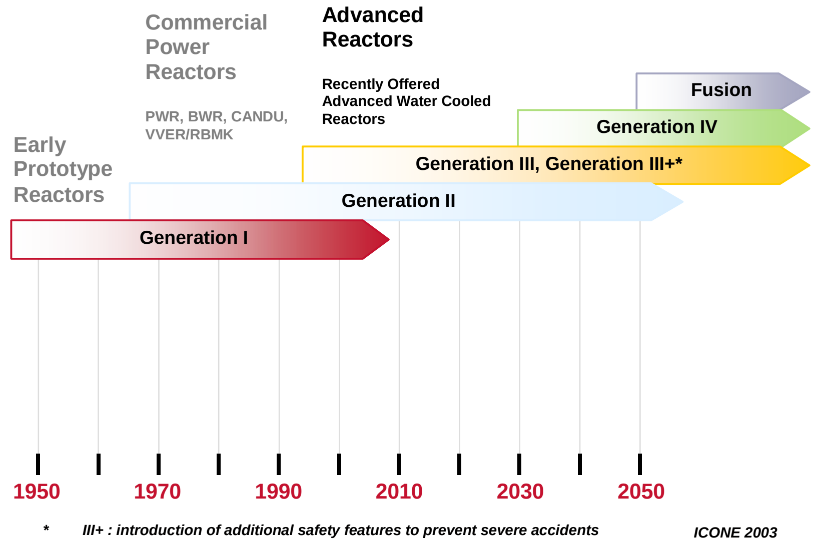


Figure 1: Historical and future evolution of the generation types of nuclear reactors

Through delivering heat or electricity, nuclear could also contribute to water desalination and help facing the fresh water supply around the world.

According to references, world projections of nuclear energy demand by 2050 may be more or less cautious. Represented on the following **figure 2** is the technological A1T/ SRES scenario **[4]** which relies on large development of renewable energies and nuclear, in an attempt to heavily mitigate emissions while preserving a high economic growth. Also shown are the low and high estimations of the IAEA **[5]** until 2030, supported by a business as usual trend. The A1T scenario appears more ambitious but could be achievable if climate concern is taken seriously into account by the governments. In the A1T case, the share of nuclear energy in the global primary energy supply could rise from 2% in 2000 up to 10% in 2050 (nuclear electricity being accounted as primary energy).

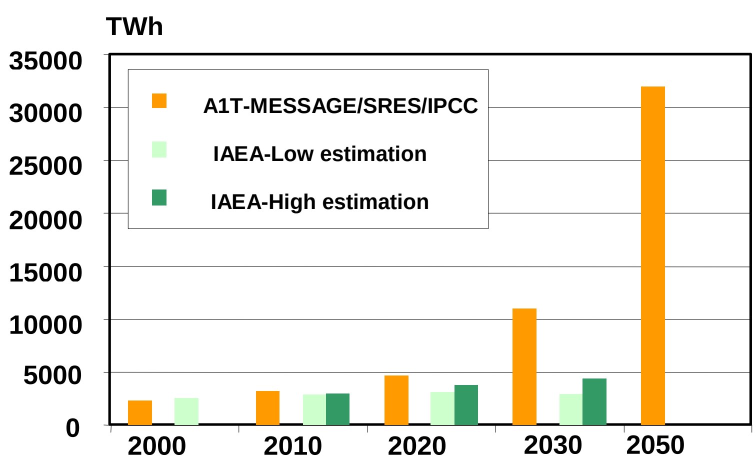


Figure 2: World nuclear energy demand

Responding to such needs with more installed nuclear capacity over the world will only be possible with respecting non proliferation principles, with careful operational safety and high environmental performance. Other definite sustainable conditions are also required: competitiveness and availability of sufficient fissile resource.

CARBON EMISSIONS AVOIDED BY CURRENT NUCLEAR POWER GENERATION

Present nuclear fleet of reactors holds about 439 units (as of the end of 2001) dominated by the light water reactors concept which represent 80% of the total as shown in **table 1**. Typical unit installed capacity is about 1,000 MW_e (600 MW_e, 900 MW_e, 1,000MWe, 1,100MWe, 1,350 and 1,400 MW_e).

Table 1: Break down of present reactors by types (as of 31/12/2003) [6]

Type	Number of units
PWR (Pressurized Water Reactor)	213
BWR (Boiling Water Reactor)	92
VVER (Russian PWR)	50
Sub-total LWR	**355 (near 80% share)**
PHWR (Pressurized Heavy Water Reactors)	38
GCR (Gas Cooled Reactor)	12
RBMK (Water Graphite Reactors)	17
AGR (Advanced Gas cooled Reactor)	14
FBR (Fast Breeder Reactor)	3
Total	**439**

About 30 countries in the world are operating civil nuclear reactors: Argentina, Armenia, Belgium, Brazil, Bulgaria, Canada, Check Republic, China, Finland, France, Germany, Hungary, India, Japan, Lithuania, Mexico, The Netherlands, Romania, Russia, Slovakia, Slovenia, South Africa, South Korea, Spain, Switzerland, Sweden, United Kingdom, United States, Ukraine, Taïwan.

Nuclear emits very low quantities of CO_2 for electricity generation. Life cycle analysis shows a value of about 2-6 gCO_2/kWh produced compared with direct emissions of about 400 g CO_2/kWh for combined cycle gas turbine and between 800-1,000 gCO_2/kWh for coal technologies generation. As of today, **the world's 440 nuclear power stations save 600 MtC/year of greenhouse gases emissions [7]** compared with what they would otherwise emit if nuclear energy were substituted by the present fossil fuels mix. Thanks to nuclear energy world emissions are thus 9% lower and related to power generation that represents a 23% reduction of world emissions.

Let us compare carbon avoidance due to nuclear power with that promised by the Kyoto protocol. The protocol requires that by 2010, Annex I countries collectively reduce their carbon emissions by 5.2% relative to 1990 levels. Assuming that without the protocol emissions would rise according to the projections of the IEA's reference scenario, Kyoto protocol effect on emissions reductions in 2010 would amount to less than 350 MtC/year –perhaps as little as 220 MtC/year if Russia sells all its unused emission allowances to countries that need them. Thus **nuclear power already achieves reductions more than twice the expected reductions from the Kyoto Protocol** seven years down the road.

NUCLEAR CONTRIBUTION TO SUSTAINABILITY

Competitiveness of nuclear power generation

Satisfying electricity demand in real time requires to know or to estimate the real time load curve on the grid. During peak hours, special means are used to fill the gap but base load means of generation represent generally more than half of the total demand. Nuclear power is used in base load generation and must be compared with technologies for similar use that are at least gas and coal generation technologies.

Competitiveness of nuclear electricity generation may vary over the world according to the specific financing conditions and regional costs of investment, operating and maintenance costs and fuel prices. Nuclear competitiveness is favoured by large unit capacities because the main factor is the high investment cost and as well by high load factors which is the case for base load supply.

It is interesting to show an overview in different regions: **Europe**, **North America** (the United States and Canada), **Eastern countries** (Russia), **Asia** (Japan, China, South Korea), **South America** (Brazil).

Europe

Several recent European studies demonstrate a competitive cost of nuclear MWh compared with that of combined cycle gas turbines (CCGT) and coal technologies:

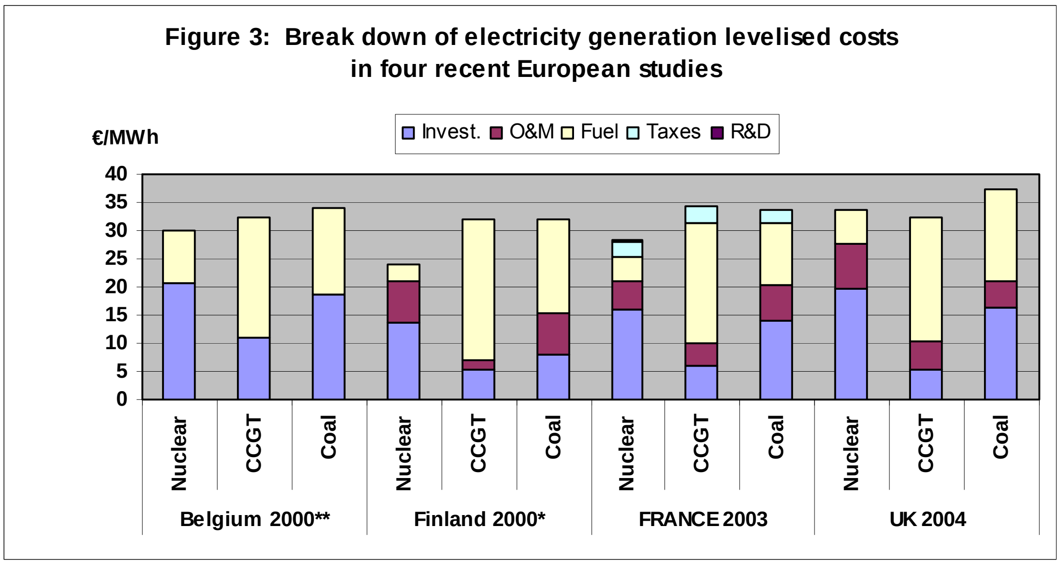
2000: the Belgian report from the AMPERE Commission **[8]**.

2000: the Finnish study **[9]** (Sauli RISSANEN and Risto TARJANNE) in view of building the fifth domestic reactor for electricity generation.

2003: the recent French study **[10]** from the Ministry in charge of Industry, issued by the DIDEME Department, that takes the EPR reactor as reference for nuclear.

2004: the British study **[11]** from the Royal Academy of Engineering that aims to provide decision makers with some indicators of competitiveness of a range of technologies.

In the four studies costs are estimated for new installations to be installed, using the best available technology. **Figure 3** summarizes the results of the four European studies investigated. For coal, the costs mentioned refer to pulverised coal technology.



* More recent values as of April 2001 prices by Tarjanne & Rissanen

** For Belgium, O&M costs are not separated from investment cost

Figure 3: Bread down of electricity generation levelised costs in four recent European studies

We observe that the investment share for nuclear is more significant than for gas (around 60% for nuclear against 15-20% for gas), while gas CCGT technology is more sensitive to gas price which represent about 70-80% of the electricity cost. Coal technologies appear as rather capital intensive. But coal price may be volatile.

The birth of a new CO_2 exchange market in Europe by January 2005 when the European Directive for ETS (Emissions Trading Schemes) enters into force and the applied national regulations will lead to internalise the greenhouse gases emissions cost in the kWh cost from fossil fuels.

Besides generation cost, external costs incurred by society have to be considered in an exhaustive assessment. The ExternE programme of the European Commission has made an attempt to assess those costs since 1990's. The first ExternE studies for power generation technologies were released in 1995 including national implementations [12]. The external costs were assessed for normal operation and in case of a reactor accident for nuclear. For nuclear the results are addressed in a local, regional and global approach with temporal sequences: immediate impact, medium and long-term impact. The results are presented discounted or not. Table 2 indicates the ranges obtained for European countries assessments in the 1998 update (not discounted and including climate change damages for fossil fuels).

Table 2- European external cost of power generation technologies

Electricity source	External cost [€/MWh]
Coal and lignite	20 to 150
Gas	10 to 40
Nuclear	2 to 7
Biomass	10 to 30
Wind	0.5 to 2.5
Hydropower	1 to 10

North America

In the US, nuclear is perceived as financially risky because it is very capital intensive and that the current nuclear fleet has a bad history of investment costs. The MIT 2003 study 'the Future of Nuclear Power' [13] has shown quite high value of nuclear MWh levelised cost. That is due to penalizing assumptions. The first major one being the high overnight investment cost of 2,000 $/kW$_e$ (compared with about 1,500 €/kW$_e$ in European cases); the second being the high specified return on equity (ROE) to investors, about 15% nominal after tax for a nuclear unit instead of 12% for a coal or gas unit. The table 3 below illustrates what could be the levelised cost of MWh if more industrial hypotheses had been chosen.

The figure 4 hereafter puts the results in perspective. Considering a return on equity for nuclear equal to that for gas CCGT, i.e. 12% instead of 15% saves 12$/MWh on the cost of generated electricity. If the investment cost is closer to an industrial cost applying to a series of reactors, that is about 1,500 $/kW$_e$ installed, the cost of electricity decreases by 9$/MWh. Whit a shorter building time and a better operating cost of the plant, it is possible to save additionally two plus two $ per MWh. Nuclear is then fully competitive with gas CCGT and coal plants.

The European values for discount rate (from 5 to 8% real) do not make a difference between the technologies; they give evidence of higher level of confidence. The overall investor risk over the plant lifecycle can be considered as higher for fossil fuelled plants, because of natural gas price versatility and future carbon emission control.

Table 3: Synthesis of generation costs ($/MWh) from the MIT study - 2003 [13]

Nuclear		Coal[81]	Gas CCGT	
Base case	**67**	**42** (coal price 1.2$ /MBtu)	**38**	Low gas price 3.77 $/MMBtu
Examined Variations			**41**	Moderate gas price 4.42 $/MMBtu
• **Reduce construction cost 25%**	**55**			
• **Reduce construction time 5 to 4 years**	**53**		**56**	High gas price 6.72 $/MMBtu
• **Further reduce O&M to 13 $/MWh**	**51**			
• **Reduce cost of capital to gas/coal**	**42**			

81 Pulverized coal, does not take into account the coal price doubling during 2004, which would step up the electricity cost.

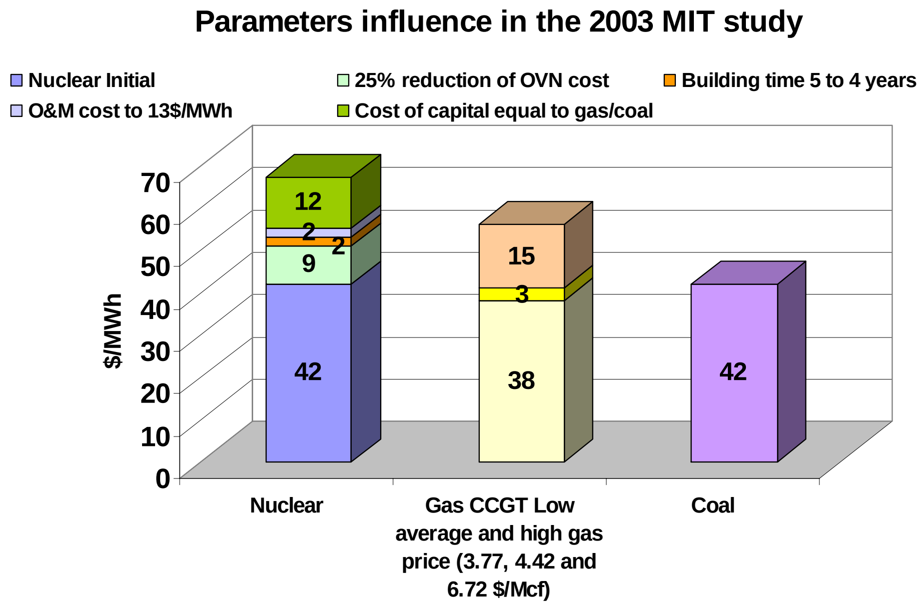


Figure 4: MIT base case and examined variations

The MIT study explores the impact of a fully passed CO_2 cost on the generation cost for several indicative values of carbon: 50 US$/tC, 100 US$/tC and 200 US$/tC that leads respectively to about 13.6 US$/t$CO_2$, 27.33 US$/tCO_2 and 54.6 US$/t$CO_2$. The resulting MWh over costs appear in Table 4.

Table 4: CO2 over-costs considered for CCGT in the MIT study – 2003

US$/MWh over costs	50 US$/tC	100 US$/tC	200 US$/tC
Coal	12	24	48
Gas CCGT	5.25	10.5	21

Conversely, it should be emphasized that the dismantling cost of nuclear reactor is already included in the total reported capital cost. Also, the cost of final waste disposal is included in the nuclear fuel cycle cost. While those future costs are estimated with a margin of error, the real weight of these uncertainties in the total lifecycle cost is limited by the effect of time discounting.

The study recently issued by the University of Chicago in August 2004 **[14]** shows similar results as those of the MIT 2003 study. On **figure 5**, the effect of reducing lead time from seven to five years is displayed. Despite considering the nuclear investment as a mature industrial value, the high requirement for return on equity (ROE) disfavours nuclear power.

Figure 5: Chicago University LCOE's 2004 assessment

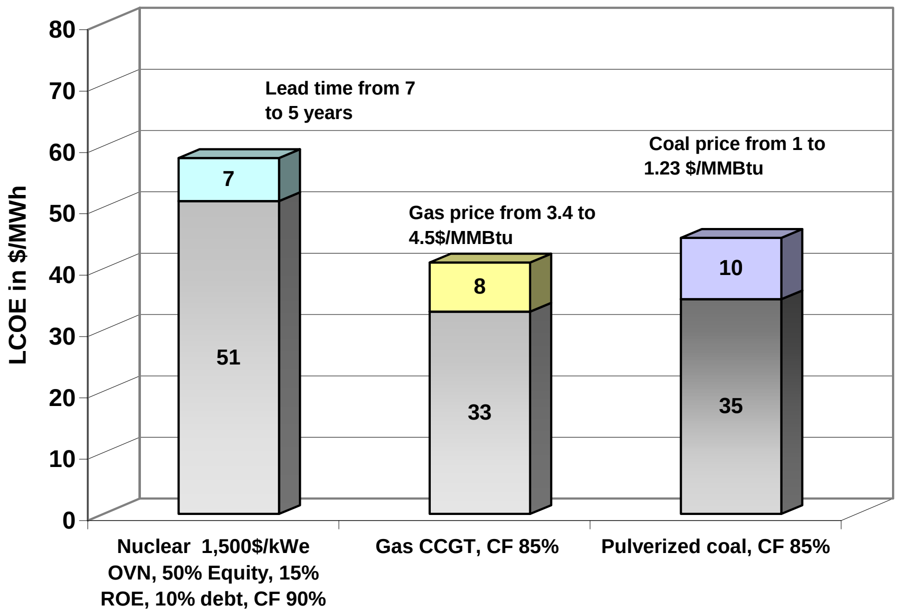


Figure 5: Chicago University LCOE's 2004 assessment

The study issued in August 2003 by the CERI (Canadian Energy Research Institute) for base load generation in Ontario (**Canada) [15]** shows that nuclear generation can be cost-competitive with coal.

Using a 30-year plant lifetime base, CERI assesses the production cost of operating a 1,346 MW_e two unit Candu-6 plant and a 1,406 MW_e two unit ACR-700 plant against 500 MW_e scrubbed coal and 580 MW_e gas turbine plant. Both publicly and privately financing and operating scenarios are examined. The study concluded that the series ACR-700 plant (n^{th} of a kind) could provide the least cost generating option in both merchant and public financing (load factor of 90% in the base case) compared with coal as shown on **table 5**.

Table 5: Levelised Unit Electricity cost assessed by the CERI study (2004)

Can$/MWh	Coal	Gas	Nuclear Candu-6	Nuclear ACR-700 1^{st} of a kind	Nuclear ACR-700 n^{th} of a kind
Merchant	59.3	75.3	88.3	73.3	53.3
Public	**47.7**	72	63.4	53.3	**47.4**

Eastern countries (Russia)

For Russia as representative of Eastern countries, an assessment was provided in the 1998 publication of the OECD/NEA 'Projected costs of generating electricity'**[16]**. The levelised cost of electricity was calculated for a 5% discount rate and a 10% discount rate. Results show a good competitiveness of nuclear power generation against gas and coal technologies in both cases (**table 6**).

Table 6: Levelised cost of electricity in Russia [16]

US$1996/MWh	Coal	Gas	Nuclear
5% discount rate	46.3	35.4	26.9
10% discount rate	55.3	39	46.5

Asia (China, India, Japan, South Korea)

Reference **[16]** provides also information for China, India and South Korea for two discount rates 5% and 10% (**table 7**).

Table 7: Levelised cost of electricity in China, India, Japan and South Korea [16]

US$1996/MWh	Discount rate	Coal	Gas	Nuclear
China	5%	32	-	25.4 to 31
	10%	40	-	39 to 51
India	5%	33 to 37	-	33
	10%	40 to 44	-	51
South Korea	5%	34.4	42.5	30.7 (LWR)
	10%	45	47	48.3

In some cells of table 7, ranges are presented. They reflect the assessment for various types of the same technology basis.

In 1999, the Ministry of industry in Japan had assessed the comparison of electricity costs for all electricity sources where nuclear was the least cost options. Recently by 2003, the Federation of Electric Power Companies has refreshed the assessment with a focus on the back-end of the fuel cycle **[17]**. Assumed discount rate is less than 5% and nuclear remains the least cost option compared with the other technologies. With a 4% discount rate and a 80% load factor nuclear levelised cost is 5.6 yen/kWh compared with coal at 6 yen/kWh and CCGT using liquefied natural gas at 6.4 yen/kWh. These levelised costs are significantly lower than those presented in the 1998 OECD study **[16]**.

South America (Brazil)

Information for Brazil is available in reference **[16]** for the two discount rates 5% and 10%. The results show that in that country gas is cheaper than nuclear for the two discount rates. Again, various types of technologies are assessed leading to two values per cell of **table 8**.

Table 8: Levelised cost of electricity in Brazil [16]

US$1996/MWh	Coal	Gas	Nuclear
5% discount rate	35.4 ; 56.5	28.5 ; 29.7	36.8 ; 33
10% discount rate	43.2 ; 61.8	32.7; 34.9	51.5 ; 46.7

GENERAL CONCLUSION FOR COMPETITIVENESS

On the grounds of technical and economical arguments, we can build a summary of competitive aspects of nuclear, gas CCGT and coal technologies for future investment.

Table 9 collects main advantages and drawbacks of each technology.

Table 9: Summary of advantages and drawbacks of each technology

	Advantages	Drawbacks
Nuclear ***Secures market sales and long term cash flows***	➢ Low fuel cost share to MWh ➢ Very small fuel price influence ➢ Low marginal cost ➢ High capacity factor ➢ Long-term investment – 60 years – Lowest MWh cost ➢ Takes into account the costs of dismantling and of long term waste management	➢ High investment cost per kW_e ➢ Full investment cost depends on financing conditions – and therefore on risk mitigation
Gas CCGT ***Major uncertainties resulting from gas price***	➢ Low investment cost per kW_e ➢ High capacity factor	➢ Gas price contributes to about 70-80% of MWh cost ➢ High marginal cost ➢ Volatility of gas price ➢ Cost of CO_2 emissions
Coal plant ***High cost of externalities***	➢ Relative stable price of coal, despite some peak price periods ➢ High capacity factor	➢ High investment for clean coal ➢ Full investment cost depends on financing conditions ➢ CO_2 cost + air pollution

The regional approach has shown that those criteria apply differently according to national conditions leading to challenge nuclear competitiveness in some cases. But in most developed countries relying on mature technologies and fair financing conditions, nuclear is potentially competitive. Even for similar total lifecycle costs, different relative weights of fixed and variable costs can influence the choice between nuclear and CCGT. Nuclear benefits from a low marginal cost less than 10 €/MWh compared with CCGT (lowest marginal cost around 22 €/MWh). This ensures connexion priority on the grid for nuclear and a higher load factor. It secures market sales and long-term cash flows. CCGT is sensitive to gas price volatility. On the other hand, nuclear is a capital-intensive production mean, demanding a large upfront expense. Gas is often presented as far less capital intensive. But this does not reflect the life cycle total investment. In fact, the major amounts of investment for gas are located in the gas chain. The assessment for a LNG chain providing gas to a CCGT plant gives an investment share of about 50% in the levelised cost of electricity for CCGT supplied by liquefied natural gas (LNG) (see **figure 6**) while it is about 50 to 60% for nuclear **[18].**

Each technology is facing new sales conditions in deregulated electricity markets and must secure its investment by long term power purchase agreements. Choosing CCGT means long term confidence in a well-established gas supply infrastructure, from wells to plant. Choosing nuclear means long-term confidence in the electricity market demand.

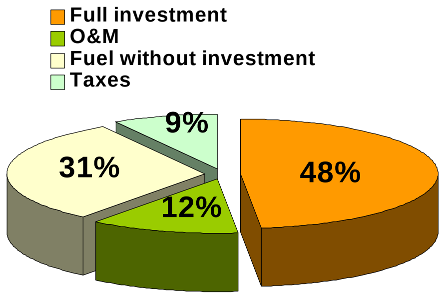


Figure 6: Life cycle break down levelised cost of CCGT electricity generation supplied by liquefied natural gas

Abundant fissile resources

The estimated world uranium resources are periodically updated by IAEA and OECD/NEA agencies. The figures mentioned here are issued from current assessment in the latest update of what is called 'the OECD/NEA red book' [19].

The known uranium deposits, recoverable with today's technology at an extraction price inferior to 130 $/kgU, represent 3.2 million tU. If we consider the estimated additional resources, we reach about 4.7 million tU of reasonably assured resources. To feed the current 360 GWe world fleet of reactors, about 70,000 tons of fresh uranium are needed each year. Present known deposits will last 50 to 70 years for current consumption levels without any recycling of used fuel.

Total conventional resources come up to a gross 15 million tU when more speculative resources are included. Since the eighties, persistent low uranium price has discouraged exploration. Exploration and extraction technology advances would make them available on demand in the future at reasonable cost.

In addition there are substantial unconventional resources, e.g. in phosphate rocks which may represent between 15 and 25 million tU (22 million cited in reference [19]).

More hypothetically, uranium present in oceans could be concentrated and extracted. It is a huge potential of more than 4,000 million tU. But uranium is so diluted in seawater that large volumes of water would have to be handled and chemically processed. Currently considered technologies are far from feasibility [20]. As of today, the incurred costs would be so high that this resource should not reasonably be taken into account.

Breeding, i.e. conversion of isotope 238 into fissile plutonium, is more likely to be implemented since technologies have already been developed in several countries and it can extend the natural fissile resource by a factor of 60 at least. The extensive use of breeders will be decided when the price of fissile resources becomes high enough to make up for the higher investment cost of such reactors.

Thorium also seems accessible as a long term resource assuming new investment and qualification of dedicated reactor technology and nuclear fuel cycle. Present estimation displayed in reference [19] is of more than 4.5 million tons (reserves and additional resources).

We can conclude that currently reasonably assured resources, about 4 million tonnes of uranium, are only the tip of the iceberg. Total conventional resources allow operating about 200 years worldwide at current level of consumption without recycling (70,000 tU/year). The total resource available for the future, combining extraction and breeding, is more than two orders of magnitude higher and is likely to be exploited since the general price of energy is bound to rise.

Risk control

Another prerequisite to the increased global consumption of nuclear energy is the control of associated risks. That means nuclear safety, waste minimisation and non proliferation have to be maintained and further promoted in all the countries where nuclear energy would be expanded.

Safety

The basic safety principle is that nuclear power plant shall not cause injury to people or damage to the environment or property. Reactors nuclear safety is based upon the three level 'in-depth defense' concepts:
First to prevent any accident
Second to monitor and protect safety
Third to avoid unacceptable consequences.

Safety is realised in the form of precautionary measures in design, construction and operation. These basic safety functions are protecting the plant in cases of incidents and failures, as well as limiting the consequences of accidents. The safe design relies on the three barriers principle.

A series of strong, leak-tight physical 'barriers' which form a shield against radiation and confine radioactivity in all circumstances:

- The metal cladding of the fuel rods
- The metal enclosure of the reactor primary circuit
- The containment surrounding the reactor.

Nuclear safety record is based on more than 11,000 years of cumulated reactor experience globally. This large experience and extensive research and development programmes have had a significant impact, improving plant performance and availability and enhancing safety.

Nuclear energy sector is most strictly regulated with regulatory bodies operating nationally and following internationally agreed IAEA standards. Development and implementation of the methods ensuring high level of safety are largely based on wide-scoped international cooperation. As nuclear technologies continue to expand internationally and more countries develop indigenous concepts of reactors, it is important to share common views and methods. The IAEA is the core international safety body, issuing binding conventions, safety standards, practical guidelines and recommendations, leading thorough safety reviews of the installations and coordinating technical exchanges and R&D programs. An international Incident Reporting System, jointly managed by the IAEA and the nuclear Energy Agency of the OECD **[21]** has been set up for exchanging experience to improve the safety of nuclear power plants. Introduced in March 1990, the International Nuclear Event Scale (INES) jointly by the IAEA and the NEA/OECD **[22]** facilitates communication and understanding between the nuclear community, the media and the public on the safety significance of events occurring at nuclear installations. The World Association of Nuclear Operators (WANO) also promotes thorough exchange of experience between the operators. Performance indicators for plant safety and reliability have been elaborated and are now reported by practically all operating nuclear power plants. More details on the indicators and their values are available on the WANO website **[23]**.

The new reactors currently proposed by the vendors are still safer by design. Key improvements are the total confinement of radioactivity even in the most serious accident scenarios and reinforced protection against external events. They are quoted as 'Generation 3+' models. The EPR reactor proposed by Framatome-ANP can be taken as an example (see detailed technical characteristics in **table 10**). Several novel features are noteworthy and fulfil the demands expressed by the European electricity companies and Safety Authorities (see **figure 7**):

- According to safety margins compared with the other French reactors, the EPR has a ten times lower probability of major accident.
- Even in case of severe accident with core melt, containment ensures no external radioactive release and no consequence on neighbouring population.
- Also in case of severe accident and core bleed through the vessel bottom, a special 'ash-tray' underneath would recover the melted material, preventing any radioactive intrusion underground.
- Protection against external events (fire, flood, falling aircraft…) has been reinforced, including independent redundant systems to prevent common failure and a double containment of two 1.3 m thick walls.

For the future, more novel designs are developed by R&D bodies within the international 'Generation 4' initiative, involving ten countries.

Table 10: EPR technical characteristics

Thermal output power	4250/4500 MW
Net output electrical power	From 1500 to 1600 MW
Efficiency	36%
Reactor pressure	155 bars
Average core temperature	313°C
Pressure vessel height	12.7 m
Core diameter	3.8 m
Core length	4.2 m
Core power density	89.3 MW/m^3
Fuel assemblies	241
Core heavy metal inventory	130.9 metric tons
Control devices	89
Secondary pressure	78 bars
Service lifetime	60 years

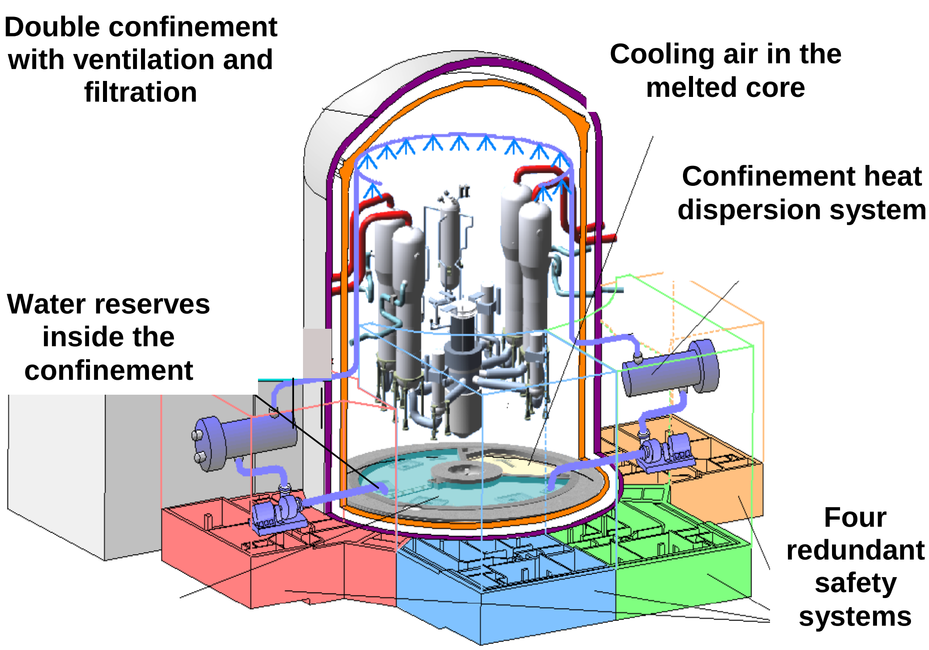


Figure 7: EPR safety features

Used fuel and waste management

Different types of wastes are produced in the nuclear fuel cycle: low radioactive level waste, intermediate level waste end high level waste. In the open fuel cycle, the ultimate high level waste is the used fuel containing uranium, plutonium and fission products, while in closed cycle with reprocessing it consists mainly of vitrified fission products in canisters, from which the major part of actinides has been separated and recycled.

Half a ton of enriched uranium in a PWR fuel assembly generates as much electricity as 50,000 t of coal. The resulting waste quantities are small in comparison with other industrial sectors. For instance, the European Commission has estimated that 40,000 m^3 of radioactive waste are generated each year in the former EU-15 where 33% of electricity is generated by nuclear power plants**.** About one percent is high level waste. To keep these quantities in perspective, we can simply mention the average waste density is less than 5, which makes less than 200,000 tons per year. The Commission mentions that 2 billion tonnes/year of conventional waste are generated in the same EU-15, including 35 million tonnes/year of hazardous waste. A key feature of nuclear power is that the small quantities of waste permit sophisticated conditioning and management.

As for low level waste, management procedures are rather well established. In the EU, a very large percentage is now disposed of in closely regulated sites. High level waste management remains an issue. For the long term, the scientific and technical communities (e.g. from OECD, IAEA, European Commission…) generally agree that high-level waste and spent fuel can be disposed of safely in suitable geological formations (rock, salt or clay), using appropriate combination of natural and engineered barriers to contain radioactivity as long as necessary.

The issue of geological disposal is related to long term management and impact: even with radioactive decay, the waste packages will remain more toxic than natural uranium ore during several centuries. Safety assessments have to demonstrate that the waste will have no impact on public health all over the lifetime of the repository. Demonstrations are built upon available scientific knowledge, including quantitative models and qualitative natural analogues, taking into account the effect of the barriers installed. Radioactive decay combined with delayed diffusion through the barriers ensures that only a very small fraction of initial radioactivity will come back to the biosphere. The residual risk at stake in low probability 'accidental' events is local, well circumscribed and quite limited in the hypothetical health consequences for the concerned populations. There is no common measure with the global threat of climate change induced by the emission of greenhouse gases.

Non-Proliferation

Non-Proliferation has become an essential issue of public interest and more generally for the acceptance of nuclear energy systems.

Proliferation resistance is achieved every day in operating nuclear plants through a combination of technical features which are defined as 'intrinsic' to the technology and institutional and other measures, including safeguards inspection, defined as 'extrinsic' measures. Physical protection addresses different threats and can be complementary to proliferation resistance.

As for safety 'defence in depth' principle, three categories of non proliferation barriers can be defined: barriers pertaining to the nuclear material itself, technical barriers pertaining to the technology and the facility, Institutional barriers which cover extrinsic measures.

The IAEA as well as regional safeguards and verification organisations (EURATOM, ABACC, ...) are applying effective controls on nuclear material to ensure they are used as declared. Safeguards approaches and equipments are integrated as early as possible in the design of fuel cycle plants currently under extension or commissioning such as enrichment plants in Europe or reprocessing plant in Japan. Another example is the development in the 90's of a 'safeguards in depth approach' for the AREVA MELOX fuel fabrication plant in France **[24]**.

Export control is a widely applied tool to prevent proliferation of nuclear weapon and ensure that nuclear material and technology are put to peaceful use.

