Status Report

Summary of IPCC/EIS-IIASA International Workshop on Energy-Related Greenhouse Gases Reduction and Removal 1–2 October 1992

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SR-93-1
February 1993

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Contents

Introduction	1
Opening Remarks	3
Session 1. Energy End-Use and Conservation	9
Session 2. Renewables and Zero-Carbon Options	19
Session 3. Clean Fossils, Carbon Removal and Storage	29
Session 4. Technology Assessment and R&D Priorities	39
Appendix: Workshop Agenda and List of Participants	49

Introduction

Many technological measures to minimize energy-related carbon dioxide and other greenhouse gas (GHG) emissions have been suggested and studied. There is a need for more systematic and comparative treatments of these technologies and more comprehensive evaluations of promising and innovative technologies. The analysis should take into account: current status, implementation prospects, applicability in different parts of the world, technical performance, cost evaluations, market potential, technology transfer to developing countries and possible diffusion timing.

A two-day "IPCC/EIS-IIASA International Workshop on Energy-Related Greenhouse Gases Reduction and Removal" was held at IIASA from 1-2 October, 1992 to meet such needs.

The objective of the meeting was fourfold: first, to review current research and present understanding of appropriate measures to reduce energy-related carbon dioxide and other GHG emissions, and to review their potentials and constraints of implementation; second, to evaluate critically current assessments of mitigation and reduction technologies such as those conducted by the IPCC and IIASA; thirdly, to provide an overview of other similar international and national studies; and finally, to identify knowledge gaps and possible research activities. Emphasis was given to discussions and interaction between participants, rather than to formal presentations.

The Energy and Industry Subgroup (EIS) of the old Working Group III (new Working Group II, Subgroup A) of the IPCC has completed the peer review of energy-related assessments of the Supporting Materials giving background information contained in the IPCC 1992 Supplement completed for the February 1992 IPCC Plenary. Although limited in scope and depth, they provided the present assessments of various energy-related response technologies to reduce CO_2 and other GHG emissions, which are supplementary to the earlier assessment made in the summer of 1990. The workshop contributed to enhance studies built on the review of the Supporting Materials.

For IIASA, the workshop represented part of its research efforts. The Environmentally Compatible Energy Strategies (ECS) Project at IIASA is currently undertaking an evaluation and assessment of technologies and policy measures that could contribute toward postponement and mitigation of GHG emissions during the next hundred years. This research effort includes, *inter alia*, a review of recent and current studies in the field and an evaluation of various measures and technologies for reducing global energy-related carbon dioxide emissions in the long run. The workshop was a sequel to a previous IIASA workshop on "CO_2 Reduction and Removal: Measures for the Next Century", 19-21 March, 1991.[1]

The workshop immediately followed the IIASA International Workshop on "Costs, Impacts and Possible Benefits of CO_2 Mitigation", 28-30 September, 1992, jointly supported by the Central Research Institute of Electric Power Industry (CRIEPI) of Japan, IIASA, and Yale University in association with IPCC/EIS.

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[1] For a summary of the 1991 meeting, see Nakićenović, N. and John, A., 1991, CO_2 reduction and removal: Measures for the next century, *Energy* **16**(11/12): 1347-1377.

Opening Remarks

The workshop was opened by Peter de Jánosi, Director of IIASA. First, he expressed his pleasure that so many prominent participants attended the workshop and welcomed them to the Institute. He stressed that the subject of the workshop on energy-related GHG reduction and removal is an extremely important one and voiced his pleasure that the meeting was co-organized by the IPCC/Energy and Industry Subgroup (EIS) and IIASA. He also thanked the co-organizers of the workshop, Keiichi Yokobori, Cochair of IPCC/EIS, and Nebojša Nakićenović, Leader of the Environmentally Compatible Energy Strategies Project (ECS) at IIASA. Many other participants and IIASA's staff members helped with the organization of the meeting and de Jánosi thanked them as well for their contributions. Next, de Jánosi gave a short description of IIASA, its origins and current research agenda. He explained that the Institute was founded 20 years ago primarily at the initiative of the United States and the former Soviet Union and has member organizations in 15 countries.[2] He also indicated that global energy issues have been on IIASA's research agenda since its inception. Currently, the Institute is involved in three broad research areas including global environmental change, global economic and technological transitions, and related methodological questions. Energy-related sources of GHG emissions and mitigation and adaptation strategies constitute an important part of this overall thematic orientation of the Institute. De Jánosi explained that for this reason he is eagerly awaiting the outcome of the workshop. In his opinion, it would also serve, among other functions, to guide IIASA in focusing its future research activities in this area.

Currently, the Institute hosts about 65 researchers from different disciplines and countries with an annual budget of about 130 million Austrian Schillings. The ECS Project is carried out by one of the larger groups of the Institute, and the Director indicated that this topic of research will continue to have an important role at IIASA.