OTHER POSSIBLE CONTRIBUTIONS OF NUCLEAR TECHNOLOGY (HEAT AND HYDROGEN PRODUCTION)

To achieve the target of climate change mitigation, carbon-free sources of energy are desirable for all energy final uses and not only for electricity consumption. Transportation sector is fuelled today at 95% by fossil fuels and is forecasted as a major source of GHG emissions. Among other substitutes to oil refined products, hydrogen is a promising clean fuel. Space heating could also benefit from carbon-free energy carriers.

Beyond power generation, nuclear energy can contribute to a variety of final energy usages if future reactor designs incorporate corresponding specifications. Several international R&D initiatives are investigating new designs of reactors for the future:

- INPRO (Innovative Nuclear Reactors and Fuel Cycles) by the IAEA
- GIF (Generation IV International Forum) by the US DOE.

Different concepts with technological gaps from Gen 3 reactors are envisioned. GIF for example has selected six systems:

- Very High Temperature Reactor (VHTR)
- Supercritical Water Reactor (GFR)
- Gas Fast reactor (GFR)
- Lead Fast Reactor (LFR)
- Sodium Fast Reactor (SFR)
- Molten Salt Reactor (MSR).

In those initiatives some types of reactors mainly studied for their electricity generation potentialities are compatible with other final uses. Energy delivered at higher temperature would open the way for a **wider scope of applications** (high temperature process heat applications and in particular hydrogen production) and would ensure **a better energy efficiency** (see **figure 8** hereafter).

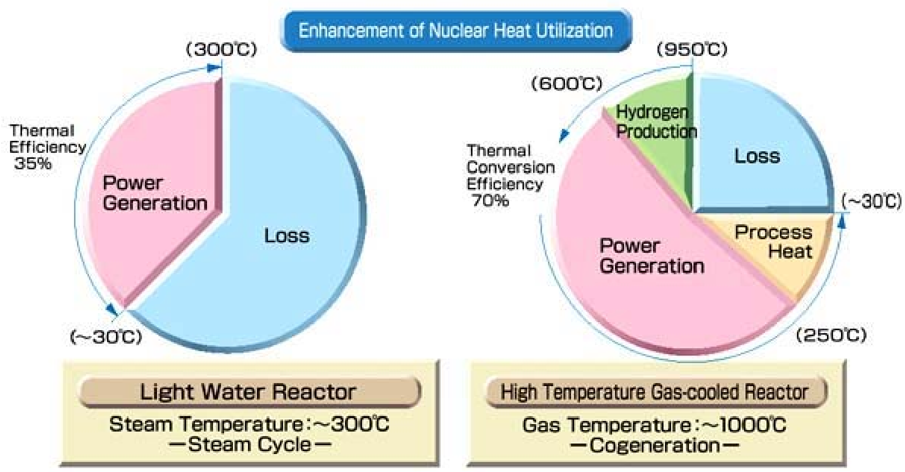


Figure 8: Future energy efficiency of reactors (from current 35% to potentially 75%)

Until now, researchers are thinking that a minimal temperature is necessary for the thermo-chemical process generating hydrogen. Outlet temperature of current reactors are about 300°C and not sufficient with today knowledge. The lead cooled reactor and the sodium fast reactor produce sufficient heat for SMR (Steam Methane Reforming) about 600°C in outlet temperature. Following **table 11** presents some orders of magnitude of H_2 generation costs.

Table 11: Order of magnitude of hydrogen generation cost by different means

Hydrogen generation mean	Assumptions	Generation cost ($/kg$H_2$)
Steam Methane reforming	Gas 3$/GJ	0.9
	Gas 6$/GJ	1.4
Low temperature electrolysis	Electricity 25$/MWh	2.1
	Electricity at 50$/MWh	3.3
HTR reactor + chemical cycle Iodine Sulfur	Large uncertainties-necessary R&D and progress	2.1 to 4

In case of reforming the CO_2 the applying over cost could be around 0.04 $/kg of hydrogen considering extra cost of 20$/t$CO_2$ (tax, emissions trading or capture). According to the generation process specifications of H_2 are not the same. Finally generation specifications could match those of the demand side.
Some high temperature reactor designs are studied to manufacture hydrogen:

- Framatome-ANP has engaged to develop R&D on the VHTR concept, a 600 MW thermal unit with a target core outlet temperature of 1,000°C.
- The similar concept GT-MHR (Gas turbine-Modular helium reactor) is studied by general Atomic.

The Very High Temperature Reactor (VHTR) is recognized as a promising technology for such applications. Helium is used as the primary heat transport medium. The advantages of the VHTR derive from its ceramic-based fuel particle system, graphite moderator and helium coolant, which provides for a high temperature capability that is unique among established reactor concepts. Based on this capability, the possibility of fuel damage is inherently eliminated through this concept and no prompt operator actions are required.

The prismatic block fuel system and the indirect cycle architecture are two major options for its nuclear heat source (NHS). The nuclear heat source is coupled to the applications of interest through an intermediate heat exchanger (IHX, see **Figure 9**), thus decoupling the nuclear related issue from the process using the heat. For electricity production this arrangement enables the coupling of a quasi standard CCGT.

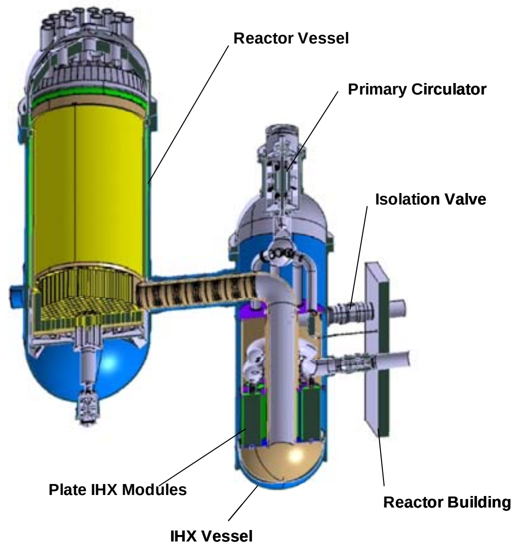


Figure 9: Framatome-ANP VHTR concept (Helium Coolant Primary Loop and Vessel System Arrangement)

To support the design and the licensing of this product, Framatome-ANP has launched an extensive program of project driven R&D (materials development, Helium experimental facilities, fuel development and qualification…) and industrial calculating tools and methodologies adapted to the specificities of the VHTR reactor physics (the coupling of 3D neutronics and thermal hydraulics codes and the definition of an optimized scheme for decay heat computation). This project federates the company engineering teams in the USA, in Germany and in France. More information is available in reference **[25]**.

A VECTOR OF FUTURE NUCLEAR GLOBAL CONTRIBUTION: TECHNOLOGY TRANSFER AND PARTNERSHIP

The contribution of nuclear energy to the mitigation of global GHG emissions will be significant if it is developed in some key countries which have a significant weight in the world primary energy consumption and production. That is the case of China, world's second largest energy consumer, second oil consumer and first coal producer.

Here we will present the AREVA partnership with the nuclear companies of People's Republic of China as an example of successful transfer of nuclear technology. AREVA industrial group has been involved as reactor and fuel supplier from design to construction. The French utility EDF is also involved for many aspects of the partnership developed between the Chinese and French nuclear industries.

At the end of 2003, China's total installed power generating capacity was 384 GWe, with a planned expansion to 450 GWe by the year 2010 and 900 GWe in 2020. Eight nuclear power plant units provide a total installed capacity of 7 GWe and two new reactors are under construction (+2 GWe). Nuclear power is emerging in the country. It has represented 1.4% of total electricity generation in 2002. The goal declared by China in 2004 is a total nuclear capacity of 36 GWe in 2020, then representing 4% of total power capacity.

Over 20 years, since China has been developing the nuclear technology for generating electricity, Framatome-ANP has established a long history of partnership in China for nuclear development towards self-reliance in plant design, equipment and fuel manufacturing.

Three key factors have made the success story:

- A clearly defined and 'enabling' political framework between France and China for peaceful use of nuclear energy,
- Challenging nuclear power plants projects to focus commitment and resources in recipient country,
- Contracts to warrant normal supplier customer relationships.

Plant design self reliance

The **initiating event** in **1986** was the signature of the contract between Guangdong Nuclear Power Joint Venture Company Limited (GNPJVC) and Framatome (now Framatome-ANP, an AREVA and Siemens Company) to build two 1000 MW_e reactors at Daya Bay. The CNI 23rd Company, a Guandong province construction company cooperating with Framatome, was responsible for the construction work of the nuclear island. Framatome provided major technical assistance through the self-reliance program for enhancing the autonomy of the Chinese company.

Then in **1992, a Cooperation Agreement was signed with CNNC** (China National Nuclear Corporation), allowing the transfer of the nuclear island design implemented for Daya Bay (see **figure 10**). Framatome assisted NPIC (Nuclear Power Institute of China) and BINE (Beijing Institute of Nuclear Engineering) designated by CNNC to implement this agreement for Qinshan II units 1&2. Chinese factories received the technology for the detailed design and manufacturing of the main equipment and coolant system. The success of this technology transfer has been demonstrated by the construction of the Qinshan Phase II units.

In **October 1995** a further step was the signature with the **Ling Ao Nuclear Power Company** (LANPC) for supply of two 1,000 MW_e nuclear units in China's Guandong province. Framatome-ANP was contracted to supply the nuclear island of the power station, from the construction works until start-up of commercial operation (see **figure 11**). The CNI 23rd Company was associated. A technology transfer agreement was signed with Chinese General Nuclear Power Corp. (CGNPC) in 1995, extending the scope of technology transfer of Framatome in China to the fields of construction, start-up, licensing and operation up to the latest N4 model. This agreement also covers the design and fabrication of high-technology equipment, and is still in effect today. Necessary computer codes have been transferred too. Many Chinese trainees have enhanced their knowledge as residents in Framatome offices. In September 1997, a third technology transfer agreement was signed to assist CNI 23rd in the construction of Ling Ao in order to allow CNI 23rd to reach self-sufficiency. Framatome provided technical assistance through the self-reliance program (technology transfer) with the objective of enhancing the autonomy of the Chinese company.

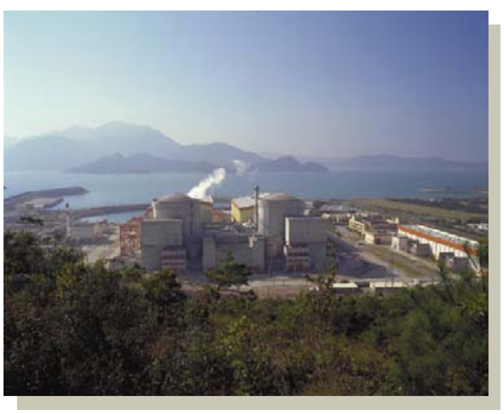


Figure 10: View of Daya Bay (two units)

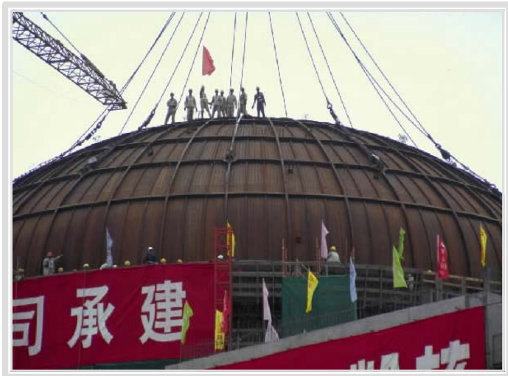


Figure 11: Ling Ao plant construction (containment structure)

This cooperation has been extended to maintenance services with CNI 23rd, BINE and RINPO for the modifications and inspections to be implemented during the first 10-yearly outages of the Daya Bay plants scheduled for 2004. A joint venture named the Shenzhen Nuclear Engineering (SNE) to provide services for the entire Chinese fleet of reactors has been launched between CNI 23rd and Framatome-ANP as major contractors each having 35% share.

Cooperation with the Chinese Design Institutes is also continuing in the field of development such as R&D programs, qualification tests, assisting on new projects.

Manufacturing self reliance
Framatome-ANP has been cooperating with Chinese equipment manufacturers for the Qinshan II project and the Ling Ao units 1 & 2.

For Qinshan II, NPQJVC ordered the reactor internals and control rod guide tubes from Framatome-ANP, some of which have been manufactured by Shangaï N°1 Machine Tools Works (**figure 12**).

Within the scope of the Ling Ao contract, Framatome-ANP has undertaken to localize manufacture of about 11% of the equipment supplied in China. Through this initiative, more than 30% of the largest fabricated components of the reactor – excluding the vessel itself – for the second unit at Ling Ao were localized. Framatome-ANP was responsible for selecting and qualifying its Chinese suppliers, as well as for the quality and delivery schedule of the equipment.

Figure 12: View of Qinshan plan

In this context, the order was placed with the DongFAng Electric Corporation (DEC) in Sichuan province in July, for the manufacture of the large nuclear components – steam generators and pressurizer – at the DBW factory using Framatome-ANP's technology. This localization has been extended to the other equipments for Tianwan units 1 & 2 and the Daya Bay 10-yearly outage.

This successful experience and the localisation now in progress constitute the soundest foundation for achieving full self-reliance for equipment manufacturing (see **figure 13**).

For the last five years after Ling Ao, the group has been preparing the extension of manufacturing self reliance with the close cooperation of Chinese partners who are well aware of Chinese industrial potential, such as DEC, BINE and the Nuclear Power Offices of Sichuan and Shangaï.

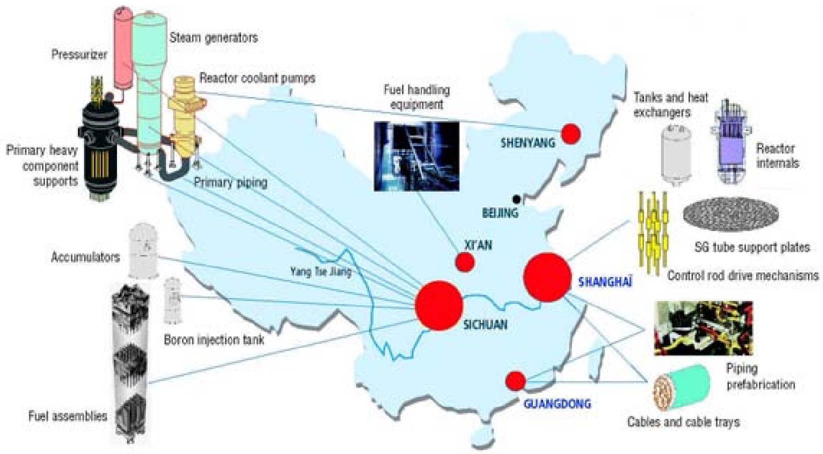


Figure 13: Chinese locations of equipments supply

Fuel design and fabrication

The technology transfer for fuel has enabled the Yibin plant in Sichuan, owned by CNNC, to supply all the reloads for the Chinese PWR units. The first technology transfer program started in 1991 with the AFA 2G fuel assembly technology and lasted until 1994. The AFA 2G fuel technology transfer (1991/1995) involved China Nuclear Energy Industry Corp. (CNEIC) as contractual interface, NPIC as designer, and Yibin Fuel Plant (YFP) as manufacturer. As a result, YFP mastered the fuel manufacturing and provided GNPJVC with reliable products. In order to reduce the kWh cost by shifting from annual to 18-month cycle operation, GNPJVC decided at the end of 1998 to extend its cooperation with Framatome. Therefore a new fuel technology transfer covering design, licensing support and manufacturing was set up among Chinese partners and Framatome. AFA 3G fuel assembly meets the ambitious objectives of GNPJVC: proven high performance, increased burn-up capability, thermal hydraulic operational margins, and the most economical solution. The AFA 3G technology transfer allowed French and Chinese counter-parts to visit each other's countries, and provided friendly exchanges.

Figure 14: Yibin fuel manufacture

New nuclear program
Having now acquired sound experience in the field of power plant design and construction, China is ready to launch a major nuclear program. Chinese authorities have set the following conditions for constructing nuclear power stations:

- The technology shall be safe, reliable, proven, and advanced
- The Chinese industry shall achieve self-reliance
- The localization of engineering activities and equipment manufacturing shall progress quickly and reach a high level
- The units shall be competitive with other sources of electric power.

The content of partnership will evolve to combine full benefit from the latest advanced designs and as high as possible localisation of engineering and manufacturing.

This example shows how a sophisticated technology such as nuclear power can be shared on the basis of long-standing partnership, involving both industrial companies and State authorities. Stable political framework and normal trading rules are also required.

CONCLUSION

A significant contribution of nuclear energy to the mitigation of GHG emissions can be contemplated on the following basis:

- Nuclear energy is already a reliable and competitive source of energy, currently saving the emission of 600 Mt of carbon each year.
- The available industrial experience worldwide and the established architecture of international regulations and institutions for risk control make it reasonable to expand the use of nuclear energy to more countries and to more final energy uses while maintaining the same high level of security and environmental protection.
- Lessons can be drawn from cases of successful technology transfer such as between the French and Chinese companies: clear and enabling political framework, normal supplier/customer relationships and both companies' and governments' steadiness are all required.
- New designs of reactors, such as the VHTR, can extend the domain of applications to process heat delivery and to hydrogen production. Ambitious concept engineering and related R&D programs have been launched. Thus serving more final end-uses, nuclear energy might see its share in the world primary energy supply four or five-fold larger than now in 2050.
- As of today, the policy framework should give equal chances to all technologies, without exclusion for political reasons at the beginning of the game. Once the carbon value is accounted for by appropriate mechanisms such as emissions permits trading or taxation, the market should decide.

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Prospects for Electric Power Technology to Address Climate Change

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ABSTRACT

The electricity industry has an essential role to play in meeting the long-term challenges of climate change, sustainable development and sustainable energy supply. Further electrification, in both developed and developing countries, based on a mix of primary energies, is a prerequisite for poverty eradication and for a global strategy to reduce greenhouse gas emissions (GHG). Electricity itself can deliver considerable reductions in energy consumption and CO_2 emissions.

The means used to reduce GHG emissions should be flexible, cost-effective, and consistent with the transition to competitive energy markets and should not introduce market distortions.

Climate change, energy needs, including the access to energy, and security of supply are long-term inter-related subjects. A sustainable solution will only emerge through open and objective debate about all available and emerging energy options. The keys to this solution must include: a maximum focus on market solutions; upstream competition among fuel sources and suppliers; a significant focus on ongoing energy R&D, with a view to maintaining all viable energy options.

In the short- to medium-term, options for CO_2 reductions, in the developed world from a technical and investment view, are fuel conversion from coal to Natural Gas (NG) or re-powering coal capacity with NG fuelled gas turbines. Nuclear, Combined Heat and Power (CHP) - NG and Natural Gas Combined Cycle plant (NGCC) are, at present, the lowest-cost solutions with respect to total CO_2 reduction costs (including Operation & Maintenance - O&M - costs). Effective options in technical terms are to increase renewables or nuclear capacity. These CO_2-free options require minimum capacity exchange or upgrading.

As coal base-load plants will be the dominating base-load capacity in many systems for some time to come; re-powering and CHP should be considered before building new condensing capacity. New clean coal should, however, be considered.

In the developing world, there are differing challenges due to the lack of infrastructure. This means that, even though there will be a substantial need for conventional technologies, a wider range will need to be considered.

This paper examines all the strategic technology options for reducing carbon emissions from the generation and supply of electricity and discusses how those technologies could be implemented, transferred and diffused.

INTRODUCTION

Addressing climate change is imperative for sustainable development and a driver for a future sustainable energy supply. The electricity industry has an essential role to play in meeting these long-term challenges, in particular because of the demand for electrification which exists in developing countries. Further electrification, based on an appropriate mix of primary energies, is a prerequisite for a global strategy to reduce greenhouse gas emissions. Electricity itself can deliver considerable reductions in energy consumption and CO_2 emissions. The means to reduce greenhouse gas emissions should be flexible, efficient, cost-effective, consistent with the competitive nature of energy markets and should not introduce market distortions. The European electricity industry considers that the Kyoto market mechanisms [i.e. Emissions Trading, Joint Implementation (JI) and Clean Development Mechanism (CDM)] are essential elements in reducing greenhouse gas emissions. Electricity provides a clean, secure and efficient supply of energy in a cost-effective manner. On both the supply and demand side, diverse strategies can be utilized to achieve sustainable development and meet the challenge of climate change. On the supply side, electricity companies are limiting emissions from electricity generation by improving efficiency and by increasing the use of non- or low-emitting supply technologies (e.g. hydro-electricity and other renewables, nuclear power, combined heat and power, natural gas and advanced coal technologies). In the medium- to the long-term, CO_2 capture and storage and the use of hydrogen as a fuel could also become a viable and effective means of mitigating GHG emissions. However, for security of supply reasons, it is essential to maintain a wide range of fuels in a balanced supply portfolio.

On the demand side, we support the goal of promoting the efficient use of energy and stress the positive role that electricity can play in reducing energy use and adverse environmental effects through a wider application of electric technologies. The greater use of energy-efficient electric technologies is one of the most significant factors supporting economic growth, improving energy efficiency and reducing CO_2 emissions. This happens both by replacing less efficient electrical equipment with energy-efficient electric technologies, and by switching from fossil fuel end-use applications to more energy-efficient electric technologies. Therefore, the creation of a framework for fostering market penetration of energy efficient electric technologies through market-oriented mechanisms should be pursued (e.g. labelling, energy audits, information and dissemination of best practices).

There is a risk that policy-makers may tend to assume that end-of-pipe technical solutions in a 'centralized' industry like the electricity sector can deliver the objectives. Hence they may fail to address adequately the major part of the problem which comes from politically more difficult sectors of the economy - not just other industry, but in particular the transport sector. Notwithstanding the difficulty in changing behaviours, policy-makers should not avoid seeking appropriate and proportionate solutions and contributions from these sectors also. Electricity is also a key element in the achievement of the economic and social dimensions of sustainable development. The consequences of not having electricity are stark: poor health, little information, no automatized processes, restricted mobility, absence of comfort and dubious safety. A compromise has to be found between an increase in the use of electricity and the impact of the electricity industry's activities on the environment, the reference being sustainable development and sustainable energy supply technologies. Developing countries need electricity for their development. Therefore, electricity is a decisive factor for the elimination of poverty and social exclusion.

THE EUROPEAN UNION CONTEXT
THE POLITICAL AND MARKET CONTEXTS

We are witnessing the creation and development of a pan-European and Mediterranean electricity market. Since the adoption by the European Union (EU) of the Electricity Directive in 1997, rapid progress has been made towards establishing a more competitive market in Europe. Lower electricity prices and consistently high standards of service are helping EU business to maintain its position in the global marketplace and to improve the situation of individual customers. The European electricity industry fully supports the process of accelerated liberalisation provided that reciprocal, fair and market-oriented rules are implemented in all related areas. Practicality and flexibility are key prerequisites for markets to function properly. Competition is bringing new opportunities but also risks, mainly in sales and prices. Power plants are only one of a number of issues in a utility's portfolio. It is difficult to assess what will be the economic feasibility and competitiveness of new power plants on a liberalised power market. This depends on power prices, and long-term development of fuel prices. Other issues include political investment risks, taxation or subsidization of power production methods. Important elements taken into account in investment decision are capital invested, long amortisation periods and payback. Therefore, in view of the market price risk, less capital-intensive power plants, which can also be built more quickly, seem to be the preferred option. However, this may not be true, in a scenario where power generation costs, notably fuel prices are unstable, and tougher environmental and climate requirements are in place. Policy-makers should develop and adopt a consistent and coherent view on the hierarchies and interactions between different policies and measures in order to create the clarity and the incentives needed for their application. Policies and actions should be based upon fairly shared efforts from all sectors, including the transport, industry, business, domestic and agricultural sectors. Diverse, secure and sustainable supplies of energy are required now and in the future in order to sustain competitive economies. It is important that the measures applied should contribute to the development of a competitive energy sector and unsuitable measures such as taxes, subsidies and excessive regulation should be avoided.

Research and Development (R&D), and consequent technological innovation, have a vital role in tackling climate change. Energy R&D funding should be channelled to more efficient technologies on both supply side and demand side, notably into: more efficient production and related technologies (e.g. clean coal, CO_2 capture and storage); transmission and distribution savings (reduced losses) through superconducting materials, distributed resources such as energy storage devices and distributed generation technologies; efficient demand-side technologies for industry and domestic sectors; and dissemination of information on the economic and environmental benefits.

The European Union is a party to the international agreements in the various areas associated with global change such as the Kyoto Protocol on Climate change and the UN Conventions on Biodiversity and Desertification. It has a duty to make a substantial and coherent contribution to the efforts made through the major international research programmes on clean technologies and on climate change. Under the Kyoto Protocol, the EU is required to reduce its greenhouse gas emissions by 8% compared with the 1990 levels in the period 2008–2012. Achieving this objective in the short term requires a major large-scale effort to deploy technologies currently under development.

Demonstration and mixed research-demonstration projects in the field of clean energy conversion systems (for example electricity production) will be needed to satisfy the short term objectives, as well as preparing the ground for a long-term technological shift (e.g. hydrogen). Above and beyond this objective, the long term implementation of sustainable development in the coming decades makes it necessary to ensure the availability, under economic conditions, of the most appropriate energy sources and carriers in this respect. On the last point, a special attention should be paid to the development of energy networks. An example can be given with the need for the European grid to cope with totally new transit conditions, due to the implementation of distributed generation, renewable energy sources, and the development of electricity trading encouraged by the deregulation process. This will require a sustained longer-term research effort. Currently, security of supply issues, renewable energies and climate change are topics high on the EU political agenda. The Directive on Renewables and the Emissions Trading Directive will constitute important drivers for the development and implementation of clean technologies in the European Union.

THE TECHNOLOGICAL CONTEXT

A common action framework can help to ensure this vital coordination of Europe's contribution to the world effort. Efforts in the short and medium term will need to concentrate on a limited number of large-scale actions in the following areas:

Renewable energy sources, carbon capture and storage, energy savings and energy efficiency in connection with the whole supply chain - generation, transmission, distribution as well as end-use. Demonstration and deployment of high efficiency power generation systems should be encouraged, providing energy services to the final users with minimal fuel consumption and waste emission. Together with new, cleaner and more distributed energy sources, the need to carry energy safely and economically will require specific research. The latter will be increasingly important as markets become more liberalised.

Market mechanisms that internalise environmental and social objectives by generating the appropriate signal at the appropriate time.

Turning to the longer term, activities will concentrate as a matter of priority on:

Fuel cells (stationary and mobile application), microturbine generators, advanced photovoltaics (PV) and biomass technologies for stationary applications.

Hydrogen technology.

New concepts in solar photovoltaic technologies and advanced uses of biomass.

Carbon capture in processes utilising fossil fuels, for example for electricity production.

There are many different technologies with many options to satisfy future energy demand:

Improving efficiencies of established processes,

Developing and commissioning of advanced and new techniques, some in more decentralized supply structures, also

Fuel switching and replacing old power plants with state-of-the-art plants are the key measures to preserve resources and environment.

Measures concerning the preservation of the environmentally oriented resources at the supply side are only sustainable if they are economically as well as ecologic. Therefore, costs per resource preserved and emission avoided play a key role.

To estimate the impact on the environment, not only fuel consumption and emissions at the operating period of a power plant have to be calculated, but also construction of the site, fuel supply and decommissioning have to be taken into account. A full Life Cycle Balance may show in detail that not every new or advanced technique is of advantage.

NUCLEAR ENERGY AND LARGE HYDRO

Without a continuing contribution for nuclear and large hydro, Kyoto targets and the targets beyond Kyoto will not be met. Nuclear energy provides 35% of EU electricity, without producing CO_2. In view of its positive role in reducing greenhouse gas emissions, political support is needed to overcome the low public awareness of basic nuclear energy facts, which impacts strongly on acceptance. Nuclear power also contributes significantly to Europe's security of supply, due to the wide physical availability of uranium, and the real lack of any significant fuel price risk. Solutions for dealing with wastes from nuclear power plants do exist and problems linked to this issue are of a political and communication rather than technical or economic nature. Expanding nuclear power may compensate fossil power emissions especially in industrialized countries that are able to raise the typically high capital costs.

RENEWABLE ENERGY SOURCES

The European electricity industry supports efforts to develop renewables energy sources (RES). Renewable energy and advanced conversion techniques like Fuel Cells will be a future pillar of the fuel mix for power supply - with a considerable potential for resource preservation. Many efforts have to be made to reduce costs drastically and to optimize full life cycle. The best guarantee of optimal RES penetration in the future is for RES-technologies to be competitive. Therefore, we support market mechanisms (such as internationally traded green certificates) as the preferred means for supporting renewables. Moreover, sustainable growth of renewable energies can only be achieved through a regulatory framework which complies with the rules of a competitive market (i.e. support schemes have to be market-based, capital-efficient, and avoid market distortion via harmonization).

FOSSIL FUELS

Combined Heat and Power (CHP) applications have a large potential for better fuel utilization. But, extending CHP has to be calculated carefully for each individual case in comparison to efficient but separated power and heat generation, especially if there is no constant demand for the heat generated. Coal and other fossil fuels dominate the worldwide power supply due to their economically attractive utilization in large central units—for industrialized countries as well as in developing and threshold countries. Though a high standard of the fossil conversion techniques has been achieved up to now, further improvement of the classical processes is possible, i.e. through realizing advanced steam parameters with new materials. Emission abatement through efficiency improvement is comparatively cheap and therefore has great effects on fuel consumption and environmental impacts. Development of advanced coal technologies in Europe has therefore a worldwide dimension.

For some fuels like coal, large central power plants represent the only way for an environmental and economically efficient utilization. In contrast to gas and oil, coal resources are plentiful and distributed over many regions of the world.

DISTRIBUTED GENERATION

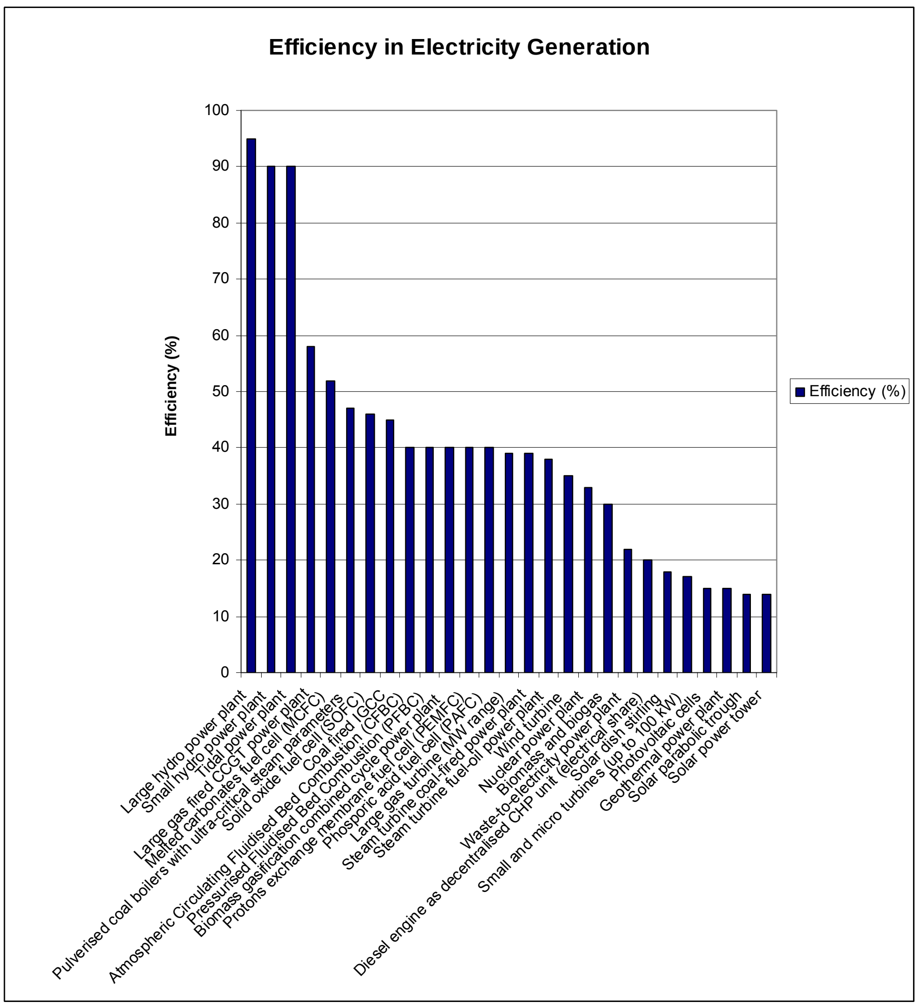
In a changing supply scenario, distributed generation technologies have increased visibility. Short-term energy-storage technologies such as mechanical flywheel, chemical batteries and fuel cells, magnetic superconducting, electric ultra-capacitor, can be incorporated in a multi-energy system. Distributed generation offers a variety of value-added and cost effective solutions to customers, distribution grid operators and energy service companies—and has the potential to fundamentally transform the power industry. Apart from renewables, manufacturers are spending considerable funds in developing gas or hydrogen fuelled technologies such as micro-turbines and fuel cells. The latter are expected to possibly replace internal combustion engines for road transport, as a zero-emissions alternative. However, static applications, for local power generation, are also being developed, most often in CHP mode. Some manufacturers are developing 'black boxes' to allow 'plug n' play' connectivity, without polluting networks with harmonics. It is 'global control without central supervision'. Distributed power plants of small scale will contribute to the power supply more and more and might contribute to fuel preservation due to their specific high efficiency. Large central units will be necessary for economically feasible base power supply for a long time. Therefore, both power supply concepts are not rivals but supplemental.

THE ENVIRONMENTAL DIMENSION

Electricity is part of the solution for achieving sustainable development. In a liberalized and competitive electricity market, sustainable environmental actions are those that achieve environmental goals while respecting market principles. We support the integration of environment and sustainable development into all policy areas, including energy, and consider that, under appropriate conditions this will lead to new business opportunities and to the economic development which can help to fulfil the environmental and social dimensions of sustainable development. It is important to recognize that electricity is essential to the technologies needed for the achievement of sustainable development. Environmental policies and actions that are consistent with a liberalized and competitive market have the greatest chance of success. An important aspect of this is non-discrimination among the economic actors involved. In a labyrinthine range of measures linked to the environment dossier, such as technical standards, regulations, permits, emissions trading, internalization of external costs, fiscal measures, negotiated agreements, subsidies, etc, it is important to keep a balanced, fair and consistent approach, a key element being the use of market mechanisms (i.e. leave decisions to economic actors). Mainly due to technological innovation, the European electricity industry has considerably reduced emissions over the last decades, such as CO_2, SO_2, NO_x, dust/particulates, and persistent chemicals such as Polychlorinated Biphenyls (PCBs), thereby helping to protect nature.