De Jánosi expressed his gratitude to the organizations helping to sponsor the workshop and thanked the Global Industrial & Social Progress Research Institute (GISPRI), Aeon Group Environment Foundation, Asahi Glass Foundation, and SECOM S&T Foundation for their financial support.

De Jánosi reiterated that the objective of the meeting is to provide scientific overview of technological options and related strategies for reduction of GHG emissions from the energy sector which was conveyed to the participants by the letter of invitation. This includes a number of subtopics represented in the individual sessions of the workshop, such as energy-efficiency improvements, energy conservation, renewable and other zero-carbon options, transition to energy sources with lower carbon intensity and carbon removal and storage. He also mentioned that IIASA is actively pursuing research on these topics and that in March, 1991 the "International Workshop on CO_2 Reduction and Removal" had also been held at IIASA. Thus, the IPCC/EIS workshop can be viewed as a sequel to the first workshop. In conclusion, de Jánosi mentioned that although the subject of the workshop is

[2] In 1990-1992 these were: Austria, Bulgaria, Canada, Czech and Slovak Federal Republic, Finland, France, Germany, Hungary, Italy, Japan, Netherlands, Poland, Russian Federation, Sweden, and United States of America.

technologically oriented and basically scientific in nature, it is of course closely tied to policy. The proceedings of this workshop, despite many controversies inherent in these issues, would hopefully turn out to be useful to policy-makers and politicians. This is consistent with the goal of the Institute in concentrating on the scientific level of analyses and communicating the results of the analyses to the policy-makers without wishing to interfere with the policy-making process. Further, he expressed his impression that, by looking at the list of participants, the organizers have managed to assemble most of the important groups working on technological GHG mitigation and that this is a major achievement in itself. De Jánosi explained that in the course of the meeting the Institute would also present its own activities in this area and he looked forward to the advice and suggestions of the participants, especially to learning more about their activities in this area. The Director then turned the meeting over to Yokobori and Nakićenović, the co-organizers of the meeting, for their introductory addresses.

Keiichi Yokobori introduced himself as the Cochair of the Energy and Industry Subgroup (EIS) of the IPCC and expressed his gratitude to IIASA for co-sponsoring the workshop together with the IPCC. He mentioned that one of the purposes of the workshop was to introduce the assessments made by EIS to a wider audience. He also mentioned that prior to this technology-oriented workshop, there was a similar workshop on "Costs, Impacts and Possible Benefits of CO_2 Mitigation" also held at IIASA and organized in association with the IPCC.

Next, Yokobori gave a brief background of the workshop. He recalled that IPCC was established jointly four years ago by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to assess the issues of climate change. The original structure of the IPCC consisted of three Working Groups (WG): WG I on scientific issues, WG II on impacts of climate change, and WG III on response options. WG III is subdivided into four subgroups, one of them being the EIS, cochaired by Yokobori and Xie Shaoxiong (see Figure 1).

Further, Yokobori explained the planned reorganization of the IPCC structure (Figure 1) which would be proposed for approval at the 8th Plenary Session of the IPCC in Harare, 11-13 November, 1992. The new structure leaves the old WG I intact, merges the old WG II and WG III into a new WG II[3] on environmental and socioeconomic impacts of climate change and on the response options to mitigate and adapt to climate change. A new WG III was established to deal with cross-cutting issues such as economic assessment and scenarios. The main objective of the reorganized IPCC structure is to complete the second assessment between late 1994 and early 1995.

EIS will continue its work under the new WG II as subgroup A, including further extensions of some of the ten thematic studies commissioned by EIS (Figure 2). Eight of these studies were presented by their respective lead authors later during the course of the meeting, and Yokobori summarized the major findings of these studies. He also mentioned the planned

[3] The new WG II is composed of four subgroups. Subgroup A deals with energy, industry, transportation, urban issues including related human settlements, air quality and health, and waste management and disposal.

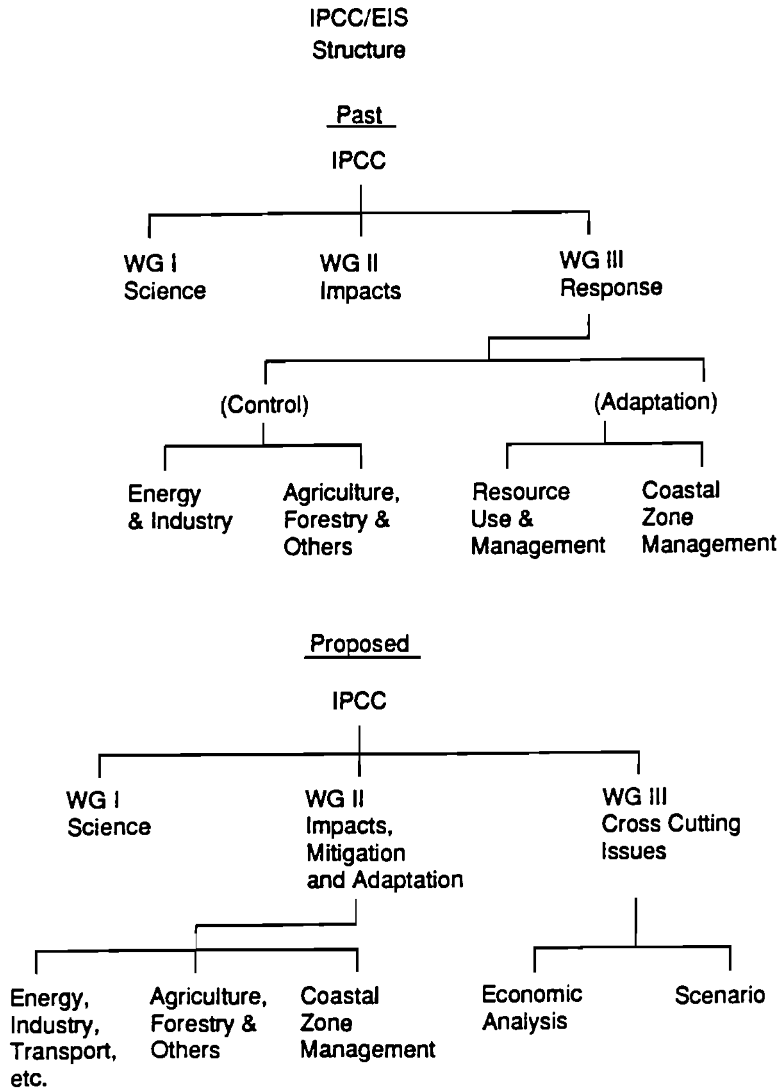

Figure 1. Past and revised IPCC structure. Source: Yokobori.

activities of EIS under the new IPCC structure including further thematic studies and completion of the technology inventory.

Nebojša Nakićenović also welcomed the distinguished group of participants to the workshop, reiterated the main objectives of the proceedings and discussions, and gave a brief description of IIASA's research activities in the area within the ECS Project.

Nakićenović summarized the results of the economics workshop held earlier in the same week, 28-30 September, 1992, at IIASA. He mentioned that one of the conclusions was the need to emphasize further the role of technology in the economic assessments of mitigation, adaption, and impacts of climate change. Technology is still treated in economics largely as an exogenous variable.

He stressed that the main objective of the ECS activities at IIASA is to determine the conditions and requirements for achieving further decarbonization of the global energy system. Central to this research is the analysis of GHG mitigation measures and options, which include reduction and removal technologies discussed at the workshop. An integral part of the

	Theme	Co-authors	IPCC/EIS-IIASA
1.	Comprehensive assessment of technological options	Prof. Y. Kaya *et al.* (Japan)	To be introduced
2.	Technology characterization inventory	Dr. E. Williams (USA)	To be introduced
3.	Methane emission reduction potential	Dr. K. Hogan (USA) Dr. K. Sato (Japan)	
4.	Biomass	Dr. A. Riedacker (France)	To be introduced
5.	Natural gas	Ms. C. Smyser (IEA)	
6.	Electricity end-use	Dr. M. Levine (USA)	To be introduced
7.	Factor analysis of regional and sectoral energy consumption and CO_2 emission	Dr. Y. Ogawa (Japan)	To be introduced
8.	Road transport	Prof. R. Pischinger (Austria)	To be introduced
9.	Impacts of response measures on global economy	Dr. M. Al-Sabban (Saudi Arabia)	Introduced in the IIASA Economics Workshop
10.	Country studies guidelines	Dr. O. Tirpak (USA)	Introduced in the LBL Workshop

Figure 2. Overview of thematic studies commissioned by IPCC/EIS and presented at the meeting. Source: Yokobori.

research activities is the technology inventory and associated database (CO2DB) that is operational at IIASA. The inventory is used for the assessment of reduction and removal technologies together with the global reference baseline scenario called "dynamics-as-usual" that incorporates historical rates of technological change for the coming decades. Additional measures are analyzed to determine mitigation potentials and costs with respect to this scenario. In particular, the technologies analyzed include efficiency improvements in energy end-use and conservation measures. Nakićenović mentioned that the IIASA results indicate a large potential for reducing energy demand and GHG emissions by these measures. This is especially attractive in the medium-term over the next decade or two before more fundamental changes in the energy system could lead to a further shift toward low carbon intensity. Other technologies considered include the enhanced use of cleaner fossil energy resources such as natural gas that result in both lower local and regional pollution as well as in substantially lower carbon dioxide emissions. However, more stringent control of methane emissions would also be required. Another option for using clean fossil fuels includes carbon removal prior to combustion. Candidate technologies are steam-reforming and separation of carbon dioxide from synthesis gas. The other alternative is to scrub carbon dioxide after combustion. Long-term storage of separated carbon is required in both cases. The next group of technologies analyzed includes a complete shift away from carbon-based fuels in the long-term future towards genuine zero-carbon options. These include nuclear energy, solar power and other renewables. Whereas nuclear energy faces serious public opposition and technical problems today, it still holds the promise of helping to reduce carbon dioxide emissions in the long run. In contrast, solar and renewables are still quite costly options, but it can be expected that their costs would decrease sufficiently to make them more attractive in the future. Renewable use of biomass can also be a zero-carbon option provided that the released carbon is reabsorbed by new plants in a sustainable manner.