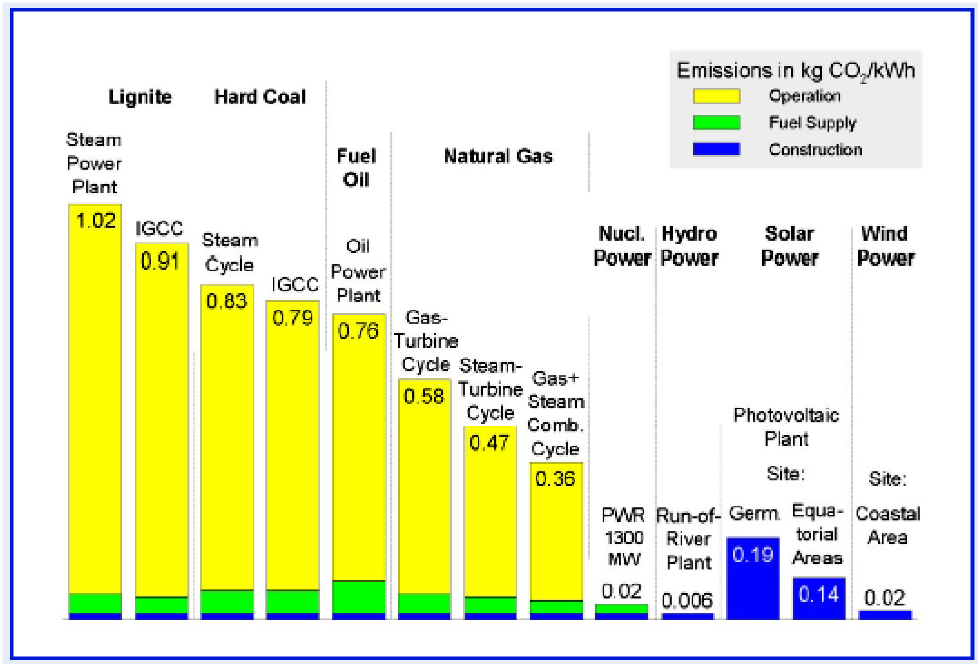
TECHNOLOGIES TO ADDRESS CLIMATE CHANGE: ELECTRIC POWER

Environmental improvements in existing power generation systems can be accomplished by upgrading or uprating existing plants or by investing in new plants. The specific CO_2 emissions for each technology are dependent on the fuel type and the efficiency. A reduction of CO_2 emissions in a system based in part on fossil fuel can be achieved by increased efficiency, fuel conversion or introducing lower-CO_2 or CO_2-free capacity. The figure below summarises the efficiency in various generation technologies.



Ref: EURELECTRIC-VGB Report on 'Efficiency in Electricity Generation', July 2003

For an overall comparison of specific CO_2 emissions (i.e. $kgCO_2/kWh$) a full Life-Cycle Balance, including site erection and fuel supply, is necessary. The graph below shows that the specific emissions cannot be neglected for solar power; on the other hand, nuclear power is very competitive in this sense. Other greenhouse gases like methane have higher Global Warming Potential (GW_p) than CO_2. Therefore, gas pipeline leakages, for example, could have a considerable impact on the Life-Cycle Balance of gas-based power supply, but they are difficult to assess (2% to 8%).



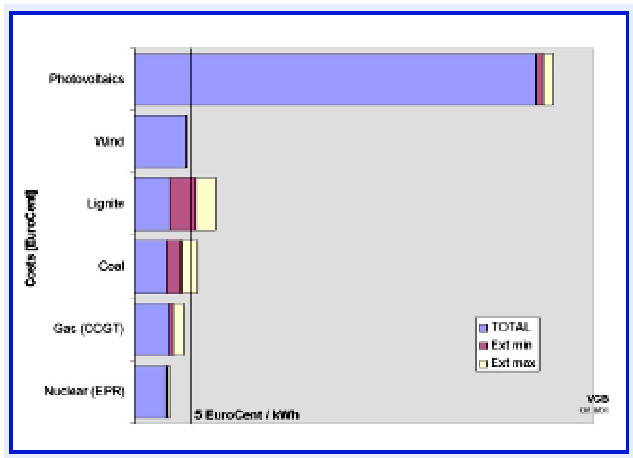
Ref: VGB PowerTech e.V.

Increasing efficiency even at a very small scale has a remarkable impact on emissions reductions and on fuel consumption. The following table gives an overview on the main figures of fuel consumption and emissions for state-of-the-art power plants and different types of fuel including figures for increased efficiency of +0.1%.

	Hard Coal	+ 0.1% efficiency	3.1.1.1 Lignite	+ 0.1% efficiency	Oil	+ 0.1% efficiency	Gas-CC	+ 0.1% efficiency	3.1.1.1.1 uclear	+ 0.1% efficiency
Output MWel	800		900		500		300		1,000	
Load factor h-peak/a	6,000		7,500		1,000		4,500		7,500	
Energy output MWh_{el}/a	4,800,000		6,750,000		500,000		1,350,000		7,500,000	
El. Efficiency%	42.0%	42.1%	40.0%	40.1%	44.0%	44.1%	57.0%	57.1%	34.0%	34.1%
Fuel Consupt t/a	1,400,000	-3,382	7,790,000	-19,400	98,000	-200	189,000	-331	22	-0.067
Oxygen cons t/a	2,700,000	-6,500	4,900,000	-12,220	248,000	-600	328,000	-574		0
CO_2 emiss. t/a	3,800,000	-8,938	6,750,000	-16,800	341,000	-800	451,000	-790		0
SO_2 emiss t/a	2,700	-7	4,400	-11	240	-1	250	0		0
NO_x emiss t/a	2,700	-7	4,400	-11	240	-1	720	-1		0
Dust emiss t/a	400	-1	700	-2	40	0	40	0		0
Ash t/a	107,000	-254	970,000	-2,400	150	0	0	0		

Ref: Calculations made by VGB PowerTech e.V. following ELVs required by the EU Directive on Large Combustion Plants

Approximate values of the costs of electricity generation techniques (see figure below):
Total: Total operating costs (capital + O&M + fuel) with base load 7500 h/a, operating time 35 years, fictitious commissioning in 2005, real costing rate 6 per cent.
Ext min/max: External costs, minimum/ maximum, see below.
Photovoltaics and Wind: Total operation costs at best solar/wind farming areas; have to be at least doubled under ‘normal’ conditions (i.e. northern Europe, inland).
CCGT: Combined Cycle (steam and) Gas Turbine power plant.
EPR: European Pressurized Water Reactor, especially designed for being competitive in comparison to conventional (fossil-fired) power plants.



Ref: VGB PowerTech e.V.

In comparison to some renewable techniques there is no significant difference between operating costs for coal-, lignite-, gas-fired and nuclear systems at this generalised level. External costs include the impact on the environment of the power generation techniques including health effects, acidification/nutrification and global warming (quantified as marginal CO_2 abatement costs (19€/tCO_2) required to reduce CO_2 emissions in Germany by 25 per cent in 2010). Of course, they are complex to assess, so there is a bandwidth (minimum-maximum).

When evaluating the best CO_2 reduction solution, the following factors should be considered:
Total CO_2 reduction costs
Required exchanged/upgraded capacity and system limitations
Total economic and environmental impact
Political aspects.

TECHNOLOGY TRANSFER AND DIFFUSION

A.1 The factors mentioned above when evaluating the best CO_2 reduction solution are also applicable in decisions on technology transfer and diffusion. However, there are other fundamental drivers that lead to investment, economic growth and prosperity in industrialising countries. These are: the rule of law and respect for property rights, democracy, political stability, stable monetary policy, functioning institutional framework, adequate organisation of the market so as to offer fair conditions to all economic actors, transparency and access to information, so that customers are able to choose the most efficient solution, and consultation/partnership with stakeholders/business. The Kyoto Protocol’s Clean Development Mechanism will be a key driver for technology transfer, therefore, its rules and procedures, if simplified and designed in a more business-friendly manner, would stimulate further investments in developing countries. The potential for a specific generation technology to be transferred must be dealt on a case-by-case basis, because it depends, as well, on the region’s energy needs and availability of and accessibility to resources.

UPGRADING OLD PLANTS

There are several terms describing upgrading and modernization projects. The following basic definitions, from IEA Coal Research, will be used in this paper:

Upgrading: Describes non-routine replacement of components, such as mills, burners, superheater tubing, turbine blading, air heaters or other items with the specific intention of improving efficiency, increasing potential output or extending the life of an existing system. Modifications to steam conditions or other significant changes to cycle design, together with the replacement of major items such as boilers or turbines are not considered here.

Repowering: Describes more substantial changes to the plant, such as complete replacement of the boilers or turbines, often including changes to cycle design. Conversion to combined cycle operation by introduction of gas turbines into systems that have only used steam cycles, is one well-known example.

In all cases of refurbishment, upgrading or repowering, it is assumed that emission control is or will be improved, in order to meet actual regulations for long term base load operation. This includes required Electro-Static Precipitation (ESP) – for removing particulates from exhaust stack, SO_2/SO_3 emission reduction techniques – Flue Gas Desulphurisation (FGD) and Selective Catalytic Reduction / Selective Non-Catalytic Reduction (SCR/SNCR – for NO_x reduction via insertion of ammonia in flue gas stream) 'retrofit'. Further it is assumed that the technical life is analysed and required life extension and reliability measures will be taken for at least 15 years of operation.

Uprating: However the above terminology and description cannot apply to nuclear power plants, for which the term 'uprating' is used to define an increase of the nominal power output.

TECHNOLOGY OPTIONS

There is a wide range of different refurbishment technology options, with many individual solutions for each plant. Some typical examples of possible refurbishment measures for fossil and nuclear base load power plants, and the actual motives, are listed in the table overleaf.

Introduction of emission control with FGD, SCR and ESP actually reduces efficiency. A significant reduction of CO_2 can be reached by fuel conversion or by repowering conventional plants. Another efficient CO_2-reduction measure is by uprating existing nuclear power stations, which leads to additional CO_2-free capacity that could replace existing fossil based capacity. As an alternative to a total fuel conversion to a low CO_2 emission fuel, just a part of the fuel input could be replaced. This can be done by co-firing natural gas with coal or oil. An effective CO_2-reduction is accomplished by co-firing biomass in large base load fossil plants, in the existing furnace or via external furnace or gasifier.

TECHNOLOGY DESCRIPTIONS

Steam turbine upgrading
Existing Steam Turbine (ST) plants can be upgraded by exchanging blading with state-of-the-art technology. Together with other ST retrofit measures this will increase efficiency by 1–2 per cent. Investment cost for Low-Pressure (LP) upgrading is about 300-400 US$/$kW_e$ and High-Pressure / Medium-Pressure (HP/MP) upgrading about 500-600 US$/$kW_e$.

Repowering
The highest degree of repowering measure based on gas turbine introduction, is the Heat Recovery Steam Generation (HRSG) technology. In this case only the steam turbine is reused. This is usually applied to non-reheat plants, where steam conditions can match the commercial HRSG data, but could be interesting in other cases when the existing boiler is no longer economically available. Depending on the gas turbine chosen, capacity will increase about 20 per cent and heat rate by about 30 per cent. Investment is expected to about 250-300 US$/$kW_e$. Another option is 'Hot Windbox' repowering. This option uses the combustion turbine exhaust gas as 'pre-heated combustion air' for the existing boiler, which remains. Hot-wind repowering increases the capacity by approximately 25 per cent and the heat rate by about 4–6 per cent. Investment cost is estimated to 150–175 US$/$kW_e$.

The third and maybe the simplest repowering option is the 'Feedwater Heating' technology. In this case exhaust gas from the gas turbine is recovered for feed water heating in the existing steam cycle. This option could improve the turbine capacity by about 15 per cent and the efficiency by 2–5 per cent. Investment is estimated at approximately 100–170 US$/$kW_e$. Another repowering option is Steam Repowering. In this case a gas turbine HRSG is generating steam for an existing steam turbine. This option is not further described in this paper.

Nuclear uprating

There are several possible nuclear uprating methods, depending on the type and age of the plant. One example is the plant in Krsko, Slovenia. This Pressurized Water Reactor (PWR) plant – a common type of nuclear plant – was uprated by replacing two steam generators. Output increased from 620 to 662 MW (+ 7 per cent), at a specific investment cost of 1700 US$/kW$_e$. Another example is the modernization of the Olkiluoto plants in Finland 1996–98. The capacity was increased by 15.7 per cent (2x130 MW$_e$), at a specific investment cost of 510 US$/kW$_e$.

Measure	Motive	Efficiency, CO_2-impact
Emission control retrofit		
ESP	Enhanced restrictions	
FGD	Enhanced restrictions	- 0.6 % efficiency
Low-NOx combustion	Enhances restrictions	
SCR (High dust)	Enhanced restrictions	- 0.1 % efficiency
Upgrading/uprating		
Control system	Life extension	small increase possible
Turbine blading, seals, etc	Efficiency, output	+ 1–2 % efficiency
Fuel conversion	Economy, emissions	possible CO_2-reduction
Nuclear uprating	Output	+ 5–10 % output
Repowering		
Gas Turbine—HRSG (boiler exchange)	Output, eff., emissions	+ 12 % efficiency
Gas Turbine—Hot wind box	Output, eff., emissions	+ 4–6 % efficiency
Gas Turbine—Feed water heating	Output, eff., emissions	+ 2–5 % efficiency

Ref: [19, 31, 32, 33, 35].

TYPICAL REFURBISHMENT TECHNOLOGY OPTIONS AND CO_2 EMISSIONS

The following selected typical refurbishment technology data for base load condensing plants with capacities of 300-600 MW$_e$, are used in this paper:

Emission control equipment such as ESP, FGD and SCR retrofit typically reduces efficiency by approximately 1 per cent, which increases CO_2 emissions. CO_2 reduction requires increased efficiency or conversion to another fuel. For this paper, it is assumed that the reference plant is equipped with FGD and ESP. The reference plant is assumed to be a sub-critical Pulverized Combustion system (PC) of approximately 300-600 MW$_e$ with cooling water tower.

NEW PLANTS

Technology options

There exist the following main options for reducing CO_2 by introducing new capacity into the system:

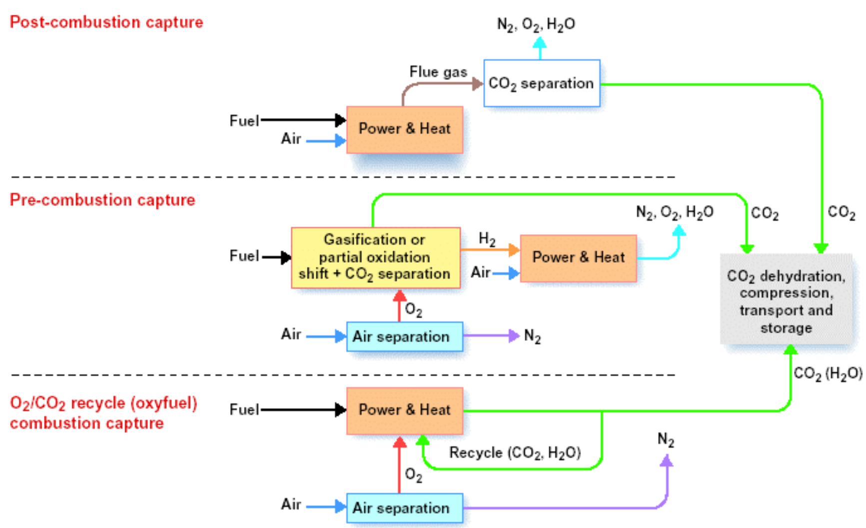
- New clean coal with high thermal efficiency
- Natural gas based Combined Cycle power plants
- CO_2-free technologies (Biomass, Wind, Nuclear, Hydro)
- CHP (vs. Condensing plant)

In practice, there are significant differences in terms of potential capacity, considering fuel availability and other physical limitations as well as political restraints. For example, CHP plants can offer high fuel efficiency, but to deliver this they also require a real need for the heat, such as industrial steam processes or district heating systems. In this paper, CHP plants are described a high efficiency rating on the assumed basis that a real and proportionate heat load is being satisfied. Biomass based plants capacity is often limited by fuel availability and handling capacity.

OTHER OPTIONS

CO_2 CAPTURE AND STORAGE

Numerous concepts for CO_2 capture from power processes have been proposed. These concepts are in various development stages, and have consequently various timeframes for possible commercial application in power plants. The major concepts for CO_2 capture are: Post-combustion capture, Pre-combustion capture, and O_2/CO_2 recycle (oxyfuel) combustion, which are based mainly on existing technologies (see graph below). They can be demonstrated in large scale within the near future (e.g. within ten years) and can be adopted for both coal and natural gas-fired power plants. The main development challenge is to decrease the energy demand from the capture process, which could reduce the power plants' efficiency with up to 20 percent, and also to decrease the additional equipment cost for the capture equipment. The reduced efficiency increases the amount of fuel needed to produce 1 kWh of electricity, which in turn together with the increased equipment cost leads to a higher cost to produce electricity.



Ref: VGB PowerTech e.V.

CO_2 storage in deep geological formations is generally considered to be the only feasible option within any foreseeable timeframe. The three basic types of geological formations that are widespread and are estimated to have adequate CO_2 storage potentials are deep saline aquifers, oil and gas reservoirs and deep unmineable coal seams. Of these, deep aquifers are estimated to have the largest storage potentials in Europe as well as world-wide. To inject CO_2 in partially depleted oil fields using it for EOR, Enhanced Oil Recovery, can however be economically attractive, since it will extend the economic life of these fields. On the other hand, carbon leakage and public acceptance are issues that need to be dealt with.

CO_2 is currently transported on-and off-shore by several means of transportation. In North America, but not in Europe, quantities of the same order of magnitude as the quantities emitted from large power plants are transported on-shore by means of pipelines, which for such large quantities is the only feasible and economically viable transport alternative. For CO_2 transport off-shore, studies show that pipelines and/or ships will become the most cost-effective alternatives. Of course, the specific transport costs (€/tCO_2) increase with the transport distance. On the other hand, they decrease if larger quantities are transported. Longer transport distances would only become economically viable for large power plants. Co-ordinated networks collecting CO_2 from several power plants within the same region would reduce the specific costs further.

HYDROGEN (H_2)

Hydrogen is not a primary energy source. It is an energy carrier. In the short-term, hydrogen will be produced via conventional primary energy sources, in the long-term RES could become the most important source for the production of hydrogen. Hydrogen produced from nuclear sources or fossil fuel sources with CO_2 capture and storage would result in nearly carbon free energy pathways. Hydrogen is a core technology for the 21st century and represents one of the most promising ways to realise sustainable energy. However, as considerable technology bottlenecks, i.e. hydrogen production, storage and safety, infrastructure and economic barriers exist moving from a fossil fuel-based economy to a hydrogen-oriented economy might take several decades.

CONCLUSIONS

Security of supply, climate change and energy needs are long-term inter-related subjects. The best way to find a solution is to open and continue a dispassionate debate about all available energy options. Key solutions for these major challenges comprise: a maximum focus on market solutions, renewable energy sources (RES) and combined heat and power, or cogeneration, (CHP) in particular; upstream competition among imported fuel sources and suppliers; a continuing significant focus on ongoing energy R&D, with a view to maintaining all energy options.

The Kyoto's Clean Development Mechanism will be a key driver for technology transfer, therefore, its rules and procedures, if simplified and designed in a more business-friendly manner, would stimulate further investments in developing countries.

The 'easiest' ways to reduce CO_2, in terms of technical installations and measures, and cheapest in terms of investments, are fuel conversion from coal to Natural Gas (NG) or repowering coal capacity with NG fuelled gas turbines. Nuclear, CHP-NG and NGCC (Natural Gas Combined-Cycle plant) are lowest-cost solutions, with respect to total CO_2 reduction costs (including Operation and Maintenance - O&M - costs). These are also some of the favourable solutions when it comes to generation costs. The latter is however very sensitive to fuel prices and possible utilization in the actual system. New coal is relatively favourable in terms of generation costs, but not in terms of CO_2 reduction costs. Effective options in technical terms are to increase renewables or nuclear capacity. These CO_2-free options will require minimum capacity exchange or upgrading. This includes nuclear uprating (less political obstacles today) and limited introduction of renewable fuels in existing fossil power plants.

When it comes to coal baseload plants, which is expected to be the dominating baseload capacity in many systems for some time to come, repowering and CHP should be considered before building new condensing capacity. New clean coal should however be considered before upgrading (for example Steam Turbine - ST - upgrading) old plants. ST upgrading is one of the most expensive technologies studied for CO_2 reduction.

System limitations, fuel availability, and the real heat demand for CHP have to be considered. Targets for CO_2 reduction and other emission restrictions could mean that old plants have to be closed or mothballed if not upgraded. This can of course lead to a certain capital waste where there is a remaining technical and especially, economic life. The capital waste can be minimized by using the most effective options such as increased amount of renewables and upgrading of old plants. Strictly speaking, this capital waste however does not represent new 'costs'. However, for plants which are otherwise generating electricity at competitive market prices, i.e. generating a stream of profits, there can be a real and significant economic loss, which is not associated with the replacement plant, but with the closure of the existing profit-making plant due to the CO_2 constraint. Technologies for CO_2 capture can be demonstrated in large scale within the near future (e.g. within ten years) and can be adopted for both coal and natural gas-fired power plants. The main development challenge is to decrease the energy demand from the capture process, which could reduce the power plants' efficiency by up to 20 percent. If CO_2 capture and storage become viable it would be one of the key factors governing siting of future power plants.

Hydrogen is a promising energy carrier potentially capable of delivering carbon free energy pathways. However, considerable technology, infrastructure and economic barriers exist. Moving from a fossil fuel-based economy to a hydrogen-oriented economy might take several decades.

The global implementation of sustainable development requires more, particularly:
The design, development and dissemination of technologies making it possible to ensure more rational use of natural resources, less waste production and a reduction in the impact of economic activity on the environment;
A better understanding of the mechanisms of global change, and in particular climate change and related forecasting capacities.

The electricity industry can maintain leadership for a sustainable energy supply provided that the political authorities provide well designed policies: supporting a balanced supply approach; providing a consistent environmental policy framework and promoting market-oriented solutions.

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Factors and Barriers Influencing the Transfer and Diffusion of Biofuels Producing Based Technologies With Particular Reference to Southern Africa

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BACKGROUND ON BIOFUELS

Agriculture biomass can be converted into a variety of fuels, such as ethanol and biodiesel, which can be used as transport fuels. Ethanol can be made directly from sugar-bearing crops, and indirectly by converting the cellulosic portion of biomass into sugar [1]. Biodiesel is produced from vegetable oil seeds through use of extraction technologies, and a chemical process known as 'Esterification' [2].

Biofuels producing based technologies can support substitution of fossil transport fuels, and electricity production, particularly in isolated areas of sub-Saharan Africa, where national grids do not exist. This would reduce negative environmental impacts (local, regional and global) associated with combustion of fossil based fuels.

Driving forces to transfer and diffusion of biofuel technologies

The overall driving force to transfer and diffusion of biofuels producing technologies is the need to move towards a sustainable development path including poverty reduction against global expectations of safeguarding the environment. In the transport sector, the fuels used are petrol (gasoline) and diesel (gasoil), which are described as 'fossil fuels'. As is well known these are finite in nature and have corresponding environmental effects [3].

The specific driving forces in the transfer and diffusion of biofuels producing technologies include sustainability and competitiveness of the sugar industry, and environmental concerns from both local and global perspectives. In considering such technologies, it should be noted that there are financial and environmental benefits, and also policy issues to consider. Traditionally, ethanol most is produced from sugarcane, and biodiesel from vegetable oil seeds.

Sustainability and Competitiveness of the Sugar Industry

The sugar industry is a major worldwide industry that faces many problems, since sugar prices are extremely volatile. The industry also faces difficulties such as competition due to saturated markets in industrialised countries, and competition from other sweeteners [4]. For the industry to be sustainable and competitive, there is increased need for it to diversify its product portfolio by investing in co-products such as ethanol.

Environmental Concerns of Use of Fossil Fuels

At a global level, the need to contribute to efforts to reduce GHG emissions aimed at achieving stabilsation of GHG concentrations in the atmosphere cannot be over-emphasised. Accumulation of GHGs in the atmosphere result in global warming, which has far reaching negative environmental impacts.

At a regional level, local pollution (CO, NO_x, UHC, SO_2, Soot) is a major concern. Taking into account economic issues, the following issues thus provide an excellent opportunity to implement a biofuels programme in Southern Africa.
Petroleum products are a drain on foreign exchange
Local pollution (CO, NO_x, UHC, Soot)
Lead, which has historically been added to gasoline in order to increase its octane number, has been identified as a dangerous pollutant since low levels of exposure to lead causes a range of learning and neurological defects; children are most vulnerable

Ethanol Blending

In most parts of the world, use of lead additives in gasoline has been eliminated, except for most parts of Africa. Instead of lead, other additives like MTBE (methyl tertiary butyl ether) can be blended with gasoline, and is most commonly used, but is increasingly being viewed as a poor choice, because it leads to significant ground water contamination. Another additive option is MMT, a manganese compound, but it also faces different concerns over potential health risks, and is thus viewed controversial. Another approach is for refineries to manufacture high octane gasoline through use of catalytic reforming units. For many refineries in Africa, this will require upgrades and large capital outlays, which may not be affordable [5]. Fortunately, octane can be boosted from natural bearing fuels such as ethanol from crops – such as sugarcane, sweet sorghum, etc.

Biodiesel Use

Biodiesel is a cleaner-burning fuel than petroleum diesel. Blends of up to 20% can be used in nearly all diesel equipment without modifications and are compatible with most storage and distribution equipment. Higher blends of up to 100% can be used in many compression ignition engines built since 1994 with little or no modification [6]. Transportation and storage, however, require special management. Using biodiesel substantially reduces emissions of unburned hydrocarbons, carbon monoxide, sulphates, polycyclic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter.

A comparison of the physical properties of biodiesel and petroleum based diesel indicates that the two are similar as shown in Table 2.1 [6,7].

Table 2.1: Physical Characteristics of Biodiesel and Petroleum based Diesel

Characteristic	Value	
	Biodiesel	Conventional Diesel
Specific gravity	0.87 to 0.89	0.84 to 0.86
Kinematic viscosity @ 40°C	3.7 to 5.8	2 – 4.5
Cetane number	46 to 70	45 - 52
Higher heating value (MJ/kg)	39.4 to 41.9	Average 42.5

Although there may be disadvantages associated with biodiesel, there is are overall benefits to its use. Listed below are the benefits of biodiesel [2,8]:

Benefits of Biodiesel

Biodiesel has a lower flash point than petroleum diesels and thus helps prevent 'rumbling'during combustion
Biodiesel burns cleaner than petroleum diesel and thus reduces particulate matter, thus lowering emissions of nitrogen, CO and UHC
The odor of biodiesel is considered by many as less offensive than petroleum diesel
Biodiesel has similar combustion performance characteristics, including fuel consumption (km/litre), and better heat dissipation to the cooling water
There are only limited or no modifications needed to current engines whilst using biodiesel
There may also be no need to change transportation and storage systems.

The disadvantages of biodiesel include the following:
can be corrosive to rubber and liner materials;
cannot be stored in concrete lined tanks;
in some cases, injector fuel orifices need to be reduced to create a higher cylinder pressure; and
economics of production varies depending on the feedstock

PROSPECTS AND OPPORTUNITIES

Both ethanol (for gasoline blending) and biodiesel can be produced from agriculture based feedstocks. The former is produced from sugarcane juice and / or molasses, sweet sorghum juice, maize, cassava and cellulose. Biodiesel can be produced from jatropha (which is abundant in Southern Africa) and other oil-bearing seeds. It can be blended up to 20% in most diesel engines without modifications, and up to 100% for engines built after 1994 [6].

The key elements required to ensure bioenergy fuels programmes succeed are technology, availability of feedstocks at low cost and project economics. The others which are essential, but not elaborated in this paper are land availability, conducive regulatory fiscal and policy framework and innovative financing mechanisms. Suffice to say that there is abandant land in Southern Africa for growing feedstocks.

Ethanol Production

Production Technology for Ethanol

Various technology configurations are available on the market for ethanol production. Their concepts are largely influenced by the feedstocks used and composition, whether anhydrous or hydrous. The former is suitable for production of fuel as a transport fuel. The type of technology used can either be annexed or autonomous. For Southern Africa, annexed distillery has the greatest potential, in view of the structure of the sugar industry.

Given in Figure 3.1 (page 13), is the traditional ethanol production process, which is well known and has been exploited worldwide. The main processes are fermentation of either molasses or juice with yeast to produce 10-15% ethanol, distillation to separate ethanol from water, and rectification to produce anhydrous ethanol, suitable as a transport fuel. The technology, although suitable, cannot sufficiently meet the high demand of fuel for blending due to a high gasoline consumption in Southern Africa.

In the recent past, there have been tremendous efforts in R & D to produce a technology of a higher conversion efficiency, and which can handle a wider range of feedstocks to include both cane and lignocellulosic. Given in Figure 3.2 (page 13) is the extractive hydrolysis process and distillery scheme [9]. The process involves conversion of cellulosic material into fermentable sugars under the effect of mineral acids in a process called hydrolysis. The sugars produced are then fermented and distilled as in the traditional approach.

Feedstocks for Ethanol Production

Ethanol can be obtained from many different feedstocks, in fact from any sugar containing raw material. Feedstocks can be classified into three main groups:

Sugars: (i.e. sugarcane, molasses, fruits, etc) that can be converted to ethanol through fermentation and distillation

Starches: (i.e. grains like maize, root crops like cassava), which must be first be hydrolysed to fermentable sugars

Cellulose (i.e. woody material, agricultural waste, black liquor from pulp and paper which must be converted to sugars by action of mineral acids.

From an economic point of view, very few materials can seriously be considered as feedsock. And from Southern Africa's perspective, sugarcane and sweet sorghum offer promising feedstocks (examples: Brazil, Malawi, India, Kenya and Zimbabwe) [10]. Quantities of ethanol and feedstock required depend on the demand, which in turn is influenced by the level of blending (5%, 10%, 15%). At present, most of the ethanol is produced from cane molasses, which, however, have limited availability, being a by product of sugar factories and has limitations on waste water control.

In view of such limitations, there is need to exploit new agro-based feedstocks. For such feedstocks to be attractive, they need to have the following characteristics: sugar bearing, remunerative for the farmers, low cultivation costs, viable for alcohol production and giving zero discharge of waste water.

Taking into account the climate and soils in Southern Africa, one such feedstock that can be effectively exploited is sweet sorghum. It has following characteristics:
Sugar bearing feedstock
Short cycle crop –3.5 months
Can be grown across warm climate regions
Easier to grow and handle (Viz-a-Viz sugarcane)
Low cultivation costs
Known to farmers – Robust crop- Practices similar to sugarcane
Gives fodder for cattle
Gives bagasse similar to sugarcane – Energy for distilleries.

A comparison of the characteristics and requirements for sweet sorghum and sugarcane indicates that overall, the former is a better source of ethanol production. Shown in Table 3.1 is the comparison between sweet sorghum and sugarcane as feedstocks for production of ethanol.

Table 3.1: Comparison of Growing Characteristics Between Sweet Sorghum and Sugarcane

Properties	Sugarcane	Sweet Sorghum
Crop Cycle	10-11 months	3.5 – 4 months (Grown twice / year)
Yield per Acre	28 – 32 tonnes	17 – 22 tonnes x twice/year = 34 – 44 tonnes
Sugar content	11 – 13%	9 – 11%
Conventional ethanol yield	68 – 74 litres/tonne	45 – 55 litres / tonne of stalks
Water requirement	100%	65 – 70% of cane
Fertiliser	100%	35 – 40% of cane
Bagasse availability	30% of cane	28 – 30% of sweet sorghum

Source [Reference 8]

The total cost to include seed cost, land preparation, sowing, weeding, fertilisers, miscellaneous labour cost, water, electricity, harvesting and transport is typically US$306/ha for sugarne, while it is US$90 for sweet sorghum [9]

The amount of feedstock requirement in the region depends on the amount of gasoline consummed and the level of percentage blending required by a policy guideline. Ethanol provides a better option as an octane enhancer than lead. The region can take advantage of this resource to replace lead as an octane enhancer. The effect of such a policy requires considerable amount of feedstock to produce ethanol equivalent with lead. Table 3.2 shows a list of selected countries in Southern Africa, with lead requirement, ethanol equivalent and possible GHG savings per annum, at 10% ethanol blending.

Table 3.2 - Feedstocks Requirements Through The Blending Route At 10% Blending for Selected Countries

Country	Gasoline Consumed (million litres/yr)	Lead concentration (g/litre)	Total lead used (t/yr)	Ethanol Equiv. (million litres/yr)	Ethanol Availability (million litres)	Ethanol Deficit (million litres)	GHG Saving (tonnes)
Mozambique	71	0.5	40	7.1	3.6	(3.5)	15756.8
Namibia	331	0.4	180	33.1	-	(33.1)	73457.7
South Africa	10,358	0.2	2100	1035.8	216.0	(819.8)	2298714.6
Zambia	187	0.7	130	18.7	19.0	-	41500.3
Zimbabwe	433	0.8	350	43.3	38.0	5.3	96094.2
Totals	11,380		2800	1138	273.0	861.7	2525523.5

The table shows that at 10% ethanol blending (the minimum required to meet the ethanol equivalent to replace lead), there is an overall deficit of ethanol amounting to 862 million litres. To meet the deficit, will require expansion of sugarcane estates. However, since expansion of sugarcane estates can only grow at a rate of about 2% per annum due to various constraints [11], alternative feedstocks like sweet sorghum can be used for this purpose. To meet the deficit through use of sweet sorghum will require land availability of about 400,000 – 500,000ha. Southern Africa has abundant land to accommodate this demand. Such a policy will add additional environmental benefits through saving of over 2.5million tCO_2 per annum in the region from the transport sector.

Biodiesel Production

Production Technology of Biodiesel

The production of biodiesel is well known. Three basic routes to diesel production from oils and fats exist, and are listed below:

Base catalysed transesterification of the oil with alcohol
Direct acid catalysed esterification of the oil with methanol
Conversion of the oil to fatty acids, and then to alkyl esters with acid catalysts

The most commonly used and most economical process is called the base catalysed esterification of fat/oil with methanol, typically referred to as 'the methyl ester process', due to the following [2,8]:

Low temperature (65.6^{o}C) and pressure (20psi) processing
High conversion (98%) with minimal side reactions and reaction time
Direct conversion to methyl ester with no intermediate steps
Exotic materials for construction are not necessary

Figure 3.3 illustrates the biodiesel production process. Prior to this process, some of the suitable feedstocks may require some pre-processing to remove materials that may affect the process. Pre-processing can take the form of refining, degumming and/or filtering to remove the impurities. Degumming involves mixing a small amount of water (about 3-5%) with the feedstock which precipitates the gums which then can be separated by centrifuging the mixture. The crude or unrefined vegetable oils contain free fatty acids and gums that must be removed before entering the 'methyl ester process'. The esterification process involves reaction of the crude oil with an alcohol (usually methanol) and a catalyst (sodium or potassium hydroxide) to produce biodiesel and a co-product glycerine [2,8].

Feedstocks for Biodiesel Production

The amount of feedstock requirements in the region to produce biodiesel depends on the amount of diesel consummed and the level of percentage blending. Traditionally, conventional major feedstocks for the 'methyl ester process' are cotton seed oil, soy bean and peanut oil. Other suitable feedstocks for the 'methyl ester process', which can be used and grown in Southern Africa, is Jatropha, in view of uncertainty of conventional feedstocks and also to avoid conflict between energy and food, since it is a non-edible oil. The characteristics of Jatropha that makes it superior to conventional feekstocks are listed below [12]:

Jatropha curcas L. belongs to the family euphorbiaceae
Growing period = approx. 100 days
Drought resistant
Grows on well – drained soils with good aeration, and is well adapted to marginal soils with low nutrient content

Yield ranging between 5 to 10 tonnes per hectare
Oil content = 40%
Grows as a shrub, and needs no fertiliser.

Diesel consumption in the region is around 15 million tonnes per annum. A policy of 20% diesel blending would require 3 million tonnes of biodiesel. Such a substitution would need 7.5 million tonnes of jatropha seeds for processing. The land requirement to grow such an amount would be about 1 million hectares of land, which is also plausible given the amount of abundant land available in the region. Such a policy will again bring environmental benefits through saving of GHGs amounting to 9.4 million tCO_2 per annum.

Project economics
In addition to technology and feedstock availability, project economics is a critical consideration for successful implementation of a biofuel programme in Southern Africa. This section, therefore, considers the project economics of ethanol and biodiesel production.

Economics of Ethanol Production
To determine the project economics and financial viability (through the IRR route), requires knowledge of investment costs, operations and maintenace costs, and production parameters of typical sugar factories in the region. Given in Table 4.1 is such information. From the table, it is clear that the size of typical sugar factories in the region ranges from 100 – 500 tonne/cane hour.

Table 4.1: Production Parameters

Typical Factory Size	Actual output (tonne/ cane hr)	Actual output (tonne/annum)	Molasses-cane output ratio	Molasses production (tonnes / hr)	Alcohol production, (litres per day)	Investment Cost Molasses to Ethanol (Anhydrous)		O+M% of investment or output related
						Installed capacity, kL/day	Investment, (US$m)	
100	95.69	462,294	0.04	4	21600	20	2.30	5
150	160.04	688,226	0.04	6	32400	30	2.93	5
250	250.84	1,007,183	0.04	10	54000	50	3.99	5
300	305.47	1,211,236	0.04	12	64800	60	4.45	5
350	356.1	1,655,682	0.04	14	75600	70	4.88	5
400	408.96	2,217,396	0.04	16	86400	80	5.29	5
500	492.86	2,193,737	0.04	20	108000	100	6.04	5

Source [Reference 10]

Results of financial analysis (IRR vs Ethanol Production Price) were obtained for three scenarios namely:
BAU without CDM consideration
CDM scenario spread over 21 years, at US$5 per tCO_2
CDM scenario with 33% down payment from sale of carbon credits, and the rest being sold over the remaining crediting period US$5 per tCO_2.

Given in Figures 4.1, 4.2 and 4.3 are the results of financial performance for scenarios described above.

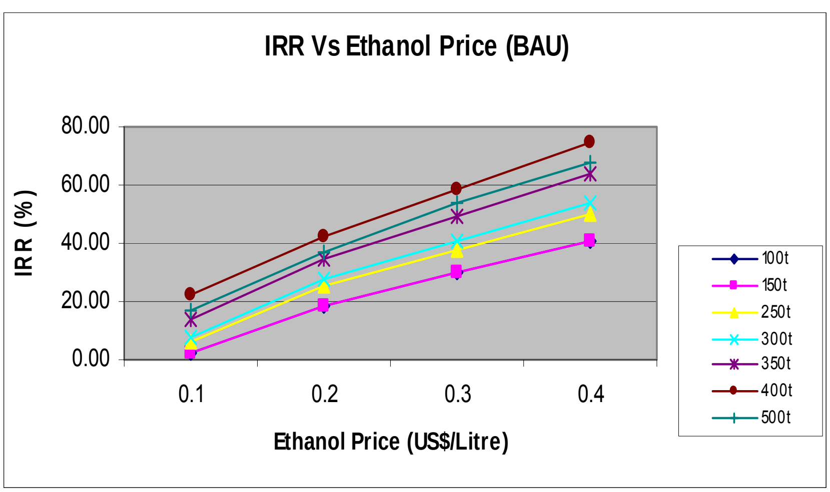


Figure 4.1: BAU Scenario (Ethanol Financials)

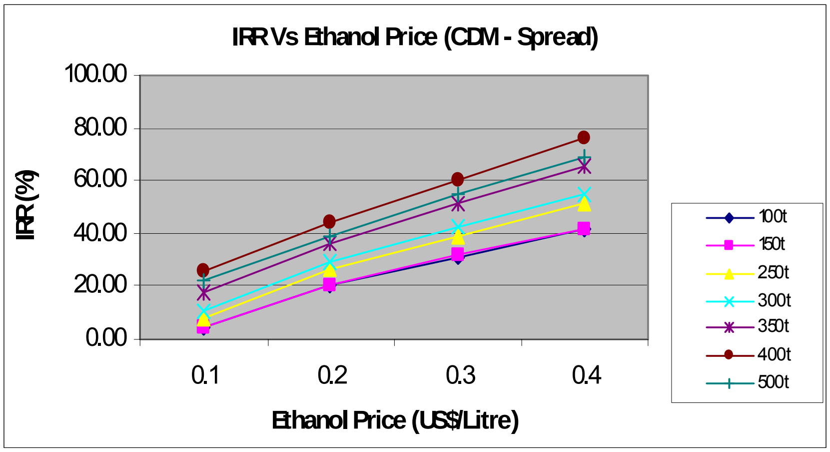


Figure 4.2: CDM (Spread) Scenario (Ethanol Financials)

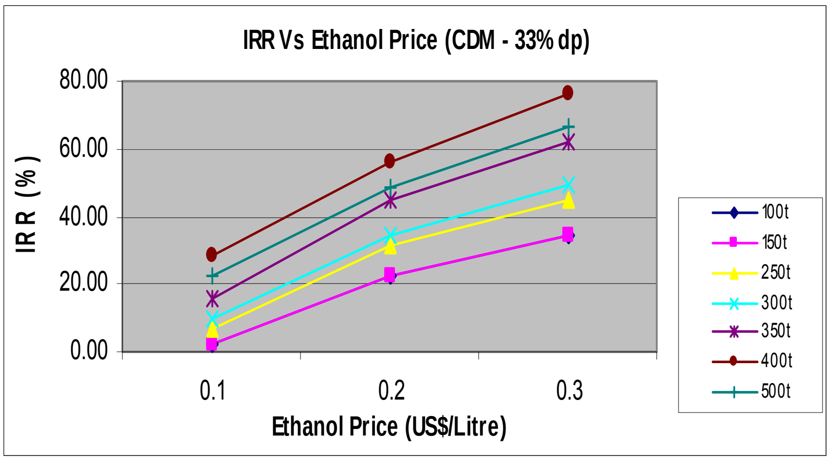


Figure 4.3: CDM (33% Down payment) Scenario

For each scenario, it is clear from the figures that larger plant sizes have a better financial performance due to economy of scale. Assuming an IRR of 20%, which is quite reasonable return on investment, the ethanol production prices are given in the Table 4.2 below:

Table 4.2: Ethanol Production Prices for Diferent Scenarios at 20% IRR

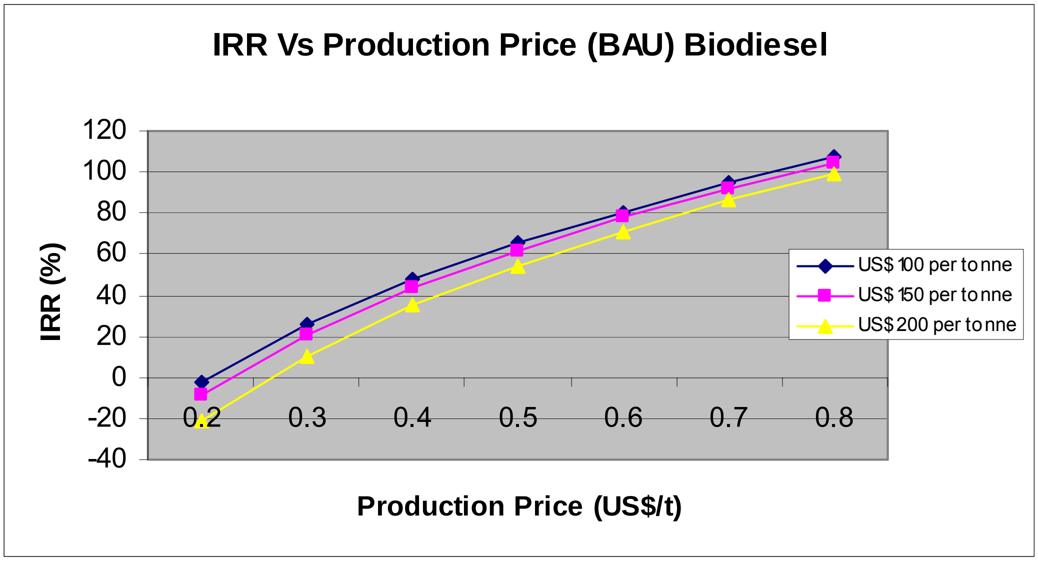
Factory Size (tonne/cane hr)		**100**	**150**	**250**	**300**	**350**	**400**	**500**
Scenario	**BAU (UScents)**	21	21	17	16	13	10	12
	CDM Spread (US-cents)	19	19	16	14	11	8	10
	CDM Advanced Payment (UScents)	18	18	15	13	10	5	9

It is clear from Table 4.2 that the ethanol price ranges between 10 and 21 US cents per litre for BAU. It ranges from 8 to 19 US cents for CDM spread, while it ranges from 5 to 18 US cents per litre for CDM advanced payment.

In case of Zambia, for example, the current gasoline price (ex-factory) is 40 US cents per litre [13], which gives an economic advantage to ethanol use as an octane enhancer. It is interesting to note from the above that CDM at US$5 per tonne CO_{2e} is not attractive to business. Unless the value of carbon credits is increased, it is unlikely that the business sector will be attracted by CDM.

Economics of Biodiesel Ethanol Production

Given in Figure 4.4 is the project economics for a 50,000-tonne per annum biodesel plant with a capital outlay of US$20million, with an O & M cost of 60% of investment cost at different jatropha raw material prices.



NB: The curves show cost of raw materially (i.e. 100, 150, 200 US$ per tonne)
Figure 4.4: BAU Scenario - economics for Biodiesel Production

The results above are for business as usual scenario. Using results from Figure 4.4, biodiesel price for different raw material prices at 20% IRR are given in Table 4.3.

Table 4.3: Biodiesel Prices for Different Raw Material Prices at 20% IRR

Raw Material Price (US$/tonne)	100	150	200
Biodiesel Price (US Cents)	28	30	35

It is clear from Table 4.3 that the price of biodiesel ranges from 28 to 35 US Cents against 40 US cents for petroleum diesel [13]. The viability of biodiesel production depends largely on the price of the raw material and benefits to accrue to farmers. Between the price of US$100 to US$150, the economics of biodiesel production is relatively attractive.

REVIEW OF BARRIERS TO TRANSFER AND DIFFUSION OF BIOFUELS TECHNOLOGIES

Barriers to Transfer and Diffusion of Biofuels Technologies

Implementation of bio-fuel producing technologies is still ironically on the low side, despite the the environmental and economic benefits to accrue, existence of bio-fuels producing technologies on the market, and similar successful programmes elsewhere in the world. Furthermore, bio-fuels have great potential for electricity generation in isolated areas in stationary engines. There are also opportunities for additional revenue stream by selling carbon credits under the Clean Development Mechanism (CDM). The aforesaid constitute sustainable development benefits which are in line with Africa's development goals. With the ever-increasing prices of petroleum based fuels, which is finite in nature, biofuels, which can be produced locally, present the best sustainable development path for the petroleum industry.

Various barriers currently inhibiting the penetration of such technologies in Southern Africa have been identified as policy, technical/technology, financial and legal [14], elaborated in Table 5.1.

Table 5.1: Barriers to Transfer and Diffusion of Bio-fuels Producing Technologies

Category	Barriers
Policy	• Limited awareness of the benefits to accrue from investment in bio-fuels producing technologies • Limited awareness of CDM objectives and its cy-cle in Government, NGOs and Private Sector • Limited awareness of benefits of RETs and its relationship to business by Government, NGOs and Private Sector
Technology	• Limited awareness of availability of information on bio-fuels producing technologies • Limited and sometimes non-existence of knowl-edge of selection of appropriate bio-fuels producing technologies as potential RETs • Limited human resource in the development of a bankable business proposals under sustainable energy path development • Few support services for PIN and PDD elaboration and conducting feasibility studies, and formulation of business plans related to RETs
Financial	• Lack of financial base from local investors to con-tribute to equity for project implementation • Limited, and sometimes no, awareness of lo-cal/regional institutions of the need to invest in RETs projects • Limited awareness of availability of international investment sources • Low market value of carbon credits and hence no financial attractiveness for business
Legal	• Limited, and sometimes no, awareness of the Kyoto Protocol as an international law at the levels of NGOs and Private Sector • Limited, and sometimes no, awareness of legal issues in the development of RETs projects at all levels (Government, NGO and Privates Sector) • Limited, and for private sector almost no, aware-ness of Legal arrangements during CDM development • Lack of capacity in most countries to negotiate for a CERPA

Policy Issues Arising from Barriers

From the barriers above, a number of policy issues arise. Such policy issues would be aimed at enhancing sustainable development. For ethanol production and use, key policy issues include the following: the use of ethanol as an octane enhancer; standards should be developed in use of ethanol as an octane enhancer and there is need for agricultural policy on outgrower schemes. To meet the increasing demand of ethanol and improve the livelihoods of the growers requires promotion of private sector participation in ethanol blending and the need for governments to offer fiscal incentives

In the production and use of biodiesel, a general policy on biodiesel would be required. Like for ethanol, standards should be developed for production and use of biodiesel. For isolated electricity generation, low level of electricity tariff (currently at US-cents 2 to 4) for most SAPP countries, which in most cases does not take account of environmental externalities, need to be reviewed. Studies have shown that on commercial basis, the tariff should be over US-cents 5 [15]. In order to promote private sector participation, therefore, a policy on Independent Power Producers (IPPs) needs to be implemented which takes into account the dis-pariry between the prevailing (usually subsidised) tariffs and commercial ones.

Barrier Removal Strategy

From the dicussion of policy/institutional, technology and financial/legal barriers identfied, three specific bar-rier removal strategies have been recommended namely awareness and information on the benefits for im-plementation of biofuels producing technologies under sustainable energy path development and CDM ar-rangements, capacity to develop portfolio of sustainable bio-fuels producing bankable projects, and condu-cive fiscal and financial environment for easy implementation of such projects.

Concluding remarks

Southern Africa has great potential to benefit from use of its natural resource endowment base to produce transport fuels, which if implemented will go a long way in achieving a sustainable energy path and also con-tribute significantly to poverty reduction through creation of numerous jobs from agriculture, processing and marketing. In order to achieve this requires a conducive policy framework, with supporting awareness and information programmes, and development of capacity to develop sustainable bio-fuels producing projects.

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NOMENCLATURE

BAU	Business as usual
CDM	Clean Development Mechanism
GHG	Greenhouse Gas
IPP	Independent Power Producer
IRR	Internal Rate of Return
O & M	Operation and Maintenance
RETs	Renewable Energy Technologies
SAPP	Southern African Power Pool

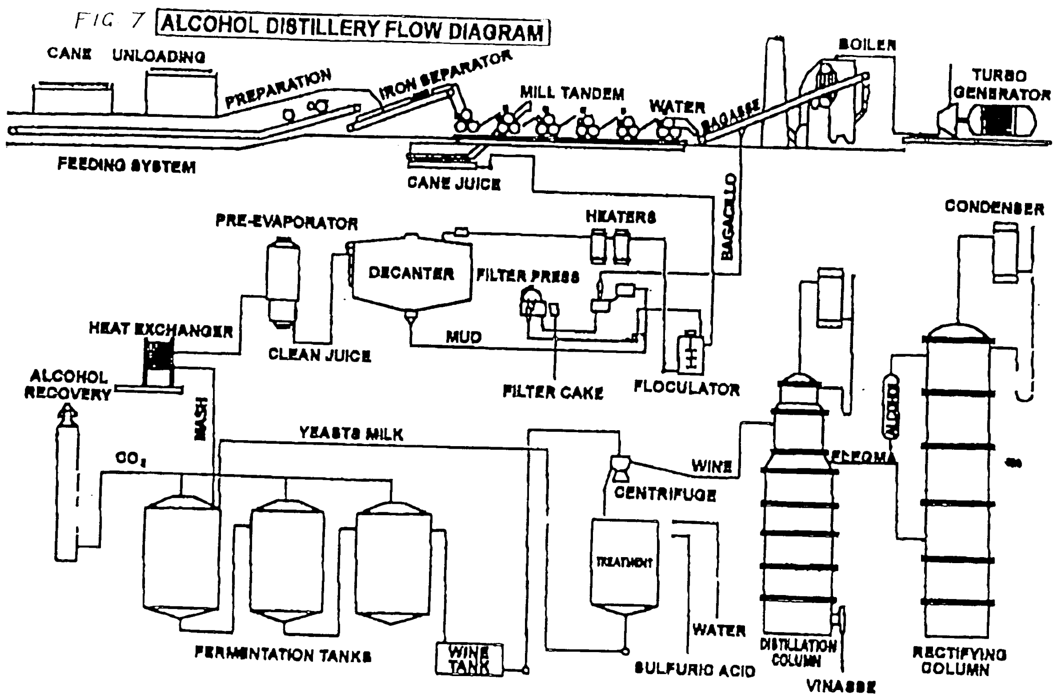


Figure 3.1: Alcohol Distillery Flow Diagram

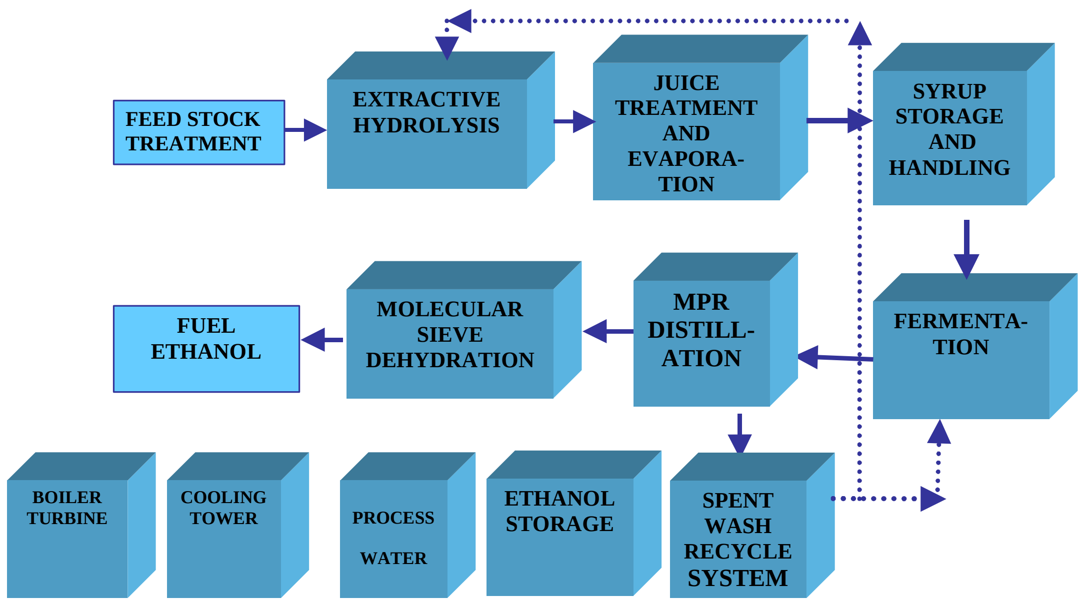


Figure 3.2: Extractive Hydrolysis Concept & Distillery Scheme

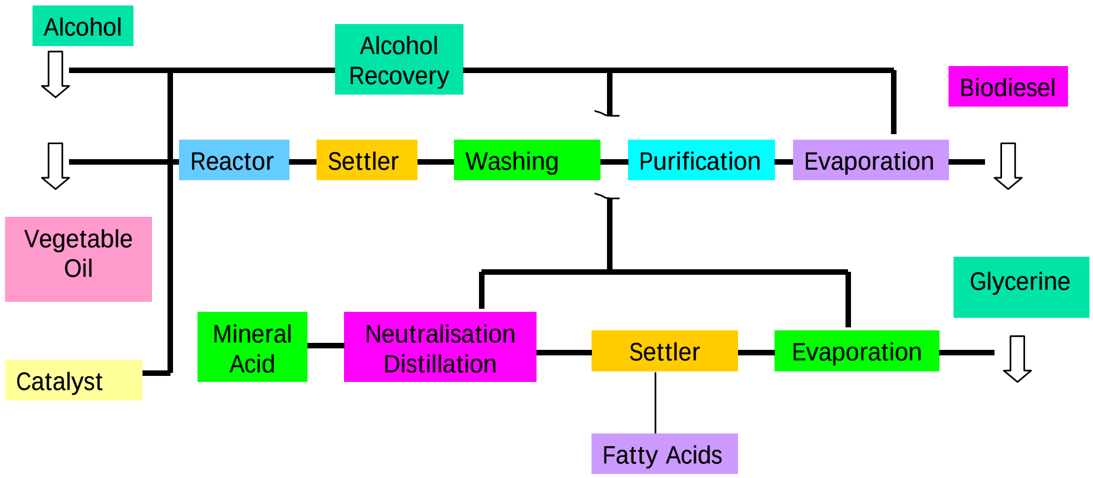


Figure 3.3: Biodiesel Production Process

Petrobras and Climate Change Mitigation

Ildo Luís Sauer, Márcia Leite Drachmann, Anário Rocha Quintino Júnior, Carlos Augusto Arentz Pereira, Mozart Schmitt de Queiroz, Vicente Hermogerio Schmall

Abstract

The largest enterprise in Brazil, Petrobras has stated in its Strategic Planning its decision to develop into an energy enterprise by 2010. This decision includes social accountability and environmental responsibility standards linked to climate change mitigation policies. Within this context, Petrobras has implemented a series of actions focused on enhancing energy efficiency and mitigating climate changes, including a renewable energies portfolio, an in-house energy efficiency program, external programs for rational use of fossil fuels, extensive participation in Brazil's fuel alcohol program, large-scale use of natural gas, an in-house emissions inventory system, among others. The climate mitigation benefits resulting from these actions include savings of more than 300,000,000 liters (254,400 toe) per year of diesel from 1997 to 2003, a drop of 1.5 million m^3 (901,500 toe) per year in LPG consumption, and the avoidance of 26,000,000 tons per year of CO_2 emissions through Brazil's fuel alcohol program, promoted largely by Petrobras, in parallel to savings of more than 1.5 million toe through its in-house energy efficiency enhancement program, avoiding emissions of 4.6 million tons of CO_2 between 1992 and 2003.

INTRODUCTION

Signed during the Earth Summit held in Rio de Janeiro in June 1992, the United Nations Framework Convention on Climate Changes was the first of a series of agreements on climate changes mitigation. Outstanding among the more recent pacts is the Kyoto Protocol, through which countries have been adhering to the commitment on stabilizing atmospheric emissions, particularly in terms of greenhouse gases that cause global warming. Within this context, it is recognized that anthropic activities are altering the way in which solar energy interacts with the atmosphere, giving rise to the risk of changing global climate patterns and prompting an increase in the average temperature of the Earth's surface. (MCT. 2004)

As the largest enterprise in Brazil and keenly aware of the potential impact of industrial activities, Petrobras is closely attuned to the movement inspired by the Framework Convention on Climate Changes. In step with a worldwide trend among major oil conglomerates, this consists of acting institutionally as an energy enterprise, deeply committed to the concept of sustainable development, linked to social accountability and environmental responsibility.

In its Strategic Planning 2001 – 2010 and its 2004 – 2015 review, Petrobras established the guideline to become an energy enterprise, operating internationally and leading this segment in Latin America. One of the most outstanding aspects of its corporate strategy is the stress placed on integrated operations with the Southern Cone countries in the gas and energy markets, and the development of renewable energy initiatives. As a result, the Gas and Energy Division was established, whose duties and responsibilities include the coordination, identification, implementation and feasibility of business opportunities in the gas and energy areas, with emphasis on energy efficiency and the use of clean technologies.

A Brazilian State-controlled enterprise, Petrobras operates at an international level in twelve countries, with a track-record stretching back more than half a century in the fields of oil and natural gas prospecting, exploration, production, refining and distribution. It produces 279,698 toe/day (233,677 toe of oil and 46,090 toe of natural gas/day), refining 1,732,000 bpd and supplying some 98% of Brazil's oil product consumption requirements. Moreover, it already has a total of 1,800 MW thermal-power plants fueled by natural gas and a hydropower plant (285 MW) in the Comahue region, Neuquén Province, Argentina.

Closely aligned with international climate changes targets, Petrobras has implemented a series of actions that converge on enhancing energy efficiency and mitigating climate changes, while introducing clean production processes. These aspects are assigning top priority in the corporate culture, clearly apparent in the selection of technologies, energy feedstock, equipment and production processes, as well as in the goods produced and their end-uses, in addition to the treatment and disposal of industrial solid wastes, while also noting the economic conditions that ensure the profitability of its enterprises.

Outstanding among the activities undertaken by Petrobras that are associated with mitigating climate changes and sustainable development are:

In-House Energy Conservation Program;

CO_2 Injection for Recovering oil from Depleted Wells;

Oil products use rationalization programs in the transportation and industrial sectors;

Natural Gas Re-Injection;
Use of Geothermal Energy to upgrade natural gas line flows;
Extensive participation in the alcohol fuel program (Pro-Alcool);
Petrobras Atmospheric Emissions Inventory System;
Large-Scale Natural Gas Use Program;
Renewable Energies Project Portfolio.

By reviewing Petrobras' past experience and future plans we expect to contribute to provide answers to key questions posed by IPCC, namely:
- What are the driving factors of industrial technology development?
- What are the factors that drive or limit the process of transfer and diffusion of technologies?
- How to make accurate estimates of future cost and future market potential of technologies?

IN-HOUSE ENERGY USE RATIONALIZATION PROGRAM FOR PETROBRAS ACTIVITIES

Actions designed to upgrade the energy performance of Petrobras date back to the first oil crisis in the early 1970s, and were implemented mainly at the refineries. At that time, Petrobras was largely a refining company that imported most of the processed oil. As refining activities accounted for 85% of its energy consumption, the oil price hike increased the cost of consuming this energy – basically oil – slashing its profit margins and making energy savings critical for the survival of its business. This is when the **In-House Energy Use Rationalization Program for Petrobras Activities** was established, initially designed to lower energy costs. These assorted actions were gradually expanded to include the entire company, and today are closely associated with all its activities, consolidating its image as a socially and environmentally responsible enterprise.

The **In-House Energy Use Rationalization Program for Petrobras Activities** consists of a wide variety of programs and projects that have been implemented throughout the company over more than thirty years. They include upgrading the operating procedures in the furnace and boiler burning processes, optimization of steam and energy generation and distribution systems, fixing leaks, installing heat-recovery boilers, as well as air pre-heating systems, etc. All of them still ensure significant savings for Petrobras.

The main operating measures taken that help save energy with little or no additional investment were: (TOUMA. 1999)
Furnace and boiler operations with minimum excess air;
Strict control of combustion gases temperatures, kept at the lowest possible required by the fuel and equipment;
Strict control over the steam system, preventing discharges into the atmosphere and the condensation of low-pressure steam;
Operation of the power generation system in parallel with the grid, in order to minimize steam condensation in the extraction and condensation turbines;
Systematic efforts to avoid and eliminate steam leaks;
Making the best possible use of steam condensate;
Heat-exchanger cleaning program based on energy savings criteria;
Rigorous maintenance of insulation materials around piping and equipment;
Maximum use of waste gases generated during the process, eliminating their discharge into the atmosphere;
Control of process steam at the lowest possible level required to ensure product quality;
Strict control over contracted power demands;
Operation such as product pumping undertaken at low electricity tariff periods;
Interruption of oil production in certain wells at times when purchased energy is more expensive;
Office cleaning schedule, moved to normal business hours, instead of at night;
Training courses and seminars;
Educational campaigns in energy efficiency improvement, publicizing successful case studies.
In order to foster engagement and a culture of improving energy performance throughout Petrobras workforce, a crucial step during the 1970s was to set up the In-House Energy Conservation Commissions (CICEs). The mission was to draw up, implement and monitor the targets of the Energy Conservation Program and to disclose its results within the entity or company of the Petrobras system to which they were linked. The activities of these CICEs played a vital role in the results achieved over these years, and it is through them that most of the measures listed above were drawn up and implemented. At the moment, there are 32 CICEs at Petrobras.

The In-House Energy Conservation Commissions (CICEs) consist of at least six members, all with a two-year term of office, with at least one employee representative appointed by the respective trade union, or a representative selected by the workers themselves and another representative from the In-House Accident Prevention Commission (CIPA) if any.

The functions of the Executive Secretary should be handled by a professional-level employee (engineer, architect, etc.) with a solid knowledge of energy efficiency. Whenever possible, the members of the CICE that are not appointed as President, Vice-President and Executive Secretary – should include an industrial safety specialist, a social communication expert and an administrator.

In entities with annual fuel consumption levels of over 500,000 toe (tons equivalent petroleum) the Executive Secretary of the CICE should perform his or her functions on a full-time basis. At the discretion of each CICE and when its operating area includes more than one location, Energy Conservation Sub-Commissions should be set up to provide technical and operating support for the CICE and subordinate thereto.

The CICEs are in charge of:
Surveying the potential for lowering consumption and/or reducing expenditures on energy, working closely with the Internal Energy Conservation Commissions Coordination Committee (COMCICE), if necessary;
Drawing up each year, in compliance with the guidelines issued by COMCICE, the Energy Conservation Program for their operating areas, with targets designed to lower consumption and/or expenditures;
In accordance with the guidelines laid down by the COMCICE, preparing the budget for enterprises involving energy conservation, integrated with the Company Planning Progress;
Undertaking actions designed to heighten awareness and involve all the employees in the Energy Conservation Program (seminars, lectures, contests, etc.);
Participating in the preparation of technical specifications for projects, designs, construction and acquisitions of goods and services, as well as the resulting competitive bidding processes that involve energy consumption;
Undertaking an ongoing analysis of energy consumption levels, monitored through standardized spreadsheets that should be subsequently forwarded to COMCICE for the consolidation of the report on Energy Conservation by the PETROBRAS system;
Calculating the specific consumption for the various energy sources, as an input to COMCICE's definition of standard consumption figures that must be complied with;
Participating in the Preventive Maintenance Program, in order to optimize energy source consumption, undertaking an annual assessment of the results and stressing the measures implemented, together with quantification of the gains;
Coordinating in accordance with COMCICE's guidelines the performance of specific studies designed to reduce energy consumption and/or expenses;
Encouraging and motivating employees to sign up for the Petrobras Energy Conservation Prize.

This experience with the CICEs prompted the Brazilian Government to make them a legal requirement for all organs or entities in the direct or indirect Federal Civil Service with annual electricity consumption of over 600 MWh, or consuming more than 15 tep (tons equivalent petroleum) in fuel. Government Decree N° 99,656 dated October 26, 1990, which established the mandatory requirement for the CICE predates the legislation that introduced the CONPET Program in 1991. These Commissions spread all over the Company have played the role of multiplier agents for an energy efficient culture among the employees.

As a result of these efforts, the need arises for improvements that indicate larger-scale projects and higher investments. These energy use rationalization projects addressing the activities of Petrobras are entrepreneurial by nature: they should ensure an economic payback, so that they can be implemented. However, environmental aspects are always taken into consideration when selecting the projects to be implemented.

Some of the investments with more significant energy efficiency impacts are listed below: (FARACO. 1981)
1975 Start-up of CO boiler at the Gabriel Passos Refinery (Minas Gerais State) with an annual reduction of 14,000 tons of fuel oil and savings of US$ 2,200,000 per year;
1977 Start-up of the CO boiler at the Duque de Caxias Refinery (Rio de Janeiro State) with an annual reduction of 53,000 tons of fuel oil and savings of US$ 4,000,000 per year;
1980 Start-up of eleven air pre-heating systems in process refineries, ensuring annual savings of 87,000 tons of fuel oil;
1983 Review of the crude pre-heating systems in two refineries with potential annual savings of 15,650 toe;
1993 Modification of the catalytic cracking unit for total combustion at the Gabriel Passos Refinery (Minas Gerais State), with a reduction of 8,000 m^3 fuel oil and savings of US$ 400,000 per year;
1994 Air pre-heating system in furnaces at the Alberto Pasqualini Refinery (Rio Grande do Sul State) with a reduction of 13,700 tep/year of fuel oil.
2001 Increase in the associated gas usage rate tapped from onshore oil production fields in Rio Grande

do Norte State, with a reduction of 3,650,000 m^3 gas/year and savings of US$ 239,470 per year.

Table 1 provides an estimate of the amounts of atmospheric emissions of CO_2 (a greenhouse gas), through these initiatives. Moreover, the Technical and Economic Feasibility Studies for new enterprises cover two other aspects: social and environmental matters, and are now called Technical, Economic, Social and Environmental Feasibility Studies.

The data in Table 1 show the savings from 1992 through to 2003: (PEREIRA. 2004).

Table 1: PETROBRAS IN-HOUSE ENERGY EFFICIENCY PROGRAM 1992 - 2003

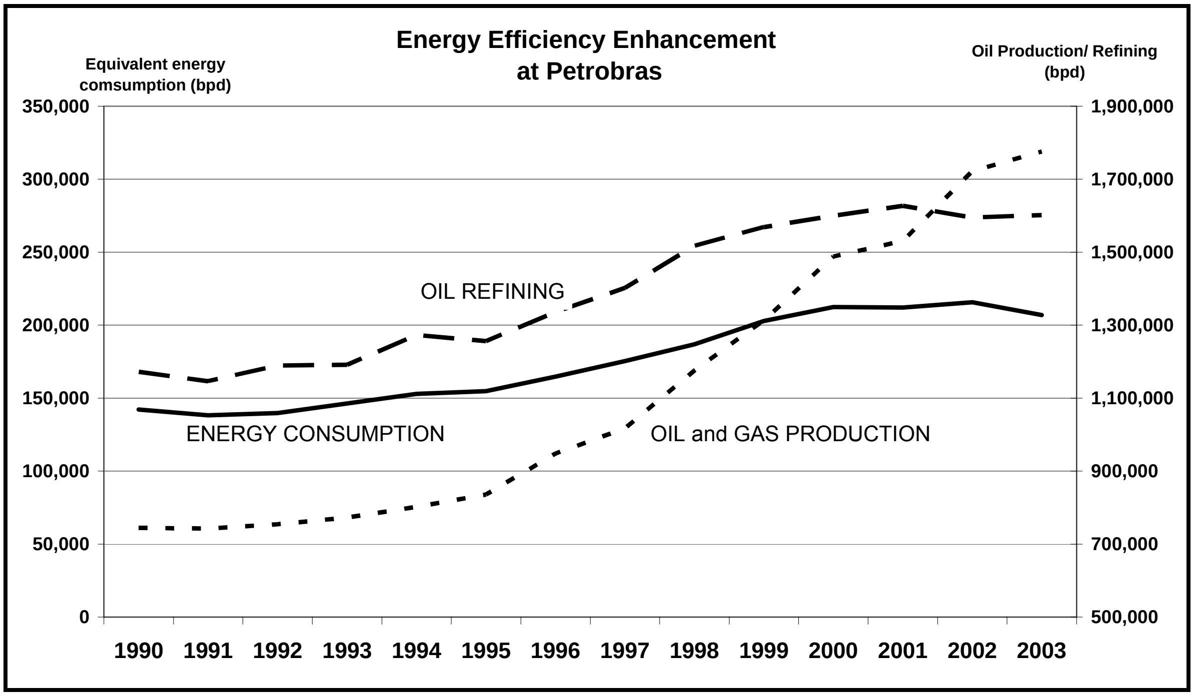
Reduction in Natural Gas Consumption (A)	713,036,000 m^3	650,289 toe
Reduction in Fuel Oil Consumption (B)	840,063 m^3	792,179 toe
Reduction in Diesel Oil Consumption (C)	64,558 m^3	54,745 toe
Reduction in LPG Consumption (D)	8,360 t	9,102 toe
Reduction in Tons Petroleum Equivalent (A+B+C+D)	-	1,506,315 toe
Avoided CO_2 Emissions	4,647,000 t(*)	-
Reduction of Peak Load Demand (kW)	54,078 kW	-
Reduction in Electricity Consumption (MWh)	320,825 MWh	-
Total Investments	72,812,000 US$	-
Accumulated Savings	198,608,000 US$	-

- CO_2 emission: 3.2 tons CO_2/tep;[82]

Source: Relatório sobre Conservação de Energia do Sistema Petrobras 2002/2003.