Furthermore, Nakićenović also pointed out that none of these options by themselves can be a panacea, but most likely all of them will have to be exploited in order to achieve a sufficient degree of decarbonization that would offset future increases in energy demand as the less industrialized countries continue to develop. Thus, all of the options will have to make a contribution, further emphasizing the need for analysis of cross-cutting issues and integration. The historical rate of decarbonization is humble at 0.3%/yr when measured as the amount of carbon emitted per average unit of energy consumed (Figure 3). Together with the long-term decrease in the energy intensiveness of the industrial societies, the carbon intensity of economic activities in most of the industrialized countries has decreased on the average of about 1.3 percent per year, while the economic output increased by about 3 percent per year. The gap of about 1.7 percent per year is the rate at which energy-related carbon dioxide emissions have increased during the last century and identifies the degree to which future decarbonization measures are required if emissions are to be stabilized during the next century.

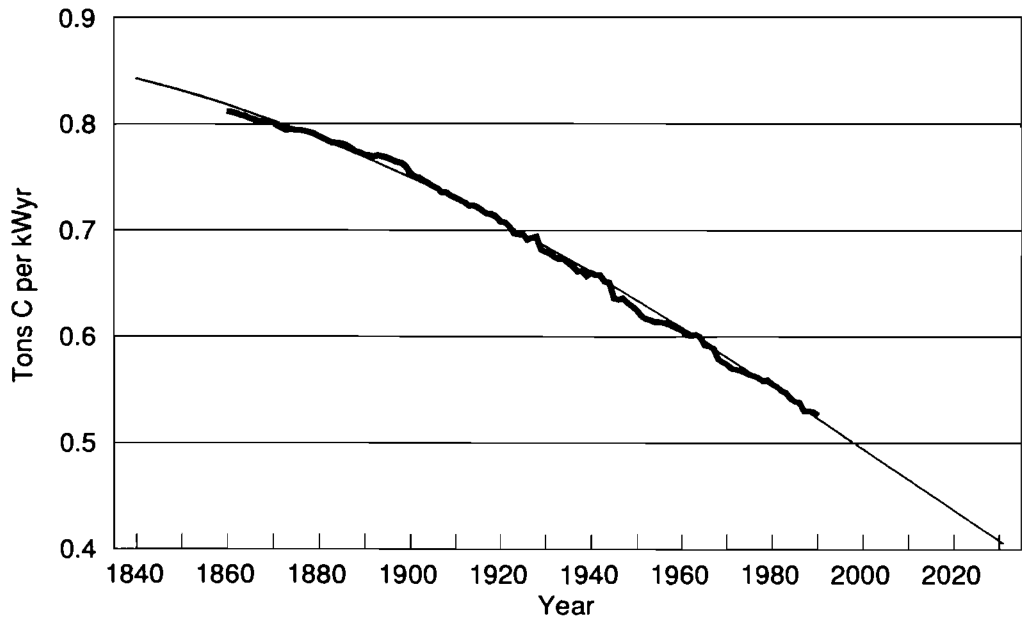

Figure 3. Decarbonization of global primary energy supply, in tons C per kWyr. Source: Nakićenović.

Session 1 Energy End-Use and Conservation

Energy-related carbon emissions in 1990 amounted to some 5.5 Gigatons (Gt) of carbon (excluding chemical feedstock uses of energy and carbon emissions from biomass use). About 3 Gt of these emissions originated from direct uses of fossil fuels by end users, and some 2.5 Gt from conversion of primary to secondary and final energy by the energy sector itself. Energy is not an end in itself. Therefore, all energy-related carbon emissions can be attributed to some end-uses of energy to supply the services required by economic activities and society at large, regardless of whether or not the emissions originate at the level of energy conversion (refineries, power plants) or at the level of final consumption (for industrial, residential and transport uses of energy). From such a perspective, any discussion of technological options for GHG reduction and removal has to start by considering energy end-use and in particular the potential for efficiency improvements and conservation. There are yet other reasons to pay particular attention to energy end-use: first, improving end-use efficiency, i.e., lowering energy demand while maintaining the level of services delivered to the consumer is a strategy of *emission avoidance*, which is clearly preferable over strategies of emission reduction or removal via technological options. A second reason is the vast potential for efficiency improvements which has been identified by many studies analyzing the technological and thermodynamic performances of energy end-use conversion processes such as industrial furnaces, heating systems, cars, etc. From a thermodynamic viewpoint perhaps only between 5 to 10 percent of the energy contained in the primary energy of coal, crude oil, gas and other energy forms ends up as a useful service delivered to the final consumer, indicating a large, although primarily, a theoretical potential, for efficiency improvements.