These figures reflect directly in the energy productivity of the process. Figure 1 shows that over time, Petrobras has produced and processed more oil with lower relative energy consumption:

82 Source: Brazilian Government - Ministry of Science and Technology (MCT). Report of Energy Emissions 1970/2001. Project: Estimation of the emissions of greenhouse gases from burning of fossil fuels in Brazil. Agreement between the Ministry of the Science and Technology - MCT and Economy and Energy - E&E - NGO, 2002.



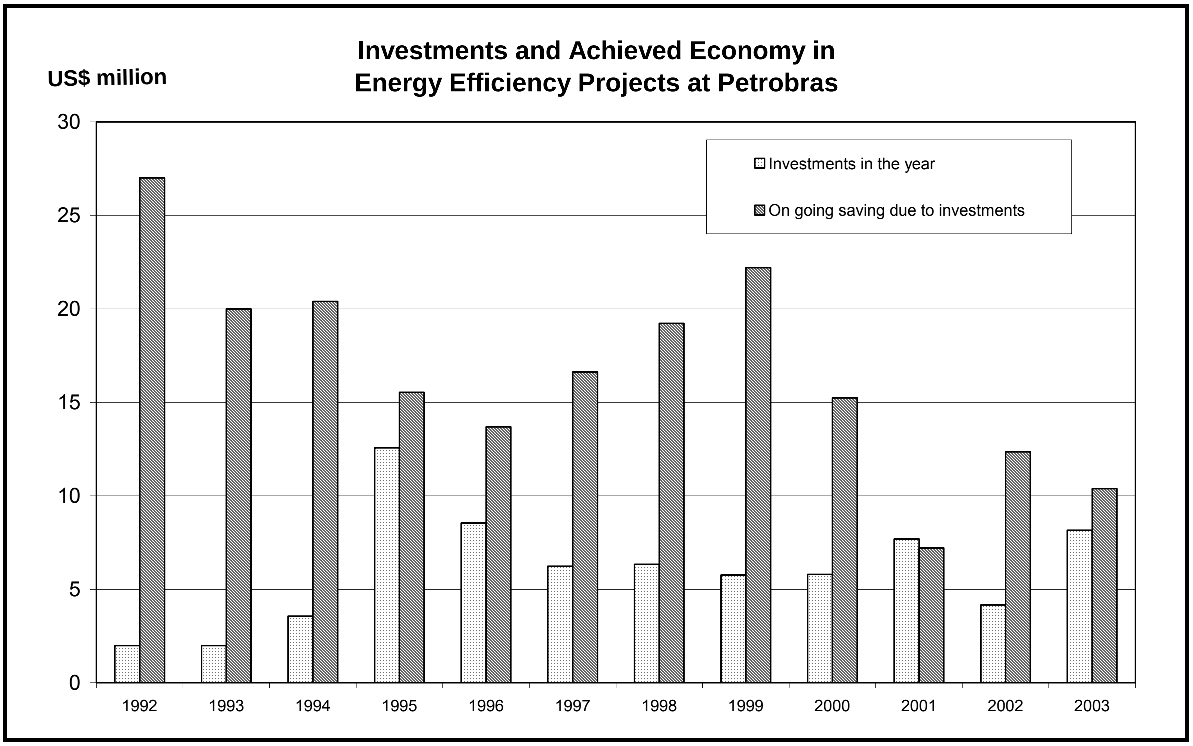
Source: Petrobras Internal Data.

Figure 1: Energy efficiency enhancement at Petrobras

Although much progress has already been made, there is still ample room for improvement. At the moment, several projects are under way. Particularly outstanding among those with higher impact is the reduction in burning off gas through flares, where several actions and projects are being implemented. Another important measure is the installation of turbo-expanders, which, at the catalytic cracking units found at most Petrobras refineries, use the energy of the catalytic regenerator combustion gas to produce electricity. The turbo-expanders in operation at Petrobras are listed below:
Capuava Refinery, São Paulo: 8 MW (65 GWh/year) in operation since March 2000;
Landulfo Alves Refinery, Bahia: 33 MW (269 GWh/year) in operation since August 2001;
Gabriel Passos Refinery, Minas Gerais: 6 MW (49 GWh/year) in operation since February 2004.

At the moment, studies are under way for installing four turbo-expanders at different refineries, totaling 68 MW.

The return on investments in Energy Efficiency correspond to a net present value of US$ 105 million for 1992 through 2003, shown in Figure 2:



Source: Petrobras Internal Data.

Figure 2: Investments and savings achieved in energy efficiency projects at Petrobras

As investments from 1992 through 2003 totaled around US$ 72 million present value, this Program represents appreciation of 45% on the amounts invested, excluding environmental gains, among others, that have not been measured. (PEREIRA. 2004).

The ample expertise developed by Petrobras in rationalizing the use of natural gas and oil products has prompted much interest among foreign companies and entities, particularly the World Bank.

At the domestic level, entities such as the Brazilian Association of Energy Conservation Services Enterprises (ABESCO), the cement industry and state federations of industries are showing interest in becoming more familiar with the activities of Petrobras, believing that the company's technical expertise is at the very least a good example to be followed.

CO_2 INJECTION FOR RECOVERING OIL FROM DEPLETED WELLS IN THE RECONCAVO BAHIANO BASIN;

Oil was discovered in Brazil during the 1930s at Lobato, near the Bahia State Capital, Salvador. After more than sixty years in commercial production, the oil fields in the Reconcavo Basin are at an advanced operating stage. The oil volumes discovered in this Basin reach just under 1.0 billion m^3, with an output of 225 million, corresponding to a recovery factor of 22.5%. Another 30.0 million m^3 of oil remain in the reservoirs as proven reserves.

The maturing of the Reconcavo Basin has imposed rising production costs in this region, due mainly to the following factors:
Low success rates for prospecting activities;
Oil outflow flow-rates have been dropping by 3% per year., with a consequent drop in production well productivity; and
Rising output of fluids used for secondary recovery – water and gas.
Petrobras has been doing its utmost to reverse or reduce the downtrends in these fields and reserves, which are having adverse effects on the economic indicators.

Among others, these efforts include the introduction of new secondary and tertiary recovery techniques, where CO_2 injections are important for recovering the oil in these reservoirs. Carbon dioxide injection techniques have been used for more than thirty years in Texas (USA). They were introduced in Brazil around fifteen years ago, particularly in Bahia State, through projects injecting around 350 tons/day sourced from industrial plants.

The process of stepping up hydrocarbons output through CO_2 relies partly on re-pressurizing the reservoirs, although the miscible characteristics of the oil are also important for flushing out higher volumes of hydrocarbons. Table 2 shows the potential production and inclusion of reserves with CO_2 requirements, for a twenty-year horizon.

Table 2: Preliminary Planning of Miscible CO_2 Used in the Reconcavo Basin oil fields

Potential for miscible CO_2 application = 337 million m^3 Original Oil In Place (OOIP)
Target for miscible CO_2 = 254 million m^3 oil Remaining In Place (ORIP = 75.4% of the OOIP)
Inclusion of reserves = 41 million m^3 (16.2% of ORIP — Anada H. *et al*:, 1982)
Total CO_2 requirements = 106 million tons (2.58 tons/m^3 — Anada H. *et al*:, 1982)
Daily CO_2 requirements (Theoretical) = 14,500 tons/day (20 years)
Daily CO_2 needs (ST/CER) = 5,000 tons/day (20 years)

One of the few industries able to consume large volumes of CO_2 is the oil segment, where the use of this miscible product to recover oil is a promising technology, with positive environmental impacts in terms of mitigating climate change, due to the substantial sequestration or retention of CO_2 injected into its reservoirs. Studies have shown that more than 50% of the injected CO_2 remains in the sub-soil.

RATIONALIZATION PROGRAMS FOR THE USE OF OIL PRODUCTS - CONPET

Presidential Decree N° 99,250 dated July 18, 1991, established Brazil's National Natural Gas and Oil Products Usage Rationalization Program (CONPET) within the Ministry of Mines and Energy (MME). This follows the guidelines established by the National Energy Use and Production Rationalization Program, also run by this Ministry. As stipulated in the Decree that established it, CONPET is coordinated by representatives of Federal Government entities and private enterprise.

The acquisition of technical expertise and experience in developing in-house energy efficiency programs at Petrobras led to the decision that the Executive Secretariat of CONPET should have Petrobras assigned to it, with responsibilities for preparing projects, bringing strategies into operation and publicizing actions.

This program encourages the efficient use of energy in transportation (which is the leading consumer of oil products in Brazil) as well as in homes, stores and industries through projects focused on these key segments. These actions make the following contributions:
Foreign exchange savings and lower cost for products and services;
Environmental preservation, reducing the emissions of gases responsible for local and global pollution;
Higher productivity and a keener competitive edge in a wide variety of economic centers;
Establishment of an anti-waste culture.

Actions implemented by CONPET, together with their effective results and potential for reducing pollutant gases emissions are given below:

Economizar Energy Savings Project: (CNT. 2003), (PETROBRAS. 2003)
Launched in 1996, the *Economizar* Energy Savings Project was established through a technical cooperation agreement between the Ministry of Mines and Energy, the Ministry of Transportation, Petrobras/CONPET and the National Confederation of Transportation (CNT), through the Quality and Technical Assistance in Transportation Institute (IDAQ).
The companies participating in the *Economizar* Energy Savings Project received technical support at no charge for upgrading their fuel and lubricant usage management methods, in parallel to upgrading the qualifications of their drivers and mechanics. Using mobile units fitted with mini-laboratories and digital opacimeters, approved and certified by the National Metrology, Standardization and Industrial Quality Institute (INMETRO), technicians specially trained by Petrobras regularly visit garages, undertaking the following procedures:
checking the quality of the diesel used;
assessing the fleet in terms of the opacity of the smoke discharged through its exhaust;
instructions on the correct handling and storage of fuels, control of consumption and emissions, vehicle maintenance and thrifty driving.

At the moment, 45 mobile units are working in 22 States of Brazil, handling the assessments under the *Economizar* Energy Savings Project. In all, 5,000 companies belonging to 24 representative entities have been assisted by this project, with more than 200,000 assessments undertaken in a fleet of around 130,000 vehicles (buses and trucks). Participation in this project is voluntary, self-sustained in financial terms by the transportation companies. The gains for Petrobras are basically associated with customer loyalty. The *Economizar* Energy Savings Project benefits from 1997 through 2003, are presented in Table 3, and were consolidated and calculated directly with the participant transportation federations, associations and unions.

An outstanding project in the transportation sector, this is the most successful partnership between the public and private sectors designed to fine-tune diesel use, which is a fuel whose supplies are critical in Brazil. The *Economizar* Energy Savings Project upgrades transportation services, saving foreign exchange for Brazil while lessening pollution in major urban centers.

The *Economizar* Energy Savings Project currently services some 7% of Brazil's bus and truck fleets. The CONPET Program is discussing the signature of the Phase 3 Agreement on the *Economizar* Energy Savings Project jointly with the National Transportation Confederation, which covers the expansion of this Project, aimed at doubling the percentage of the fleet serviced by 2005. This new Agreement also includes the preparation of strategies underpinning the sustainability of the expansion of this Project.

Some data and results of the *Economizar* Energy Savings Project are presented in Table 3:

Table 3: Economizar energy savings project 1997 -2003

Brazilian States	22
Entities (12 passenger, 8 cargo, 4 mixed)	24
Mobile units	45
Participant enterprises	5,000
Fleet	130,000
Assessments performed	200,000
Total fuel saved (liters/year)	300,000,000
Avoided CO_2 emissions (tons/year)	800,000 (*)
Avoided particulates emissions (tons/year)	18,000
Total Petrobras investment in the period (US$)	500,000
Total private sector investment in the period (US$)	2,400,000

- Diesel CO_2 emission: 2.7 tons CO_2/tons Biodiesel; IPCC Methodology for GHG Emission Inventory;[83]

- Source: Petrobras / CONPET - Internal reports.

Transportar Transportation Project (PETROBRAS. 2003)

Deploying the expertise built up through highly successful activities in the transportation area, the CONPET program adapted the *Economizar* Energy Savings Project methodology to the tanker-trucks fueling up at the Petrobras refinery supply terminals. A pilot project was set up at the Henrique Lage Refinery (REVAP) at São José dos Campos in November 2002.

Technical staff trained by Petrobras assessed the tanker-trucks free of charge, analyzing the quality of the diesel used, their maintenance levels and the opacity of the smoke discharged. After this assessment, a report was drawn up with advice and guidance for the drivers, in addition to a methodology for checking fuel consumption, helping truckers save diesel and lower transportation costs.

This 'Pit-Stop' is located close to the truck parking yard at the entrance to the terminal, and the assessment is undertaken during the time that the trucks are waiting to be loaded, without adversely affecting the terminal operating routine.

Some data and results achieved by the *Transportar* Transportation Project are listed in Table 4:

Table 4: Transportation project results to March 2004

Period	18 months
Assessments	2,000

[83] Source: Brazilian Government - Ministry of Science and Technology (MCT). Report of Energy Emissions 1970/2001. Project: Estimation of the emissions of greenhouse gases from burning of fossil fuels in Brazil. Agreement between the Ministry of the Science and Technology - MCT and Economy and Energy - E&E - NGO, 2002.

Participant enterprises	260
Vehicles assessed	1,350
Vehicles compliant with standards	1,378 (68.9%)
Vehicles non-compliant with standards	622 (31.1%)
Improvement in assessed fleet	56%
Reduction in diesel consumption	15%
Diesel saved (liters/year)	13,600,000
Avoided CO_2 emissions (tons/year)	38,000 (*)
Particulates not emitted (tons/year)	800
Total Petrobras investment in the period (US$)	90,000

Diesel CO_2 emission: 2.7 tons CO_2/tons Biodiesel; IPCC Methodology for GHG Emission Inventory;[84]

Source: Petrobras / CONPET - Internal reports.

In addition to the environmental benefits and lower fuel consumption the *Transportar* Transportation Project is an important action for Petrobras in terms of building loyalty among the customers who fill up at its terminals. In view of this, the CONPET program is currently working to expand this project to other Petrobras refineries all over Brazil.

Stoves and Heater's Labeling Program (CONPET. 2004), (INMETRO. 2004)

Structured on the basis of a Deed of Technical Cooperation signed by Petrobras, through CONPET, the Ministry of Mines and Energy, the Ministry of Development, Industry and Trade and the National Institute for Metrology, Standardization and Industrial Quality (INMETRO), the Stoves and Heaters Labeling Program is supported by the voluntary adherence of manufacturers represented by the Brazilian Electrical and Electronic Industry Association (ABINEE) and the National Electronic Product Manufacturers Association (ELETROS).

The gas consumption efficiency trials and tests follow the rules established by the Brazilian Technical Standards Association (ABNT) or international standards, with specific technical regulations stipulating the process methodology.

The trials check conformity in terms of performance, safety and security items for the consumers, including product identification, instructions, structure, resistance, balance, leak proofing, ignition, heating, overheating, flame stability, air flow, liquid overflows, flow rate, volume capacity, energy yield, gas consumption, soot, presence of CO and CO_2 in the environment, electrical parts etc.

The gases used in the trials are BUTANE, PROPANE and PROPENE, with a 95% minimum purity standard for model approval and 99% for classification in terms of energy yield and consumption. Natural gas is also used for testing natural gas devices.

The stoves and heaters labeling program developed by Petrobras/CONPET is designed to encourage the production and use of safer and more efficient household appliances run on gas. These appliances are sold in Brazil with a consumer guidance label that provides information on energy yield (gas consumption efficiency) and certification by the National Metrology, Standardization and Industrial Quality Institute (INMETRO), which is the Brazilian Government entity in charge of certifying the safety, security and quality standards of manufactured goods.

The label shown in Figure 3, classifies the various types of stoves and heaters in terms of energy efficiency, allowing Brazilian buyers to compare goods at the time of purchase in order to ensure the best cost/benefit ratio. More efficient appliances that consume less gas offer significant savings in domestic outlays over the long term.

[84] Source: Brazilian Government - Ministry of Science and Technology (MCT). Report of Energy Emissions 1970/2001. Project: Estimation of the emissions of greenhouse gases from burning of fossil fuels in Brazil. Agreement between the Ministry of the Science and Technology - MCT and Economy and Energy - E&E - NGO, 2002.

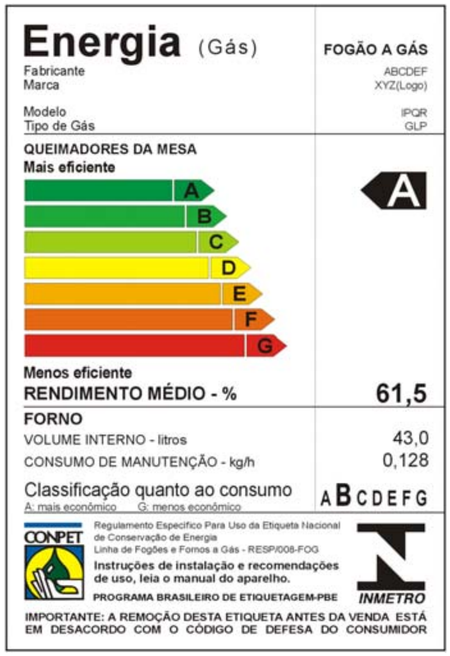


Figure 3: Typical label from labeling program

Some 3.5 million stoves are manufactured each year in Brazil, 90% of them using Liquefied Petroleum Gas (LPG), also known as kitchen gas or bottled gas. Upgrading the performance of these items of equipment means that less LPG imports are required to service the domestic market.

The energy efficiency label is affixed to more than 300 models of gas-fired household appliances. The preliminary results indicate that this Program may result in savings of some 13% in gas consumption, equivalent to a reduction of 300,000 tons of imported LPG a year. By October 2004, some 280 stove models were labeled, made by fifteen manufacturers, in addition to 27 heater models produced under three brand-names.

Assuming that each family consumes an average of one bottle of LPG a month, the potential savings for this program is around two bottles of LPG per stove per year. In the residential sector, Brazil's annual LPG consumption hovers around 10 million m^3 or 5.5 million tons/year. It is estimated that this program may save approximately 1.5 million m^3 or 825,000 tons of LPG a year.

The launch of the CONPET ENERGY SAVINGS SEAL is scheduled for early 2005. This is intended to encourage the fabrication and sale in Brazil of more efficient equipment, so that consumers can easily see which option provide the highest levels of energy efficiency within each category. This seal will be awarded each year from 2005 onward to gas-fired household appliances registered with the Brazilian Labeling Program that use the National Energy Conservation Label (ENCE).

Natural Gas Bus

The Petrobras Gas Bus Project being implemented by CONPET is undertaken in partnership with the Rio de Janeiro Transportation Company Association, which runs a fleet of 7,353 buses, carrying ninety million passengers a month. This project will underpin assessments of natural gas for urban passenger transportation purposes, guiding a strategic decision taken by transportation entrepreneurs in terms of the use of this fuel in their fleets.

The main purpose of the Project is to ascertain the operating performance of a bus fitted with an Otto-cycle engine fueled by natural gas, in terms of efficiency, consumption, emissions, maintenance and the qualifications of the related professionals, in addition to operational profitability. The results will be compared to the average values for vehicle fleets fueled by diesel and operating under the same conditions.

The gas bus being tested has a rear engine and pneumatic suspension developed by Mercedes-Benz do Brasil, including the world's latest natural gas engine technology. Fitted with air-conditioning, this bus can seat forty passengers, covering some 300 kilometers a day and consuming approximately 200 m^3 of natural gas stored in eight cylinders fitted to its chassis.

In order to ensure the reliability of the information and help analyze this business, the scope of this Project also includes the installation by Petrobras Distribuidora of a natural gas fueling station at the bus company garage, complete with a high-flow dispenser and compressor, that will result in vehicle fueling times similar to diesel (5 minutes).

The consolidation of the data on vehicular natural gas consumption by buses is being handled by the bus operator company, accompanied by the Petrobras Research Center (CENPES) and CONPET. The partial results of this consumption are shown in Table 5:

Table 5: Consumption results (base: 30,000 km driven/month)

Month [2004]	VNG Bus [km/m^3]	Diesel Bus Benchmark [km/l]
June	1.73	2.25
July	2.04	2.30
August	1.93	2.39

These results are fairly representative and indicate a lower fuel consumption ratio by the VNG vehicle. The distance traveled / fuel consumption ratio for natural gas is approximately 20% better than that for diesel.

NATURAL GAS RE-INJECTION

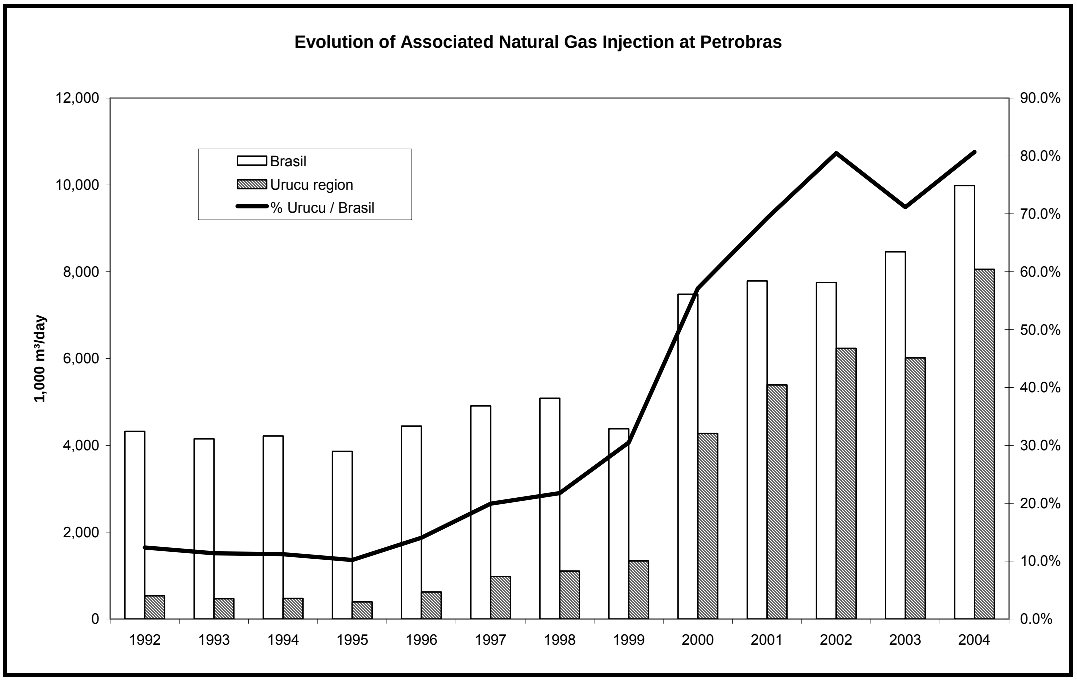
Oil output began to rise significantly in Brazil during the 1980s, when environmental concerns were still merely incipient. Striking oil in two regions that were hard to access – on its Continental Shelf and deep in the Amazon Rainforest – Brazil found petroleum with associated natural gas in both regions.

At that time, the nation's main concern was to produce oil in order to trim its importing trade deficits. Consequently, when production began on many offshore oilrigs, the gas was burned off in flares, as Brazil did not have a properly developed natural gas market at that time, nor even the infrastructure to make good use of it. However, another solution was found at the Urucu oil fields in the Amazon rainforest, right from the start. As it would be far too dangerous to burn off large amounts of natural gas through flares in the depths of the forest, Petrobras adopted the procedure of re-injecting natural gas, reflecting its concern for the environment through this cost-effective practice.

The production of oil with associated gas may require the gas to be burned off through flares as an operating requirement, depending on the production site, logistics facilities, proximity to consumption hubs etc. These burn-offs may be minimized through using the gas as a product, or re-injecting it.
Re-injection may serve three purposes:
environmental preservation;
helping maintain oil output levels;
storing natural gas for future use.

But it is not only the elimination of wasted energy that drives a re-injection program. The site with the highest natural gas recovery rates for re-injection is the Amazon Basin, where oil and natural gas are produced at Urucu, in a remote part of Brazil that is far away from gas consumers.

Consequently, in order to boost oil production while minimizing environmental impacts, some 82% of the associated gas produced at Urucu is currently re-injected, accounting for 80% of the volume of gas re-injected by Petrobras in Brazil, as shown in Figure 4:



Source: Petrobras Internal Data.

Figure 4: Evolution of associated natural gas injection at Petrobras

In addition to oil recovery, re-injecting natural gas involves aspects such as:
lower emissions of greenhouse gases (mainly CO_2 and CH_4) that are not emitted by burning off gas through flares;
reduction in regulatory risks that may result in constraints on output, under local laws;
less gas available for the market;
technical constraints linked to compression capacity, production flows, well depletion, etc.

Over the years, Petrobras has invested in associated natural gas re-injection facilities, either at the production plan level or in order to reduce wasted energy. For the latter aspect, two programs have been particularly outstanding over the past few years: the **Zero Burn Plan** and the **Campos Basin Usage Optimization Plan (POAG).** (PREZZI. 2004)

The former was developed at the sole initiative of Petrobras, prompted by the upsurge in output forecast from 1997 onwards, in order to reduce the amount of gas burned off in flares in the Campos Basin production region. This established a series of operating actions and specific investments, allocated mainly to injection and compression capacity.

Under this plan, the National Petroleum Agency (ANP) which is the Brazilian Regulator for the products and activities of the oil and gas industry in Brazil, began to step up its demands and requirements in 2000, in terms of making good use of gas associated with oil production in Brazil.

In early 2001, the Campos Basin Usage Optimization Plan (POAG) was established, when some 6,400,000 m³/day of gas was burned off in the Campos Basin, peaking at 8,000,000 m³/day, equivalent to 40% of the gas produced.

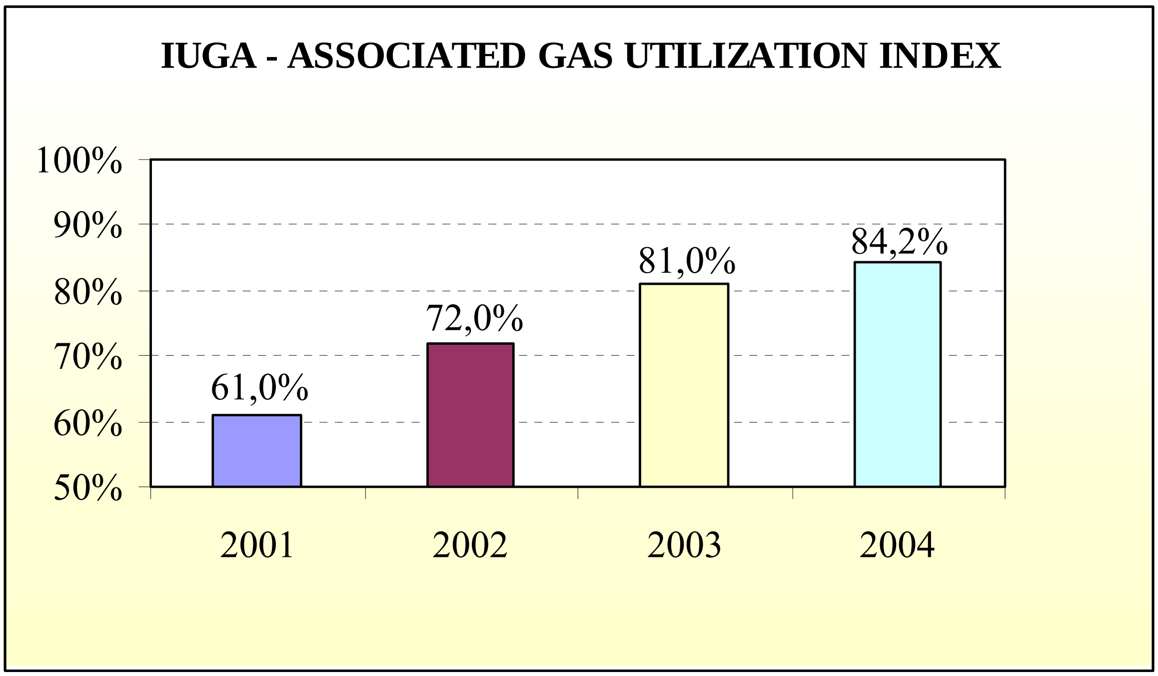
This plan had the following objectives:
to continue the actions of the previous Zero Burn Plan (PQZ**)**,
to centralize efforts to reduce gas burn-offs in the Campos Basin;
to develop new opportunities for gains;
to meet commitments undertaken with the ANP on reducing the volumes of gas burned off;
to improve responses to gas demands on the market;
to improve the use of energy resources;
to lessen emissions of atmospheric pollutants by re-injecting part of the gas back into the wells.

An integrated plan was established for all initiatives designed to reduce burn-offs and boost gas supplies

covering the entire Campos Basin, consisting of 93 actions on 24 platforms. This Plan included a wide variety of activities, from altering procedures, modernizing and upgrading equipment through to acquiring new turbo and motor compressors based on the following general guidelines:
to ensure full use of the gas right from the start of oil production activities;
to guarantee compression capacity, always operating with a stand-by compressor throughout the entire life of the project;
to make good use of low-pressure gas by installing new motor-compressors or bringing existing equipment into operation;
to associate the physical development of the Plan with a drop in gas burn-offs;
to ensure ongoing results by stepping up the availability / reliability of the compressors;
to systematize gas-lift operating routines;
to set up a special Campos Basin Usage Optimization Plan group at each platform;

The main targets established for this Plan were:
to resolve problems through burn-offs in the Campos Basin by 2005;
to reduce burn-offs to 3,000,000 m³/day (one half of the figure at the start of the Plan).

The results achieved since this Plan was implemented in order to reduce burn-offs of gas produced in the Campos Basin have reached 98% of their planned levels, shown in Figure 5 as percentages of the Gas Utilization Index (IUGA):



Source: Petrobras Internal Data.
Figure 5: Results of reduction of gas flaring

The results shown in Figure 5 prove the suitability of the many different procedures being adopted by Petrobras under this Plan to reduce produced gas flaring in the region, highlighting the following results:
gas flaring in the Campos Basin were cut from 6.2 million m³/day in 2001 to under 3 million over the past few months;
the Gas Use Index (IUGA) for the Campos Basin rose from 61% in 2001 to 81% in 2003, with a target of 84.2% for 2004.

At the moment, this Plan is moving into a new cycle in the Campos Basin, under the Regional Strategic Plan, in order to ensure its extension to new areas.

USE OF GEOTHERMAL ENERGY TO IMPROVE OUTFLOWS OF NATURAL GAS

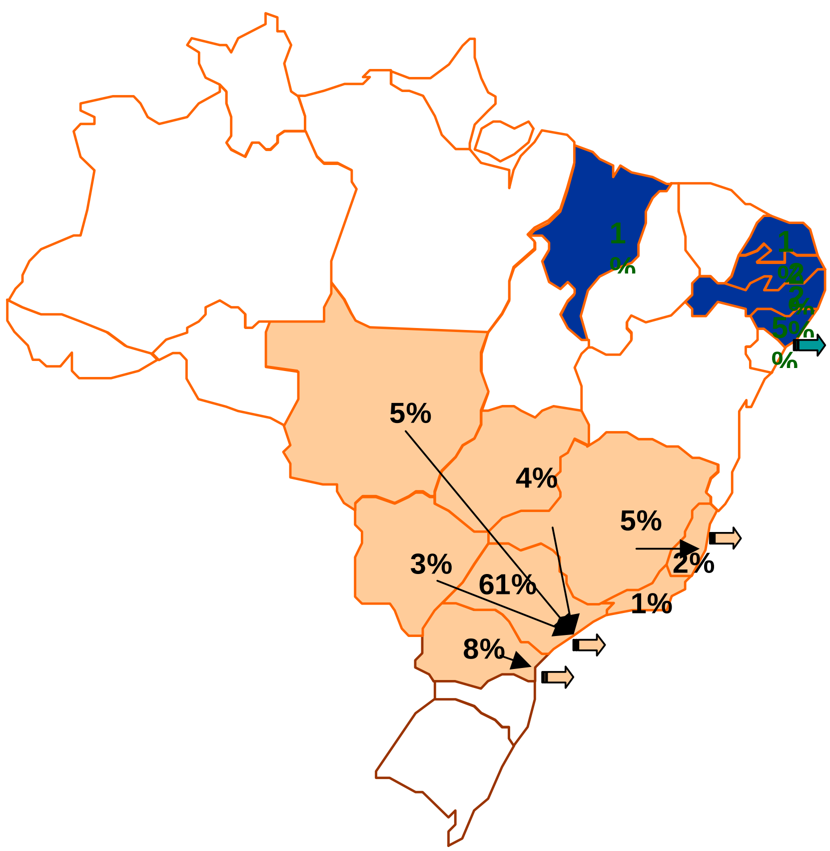
The gas-lift system at the Ubarana unit in a Petrobras area in Northeast Brazil had a critical problem caused by decompression due to rapidly-dropping gas temperatures, which could constitute a serious risk through weakening or even cracking of the gas pipeline material.

At the initiative of Petrobras in Ubarana, an innovative solution was found: prior to depressurization, the gas was run through a shut-down well, making good use of the geothermal energy in the well to heat the gas which would then be used without the risk of causing any damages to the pipeline construction material. Some 550,000 Nm^3/day of gas is heated by 17°C through this process, using a geothermal capacity equivalent to 52 kW. The benefits include avoidance of repowering the natural gas-fired thermal-power plant onboard the PUB-2 offshore production rig, concomitant to avoiding emissions of 280 tons/year of CO_2 140 kg/year of SO_2 and 80 kg/year of NO_x, through oil production activities on the continental shelf offshore Rio Grande do Norte State.

In order to make good use of geothermal energy in this region, a water pre-heating system will be installed for injecting steam into heavy oil fields, in order to save the natural gas burned in the steam generators. Capacities of 4.4 MW (15 MMBtu/h), 7.3 MW (25 MMBtu/h) and 14.6 MW (50 MMBtu/h) are planned, which will reduce the temperature delta for vaporizing water drawn from the Açu River. The forecast benefits include fostering the concept of sustainability, use of the Clean Development Mechanism as well as fine-tuning the use of natural gas in-house by Petrobras. At the same time, this will help lessen atmospheric emissions of greenhouse gases in the semi-arid drylands of Northeast Brazil. Each pre-heating capacity block equivalent to 600 kW run through the geothermal energy process will correspond to a reforestation project covering 500 acres in the semi-arid dry lands of Northeast Brazil.

PARTICIPATION IN THE PROALCOOL FUEL ALCOHOL PROGRAM

Today, ethanol is produced on a large scale in Brazil (14,000,000 m^3/year) by private enterprise, through sugarcane fermentation processes using sophisticated agro-industrial technologies. There are more than 300 industrial plants and some 60,000 farmers supplying sugarcane to the mills. (QUEIROZ, MIRAGAYA, et al. 2004a) The distribution of Brazil’s sugarcane and alcohol output is shown in Figure 6.



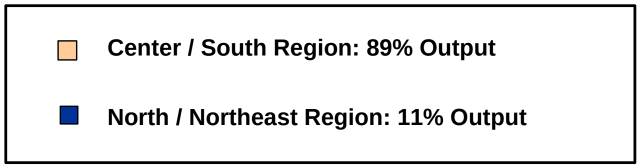


Figure 6: Ethanol production in Brazil

With 100% Brazilian technology, the National Fuel Alcohol Program (Proalcool) was established through Decree N° 76,593, dated November 14, 1975. Its initial purpose was to lessen Brazil's dependence on imported oil. By 1977, this Program was already presenting its first results,[11] producing 1.5 billion liters, twice the figure for the previous year. By 1978, production volumes topped 2.5 billion liters. One year later, another oil price hike pumped up prices to US$ 34 a barrel, providing definitive leverage for the Proalcool Program. At that time, Brazil was importing approximately 80% of its oil consumption.
As shown in Table 6, the advent of the Proalcool caused an increase from 7.25% in 1970 to 17.85% in 1985 of the participation of sugarcane derivates in Brazil's primary energy production: (MME. 2003).