The session was chaired by Yoichi Kaya. Eight papers illustrated various aspects of GHG mitigation options from the perspective of energy end-use. Technological options for improved efficiency and energy conservation were described, reasons for the observed large differences in energy efficiency between sectors and countries were discussed, and a number of constraints (economic, informational and institutional) for efficiency improvements with important policy implications were highlighted. Whereas there was wide consensus on the significant potential of energy efficiency improvements in GHG mitigation strategies, there was less agreement on the speed, extent and likelihood that such potentials will be realized more fully in view of social, institutional and economic constraints. Therefore, other technological options in the domains of energy supply and carbon sequestration would also have to be considered in any comprehensive GHG mitigation strategy. These were discussed in the following sessions on renewable and zero-carbon options, and on clean fossils, carbon removal and storage.

Ogawa opened the session with a decompositional analysis of influencing factors of CO_2 emissions. Total emissions and their evolution are analyzed along the so-called "Kaya-identity", where emissions are the product of population size, per capita gross domestic product (GDP), the energy intensity of economic activities (primary energy consumption per GDP), and the carbon intensity of energy supply (the fuel switching factor in Ogawa's terminology). The analysis was performed for the world total, for three world regions (including the industrialized countries, the reforming economies of Eastern Europe and the former USSR, and developing countries, cf. Figure 4), as well as for selected individual countries. Ogawa showed that the contribution of these four factors to the evolution of emissions are quite different in each region and that emission profiles appear to reflect distinctive development paths pursued by different economies and societies. The analysis further showed that throughout all OECD countries carbon dioxide emissions were reduced in the industrial, residential and commercial sector primarily by energy efficiency improvements and conservation measures (lower energy intensity of economic activities) between 1973 and 1988. In the power generation sector, fuel switching was the major contributor to the reduction of carbon dioxide emissions. An extreme case is the French energy system which reduced its carbon dioxide emissions by more than 20 percent between 1979 and 1988 by increasing nuclear power. Overall, the energy-related CO_2 emissions for the OECD region increased only modestly over the 1973 to 1988 period analyzed, even for an economy that grew in output terms by close to 25 percent. This is mainly the result of a nearly 20 percent decline in the energy intensity of GDP as well as some modest (5 percent) decline in the carbon intensity of the energy supply mix. Conversely, the economic growth in developing countries was a powerful agent for changes in emissions as both reductions in the energy intensity of economic activities and carbon intensity of the energy system were comparatively modest.

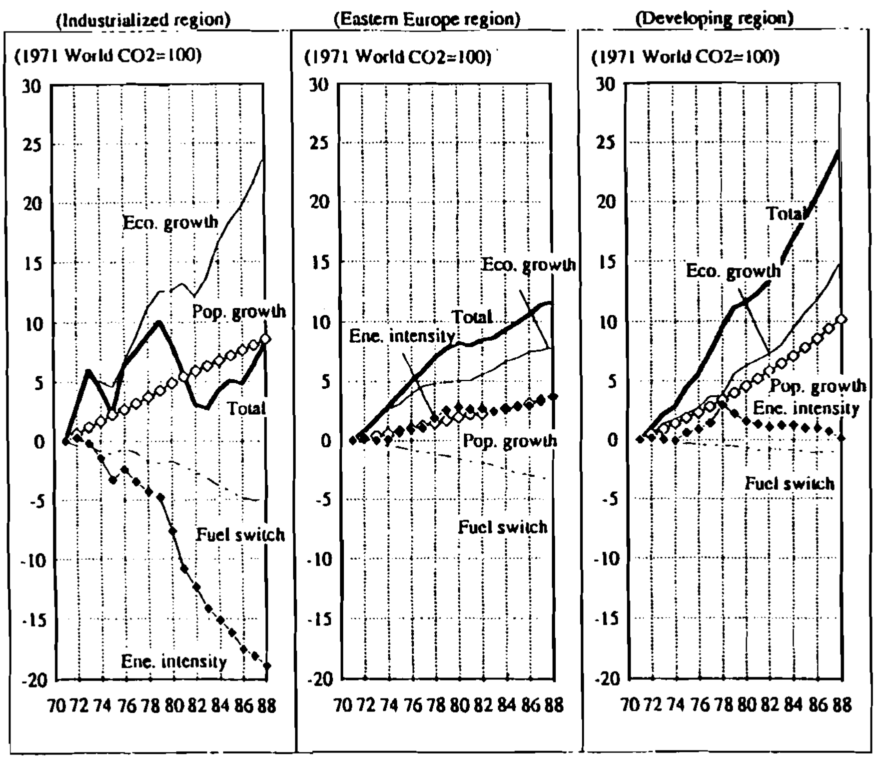

Figure 4. Evolution of factors influencing energy-related CO_2 emissions for three world regions. Source: Ogawa.