Table 6: Production of primary energy

IDENTIFICATION	1970	1975	1980	1985	1990	1995	2000	2003
NON RENEWABLE	**10,530**	**11,641**	**13,928**	**38,040**	**40,748**	**45,706**	**79,778**	**97,487**
PETROLEUM	8,160	8,727	9,255	28,079	32,549	35,775	63,848	77,245
NATURAL GAS	1,254	1,612	2,188	5,426	6,232	7,896	13,184	15,675
COAL STEAM	611	743	1,492	2,620	1,594	1,966	2,603	1,784
COAL METALLURGY	503	557	991	902	320	68	9	37
URANIUM	0	0	0	1,010	50	0	131	2,744
RENEWABLE	**39,096**	**43,910**	**52,475**	**68,949**	**66,884**	**69,789**	**73,555**	**86,387**
HYDRAULIC ENERGY	3,421	6,214	11,081	15,334	17,769	21,827	26,168	26,300
FIREWOOD	31,851	33,153	31,083	32,924	28,536	23,261	23,054	25,989
PRODUCTS OF SUGARCANE	3,600	4,179	9,300	19,107	18,451	21,778	19,894	28,348
OTHER RENEWED	223	362	1,009	1,583	2,126	2,923	4,438	5,749
TOTAL	**49,627**	**55,551**	**66,404**	**106,989**	**107,632**	**115,496**	**153,333**	**183,875**
PARTICIPATION OF SUGARCANE PRODUCTS (%)	**7,3%**	**7,5%**	**14,0%**	**17,9%**	**17,1%**	**18,9%**	**13,0%**	**15,4%**

Source: Brazilian Government: Ministry of Mines and Energy (MME), National Energy Balance (BEN), Brasília, 2003.

Anhydrous ethyl fuel alcohol was blended with gasoline in Brazil for the first time in 1931. But it was only with the 1973 oil crisis that the development of alternative fuel sources really took off.

Since the 1970s, Petrobras has been steadfastly supporting this venture, which is the world's largest renewable fuel program, mainly through blending it with gasoline, as well as distribution and sales. In fact, Petrobras was the mainspring of the Proalcool Program, opening up its logistics system to the Program backed by its actions establishing regulatory stocks as well as its logistics and transportation infrastructure that includes pipelines, railroads, highways and coastal shipping facilities. Petrobras ensures steady outflows of products. From an initial 5%, this has risen steadily to the current 25% ethanol in all Brazilian gasoline, made Brazil a global pioneer in introducing lead-free gasoline. The CO_2 emissions avoided through the use of ethanol as an automotive fuel are estimated at 26,000,000 tons/year.

In addition to reducing CO_2 emissions, this ethanol-gasoline blend Program ushered in another major environmental benefit for Brazil. The higher octane rating of the ethanol added to gasoline did away with the need for lead-based compounds. This made Brazil the first country in the world to eliminate the use of these compounds in gasoline. And the Brazilian solution, proven for almost thirty years, is now being adopted by many other countries.

The first production-line automobiles fueled solely by alcohol were launched in 1979, when output was already reaching 3.5 billion liters. Brazil's Aeronautical Technology Center (CTA), which is a State-run research center, adapted the gasoline engine to run on alcohol and made the motor available to the Brazilian automobile industry. Petrobras was one of the first companies to convert its fleet to this new fuel. Another initiative was the installation of alcohol pumps at BR service stations, still in 1979. Soon after, BR Distribuidora, which is the Petrobras fuel distribution subsidiary, launched the first lube-oil for alcohol-fueled engines.

In 1984, 94 out of every 100 vehicles produced in Brazil left the plant with alcohol-fueled engines. Petrobras also developed and installed the first tanks that were specially designed for storing fuel alcohol, installed at collection hubs located strategically close to production areas in Center-South Brazil. The Company soon had an alcohol tanking capacity of over one billion liters.

During the 1980s, environmental issues moved to the fore on the international agenda. The Kyoto Protocol is prompting the world's countries to seek multilateral solutions to these issues. This context triggered an upsurge in interest among many different countries in the use of fuel alcohol, where Brazil is endowed with global excellence in its many different segments, ranging from the agricultural through to the industrial phases. As a consequence, Brazil presents the world's lowest production cost (0.18 US$/liter), compared to USA (0.33 US$/liter) and Europe (0.56 US$/liter). At the same time, a great business opportunity is offered for Petrobras, grounded on its experience in domestic and foreign sales, technological familiarity with this new energy source, logistics capacities and solid market credibility.

Driven by environmental demands to prune the share held by oil and oil products in energy matrixes, particularly in the more developed countries such as the USA, Europe and Asia, formation of an international alcohol market is expected. Petrobras has already welcomed delegations from Japan, Germany, South Africa, Costa Rica, Thailand and China, both from governmental and industrial sectors.
Another highlight in the context of the Company's ethanol market possibilities is Petrobras' own technology for using ethanol to produce ethene, an important petrochemical feedstock. For 15 years, the company operated Salgema in Northeast Brazil, where 100,000 tons of ethene/year were produced from ethanol.

Although this market is quite promising, it is felt that the customs barriers currently imposed by the USA and Europe on alcohol imports, and subsidies offered to their domestic producers may well undermine potential sales of Brazilian ethanol. (QUEIROZ, MIRAGAYA, et al. 2004a)

Based on the possible potential of this new global alcohol market, with estimates varying from 6 to 35 million m^3/year. Petrobras has developed interdepartmental and multidisciplinary studies to assess the prospects of moving into this new business. These studies highlight good opportunities for Petrobras, particularly as a logistics operator and trader, underpinning the decision taken by the Petrobras Board which approved the entry of Petrobras into the alcohol export business.

This decision has resulted in several developments designed to bring this business into operation. They include the organization of technical information, required to render consulting services to companies interested in launching programs blending alcohol with gasoline, as well as studies for developing the logistics and operating solutions required for their implementation.

Listed below are some of the main lines of action by Petrobras for alcohol exports:
assessment and selection of alcohol production units suitable for sales activities with Petrobras;
studying and assessing logistics solutions for alcohol outflows in order to develop an alcohol corridor (alcohol pipeline) interconnecting production regions with export terminals;
reactivating the alcohol collection hubs in order to ensure ample capillarity for the receipt of alcohol from the production plants;
signing a protocol with the National Social Economic Development Bank (BNDES) and the Brazilian Agricultural Research Enterprise (Embrapa) fostering the development of agricultural research projects and structuring lines of credit;
setting up an agenda with the Ministry of Foreign Affairs for the participation of Brazil's diplomatic representatives in its alcohol export strategy;
meetings with Government representatives and business leaders in companies interested in implementing the alcohol blending program;
building up international contacts for future anhydrous alcohol sales to international markets, Proposals have already been submitted to the USA, Japan, India and China, in addition to responding to a consultation from Canada;
participation in international seminars and events to disseminate the Brazilian experience of blending alcohol with gasoline, seeking out new business opportunities, particularly for Brazilian alcohol exports.

Additionally, the advent of the flex-fuel car on the Brazilian market in 2003 – which can run with ethanol, gasoline or a blend of both fuels in any proportion is prompting significant increases in fuel alcohol consumption in Brazil.

All these actions indicate a sharp uptrend in the activities of Petrobras linked to the distribution and sales of alcohol in the near future.

PETROBRAS ATMOSPHERIC EMISSIONS INVENTORY SYSTEM (CLIMATE. 2004), (PROTOCOL. 2004)

In September 2002, Petrobras launched an Atmospheric Emissions Inventory System for the entire corporation.

The emissions measured in this Inventory are Particulate Matter (PM), Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Volatile Organic Compounds (VOC), total quantity of gas burned off in flares and greenhouse gases – methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O).

The initial stage of this project was the **Emissions Inventory 2002 – 2003,** which resulted in the final consolidation of the atmospheric emissions data all over the company during its past two years in operation. These data will constitute the initial basis for the Computerized Management System.

The main outcome of this project will be a Computerized Management System that will ensure more effective management of the Company's performance in terms of atmospheric emissions. Through this system, the quantification, categorization and notification of data on emissions will be more accurate, providing input for more effective decision-taking processes related to gas emissions reduction and monitoring actions.

Additionally, this project will:
prepare Petrobras for the introduction of a domestic carbon credits market and its future performance on the international market for these credits;
lead to the inclusion of the Company on the Dow Jones Sustainability Index, which is the first specific index measuring the performance of enterprises all over the world that are noteworthy for blending business management with sustainability;
build up the Base Year Emissions (BYE) data that will serve as the basis for corporate decisions on the investments required to attain the desired emission reductions;
constitute the Base Year Energy Consumption (BYEC) data in order to fine-tune the energy and mass balance for the fuels consumed by Petrobras, while ushering in measures that will enhance energy efficiency with a resulting drop in CO_2 emissions.

The main results of the Project are summarized in Table 7:

Table 7: Emissions' inventory - 2003 (Tons)

Emissions	E&P	SUPPLY	TRANS PETRO	BR	INTERN.	NATURAL	TOTAL		
(TON)		REFINE	LOGISTICS			BOLÍVIA & COLOMBIA	PETROBRAS ENERGY	GAS	
CO_2	10,275,183	16,203,766	1,801,553	1,396,281	6,556	912,559	4,550,259	353,120	35,499,277
CH4	89,272	5,860	-	561	1	5,156	36,984	26	137,860
N2O	658	178	-	1	-	8	30	-	875
CO_2 EQUIV	**12,353,798**	**16,381,947**	**1,801,553**	**1,408,199**	**6,615**	**1,023,437**	**5,350,631**	**353,659**	**38,679,839**
NO_x	50,316	31,490	45,727	26,126	16	9,778	26,584	966	191,003
CO	9,396	11,073	1,182	1,071	2	1,624	6,390	276	31,014
Provisional Measure	4,611	3,456	1,719	1,039	6	172	1,235	21	12,259
SOX	6,163	143,010	12,630	7,963	40	61	4,576	-	174,443
NMHC	59,126	39,245	2,824	13,856	14,179	1,642	19,646	6	150,524
THC	148,390	45,105	2,824	14,417	14,179	6,799	56,995	32	288,741

Source: Petrobras Emissions' Inventory, 2003.[85]

85 Note: For the Petrobras Social Balance – 2003, the findings for SO_X emissions by Exploration and Production (E&P) (1,963 tons), Supplies (148,021 tons), Transpetro (13,116 tons) and ANI (3,377 tons) were allocated, as obtained

Now moving into its final phase, the Petrobras Atmospheric Emissions Inventory System Project is supported by intensive contributions from the employees at the many different facilities visited since September 2002.

The goals and products to be achieved constitute a significant step forward in the quest for environmental excellence by Petrobras, which is a permanent corporate target. To do so, the involvement of its entire staff remains a key element for the success of this Project.

LARGE-SCALE NATURAL GAS USE PROGRAM

In early 2003, Petrobras located a huge field offshore São Paulo, not far away from the largest city in Brazil and containing some seventy billion cubic meters of gas. This new source of supply for natural gas (60%) in addition to gas imported from Bolivia (30%), and gas produced in the basins of North and Northeast Brazil (10%), brings Brazil's projected natural gas supplies up to 100 million m^3/day by 2010, equivalent to 440 million barrels of oil. As a result, the Petrobras Gas and Energy Board launched a broad-ranging program designed to encourage the Large-Scale Use of Natural Gas.

From 1993 through 2003, the average natural gas consumption in Brazil rose from 7 to 29 million m^3/day (up 13% per year in Northeast Brazil and 19% per year in South, Southeast and Center-West Brazil, with this distribution shown by sector in Figure 7 and 8:

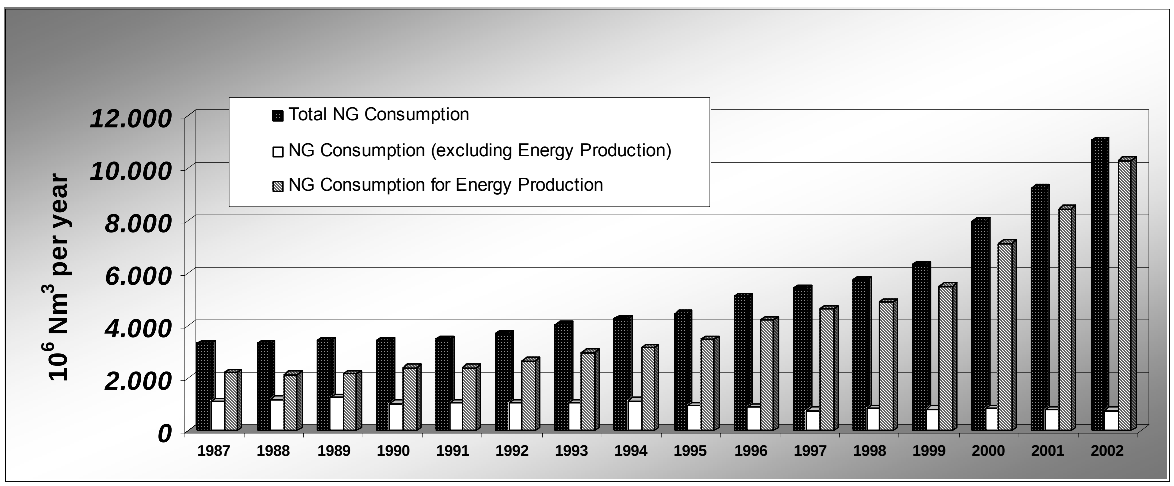


Figure 7: Natural gas consumption

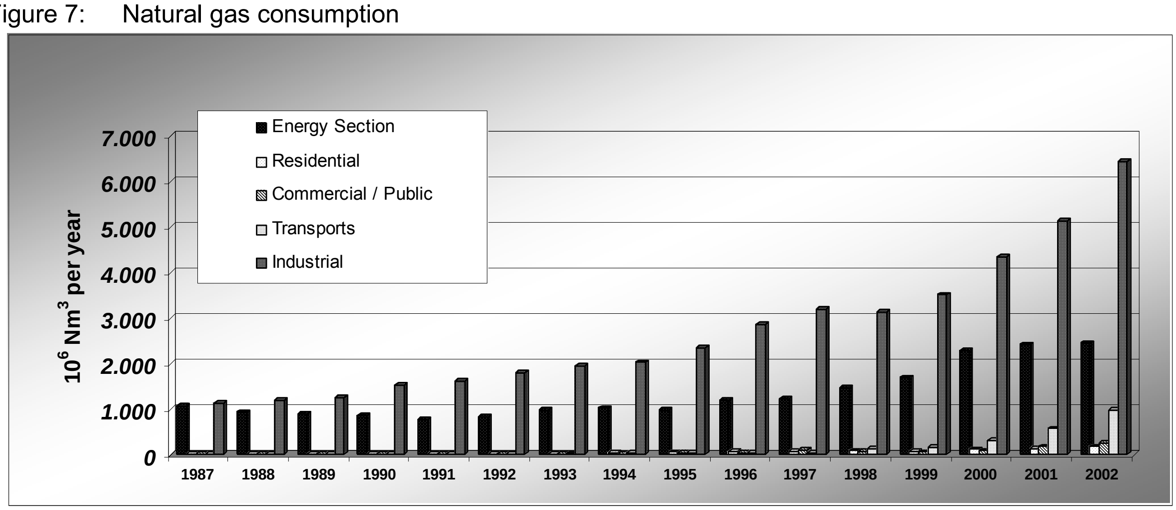


Figure 8: Energy final consumption

through the performance indicators. For the Natural Gas area (thermal-power plants) and chartered vessels, the findings obtained through the Emissions Inventory System were reported, SO_X (Social Balance Sheet – 2003): 179,107 tons.

The target of the Large-Scale Natural Gas Use Program is to boost natural gas consumption to 101 - 127 million m^3/day by 2015 in the following sectors, as shown in Table 8:

Table 8: Projected natural gas demands by sector in 2015

Estimated natural gas market by sector in 2015	million m^3/day
Industrial	41 – 43
Vehicles	14 – 20
Residential, commercial and services	6 – 8
Thermal-power plants and in-house consumption by Petrobras	40 – 55
TOTAL	101 – 127

Broad-ranging and closely-articulated actions are needed to ensure the success of the Large-Scale Natural Gas Use Plan, requiring investments in exploration and production, expansion of the distribution infrastructure, technological development, Government actions, etc.

New technologies associated with this Plan include virtual gas pipelines for compressed natural gas (CNG) and liquefied natural gas (LNG), in addition to the implementation of technical channels and multi-product pipelines that lower costs for the simultaneous channeling of gas, water, sewage, electricity, telephone wires, etc.

The planned benefits of the Large-Scale Natural Gas Use Plan associated with Climate Change Mitigation and Sustainable Development include:

diversification of energy sources;
upgrading industrial process quality;
allowing access to residential natural gas by low-income sectors of the population;
generating jobs and income;
lower pollution levels in major urban centers;
development of new technologies and staff capacity-building.

RENEWABLE ENERGIES – STRATEGIC GUIDELINES AND PROJECT PORTFOLIO

The new challenges and threats facing the oil industry range from depletion of the best oil reserves over the next decades through to environmental concerns, such as the burning of fossil fuels which step up carbon dioxide levels in the atmosphere, resulting in global warming.

The worldwide trend among energy enterprises is to gradually increase the use of renewable fuels, replacing their fossil-based counterparts as energy feedstock, while enhancing energy efficiency.

The 2004-2014 review of the Petrobras Strategic Planning sets aside annual allocations for its Renewable Energy businesses of some 0.5% of its investments, earmarked for R&D as well as enterprises using mature technologies. This strategy also includes the target that 10% of the energy generated by Petrobras by 2010 should come from renewable sources.

Due to widespread use of hydro-power and biomass, 35% of Brazil's energy matrix comes from renewable feedstock. This is the highest percentage in the world, establishing a scenario that is very favorable for the large-scale expansion of Petrobras' Renewable Energy enterprises.

On March 30, 2004, the Brazilian Government launched its Alternative Energy Sources for Power Generation Incentive Program (PROINFA), through Presidential Decree 5,025. This addresses technologies based on biomass, wind-power and small-scale hydro-power plants, with 1,100 MW authorized for each specific source, making a total of 3,300 MW to be installed by year-end 2006. Petrobras is gearing up for significant involvement in this drive, through stakes that are already accredited by this Program.

The Renewable Energy Projects that are under way at PETROBRAS at the R&D level, as well as business enterprises, are explained in detail below, and include the following technologies:

Wind Power
Solar Thermo-Power
Photovoltaic Power
Biomass

Biofuels.

WIND POWER
Petrobras set up its first pilot wind-power plant (1.8 MW) at Macau, Rio Grande do Norte State in Northeast Brazil. Inaugurated in January 2004, it absorbed investments of approximately US$ 2.4 million. Two other pilot plants are at the design and environmental licensing stage, each with a capacity of 3.0 MW: one in Rio Grande, Rio Grande do Sul State, in Southern Brazil and the other in Rio de Janeiro, Southeast Brazil. The installation of 60 MW in wind power plants is planned for Petrobras by 2010. (PETROBRAS. 2004)

SOLAR THERMAL-POWER
The initial phase of the Petrobras Solar Thermal-Power Project in 2001 consisted of surveying the electrical loads used for heating water that could be replaced by solar thermal-power at its industrial plants and BR service station chain. This resulted in a total of 4.7 MW, equivalent to a monthly consumption of around 362 MWh.

Solar thermal-power systems have already been installed for the canteens and change-rooms at two refineries (Minas Gerais and São Paulo States), with another under construction in Rio de Janeiro State, totaling 1,345 m^2 of solar panels that heat 85,000 liters of water a day. The implementation of several other projects is currently under discussion.

The social and environmental advantages of using solar thermal-power technology on Petrobras premises include the diversification of its energy matrix, while also encouraging a ‘green’ culture among its employees and the users of those systems.

The installation of a further 2.7 MW in thermal-solar systems is planned for Petrobras by 2010. (PETROBRAS. 2004)

PHOTOVOLTAIC SYSTEMS
Several remote photovoltaic systems have been in operation at Petrobras since the 1980s (with a total capacity of around 100 kW), installed at onshore and offshore unmanned oilrigs, supplying electricity for a wide variety of purposes, including automatic process monitoring and control, radio-communications, navigation aids, etc.

Another noteworthy system is the photovoltaic oil pumping system installed at Mossoró in Northeast Brazil. A conventional oil well pumping system producing 6 barrels a day was replaced by a photovoltaic energy system, absorbing investments of US$ 50,000 and resulting in the following benefits:
Reduction in the capacity consumed from 3 HP to 1 HP;
Emissions reduction: 15 tons CO_2/year;
Energy generated equivalent to savings of 43,000 m^3/year of water in the hydro-power system reservoirs along the São Francisco River;
Possibility of ensuring the feasibility of low-productivity wells through higher reliability and lower operating costs.

HYBRID SYSTEM FOR REMOTE COMMUNITY
Linking technological research to social responsibility, Petrobras co-sponsored the installation of a hybrid power generation system in a remote community. This project was backed by a partnership with the Federal Government through the Ministry of Science and Technology and the Pará State University. The system consists of 3.2 kW photovoltaic, 7.5 kW wind and 20 kW diesel. Since 2003 it has been supplying electricity to Vila de São Tomé, a hamlet in Pará State, in the Amazon Region, with fifty houses and 220 inhabitants, mainly fishermen and their families. Located on the riverbank, it is three and a half hours by bus from Belém, the Pará State capital.

Additionally, in mid-2005, the Petrobras Research and Development Center (CENPES) in Rio de Janeiro, plans to install 6 photovoltaic systems totaling 45 kW, the largest in South America, for comparative studies of the different fine-film technologies.

BIOMASS
Due to its vast size and suitable climate, Brazil offers very favorable conditions for growing energy biomass and consequently for enterprises using biomass as an energy source.

Petrobras is also negotiating partnerships with urban cleaning and sanitation enterprises, to use the biogas produced by garbage and sewage for power generation enterprises, making good use of the benefits offered by the Alternative Electricity Sources Incentive Program (PROINFA), with a forecast capacity of 31 MW by 2010. (PETROBRAS. 2004)

The following new power generation project based on renewal energy sources are planned at Petrobras through to 2010 as shown in Table 9:

Table 9: Planned renewable power generation project

Planned Project (MW accumulated)	2004	2005	2006	2007	2008	2009	2010
Participation in wind power projects	2	10	15	25	35	45	60
Participation in biomass power projects	0	1	3	18	21	24	31
Participation in photovoltaic power projects	0	1	2	2	3	4	5

BIODIESEL (QUEIROZ, MIRAGAYA, ET AL. 2004B)

The Brazilian Government is organizing the launch of an incentive program to encourage large-scale biodiesel production. A 2% blend of biodiesel with fossil diesel is currently being authorized, from 2005 onwards.

Brazil has a wide variety of oil-seeds which are potential feedstock for biodiesel production, such as castor beans, sunflowers, babassu and dendê nuts, etc., as shown in Figure 9. Biodiesel may have widespread social and environmental impacts, through generating jobs in rural areas, lowering fossil diesel imports, and reducing carbon dioxide emissions. Moreover, biodiesel contains no sulfur.

Sources: National Petroleum Agency (ANP)
Brazilian Plant Oils Industry Association (ABIOVE)

Figure 9: Brazil's regional potential for plant oil production

Table 10 lists the oil content and productivity per hectare per year of the wide range of oil-seeds produced in Brazil:

Table 10: Productivity potential of Brazilian oil seeds

Type of Oil-Seed	Productivity (kg/ha)	Oil Content(%)	Oil Production (kg/ha.y)
Castor bean	1,500	50	750
Sesame	900	48	432
Peanut	1,600	39	624
Rape-seed	1,700	39	663
Sun-flower	1,300	38	494
Palm	10,000	20	2,000
Soy bean	2,200	18	374
Cotton	1,000	15	150
Babassu	7,400	4	297

In view of the above, Petrobras set up an interdisciplinary and interdepartmental studies group to assess the potential of this Governmental Program and the possible effects on the Company.

These studies concluded that this proposed Program might well help generate jobs and income, while enhancing the environment. However, the economic feasibility of the production chain depends on government incentives such as tax exemptions, at least for current agricultural productivity levels and average oil prices.

These studies also recommended that Petrobras should gear up to enter the production chain by fast-tracking its technological research projects and helping establish experimental plants in order to develop the business in various parts of Brazil.

The Brazilian biodiesel program is concentrating efforts in the use of castor beans as a raw material, because it grows wild in many areas in the country and does not need much irrigation. Therefore, castor beans can be produced in semi-arid under-developed areas of Brazil. The biodiesel production can be associated with governmental social development programs in these rural areas. Petrobras is signing partnerships with the government of several States in Brazil, Embrapa (Empresa Brasileira de Pesquisa Agro-Pecuaria) - a Brazilian State-owned R&D institution actuating, among other fields, in agriculture technology and other institutions, to implement high productivity castor beans plantations in semi-arid areas of Brazil, in order to produce Biodiesel.

As part of the range of initiatives designed to consolidate the implementation of the Biodiesel Business, Petrobras has drawn up an extensive portfolio through its Research and Development Center (CENPES) that includes more than fifteen biodiesel projects, through partnerships with well-known research institutions and universities all over Brazil. Moreover, Petrobras already has patented (patent number PI 01058886, dated November 30th, 2001) a process developed at CENPES, that consists of 'in-situ' oil extraction and transesterification with ethanol, directly from the castor beans, in the presence of alkali catalyst.

In order to enhance the economic feasibility of the castor bean - ethanol process, several other projects are being developed in parallel by Petrobras and partner institutions, seeking new uses and adding value to the by-products.

Under this context, special attention is being given to obtain ethanol from the remaining castor pulp, as well as to researches of new uses of the by-product glycerin.

The Petrobras bean – ethanol process presents some advantages as compared to the traditional European process that starts from pre-refined oil and methanol, namely:
Product is a 'totally green' biodiesel, i.e. derived only from renewable sources;
Less safety/health issues involved in ethanol industrial handling in relation to methanol;
Lower production cost, with less unit operations involved (no need for oil pre-refining);
Raw material (vegetable oil) cost, a critical value in the economical viability of biodiesel production, corresponds to circa 70% of total production costs, whereas it represents around 90% of traditional oil - methanol processes.

Taking into consideration the above remarks, the minimum current market price for castor beans (0.18 US$/kg, basis 3.00 R$/US$), which corresponds to 0.36 US$/liter castor oil (basis: castor bean oil content: 50% w/w), petroleum international price over US$ 30.00/barrel, together with some Brazilian fiscal incentives and the valuation of the by-products, Petrobras castor bean – ethanol biodiesel would already be economically viable.

Table 11 lists some plants that are under experimentation for biodiesel production, at different stages of implementation, which are covered by the Petrobras investments planning in this segment, in order to develop the business:

Table 11 - Proposed experimental biodiesel plants

Projects	Oil-Seeds	Partners	Year of Operation	Status	Biodiesel Production (1,000 tons /year)	Avoided CO_2 Emissions(*) (tons/year)
Prototype Plant at Guamaré/RN	Castor bean	RN Government and EMBRAPA	2005	At the construction phase, with equipment procurement	1.6	4,000
Prototype Plant at Candeias/BA	Castor bean	Bahia Government, EMBRAPA and UFBA	2005	At the final phase of adapting to the existing area x contact with equipment manufacturers	1.6	4,000
Plant at Quixadá/CE	Castor bean	Ceará Government, TECBIO and FAO/UN	2005	Concept design project	10	25,000
Pilot Plant at Ilhéus/BA	Dendê Palm Nut	Bahia Government, CEPLAC and Local Governments	2005	Preliminary studies	1	2,500
Plant at the Petrobras Shale Unit (SIX) São Mateus do Sul/PR	All	-	2005	Preliminary studies on adapting the batch process to continuous processing	3	7,500
Plant in the Jequitinhonha Valley/MG	Castor bean	Minas Gerais Government, EMBRAPA, MDA, EMATER, EPAMIG, MST, CONTAG and ASA	2006	Preliminary studies/development of castor bean agribusiness in this region by Government entities	10	25,000
Plant at Sergipe	All	Sergipe Government, Aracaju Mayor's Office and the Zero Hunger Project	2006	Preliminary studies x Launch of Biodiesel Program by State Government	10	25,000
Plant at São Raimundo Nonato/Piauí	Castor bean	Piauí Government, SEBRAE, EMBRAPA, Banco do Brasil, MDA and BNDES	2006	Preliminary studies / Protocol of Intent signed by Petrobras and the Piauí State Government on castor bean purchases	20	50,000

(*) Basis for biodiesel avoided CO_2 calculation: 2.5 kg/m^3, assuming:
Fossil diesel CO_2 emissions: 2.7 tons CO_2/tons Biodiesel; - Reference IPCC Methodology for GHG Emissions Inventory;
Plantation energy supply: hydropower (practically no CO_2 emissions);
Biodiesel production plant energy consumption equivalent to: 0.2 tons CO_2/ tons Biodiesel;

In this broad and challenging context with marked impact on mitigating climate change, Petrobras should play a leading role in the introduction of biodiesel in Brazil, operating in the production, distribution and logistics areas, as well as transportation and sales.

CONCLUSIONS

The activities of Petrobras imply that the concept of ENERGY should be understood in its broadest possible sense. In addition to offering long-established oil products and non-conventional types of energy, an energy enterprise must also provide energy-based solutions and develop programs for the efficient use of its products. This includes all participants in the energy chain, whether consumers of Petrobras products or not. Within this context, an energy enterprise must promote sustainable development, and the best way of educating is through setting a good example – with Petrobras demonstrating the application of these concepts in-house through promoting energy-based sustainability on its premises.

In institutional terms, the corporate stance of Petrobras is closely aligned with the diversification of its energy matrix through the introduction of new clean technologies and the mitigation of climate changes.

Noteworthy results:
The In-House Energy Use Rationalization Program resulted in savings of more than 1.5 million toe between 1992 and 2003, as well as avoiding the emission of 4.6 million tons of CO_2 into the atmosphere.
The *Economizar* Savings Program run by the CONPET Project saves 300,000,000 liters of diesel/year (254,400 toe/year) and 800,000 tons of avoided CO_2 emissions into the atmosphere, between 1997 and 2003;
27 million tons CO_2/year avoided into the atmosphere through the consumption of 12,000,000 m^3 etha-

nol/year distributed and blended with gasoline by Petrobras.
With respect to the key questions posed by IPCC (item 1), based on the approaches to the various topics covered in this paper, some replies may be offered:
The factors driving the technological development of the industry are basically linked to economic aspects, with a keen competitive edge perhaps being the most important among them. Technological developments that ensure the maintenance or extension of advantages over its competitors will always be sought and encouraged. At the moment, many companies with almost no assets stay in business thanks to profits brought in through selling high-technology products and services. Many of them survive or are established through ongoing investments in research and development.

Another important factor may well be an awareness of the cultural and economic diversity and potential of its operating area, together with the availability of natural resources.

The real existence of open markets and legalization establishing their legal frameworks may also be a driving factor. Particularly in the case of technology, guaranteed Intellectual Property Rights underpin technological development, while their absence may certainly undermine it. Government policies linked to environmental and healthcare issues may well spur technologies involved in these fields.

The most critical point that is also the hardest to answer is how to draw up an accurate estimate of the future potential and costs of these technologies. Linked to energy costs and the availability of investments, the global economic scenario may be either a help or a hindrance. This is particularly relevant for alternative energy sources, as on the one hand, rising oil prices buoy this development, while on the other they well may pump up interest rates and make the available capital even scarcer. In addition to these fairly simple economic issues, many other aspects may play a key role: for instance, consumer acceptance or rejection has overturned many well-reasoned forecasts. On this point, solidly-grounded strategic planning seems to be crucial, based on a consistent scenario assessment, together with risk and sensitivity analyses, which may well prove the best alternative.

Through initiatives under way and other future projects outlined in this Report, Petrobras is indicating to the domestic and international communities its alignment with the spreading global trend towards the rational use of clean energy sources for power generation purposes, assigning high priority to actions helping mitigate climate change, in keeping with the principles of sustainable development.

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Alleviating environmental impact by networking natural gas-fuelled co-generation systems

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1. INTRODUCTION

Fossil fuels are expected to remain a vital energy source, at least, in the first half of the 21st century. Among the fossil fuels, natural gas has been reputed to be the most environment-friendly fuel, because its combustion products are much cleaner and contain less CO_2. Technological advancement and economies of scale have brought down the cost of natural gas production and transportation and, therefore, have improved the competitive edge of natural gas in the energy market. The discovery of new natural gas reserves has been extending the life of this resource (reserves by production ratio: R/P) year by year. The current R/P of natural gas world-wide exceeds 60 years and reserves are more widely distributed in terms of geography, which means better security of supply than oil. Thus, the 21st century is called the 'age of natural gas'.

In Japan's Basic Energy Plan published in October 2003, the shift of Japan's energy supply to natural gas and the acceleration of this shift is clearly recognised as one of the principal energy policy agendas of the government, because of the need both to ensure the security of energy supply and to take the environment into account. The Basic Energy Plan also mentions promotion of energy saving and levelling the peak load of electricity as measures to contain energy demand. A distributed energy system such as co-generation is referred to in the Plan as an important example that can contribute to efficient use of energy and at the same time can reduce the peak summer demand for electricity. Subsequently, 'Outlook for Energy Supply and Demand in 2030', a long-term quantitative scenario published in June 2004 by the Energy Supply and Demand Subcommittee of METI's Advisory Committee for Natural Resources and Energy, shows great potential for further introduction of natural gas and the distributed energy system into the Japanese energy supply and demand structure.

This paper first introduces the current status of distributed energy systems and the use of natural gas in Japan. Then, we will discuss and examine efforts by Japanese city gas utilities and the government to advance distributed energy systems based on gas-fuelled co-generation systems and networks based on them as a means for achieving energy efficiency and protection of the environment. We will also identify a number of challenges lying ahead in order to achieve the networking of co-generation systems. Once Japan has successfully constructed co-generation-based distributed energy networks, it will share its experience and expertise in energy efficiency with countries and regions where energy demand is increasing significantly and, thus contribute to international efforts to prevent global warming.

2. DISTRIBUTED ENERGY SYSTEMS

(1) Advantages of Distributed Energy Systems (vis-à-vis a centralised system)

Since a distributed energy system produces heat and power on the spot, or adjacent to the location of energy demand, it can make the best use of exhaust heat that would have been discarded by a remote large-scale power station. Proximity to the centre of demand will remarkably reduce transmission losses, as well. As a result, a distributed system has the potential to attain a higher level of energy savings and thus to mitigate the impact of energy use to the environment. An appropriate combination of efficient distributed systems with a centralised grid system can produce greater energy savings and environment friendliness.

Secondly, compared with large-scale thermal power stations or nuclear stations, a relatively small distributed energy system can enjoy a shorter lead time for construction, smaller investment and easier adjustment of capacity to fit the actual demand. This means that distributed generation is less risky and, hence, a favourable option as a power supply for investors to commit to, when growth in power demand is difficult to predict due to economic conditions and increasing competition resulting from the liberalisation of energy markets.

Customers benefit from having an additional power supply on top of grid electricity, thereby minimising the probability of power failures and other risks inherent to a centralised grid system. A distributed system will give customers the option of selecting energy sources according to their specific circumstances with respect to the availability of energy, which can be renewable energy rather than conventional energy, for example oil products.

Thirdly, distributed energy systems will open opportunities for a variety of related new businesses. It is easier for non-utility companies to join a new business than to join a full-scale utility. Hence, the number of new businesses will increase and the competition among them will enhance energy efficiency and service for customers. Competition will not be limited to distributed systems but will also include competition with centralised systems, which will bring about further efficiency for both types of system. Distributed systems will benefit customers as well as stimulate the economy itself.

(2) Categories and Types

Although there is no established definition of a distributed energy system, such systems always contain any form of generator other than large thermal, nuclear or hydro power stations operated by a traditional electric utility for the grid. The term 'distributed' is used to express a system in contrast to the grid system, which has large-scale power stations outside the local community. Examples of distributed power supplies and their primary energy sources are shown in the table below.

<u>Examples of distributed power supplies</u>

- Private power generation
- IPP (Independent Power Producer -- supplying electricity to a power company on a wholesale basis)
- PPS (Power Producer and Supplier -- supplying electricity to liberalised markets, etc.)
- Co-generation
  Industrial (factories)
  Commercial (hotels, office buildings, etc.)
  Residential (engines, fuel cells)
- Renewables (supplying electricity to a power company)

<u>Type of fuel</u>

- Oil Products
- LPG
- Natural gas
- Coal (inc. gasification)
- Hydrogen
- Solar
- Wind
- Biomass

(3) Natural gas for distributed energy systems

Although the quality of natural gas is already well known, it is useful to elaborate on the merit of natural gas as a fuel for a distributed energy system:

● <u>Preservation of the environment</u>

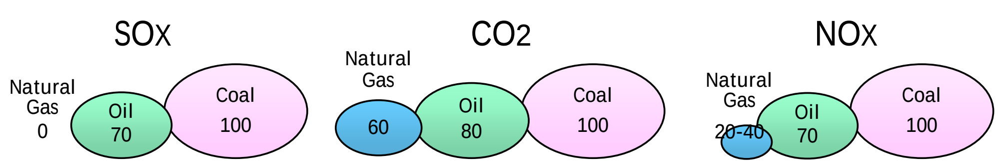


Figure 1. Comparison of combustion products

Natural gas burns without producing soot or sulphur oxides. There is an arsenal of technologies readily available to minimise the formation of nitrogen oxides (NO_x) or to remove NO_x from flue gas. Natural gas will provide a 60% to 80% reduction in emissions of CO_2 when compared with oil products and coal. It is regarded as the most environment-friendly fossil fuel.

● <u>Energy savings</u>

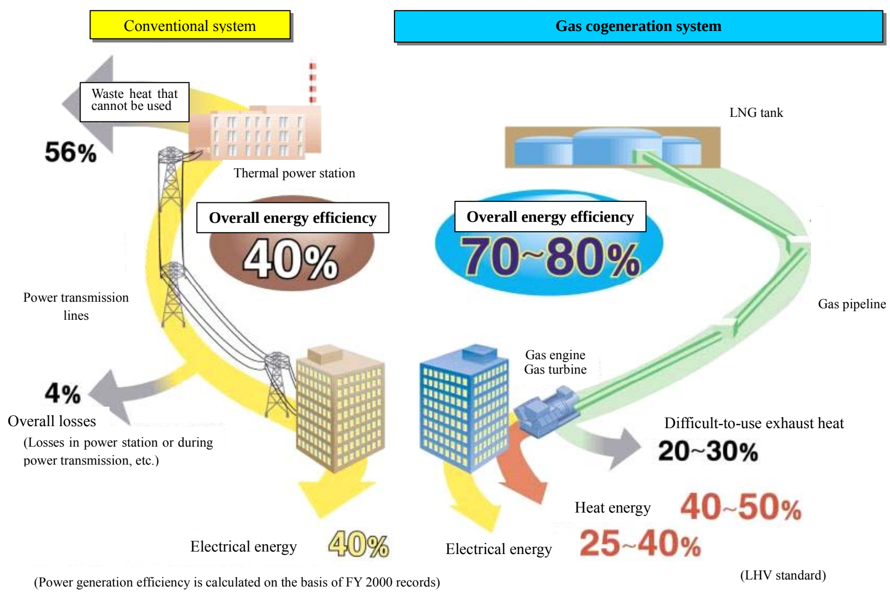


Figure 2. Energy efficiency of co-generation

Because natural gas co-generation systems produce heat and power at the location where these two forms of energy are required, there is no loss associated with power transmission or other forms of energy transportation. While conventional centralised power stations scarcely use their exhaust heat, in the case of natural gas co-generation, the exhaust heat can be recovered to generate steam, to provide hot water or to drive absorption chillers for air conditioning. In this way, the overall efficiency of primary energy utilisation of co-generation can be between 70% and 80%, as shown in Figure 2.

In Japan, a generator is driven mainly by a gas turbine or a gas engine, whose generation efficiency in the past may have been inferior to that of large-scale thermal power stations connected to an electricity grid. However, the efficiency of gas engines has recently made remarkable progress thanks to new technologies. The latest gas engines available on the market are quite comparable to large-scale power stations in terms of thermal efficiency. Improvement of gas engines and development of fuel cells will continue and is expected to result in higher efficiency of power generation for distributed systems, which keeps pace with, if not exceeds, that of large-scale stations.

So long as the generating efficiency of the distributed system is comparable with that of grid electricity, the focus for energy saving will be on the efficient use of heat. The model shown in Figure 3 illustrates a typical comparison between a distributed system and a centralised system. To obtain the same amount of heat and power, the input of primary energy for co-generation is reduced by as much as 15% compared with that of the centralised system.

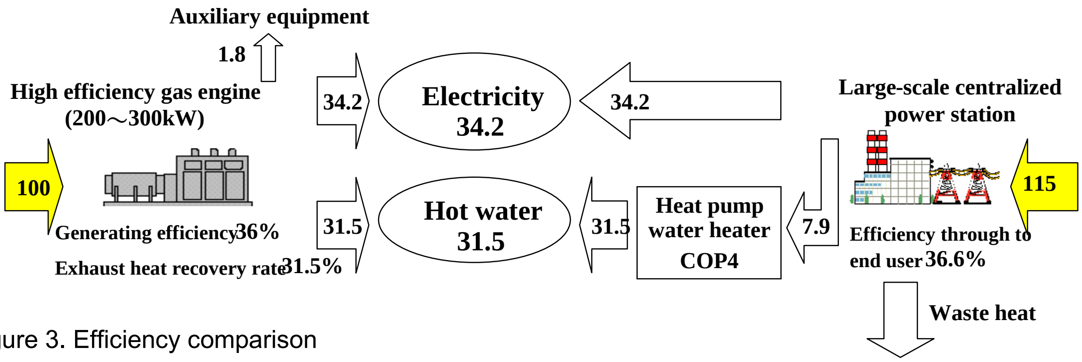
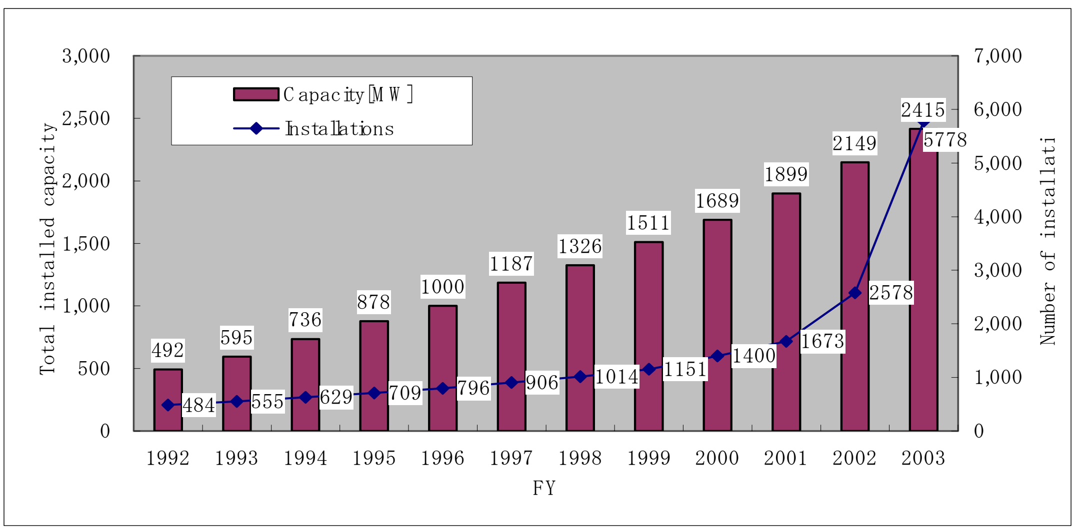


Figure 3. Efficiency comparison

3. MARKET PENETRATION OF CO-GENERATION

Although both the number of installations and the installed capacity of co-generation systems in Japan, as is shown in Figure 4, are steadily and gradually growing, the total generating capacity of gas engines and gas turbines at the end of FY2003 was a mere 2.42 GW, or less than 1.0% of the total generating capacity in Japan. In contrast, as is shown in Table 1, the corresponding figures in European countries are 28% in the Netherlands, 18% in Denmark, 9% in Germany and so on, all of which are much higher than Japan. There are a number of reasons for the difference in the degree of market penetration between Japan and Europe, but one decisive factor appears to be the extent to which each of these countries has institutional measures (see Table 2) to provide support for co-generation.



Source: Japan Gas Association.
Figure 4. Natural gas co-generation installed in Japan

Table 1. Penetration of co-generation in U.S. & Europe

	U.S.	U.K.	France	Germany	Italy	Netherlands	Denmark	Japan
Natural gas co-generation (GW)	18.96	3.21	0.67	10.31	3.48	5.93	2.14	2.42
Total generation (GW)	863.91	78.33	115.16	120.86	70.39	21.05	11.82	266.13
Proportion (%)	2.2	4.1	0.6	8.5	4.9	28.2	18.1	0.9

Source: Figures for total generating capacity are taken from Electric Power Industry in Japan 2003/2004.

Table 2. Incentives to use co-generation systems in various countries

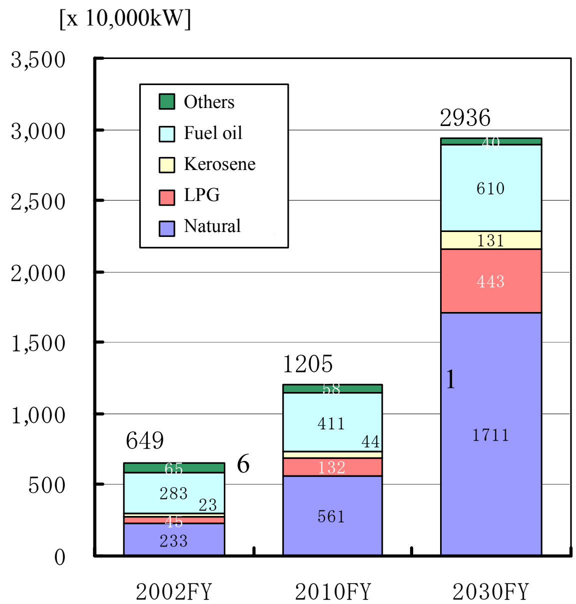
	Category	Incentive system	Outline of system
UK	Tax concessions (fuel, etc.)	Climate Change Levy exemption for co-generation	Co-generation systems that meet or exceed efficiency standards are exempt from Climate Change Levy taxation.
	Additional capital allowance	Enhanced Capital Allowance	100% amortization in the year of introduction is permitted for co-generation systems that meet or exceed efficiency standards.
	Enterprise tax exemption	A level playing field for Good Quality CHP within Business Rating	Co-generation systems that meet or exceed efficiency standards are exempt from business rating (enterprise tax).
	Subsidies for introduction of equipment (investment subsidies)	The Community Energy Programme	Subsidies are available for introduction or upgrading of district heating and cooling equipment.
		Value added tax exemptions for 'Warm Front Team' and CHP facilities installed under the same system	Equipment investment subsidies and added value tax exemptions for systems introduced for low-income groups where there are older people or children
	Subsidies for technological development	Energy Efficiency Best Practice Programme (EEBPP)	Program for general technology development relating to energy-saving technology etc. Includes education for promoting uptake as well as technological development.
France	Tax concessions	Exemption from TIPP (natural gas consumption tax) and TICGN (oil products tax)	Natural gas co-generation and oil-fired co-generation systems meeting certain standards are exempted from natural gas tax and oil products tax.
	Subsidies for amount of power generated (purchase obligation)	The Electricity Law of 10 February 2000 the Order of 31 July 2001 the Order of 3 July 2001	Electricity purchase obligation system
	Subsidies for technological development	5th Research and Development Programme - Energy, Environment and Sustainable Development (EESD)	General technical development program concerning energy and environment issues, run by the EU
Germany	Subsidies for amount of power generated	CHP Modernisation Law (Modernisierungs Gesetz Kraft-Waerme Kopplung)	Subsidies are made available with the aim of protecting the economic aspects of CHP systems.
	Tax concessions	Ecological Tax Reform and the Law on Continuing the Ecological Tax Reform	Co-generation systems that meet or exceed efficiency standards are exempt from environment taxation on mineral oils.
	Subsidies for technological development	4th Energy Research Programme - Reduction of Energy Use Program	General program aiming for technological development to enhance energy efficiency. The scope of the system includes co-generation.
Netherlands	Subsidies for introduction of equipment (Tax concessions)	Energy Investment Relief + Regulatory Energy Tax (EID)	Enterprise tax deductions from corporate profits for investment in energy-saving equipment
	Tax concessions	Exemption from environment tax	Tax exemptions for natural gas used for co-generation
	Subsides for introduction of equipment (investment subsidies)	Program for CO_2 reduction (CO_2 reductie-plan)	Investment subsidy system for programs with CO_2 mitigation
		Program for energy conservation through technical innovations (energiesparing door innovatie)	For technology with energy conservation effects: Subsidies for surveys of corporate adoption, R&D projects, market introduction projects, and knowledge transfer projects
	Subsidies for introduction of equipment (special amortization)	Accelerated Depreciation of Environmental Investments (VAMIL)	Environmental and energy-saving investments can be depreciated as desired.
	Subsidies for amount of power generated (purchase obligation)	Electric power law	Electricity purchase obligation system
	Subsidies for technological development	Economy-Ecology-Technology (EET) Program	Program providing support for fields such as development of environmentally-friendly products, transportation technology, renewable energy, sustainable industry and production technologies, etc.
		New Energy Conversion Technologies (NECT)	Technology development program for energy conversion technologies utilizing natural gas as the fuel
		Dutch Fuel Cell Corporation (BCN BV)	Program for technological development of fuel cells

Source: Japan Gas Association

4. POTENTIAL FOR DISTRIBUTED ENERGY SYSTEMS

(1) Prospects for introduction by 2030

According to the ‘Outlook for Energy Supply and Demand in 2030’, published in June 2004 by METI, up to five times the capacity of current distributed energy systems, or 20% of the total generating capacity in Japan, will be achieved, if the costs of a distributed system become competitive thanks to technological progress and economies of scale. Fuel cells, in particular, are expected to be one of the prime catalysts in this scenario, and both the industry and government are putting great efforts into the development of fuel cells. Eventually, the capacity of natural gas-fuelled distributed energy systems is expected to grow to 17 GW. The contribution to the reduction of CO_2 emission in this scenario is calculated to be 24 million tons.



Source: 'Outlook for Energy Supply and Demand in 2030', the Energy Supply and Demand Subcommittee of METI's Advisory Committee for Natural Resources and Energy (June 2004).

Figure 5. Prospects for distributed energy systems

(2) Potential demand

According to the 'Outlook 2030' document in the previous paragraph, the capacity of natural gas-fired distributed energy systems is estimated to be 17 GW in 2030, assuming certain progress in technologies and market conditions. Table 3 below, which is based on a METI report from 2000, shows the size of the potential market for natural gas-fuelled distributed energy systems in Japan, estimated sector by sector, and the corresponding reduction of CO_2, provided that each market sector is fully converted to distributed systems. The total generating capacity to be installed will reach 56 GW, as shown in the table. The Japan Gas Association estimates that the corresponding reduction of CO_2 achieved by the switch to the distributed system can be as much as 73 million t-CO_2, equivalent to 6.2% of Japan's 1990 greenhouse gas emissions, which is more than the target for Japan under the Kyoto Protocol.

Table 3. Potential for natural gas market and the reduction of CO_2 emissions

Sector	Consumer/ residential	Consumer/ commercial	Industrial	Total
Installation potential* (GW)	14	27	15	56
Estimated CO_2 mitigation**(10^6t-CO_2)	9	29	35	73□□□

* Installation potential figures are taken from 'New Energy Potential and Economy', documentation from the New Energy Subcommittee of METI's Advisory Committee for Natural Resources and Energy (January 2000).

** CO_2 mitigation figures represent the amounts of mitigation compared to conventional systems, estimated on the basis of figures for thermal power stations.

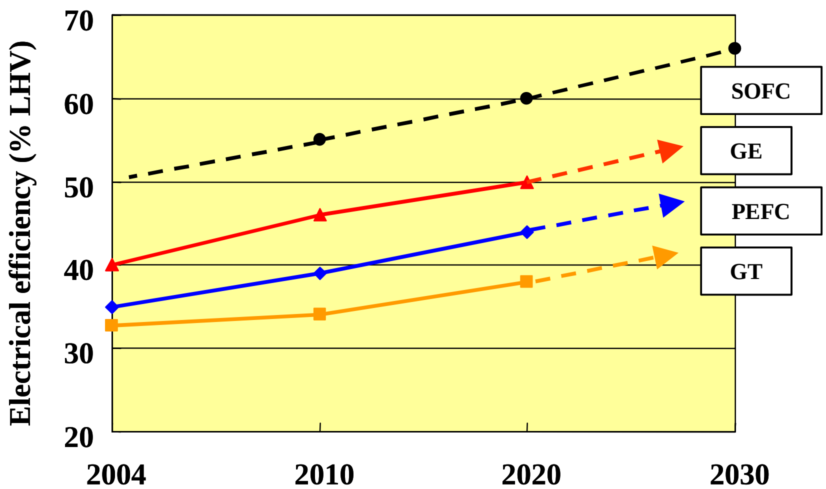
*** 73 million t-CO_2 is equivalent to 6.2% of Japan's 1990 greenhouse gas emissions of 1,187 million tons (CO_2 equivalent).

5. R&D FOR THE FUTURE

One of the most important issues with respect to technology for distributed energy systems is to further improve the thermal efficiency of gas generators such as turbines and engines. Thanks to continual hard work by manufacturers, efficiency has been rising in each type of generator and is expected to improve in the years to come, as shown in Figure 6. In order to expand the co-generation market, improvement in efficiency must be fulfilled for a wide range of capacity, from small generators to large ones. Recently, after considerable development, a new co-generation product, which replaces a conventional water heater and supplies a part of the electricity required for a household using up to 1kW, has been launched for the residential market and has been received favourably by customers.

Efforts are not limited to rotational machines. Efforts to develop polymer electrolyte fuel cells (PEFCs) and to commercialise co-generation systems using PEFCs are under way. The target is to introduce the fuel cell co-generation system, whose generating capacity is 1 kW, into the residential market as early as 2005. The government fully supports development of fuel cell technologies, not only PEFCs but also solid oxide fuel cells (SOFCs), which are a different type of fuel operating at higher temperatures and, therefore, greater efficiency, and practical applications of fuel cells with high electrical efficiency are expected to come to market in the foreseeable future. Further ventures and efforts will continue to cut costs and increase the durability of fuel cells.

Improvements in the efficiency of each generator are important both for stand-alone application of co-generation and for distributed energy systems, because they will increase opportunities for using co-generation and improve the economics of the system.



Note: SOFC: solid oxide fuel cells, PEFC: polymer electrolyte fuel cells,
GE: gas engines, GT: gas turbines

Figure 6. Projection of efficiency improvements

6. LOCAL AREA ENERGY NETWORKS

Even when individual co-generation systems have come to attain maximum energy efficiency, there appears to be more room for further improvement in efficiency when the community as a whole is taken into consideration. The proportion of heat and power required varies from customer to customer, as well as the proportion of one single customer also varies from time to time. Therefore, if the optimisation of energy efficiency is viewed from a different angle, i.e. not individually but collectively as a local community, solutions for optimisation may take a different form. To achieve this community level optimisation, what is required is a local area energy network for heat and power. If energy users in distributed energy systems are connected to a local network and can pool heat and power, it will be possible to accomplish additional energy savings. Instead of installing separate distributed energy systems at individual locations, using shared co-generation and other distributed energy systems to pool heat and electricity among customers via an area network can further increase energy efficiency and reduce CO_2 emissions.

Figure 7 shows local energy pooling of various forms of energy in the future. In a local community, several energy consumers and producers such as houses, offices, and factories exchange energy via a variety of local networks. They will use the Internet to exchange information for balancing and controlling energy demand and supply in the area. Of course, the local energy pool will operate in close co-ordination with the power grid and pipeline networks of natural gas, a preferred fuel for distributed energy systems. Each participant within the local pool will actively play its own role in improving energy efficiency, in mitigating the impact on the environment and, ultimately, in obtaining the maximum value from the pool. During this process, new businesses may emerge and, in due course, new forms of energy such as renewables and hydrogen will be incorporated into the system as local energy sources or even centralised sources.

Figure 7 also implies that local networks will encourage the development of new technologies such as fuel cells and hydrogen, and that society as a whole will gradually shift towards less energy-intensive and carbon-intensive systems.

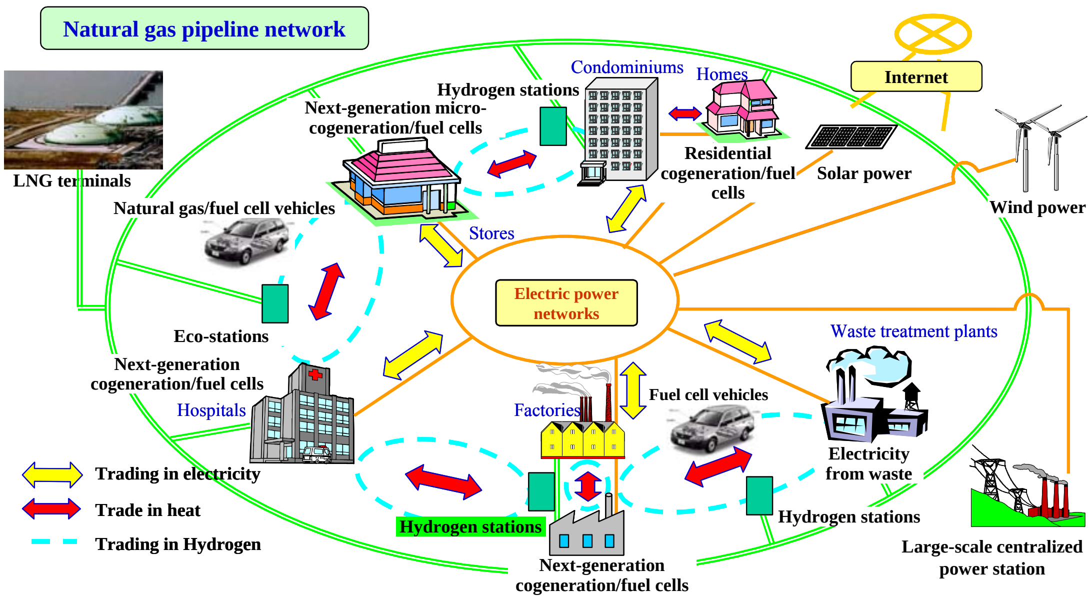


Figure 7. Local area energy networks

- Roppongi Hills

As an example of a distributed energy system, Figure 8 shows the Roppongi Hills Development Project which provides energy for eight buildings with a total floor area of 755,000 m^2. All the electricity and heat required within the area is provided by one company, Roppongi Energy Service Co., Ltd. The total capacity of gas turbines is 38 MW and their heat is used either directly for users as steam, or through absorption chillers to supply chilled water. The proportion of heat and electricity produced by the turbines is adjustable to handle fluctuations in power and heat loads within the area.

This system is designed to achieve 20% primary energy savings and 27% CO_2 reduction. An additional advantage of the system is that it reduces construction costs because individual buildings do not need space and equipment to generate heat or receive electricity.

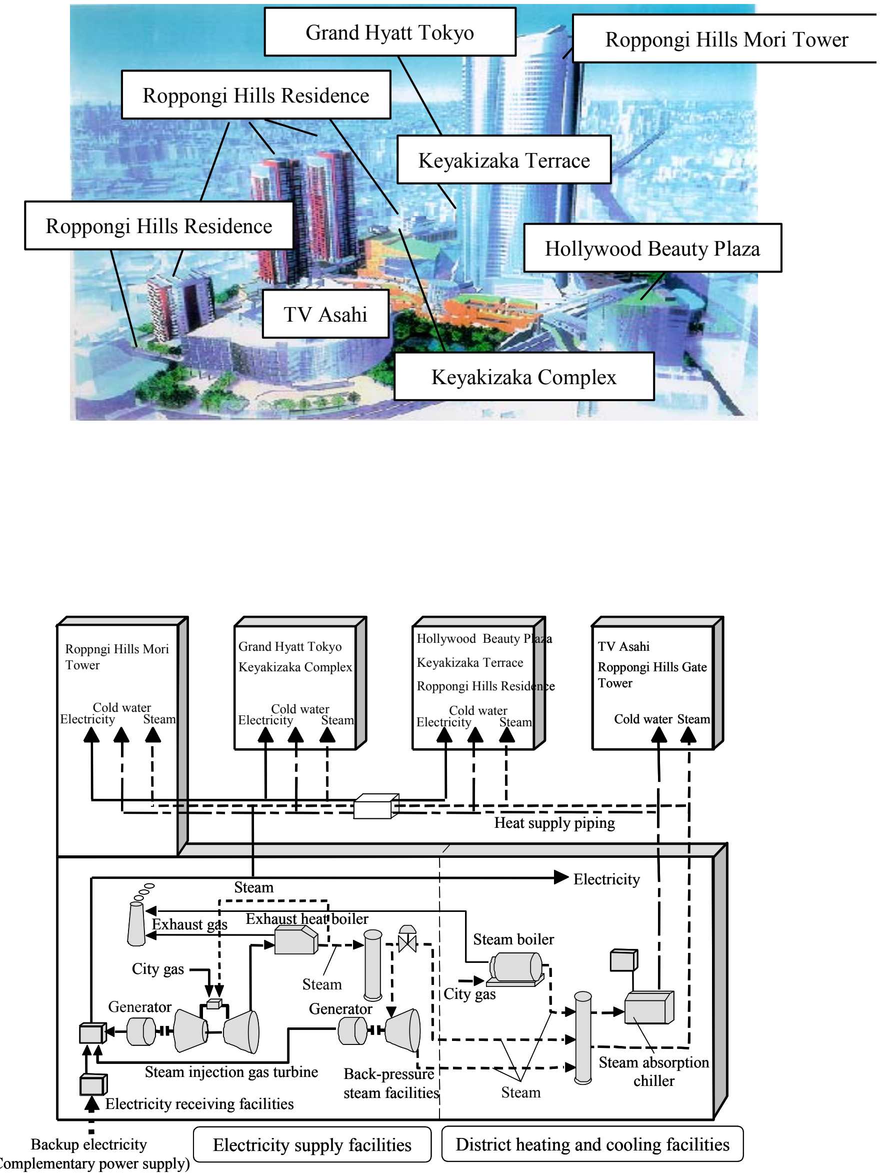


Figure 8. Roppongi Hills Project

7. NEW BUSINESS OPPORTUNITIES

An additional advantage of a distributed energy system is that it gives an opportunity to various entities to be involved in a distributed energy business. Unlike centralised power stations, there are a wide variety of stakeholders in distributed energy projects.

So-called energy service companies (ESCOs) or energy service providers (ESPs) will have an important role to play in the promotion of distributed energy systems. They have in-house specialists, know-how and financial strength to provide a variety of services such as diagnosis for energy saving, equipment ownership, control of operation, fuel provision, and financial services. They can propose attractive distributed energy projects to customers and mobilise the necessary resources for projects, which need not be confined to Japanese.

New industry players coming into the market as ESCOs, ESPs or other companies will include engineering companies, trading companies, heavy electric equipment manufacturers, and financial institutions, as well as utilities that supply energy in the form of gas or electricity. Those utilities that are ready and willing to expand their businesses can make contributions to distributed energy system projects beyond their traditional role as energy suppliers. Throughout the course of project development, from design and construction of distributed energy systems to operation, maintenance and financial services, utilities can become one of the key players in the project.

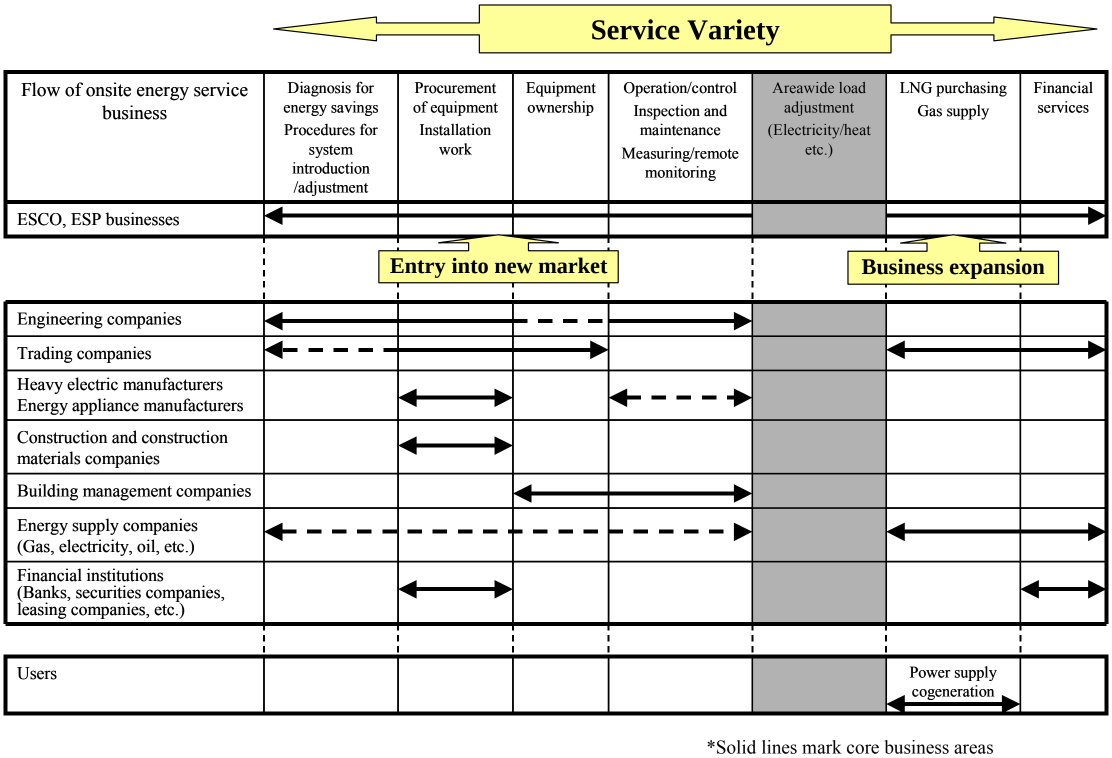


Figure 9. New businesses & players

The new players will compete and co-operate to make the system more economical and reliable and environment-friendly. In addition, possible competition and co-operation with large-scale centralised power supplies will work as a motivation for achieving greater energy efficiency, and will bring substantial benefits to customers.

8. CHALLENGES FOR DISTRIBUTED ENERGY SYSTEMS

There are many potential sites (more than 1,000) in Japan where pooling of electricity and heat is considered possible within the local area, provided an energy network existed. In practice, however, it is difficult to develop an area energy pooling scheme only through the efforts of the private sector because the co-ordination of various interests in the area to form a operationally and financially sound venture is a lengthy and painstaking process. In order to form local energy networks, therefore, it must be given an appropriate place in the national energy policy as a necessary social infrastructure, having such institutional and financial privileges as access to public funds, tax-exemption and subsidies.

For example, in the case of development or redevelopment of a property in an urban area, the developer is required to undertake an energy study. The study is to determine, with support from the local authorities, whether it is feasible to install a local area energy network for pooling energy with the surrounding buildings. Preferably, the study will include the feasibility of local renewable energy resources such as solar, wind and waste into the energy network.

There are also some technical problems. One is the problem of how to facilitate access to the power grid, which must be sorted out in order to form a local power pool. New technology may be needed to ensure a safe, reliable and cost effective connection to the grid. Easy access is vital in order to add a small-scale generator to the pool.

9. CONCLUSIONS

There is still great potential in Japan for further use of natural gas. Use of natural gas will intrinsically contribute to energy savings and reduction in CO_2 emissions, but an important factor in maximising the benefits of gas is the formation of distributed energy systems, or, to be more specific, local area energy networks, which connect co-generation systems to pool heat and power in the area. Distributed energy systems will provide both great benefits for energy consumers and many opportunities for new players in the market, and thus will vitalise the economy.

Competition and co-operation to gain customers by offering better services and prices will take place among ESCOs and ESPs as well as between distributed and centralised systems. This competition will produce a motivation to seek greater energy efficiency in energy systems, which will bring substantial benefits to customers and society in general.

Japan's experience in distributed energy systems will be transferred to other Asian countries such as China and India, where the appetite for energy is expected to grow rapidly. From a global perspective, working on energy efficiency and environmental conservation in these countries is of vital importance. Japanese ESCOs and ESPs can expand their business base overseas by taking advantage of the transfer of technology. Since energy use and available technologies differ from country to country, systems will have to be adjusted to fit regional requirements.

Japan's city gas utilities will continue to do their utmost to improve the efficiency and economics of co-generation systems. They would also like to solicit appropriate institutional encouragement from central and local governments to install co-generation systems and relevant infrastructure. Gas utilities believe that co-generation systems connected to local area energy networks will bring about an energy-efficient and environment-friendly future. Success in Japan will also pave the way to sustainable growth for other countries, and will be the key to achieving energy savings and reductions in CO_2 emissions on an international basis.

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Growth of Nuclear Energy in a Developing Country like India

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INTRODUCTION

India's economy is on a fast track of growth. Growth rate during the first three decades after it achieved independence in 1947 was disappointing, but the situation has changed since 1980. During the period 1981-2000, it has witnessed an impressive GDP growth rate of around 6 percent per year. Policy initiatives of the Government of India during the past decade have resulted in a faster growth of GDP and forecasts by several agencies point towards continued high growth rates for the Indian economy. One study, which was extensively quoted in the Indian media, was from Goldmann Sachs [1], which says, 'India has the potential to show the fastest growth over the next 30 to 50 years. Growth rate could be higher than 5 percent over the next 30 years and close to 5 percent as late as 2050 if the development proceeds successfully.' A more recent study published by IMF [2] says, '…..growth in capital stock together with growth in factor productivity will yield output growth of 5.4 percent. Over the next 20 years, the working age population is projected to grow at 1.9 percent per year. If educational attainment and participation rates remain unchanged, labor growth will contribute another 1.3 percent, yielding an aggregate growth rate of 6.7 percent per year, or a per capita growth rate of 5.3 percent. This is a lower bound estimate and, even so, would be significantly greater than the per capita growth rate of 3.6 percent achieved in the 1980s and 1990s. Over a 40-year period, a 5.3 percent growth rate would increase the income of the average person nearly 8-fold.'

ENERGY DEMAND GROWTH SCENARIO

Energy is the engine for growth and so availability of energy has to be ensured to achieve the projected growth rates. We conducted a study with the aim to quantify the likely growth in energy demand in India, and the role nuclear energy has to play in the decades to come. The ultimate objective was to formulate a strategic plan to meet the projected role to be played by nuclear energy [3].