Levine stressed the importance of efficient end-use devices from the perspective of world electricity generation growth which has increased more than two-fold since 1970: from 5,000 Terawatt hours (TWhr) to over 11,000 TWhr in 1989. On a global perspective, industry consumes about 50 percent of all electricity and buildings about 45 percent; Levine called the

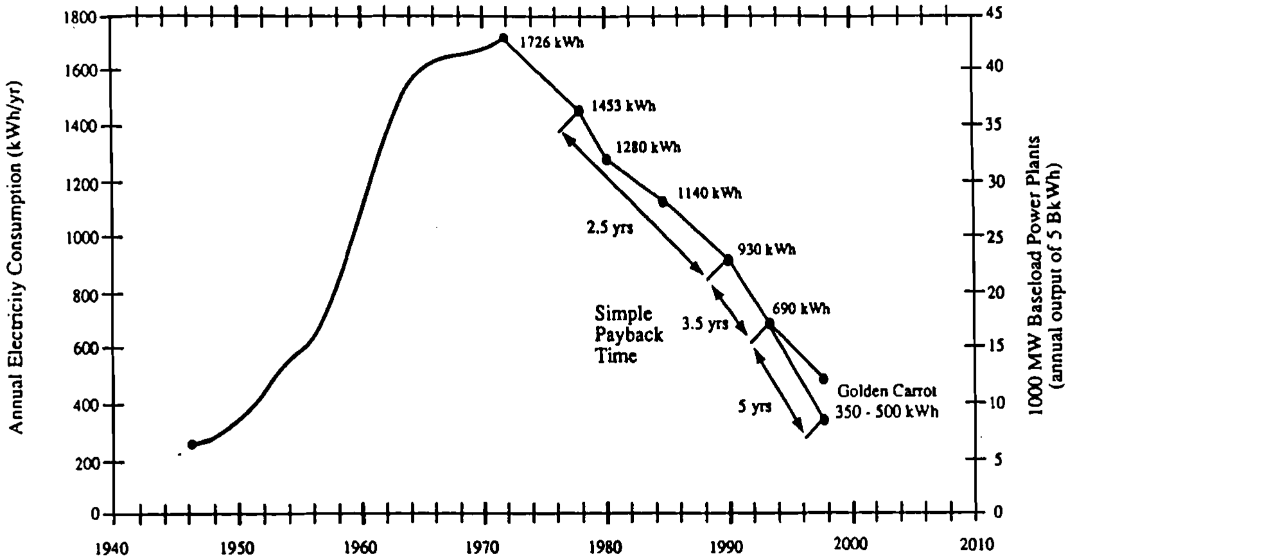

Figure 5. Annual electricity consumption for average US refrigerators and corresponding baseload capacity requirements. Source: Levine.

latter the "forgotten sector". Levine also identified a variety of existing technologies that are considerably more efficient than the average technological vintages in use. For example, the average new refrigerator purchased in the USA uses half as much electricity as a comparable model purchased 15 years ago. This reduction in the average electricity consumption of refrigerators in the USA corresponds to a total baseload power plant capacity of some 20 Gigawatt electric (GWe) (Figure 5). Further improvements are being expected, which could bring the total electricity demand reduction (compared to a case with no efficiency improvements) to up to 35 GWe. Other examples abound, according to Levine. A typical new air conditioner uses one-third less electricity to produce the same cooling as a model purchased in 1975. Heat pumps that replaced electric resistance heating cut electricity use, on the average, in half. Further possibilities for energy savings exist in the lighting sector, where fluorescent lamps with electronic ballasts and specular reflectors can reduce electricity use by more than 50 percent. In the USA, 60 percent of industrial electricity consumption is consumed by motors. Major efficiency improvements (between 15 and 40 percent) can be attained by variable speed drives rather than by improving the motor itself (1 to 4 percent possible efficiency gain dependent on the motor size). Moreover, changes in entire industrial processes, such as the replacement of several process steps by a single new step, might have a higher energy saving potential than specific technologies alone. Major problems for introducing more efficient technologies are seen in the much higher discount rates of consumers compared to those of electricity suppliers. There has been good experience in the USA with regard to appliance efficiency standards mandating certain minimum efficiency levels for residential appliances. It is estimated that such standards result in energy savings of one quad (quadrillion) BTU (33 GWyr) per year in the USA (corresponding to around 7 billion US$ per year). A number of large utilities in the USA are paying a portion of the cost of more efficient end-use appliances (up to two billion US$) to overcome the problem with different discount rates.

Pischinger gave an overview of GHG emissions in the transport sector, scenarios for their future evolution, and technological options for their reduction. Carbon dioxide emissions from the transport sector in 1988 amounted to about 1.2 Gt of carbon (about 20 percent of total energy-related carbon emissions). In a "trend" scenario (i.e., without countermeasures), carbon emissions could be about 60 percent higher by the year 2005 than in 1988. Options for reducing transport-related GHG emissions include vehicle efficiency improvements, shifting to lower carbon content fuels, modal split changes to less energy intensive transport modes, and reducing transport demand. There exist a variety of transportation policy options ranging from coordinated planning measures for reducing vehicle use, including mandatory measures such as regular vehicle maintenance, standards for specific fuel consumption, or subsidies for cleaner alternative automotive fuels. The study presented two scenarios for different modes of the transport sector -- a "trend" scenario and a scenario in which a number of emission reduction measures are applied, leading to an emission reduction of 0.6 Gt C (30%) compared to the "trend" scenario (Figure 6). Despite the large number of mitigation options identified in the study, Pischinger was skeptical whether global transportation carbon dioxide emissions can be reduced at all until the year 2005. On the contrary, they are expected to increase (close to 2 Gt carbon), and policy measures are primarily seen to reduce the rate of emission growth over the next 15 years.

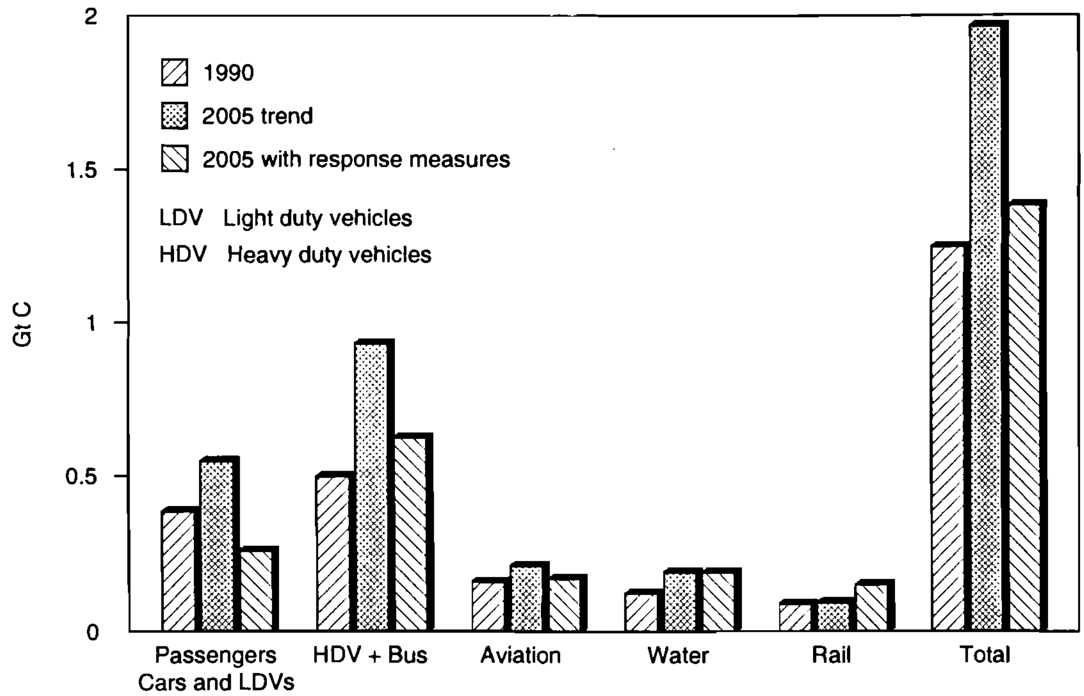

Figure 6. Carbon emissions in the transport sector by mode, 1988, and scenarios for 2005 with and without mitigation measures. Source: Pischinger.

Michaelis, reporting on a recent IEA study, recalled that transport operations were a major source of GHG emissions besides power generation and space heating. The study analyzed different transport modes as well as various technological alternatives, particularly for road transport vehicles. According to a life-cycle analysis performed (Figure 7), road vehicles contribute to all of the main GHGs with most of the emissions originating from vehicle use itself. Emissions of alternative road transport technologies, such as electric vehicles, are concentrated upstream the energy chain. The analysis also showed that 10 to 20 percent of the global warming impact of a typical European passenger car is due to emissions of CFCs and another 10 percent due to engine emissions other than carbon dioxide.