Energy Intensity of GDP, defined as the ratio of the energy consumption to the GDP, has been observed to follow a certain trend worldwide [4]. Below a certain level of development, growth results in increase in energy intensity (when energy intensity is calculated based on commercial energy only). With further growth in economy, the energy intensity starts declining[86]. Based on data by International Energy Agency [5], overall energy intensity of GDP in India is the same as in OECD countries, when GDP is calculated in terms of the purchasing power parity (PPP). Energy-GDP elasticity, the ratio of the growth rates of the two, remained around 1.3 from early fifties to mid-seventies. Since then it has been continuously decreasing. Electricity is the most important component of the primary energy. Electricity-GDP elasticity was 3.0 till the mid-sixties. It has also decreased since then. Reasons for these energy–economy elasticity changes are: demographic shifts from rural to urban areas, structural economic changes towards lighter industry, impressive growth of services, increased use of energy efficient devices, increased efficiency of conversion equipments and inter-fuel substitution with more efficient alternatives. Based on the CMIE data [6], the average value of the Electricity-GDP elasticity during 1991-2000 has been calculated to be 1.213 and that of the primary energy- GDP elasticity to be 0.907. Estimating[87] the future GDP growth rates of India from the projections made by Dominic Wilson and Roopa Prushothaman [1], taking the primary energy intensity fall to be 1.2 percent per year [7], extrapolating the electricity intensity fall from past data till 2022 and subsequently a constant fall of 1.2 percent year, the growth rates of GDP, the primary energy and electrical energy have been estimated by us as follows.

Period	Primary Energy Percent Annual Growth	Electricity Percent Annual Growth
2002-2022	4.6	6.3
2022-2032	4.5	4.9
2032-2042	4.5	4.5
2042-2052	3.9	3.9

[86] In addition to reference 4, readers may refer to Scientific American, September 2000, which is a special issue on 'Energy'.
[87] Wilson and Purushothaman have assumed that the population by 2050 would be 1.6 billion. We have assumed it to be 1.5 billion. Changes in GDP growth rate due to this difference has been accounted for.

These rates are the basis of the projections reported [3]. It may be recalled that historical primary energy and electricity growth rates during 1981- 2000 were 6 percent per year and 7.8 percent per year respectively.

Based on the growth rates given in the above table, per capita electricity generation would reach about 5300 kWh per year in the year 2052 and total about 8000 billion kWh. Annual primary energy consumption would increase from about 13.5 EJ in 2002-03 to about 117 EJ in 2052-53. By then the cumulative energy expenditure will be about 2400 EJ. The ratio of thermal equivalent of electrical energy to the primary commercial energy[88] will rise from about 57 percent in the year 2002-03 to about 64 percent in the year 2052-53. Table 2 gives projected growth of primary and electrical energy based on these growth rates.

Power generation in India was only 4.1 billion kWh in 1947-48 and in 2002-03, it was more than 600 billion kWh. Considering the past record, the future economy growth scenario and likely boost to captive power plant sector as a result of changes arising due to Electricity Act 2003, the target of generating about 8000 billion kWh per year by 2050 looks achievable.

India's fuel resources

The present status of various fuel-resources in India is given in the table 1. The domestic mineable coal (about 38 BT) [8] and the estimated hydrocarbon reserves (about 12 BT) [9] together may provide about 1200 EJ of energy. To meet the projected demand of about 2400 EJ, one has to tap all options including using the known fossil reserves efficiently, looking for increasing fossil resource base, competitive import of energy (including building gas pipe lines whenever and wherever permitted based on geo-political considerations and found feasible from techno-commercial considerations), harnessing full hydro potential for generation of electricity and increasing use of non-fossil resources including nuclear and non-conventional.

Nuclear technology in India

Before proceeding further, I would like to explain the status of nuclear technology in India. India has developed expertise in all aspects of nuclear fuel cycle and Pressurized Heavy Water Reactors (PHWRs) and PHWRs are the mainstay of its present nuclear power programme. As indicated in the table 1, India has modest reserves of uranium [10] and indigenous uranium resource can support only about 10 GWe of nuclear installed capacity. Uranium-238, the dominant isotope of uranium is a fertile material and cannot make a reactor critical by itself and has to be converted to fissile plutonium-239. The process of conversion takes place in a nuclear reactor and spent fuel from thermal reactors contains plutonium-239. On discharge from the reactor, spent fuel can be dealt with in two ways. The first one termed **'open cycle'**, consists of treating the entire spent fuel as waste and disposing it as such. With this approach only about 1% of the energy potential exploitable from uranium is utilized. To avoid this colossal waste, a **'closed fuel'** cycle involving reprocessing of spent fuel to separate plutonium and uranium-238 has to be pursued. Besides recovering valuable fissile material, reprocessing helps to sort out the wastes according to their activity levels and their decay period thereby assisting waste disposal and minimizing environmental impact. Similarly thorium is a fertile material and has to be converted to a fissile material viz. uranium-233. To ensure long term energy security for the country, India has chosen to follow a '**closed cycle'** approach. Pursuit of the closed cycle approach calls for setting up of reprocessing plants and breeder reactors. India has taken cognizance of these facts viz. its nuclear fuel resource position and need for ensuring long-term energy security and accordingly formulated **a three-stage nuclear power programme [11]**.

The first stage, comprising setting up of Pressurised Heavy Water Reactors (PHWRs) and associated fuel cycle facilities is already in the industrial domain. The speed at which India's nuclear power programme can move forward is no longer limited by technology or the country's industrial infrastructure, but by the availability of uranium. The second stage envisages setting up of Fast Breeder Reactors (FBRs) backed by reprocessing plants and plutonium-based fuel fabrication plants. In order to multiply fissile material inventory, fast breeder reactors are necessary for India's programme. Multiplication of fissile inventory is also needed to establish a higher power base for using thorium in the third stage of our programme. Accordingly, India embarked on the development of Fast Breeder Reactor (FBR) technology about three decades ago and construction of the Prototype Fast Breeder Reactor has already commenced at Kalpakkam near Chennai.

The third stage will be based on the thorium-uranium-233 cycle. Uranium-233 is obtained by irradiation of thorium in PHWRs and FBRs. An Advanced Heavy Water Reactor (AHWR) is being developed at Bhabha Atomic Research Centre (BARC) to expedite transition to thorium based systems.

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[88] This is higher than what this ratio is in developed countries and reflects the shift towards cleaner energy source due to likely advances in technology in the coming five decades

In addition to indigenous technology, to expedite the growth of nuclear power, India is planning to set up Light Water Reactors (LWRs) in technical cooperation with other countries. Two LWRs being constructed at Kudankulam, in the southern part of India in technical cooperation with Russian Federation is a part of this strategy. Medium term plan is to ensure that nuclear installed capacity by the year 2020 is about 20 GWe. In addition to PHWRs, this would consist of 8 GWe of LWRs and 2.5 GWe of FBRs.

Strategies for meeting the long-term projected demand

To meet the projected demand, fuel resource position and the plans of all the departments of Government of India were examined and it was concluded that resource position and growth scenario calls for maximizing contribution from all possible energy sources [3]. To maximize contribution of nuclear energy, it is necessary to build fast reactors having best growth characteristics. After accounting for maximum possible growth for fast reactors, the study concludes that nuclear power, mostly FBRs, can contribute only about a quarter of electricity demand in India by the middle of the century. The balance, therefore, has to be met by burning fossil fuels. India's hydrocarbon reserves are miniscule and the indigenous programme would thus inevitably involve large scale burning of coal. The table 3 and the table 4 give a detailed break up.

Considering large energy needs, India has chalked out an ambitious research and development programme to maximize contribution by nuclear energy beyond that based on just fast reactors. This involves development of accelerator driven sub-critical systems for possible deployment beyond the year 2030 and intensifying exploration of uranium exploration particularly concealed deposits [12]. Till all these efforts fructify, India would continue to depend on coal to meet its energy needs.

This scenario calling for large scale burning of fossil fuels could change if uranium were a freely tradable commodity. This, however, would depend on likely evolution of policies with regard to civilian nuclear commerce. It would be worthwhile to recall what John Ritch, former US representative to the IAEA and United Nations Organizations in Vienna has to say, 'And the largest growth markets in energy consumption are China and India, both of which already have weapons capabilities. In short, almost everywhere the reduction in carbon emissions could yield important benefits for climate protection, proliferation is not even an issue' [13].

Concluding remarks

India has the technical competence in all aspects of nuclear science and technology based on a comprehensive research and development programme nurtured over several decades. Given the track record of India, there should not be any concern with regard to proliferation and civilian nuclear commerce with India would only lead to a win-win situation involving commercial gains for the supplier's nations and expansion of a clean source of energy benefiting the whole world in terms of gains to environment.

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Table 1: Primary energy & electricity resources

	Amount	Thermal energy			Electricity potential
		EJ	TWh	GWYr	GWe-Yr
Fossil:					
Coal	38 -BT	667	185,279	21,151	7,614
Hydrocarbon	12 -BT	511	141,946	16,204	5,833
Non-Fossil:					
Nuclear:					
Uranium-Metal	61,000 -T				
In PHWRs		28.9	7,992	913	328
In Fast breeders		3,699	1,027,616	117,308	42,231
Thorium-Metal	2,25,000 -T				
In Breeders		13,622	3,783,886	431,950	155,502
Renewable					
Hydro	150 -GWe	6.0	1,679	192	69
Non-conventional renewable	100 -GWe	2.9	803	92	33

Assumptions for Potential Calculations

Fossil:

Complete Source is used for calculating electricity potential with a thermal efficiency of 0.36.

Calorific Values: Coal: 4,200 kcal/kg, Hydrocarbon: 10,200 kcal/kg.

Ministry of Petroleum and Natural Gas [7]has set strategic goals for the next two decades (2001-2020) of 'doubling reserve accretion' to 12 BT (Oil + Oil equivalent gas) and 'improving recovery factor' to the order of 40%. Considering the fact that exploration is a dynamic process and India is one of the les explored countries, reference [3] assumes that cumulative availability of hydrocarbons up to 2052 will be 12 BT.

Non-Fossil:

Thermal energy is the equivalent fossil energy required to produce electricity with a thermal efficiency of 0.36.

Nuclear

PHWR burn-up = 6,700 MWd/T of U-oxide, thermal efficiency 0.29

It has been assumed that complete fission of 1kg. of fissile material gives 1000 MWd of thermal energy. Fast reactor thermal efficiency is assumed to be 42%. Fast breeders can use 60% of the Uranium. This is an indicative number. Actual value will be determined as one proceeds with the programme and gets some experience. Even if it is half of this value the scenario presented does not change.

Breeders can use 60% Thorium with thermal efficiency 42%. At this stage, type of reactors wherein thorium will be used are yet to be decided. The numbers are only indicative.

Hydro:

Name plate capacity is 150 GWe.

Estimated hydro- potential of 600 billion kWh and name plate capacity of 150,000 MW_e gives a capacity factor of 0.46.

Non-conventional renewable

Includes: Wind 45 GWe, Small Hydro 15 GWe, Biomass Power/ Co-generation 19.5 GWe and Waste to Energy 1.7 GWe etc.

Capacity factor of 0.33 has been assumed for potential calculations.

Table 2: Projected growth of primary commercial and electrical energy

Year	Population	Coal + Lignite	Hydro carbon	Hydro	Nuclear	Non-Conv-Renew	Prim. Ener	Electricity			Elec / Primary
	Billion	EJ	EJ	EJ	EJ	EJ	EJ	EJ	TWh-e	Per	%

										Cap kWh-e	
2002	1.04	6.40	6.02	0.79	0.23	0.03	13.46	7.65	638	613	57
2022	1.33	11	13	5	2	2.4	33	22	2154	1620	66
2032	1.42	19	20	6	4	2.5	51	35	3485	2454	68
2042	1.47	31	30	6	10	2.7	80	54	5438	3699	68
2052	1.50	47	41	6	19	2.7	117	75	7957	5305	64

For calculating primary energy in EJ equivalent to electrical energy generated by hydro, nuclear or non-conventional renewable sources, thermal efficiency used is 0.30 for the period 2002-2022 and 0,36 beyond 2022.

Table 3: Projected growth of electricity installed capacities by fuel mix (including captive power)

Year	Coal		Hydro-carbon		Hydro		Non-conv Ren		Nuclear		Total
	GWe	%	GWe	%	GWe	%	GWe	%	GWe	%	GWe
2002	71.92	52.51	32.81	23.95	27.78	20.28	1.74	1.27	2.72	1.99	136.97
2022	148	34.34	57	13.23	115	26.68	82	19.03	29	6.73	431
2032	264	40.12	94	14.29	150	22.80	87	13.22	63	9.57	658
2042	435	45.36	150	15.64	150	15.64	93	9.70	131	13.66	959
2052	615	45.76	204	15.18	150	11.16	100	7.44	275	20.46	1344

Calculated assuming full electricity generation potential of hydro, non-conventional renewable is utilized. Nuclear capacity growth projections are based on fast reactor characteristics. The balance demand is met by fossil-resources.

Table 4: Projected growth of electricity generation by fuel mix including estimated captive power generation

Year	Coal		Hydro-carbon		Hydro		Non-conv Ren		Nuclear		Total	Per Cap Elec Gen
	TWhe	%	TWhe	%	TWhe	%	TWhe	%	TWhe	%	TWhe	kWh_e
2002	425.74	66.75	125.08	19.61	65.66	10.29	2.13	0.33	19.24	3.02	637.85	613
2022	907	42.11	345	16.02	460	21.36	236	10.96	206	9.56	2154	1620
2032	1620	46.48	572	16.41	600	17.22	252	7.23	441	12.65	3485	2454
2042	2670	49.10	920	16.92	600	11.03	270	4.97	978	17.98	5438	3699
2052	3774	47.43	1250	15.71	600	7.54	289	3.63	2044	25.69	7957	5305

ANNEXES

In this part of the proceedings supplementary material as discussed in the meeting is presented. It has been done in the form of annexes, which vary in length.

ANNEX B ACRONYMS

AR4	Fourth Assessment Report
BAU	Business-As-Usual
CDM	Clean Development Mechanism
CDQ	Coke Dry Quenching
CEIT	Country with Economy In Transition
CLA	Coordinating Lead Author
CRIEPI	Central Research Institute of Electric Power Industry
ECN	Energieonderzoek Centrum Nederland
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GISPRI	Global Industrial and Social Progress Research Institute
GW_p	Global Warming Potential
IAI	International Aluminium Institute
ICC	International Chamber of Commerce
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Authority
IPR	Intellectual Property Rights
LA	Lead Author
METI	Ministry of Economy, Trade and Industry
KP	Kyoto Protocol
PFC	Perfluorocarbon
TEAP	Technology and Economic Assessment Panel
TRT	Top Pressure Recovery Turbines
TSU	Technical Support Unit
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
WBSCD	World Business Council for Sustainable Business Development

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Japan

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Ministry of Economy, Trade and Industry; National Institute of Advanced Industrial Science and Technology
Japan

John Nyboer
Simon Fraser University
Canada

Hiroshi Ozaki
Japan Gas Association
Japan

Teruo Okazaki
Nippon Steel Corporation
Japan

Eiichi Onuma
Japan Cement Association
Japan

Kjell Oren
Norsk Hydro
Norway

Rajendra K. Pachauri
IPCC Chairman
India

Cedric Philibert
International Energy Association
France

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Winrock International India
India

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Toshiyuki Sakamoto
Ministry of Economy, Trade and Industry
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Masayuki Sasanouchi
Toyota Motor Corporation
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Ildo Luis Sauer
Petrobras Brasil
Brazil

Zhongyuan Shen
National Development and Reform Commission
China

John Scowcroft
Eurelectric
Belgium

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Shigetoshi Seta
Tokyo University of Agriculture and Technology
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Taishi Sugiyama
Central Research Institute of Electric Power Industry
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India

James Sweeney
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Kanako Tanaka
The Institute of Energy Economics
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Greg Tosen
Eskom
South Africa

Roberto Schaeffer
Federal University of Rio de Janeiro
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Masatake Uezono
Citizens Alliance for Saving the Atmosphere and the Earth (NGO)
Japan

Akio Ukai
Japan Gas Association
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Central European University
Hungary

Yanjia Wang
Tsinghua University
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Fengqi Zhou
Energy Research Institute of National Development
China

Peter J. Zhou
EECG Consultants Pty Ltd
Zimbabwe

ANNEX D LIST OF PAPERS PRESENTED

OPENING PLENARY SESSION

Hiroyuki Watanabe, TOYOTA	*TOYOTA Challenge on Sustainable Mobility*
Greg Tosen, Eskom	*Technology and Climate Change Policy in South Africa*
Teruki Masumoto, Vice-Chairman of Federation of Electric Power Companies	*Electric Technologies to Address Requirement for the Ultimate Resource Productivity*
Brian P Flannery & Haroon S. Kheshgi, ExxonMobil, USA	*An Industry Perspective on Successful Development and Global Commercialization of Innovative Technologies for Greenhouse Gas Mitigation*
Taishi Sugiyama, CRIEPI	*Scenarios of Technology and Infrastructure Transition in Energy Systems*
Cedric Philibert, IEA	*Energy Demand, energy technologies and climate stabilization*
Jae Edmonds and Jose Moreira**, Lead Authors for AR4**	*Conceptual Frameworks for Technology Development, Transfer and Diffusion*

ENERGY INTENSIVE INDUSTRY BREAKOUT GROUP

1. Robert Chase and Eirik Nordheim, International Aluminium Institute	*The IAI Global Aluminium Sustainable Development Initiative*
2. Jon Davis and Steve Kleespie, Rio Tinto	*Mining Industry Experience and the Commercialisation of Carbon Dioxide Capture and Storage Technologies*
3. Mrs Yanjia Wang, Tsinghua University	*Barriers of Technology Transfer in China: Four Case Study Analyse*
4. Jose Aguayo, El Colegio de Mexico	*Stepping off the Hydrocarbons Regime: The Challenge of Technological Transition*
5. M. Nakamura, K. Kotani and T. Okazaki, JATIS and Nippon Steel Corporation	*Voluntary Initiatives of Japan's Steel Industry Against Global Warming*
6. Bhanu Swaminathan, International Fertilizer Association	*Technology Transfer and Mitigation of Climate Change: the Fertilizer Industry Perspective*
7. K.Casey Delhotal & Michael Gallaher, US Environmental Protection Agency	*Estimating Technical Change and Potential Diffusion of Methane Abatement Technologies for the Coal-mining, Natural Gas and Landfill Sectors*
8. Akihisa Kanda and Eiichi Onuma, The Japan Cement Association	*Consideration of CO_2 from Alternative Fuels in the Cement Industry*

ENERGY INTENSIVE CONSUMER GOODS BREAKOUT GROUP

1.	Masayuki Sasanouchi, Project General Manager, Toyota Motor Corporation	*A View from the Automobile Industry as a Manufacturer*
2.	Suzana Kahn Ribeiro, Federal University of Rio de Janeiro	*Potential Carbon Dioxide Reduction Due the Use of Hybrid Buses in Brazil*
3.	Dr John Nyboer and Dr. Mark Jaccard, Simon Fraser University	*Technology Diffusion in Industry*
4.	Natasa Markovska, Macedonian Academy of Sciences and Arts	*Driving Factors and Limiting Barriers of Technology Transfer in the Energy Sector in Macedonia*
5.	James Sweeney, Stanford University	*Options for Hydrogen Use in Light Duty Vehicles*
6.	George Hansen, Tom Marx and Terry Pritchett, GM	*Driving Technology in the Motor Vehicle Industry*
7.	Shen Zhongyuan, The Institute of Energy Economics	*Energy Saving Potential of China*
8.	Shigetoshi Seta, Tokyo University of Agriculture and Technology	*Efforts of the Japanese Chemical Industry to reduce Greenhouse Gas Emissions*

ELECTRICITY PRODUCTION AND ENERGY CARRIERS BREAKOUT GROUP

1.	Dr. Juergen Engelhard and Dr. Johannes Ewers, RWE Power AG, Germany	*Clean Coal Technologies for Climate Protection: Utilize today's options and develop future potentials.*
2.	Dr. Hisashi Ishitani, Shinichi Tada, Tomohito Okamura, Michinobu Furukawa, Keio University, Osaka Gas and Tokyo Gas, Japan	*Life Cycle Assessment of Liquefied Natural Gas*
3.	Ms Nicole Dellero, AREVA, France	*Contribution of Nuclear Technology to Climate Change Mitigation*
4.	Xiliang Zhang and Cheng Rong, Institute of Energy, Environment, and Economy, China.	*Renewable Energy Technology Deployment in China: Opportunities and Challenges*
5.	Dr William Kyte, OBE, Powergen, UK, Dr John Scowcroft, Eurelectric	*Prospects for Technology to Address Climate Change*
6.	F. D. Yamba and Mr. E. Matsika, Centre for Energy	*Factors and Barriers Influencing the Transfer and Diffusion of Biofuels Producing Based Technologies With Particular Reference to Southern Africa*
7.	Ildo Luis Sauer, Gas and Power Director, Petrobras- Brazil	*The Experiences and Performance of Petrobras in the Rational Energy Use Area and Renewable Energy*
8.	Toshinori Shimamura, The Japan Gas Association	*Alleviating the Environment Impact by Networking the Natural Gas Fuelled co-generation Systems*
9.	Ravi Grover, Department of Atomic Energy, India	*Growth of Nuclear Energy in a Developing Country like India*

ANNEX E MEETING PROGRAMME

Key Meeting Objectives

- Identifying key drivers on industrial technology development, transfer, deployment and diffusion to be addressed in the AR4
- Contributing to building the conceptual framework for the assessment
- Gaining access to industrial information networks being relevant for the scientific assessment of climate change mitigation and improve the use of publicly available data sources from industry in the AR4
- Explicitly involving experts working in industry in the WG III AR4 process (as lead authors, contributing authors and expert reviewers).

TUESDAY 21 SEPTEMBER
SESSION 1: OPENING SESSION

08.00	Registration Desk opens
09.00	**Welcome by representative of Japan Ministry of Economy, Trade and Industry and Professor Ogunlade Davidson, IPCC-WGIII co-chair** Welcome by representative of METI: Mr. Hiroshi Saito, Director General in Charge of Technology, Standardization and Environment
09.10	**Dr. R K Pachauri, IPCC Chairman** Opening Address
09.30	**Dr. Hiroyuki Watanabe, Senior Managing Director, TOYOTA Motor Corporation** *TOYOTA Challenge on Sustainable Mobility*
10.00	**Greg Tosen, Eskom, South Africa** *Technology and Climate Change Policy in South Africa*
10.30	Coffee/Tea Break
11.00	**Mr Teruaki Masumoto, Vice-Chairman, Federation of Electric Power Companies** *Electric Technologies to Address Requirement for the Ultimate Resource Productivity*
11.30	**Dr Brian P. Flannery, Exxon Mobil Corporation, Dr. Haroon S. Kheshgi, ExxonMobil Research and Engineering Company** *An Industry Perspective on Successful Development and Global Commercialization of Innovative Technologies for Greenhouse Gas Mitigation*
12.00	Lunch hosted by Ministry of Economy, Trade and Industry
13.30	**Taishi Sugiyama, Central Research Institute of Electric Power Industry (CRIEPI), Japan** *Scenarios of Technology and Infrastructure Transition in Energy Systems*
14.00	**Cédric Philibert, Energy Efficiency and Environment Division International Energy Agency, France** *Energy demand, energy technologies and climate stabilization*
14.30	**Jae Edmonds and Jose Moreira, Lead Authors for AR4** *Conceptual Frameworks for Technology Development, Transfer and Diffusion*
15.00	**Leo Meyer/John Kessels, Technical Support Unit for Working Group III** Instructions to participants on how the Break out Groups will work
15.30	Afternoon Coffee/Tea Break
16.00	Break Out Group Sessions Begin
17.30	Close of Day One
18.30	Reception hosted by the Keidanren-Japan Business Federation

WEDNESDAY 22 SEPTEMBER
BREAKOUT SESSIONS ALL DAY

08.00	Meeting for stock take with Programme Committee and Co-Chairs of Break out Groups
09.00	Break out Group sessions begin
12.30	Lunch (Not provided)
13.30	Break out Group sessions continue
18.00	Close of Day Two

Thursday 23 September

Break out sessions continue and Presentations to the Plenary with Discussion, Summary and Recommendations for further actions

08.00	Meeting for stock take with Programme Committee and Co-Chairs of Break out Groups
09.00	Break out sessions continue
10.30	Coffee/Tea Break
11.00	Energy Intensive Industry Breakout Group report back to the Plenary
12.00	Energy Intensive Consumer Goods Breakout Group report back to the Plenary
13.00	Lunch *(not provided)*
14.00	Electricity Production and Energy Carriers Group report back to the Plenary
15.00	Summary with recommendations for further actions
15.30	Chairman Professor Ogunlade Davidson closes the meeting
15.45	Programme Committee and Co-Chairs Meeting

BREAK OUT SESSIONS

GROUP 1	GROUP 2	GROUP 3
Chairs: Lenny Bernstein, Joyashree Roy	Chairs: Diana Urge-Vorsatz, Bert Metz	Chairs: Greg Tosen, Jose Moreira
Rapporteur: To be decided	Rapporteur: To be decided	Rapporteur: To be decided
Energy-Intensive Industry (cement, refining, metals, chemicals)	**Energy Intensive Consumer Goods** (passenger cars, air conditioners and lighting equipment)	**Electricity Production and Energy Carriers** (fossil, renewables, nuclear, Less carbon intensive fuels, efficient conversion, hydrogen

ANNEX F SCOPING NOTE TO MEETING

BACKGROUND

The Intergovernmental Panel on Climate Change (IPCC) is in the process of preparing the Fourth Assessment Report (AR4), which will assess the scientific, technical, and socio-economic information relevant to understanding human-induced climate change, its potential impacts, vulnerability to it, and options for adaptation and mitigation. In 2003, the outlines for its three Working Groups were prepared and approved by the 21st session of IPCC in Vienna (November 2003). The AR4 ('Climate Change 2007') will consist of three volumes[89]:

- The Physical Science Basis, by Working Group I
- Impacts, Adaptation and Vulnerability, by Working Group II, and
- Mitigation of Climate Change by Working Group III.

In the preparation of these outlines it was recognized that Technology was one of the crosscutting issues, in particular as a key driver for the mitigation options. The AR4 of WG III should particularly address mitigation technology development and its transfer and diffusion. As mitigation technology is generally developed and produced by Industry, it was also acknowledged that the involvement of Industry in the AR4 of WG III is essential and would need reinforcement.

The 21st IPCC Plenary session therefore decided to hold an expert meeting on 'Industrial Technology Development and Transfer' as a support to the AR4 of WG III. Dr. Shigetaka Seki of METI kindly offered to host this meeting in Japan (21-23 September 2004). This meeting should be seen as a step in a process of further improving the relationship of IPCC and Industry, in support of the preparation of the AR4 of Working Group III.

INTRODUCTION

Industry, through generation of electricity, emissions generated by use of its products, and the manufacture of products, influences a significant part of worldwide greenhouse gas emissions. Industry plays an important role in possible responses to climate change. Industry decisions on investments, operation of equipment, product development, and technological innovation will have an enormous impact on future greenhouse gas emissions. Industry investments in capital exceed governments' investments by far. Industry spending on R&D and innovation is also significantly larger than the R&D funding by governments and most of the envisaged 'solutions' to climate change need to be realised by industry.

In the Fourth Assessment Report (AR4) mitigation of greenhouse gas emissions from industry will again be covered. It will not be sufficient to provide an overview of mitigation options and its potential. It is equally important to assess driving factors affecting CO_2 intensive energy systems and what roles different actors can play in such processes. Companies are producing and developing products that help to mitigate future greenhouse gas emissions. In addition, many companies are already considering and implementing mitigation of greenhouse gas emissions in their decisions. In some countries mitigation of climate change has become an important driver for the government's energy and environmental policy, which is affecting private sector decisions. The AR4 will need to reflect these developments.

WHY INDUSTRY SHOULD HAVE MORE INVOLVEMENT AND INPUT INTO THE IPCC PROCESS?

This expert meeting will provide a forum for industry experts to engage the expert community advising on the mitigation of Greenhouse gases, and consider ways for enhanced industry input into the IPCC process.
The IPCC scientific assessments provide policy relevant guidance primarily written for policy makers within Governments. Economic, technological and environmental policies that may be based on IPCC

[89] Http://www.ipcc.ch/activity/ar.htm#outline.

assessments could, therefore, have profound effects on industry. IPCC assessment reports receive worldwide coverage and are consequently used by current and future decision-makers and hence future customers of commercial products and services.

Evidently, it is important that the view of those experts involved in serving customers and competing in markets is represented in the IPCC assessment process. Participation of Industry will facilitate its decision makers' access to the latest information and thinking for their own strategic decision-making.

PREVIOUS IPCC WORK AND INDUSTRIAL TECHNOLOGY DEVELOPMENT, TRANSFER AND DIFFUSION

IPCC has paid attention to technology transfer and to mitigation of greenhouse gases from industry. In the past, there has been involvement of industry experts in the preparation of the IPCC Assessment Reports.[90] However, IPCC would like to considerably enhance this industrial involvement.

The Special Report on Methodological and Technological issues in Technology Transfer (IPCC, 2000) was a major effort to assess the literature on Technology Development and Transfer and understand the relevant processes and barriers, including those affecting the private sector.

The TAR WGIII report referred in various chapters to technology development and transfer and the role of the private sector (e.g. Chapters 3, 5 and 9) and a few remarks can be made:

1. Chapter 3 provides a view about the potential and cost to mitigate greenhouse gas emissions from various sectors. The role of industry and the private sector research and development was limited in the assessment and is not reflective of the large role that private sector R&D plays.
2. Industry was not assessed as self-acting and self-deciding entities with their own way of making (strategic) decisions in which many considerations play a role and for which environmental issues form one of the many considerations.
3. Further, it does not reveal the heterogeneous character of industry; there are many kinds of companies, ranging from energy-intensive to technology-intensive, from small to large (multinationals), from advanced to traditional, etc. Neither is it noticed that even within subsectors (e.g. car manufacturing, oil industry) there are significant differences, which are leading to different strategies to address climate change.

OBJECTIVES AND SCOPE OF THE EXPERT MEETING

The objectives of the Expert meeting on Industrial Technology Development, Transfer and Diffusion are:

- Identifying key drivers on industrial technology development, transfer, deployment and diffusion to be addressed in the AR4
- Contributing to building the conceptual framework for the assessment
- Gaining access to industrial information networks being relevant for the scientific assessment of climate change mitigation and improve the use of publicly available data sources from industry in the AR4
- Explicitly involving experts working in industry in the WG III AR4 process (as lead authors, contributing authors and expert reviewers).

The first and second objectives deal with contents. In order to have a successful meeting and useful results the meeting will focus on:

- A limited set of key issues/questions that are relevant for AR4 regarding the technology development and transfer processes - and in particular how the private sector practical experience can be integrated in more theoretical concepts (what can we learn from industry?
- A limited set of industrial sectors /products - selecting a few where major GHG emissions occur, where major mitigation potentials exist, and where major technology development and transfer options may be considered.

[90] It needs to be mentioned that some experts working in industry were involved in preparing the TAR, the SRES, SRTT and the SR Aviation. In the preparation of the Special Report on CO_2 Capture and Storage and the Special Report on the greenhouse effect of substitutes for gases affected by the Montreal Protocol (HFCs and PFCs) more industry experts are participating.

The following key questions are considered:

1. **What are the driving factors of industrial technology development?** What are the current key driving forces in industrial technology development and why? What is the role of the private sector? What is the role of co-operation between industries in the development of technology to save energy and reduce greenhouse gas emissions, including an approach to make a life cycle assessment of industrial products? How important is technology development in corporate strategies? Is mitigation of future greenhouse gases a driving role, and if so, in which industry sectors, how and how much? Is there a common view on technology development? What differences exist in driving forces by region and by company? What are the key uncertainties in driving forces? How and how much depends on industrial technology development for one sector on technology development in other sectors? How are government policies affecting industrial technology development? How does geographical distribution influence industrial technology development?
2. **What are the factors that drive or limit the process of transfer and diffusion of technologies?** Are there views which are new or which were not sufficiently covered by the IPCC Special Report on Technology Transfer?[91] In particular, what are the views of the private sector on technology transfer by investments into new market regions? What are the opportunities and barriers (including human and capital resources required) for transfer of technologies and what factors determine the rate of transfer of technologies? What are the key barriers for transfer of low carbon technologies and how can they be removed? What regional differences exist in transfer of technologies? What are the roles of the private sector?
3. **How to make accurate estimates of future cost and future market potential of technologies?** What elements need to be considered when estimating the cost and potential of technologies? What can be learnt from past estimates of cost and potential of technologies? How can new estimates of cost and potential of technologies be improved (e.g. by better considering fuel chain effects)? How to get reality checks with respect to estimates of cost and potential of new technologies? What is good practice in estimating cost and market potential of technologies? Is there a need to make regionalized estimates of cost and potential of technologies?

These three questions should apply to one or more of the following sectors/product areas:

- **Energy-intensive industry** (e.g. cement, refining, metals, chemicals);
- **Energy-intensive consumer goods** (e.g. passenger cars, air conditioners and lighting equipment);
- **Electricity production and energy carriers** (e.g. fossil, nuclear, renewables, less carbon intensive fuels, efficient conversion, hydrogen).

Mitigation options that are primarily non-technical are excluded.

To meet the third and fourth objective of the Expert Meeting, participants could be invited to give their input on the following questions:

- How to successfully involve industrial experts in preparation and reviews of the draft Assessment Report (lead authors, contributing authors, review editors, expert reviewers)?
- How insights from industrial information networks can best be used and tapped; what organizational arrangements (more expert meetings? Periodic communication with ICC, WBCSD, others) may help to keep the IPCC industry connection going?

DELIVERABLES

The main deliverable of the meeting will be a meeting report that contains:

1. Overview of key issues to be considered in AR4 with respect to technology development, transfer and diffusion.
2. The papers that are brought to the meeting will be peer reviewed and therefore eligible for input into Working Group III and AR4.
3. Recommendations on using industrial information networks in the preparation of AR4.
4. A list of key contacts with expertise on industrial technology development, transfer and diffusion.
5. Recommended further actions.

[91] See Appendix I for a definition of Technology Transfer as it was used in the IPCC Special Report on Methodological and Technological issues I technology Transfer, IPCC 2000, ISBN 0521800082.

PROGRAMME COMMITTEE

Name	First name	Company	Country
Dr. Bhombal	Hameed	Aditya Birla Group	India
Dr. N. Campbell	Nick	Atofina	France
Prof. O. R. Davidson (chair)	Ogunlade	Cochair of Working Group III IPCC	SIERRA LEONE
Dr. J.A. Edmonds	Jae	Batelle, Pacific Northwest National Lab	USA
Dr. A. B. M. Hoff	Ton	Energy research Centre of the Netherlands ECN	NETHERLANDS
Dr. H. Kheshgi	Haroon	ExxonMobil Research and Engineering Company	USA
Dr. M. McFarland	Mack	DuPont Fluorproducts	USA
Dr. J. R. Moreira	José	University of Sao Paulo	BRAZIL
Dr. G. Tosen	Greg	Eskom	SOUTH AFRICA
Dr. S. Seki	Shigetaka	Ministry of Economy, Trade and Industry	JAPAN

TECHNICAL SUPPORT UNIT

Name	First name	Company	Country
Mr. J. Kessels (Secretary)	John	ECN	NETHERLANDS
Dr. L. Meyer (vice chair)	Leo	RIVM	NETHERLANDS