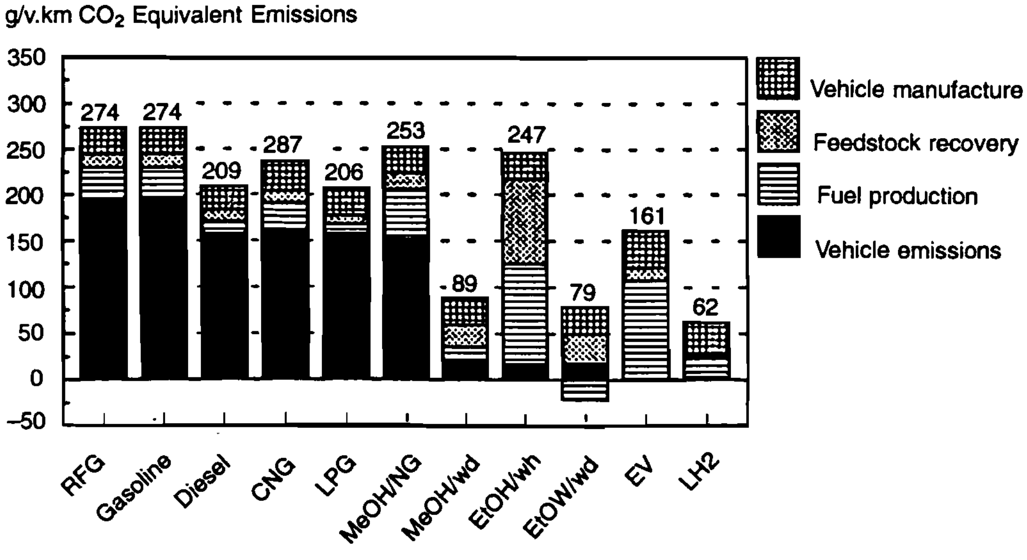

Figure 7. Full fuel cycle greenhouse gas emissions of light duty vehicles (per vehicle-km) in OECD Europe (base case in 2000). Source: Michaelis.

Kononov presented an analysis of energy efficiency of an economy in transition: the former USSR. While in 1991 the Gross Domestic Product dropped by 11 percent, electricity consumption dropped by only 2 percent and primary energy consumption by 1.6 percent. These low, short-term elasticities are in addition to the already much higher energy intensity of the Russian economy (up to a factor of three higher than in Western Europe). According to Kononov, the reasons for the higher energy intensity are outdated technologies, old economical structure and an inefficient economic mechanism. He showed a dramatic example for badly maintained technology; while official data indicates leakages in the natural gas supply system of 1 to 2 percent, his own studies suggest much higher values, which could possibly be as high as 4 to 7 percent (up to 2.5 percent for pipelines). Specific capital investments in gas production and distribution are about 300 rubles (1990) per 1,000 cubic meters (350 rubles/Wyr), which is by several factors cheaper than investments into reduction of leakages. Kononov presented results of an assessment of the energy conservation potential in the former USSR (Figure 8). Between 460 to 560 GWyr/yr (500 to 600 million tons coal equivalent), or nearly 60 percent of current (1992) primary energy consumption, are estimated as energy conservation potential through structural and technological changes and improvements in the economic mechanism. An ambitious conservation policy targets the realization of demand reduction as much as 740 GWyr/yr (or 57 percent) by the year 2010, which could reduce Russia's energy-related carbon emissions by some 410 million tons.

Bashmakov estimates that the total reduction of energy-related carbon dioxide emissions in Russia was in the range of 10 to 15 percent in 1992 (compared to 1990) due to serious economic crises and related reduction in energy demand. The corresponding "abatement costs" are in the order of almost 1 percent of GDP per percent of carbon dioxide emissions avoided. Russia's energy intensity (energy consumption per unit of GDP) is about 2.5 times higher compared to Western Europe, being particularly high in the industrial sector. When disaggregated, the gap consists of 45 percent higher material intensity, 35 percent less efficient technological process structure in industry, and the remaining 20 percent due to

Energy Conservation in Russia

	million tce
Potential (1992)	500-600
structural	120-150
technological	300-350
economic mechanism	80-120

Energy Policy Targets (million tce)

	1992	1997	2000	2010
Total conservation	20-25	200	450	800
% consumption	2	16	36	57
By structural change		100	200	350
By technologies		100	250	450

Conservation-related CO_2 Emission Reduction

1992	14 mln t C
1997	120
2000	240
2010	410

Figure 8. Energy conservation potential estimated for Russia and policy targets up to 2010 (in Mtce). Source: Kononov.

lower efficient technologies and low quality maintenance and management. Bashmakov dubbed Russia as the "Saudi Arabia of energy savings": According to the estimates of the Moscow Center for Energy Efficiency, about 630 GWyr/yr (20 EJ/yr) primary could be saved by the year 2005 with investment costs below 300 to 400 rubles (1990) per kWyr, i.e., at costs lower than the expansion of natural gas supply (Figure 9). He stressed the resulting low investment costs of 200 rubles (1990) per ton of carbon avoided, with a total reduction potential of 275 million tons of carbon emissions. Bashmakov highlighted the multiple benefits of such an energy efficiency strategy, including: a 34 percent reduction of primary energy consumption, reduced energy costs by US$ 40 to 60 billion by the year 2005, a reduction of new power plant capacity expansion by 70 GWe, 5 times more jobs per dollar invested in energy efficiency than per dollar invested in energy supply and a reduction of atmospheric pollution between 15 (ash) to 37 percent (carbon dioxide, methane and nitrogen oxides).

Gupta discussed energy end-use efficiency from the perspective of developing countries in analyzing energy intensity and efficiency in several sectors in India and China. The economy of both countries is primarily based on coal, which accounts for nearly 61 percent of the commercial primary energy use in India and 76 percent in China, respectively. In India, biomass energy still contributes to around 40 percent of total energy consumption, which

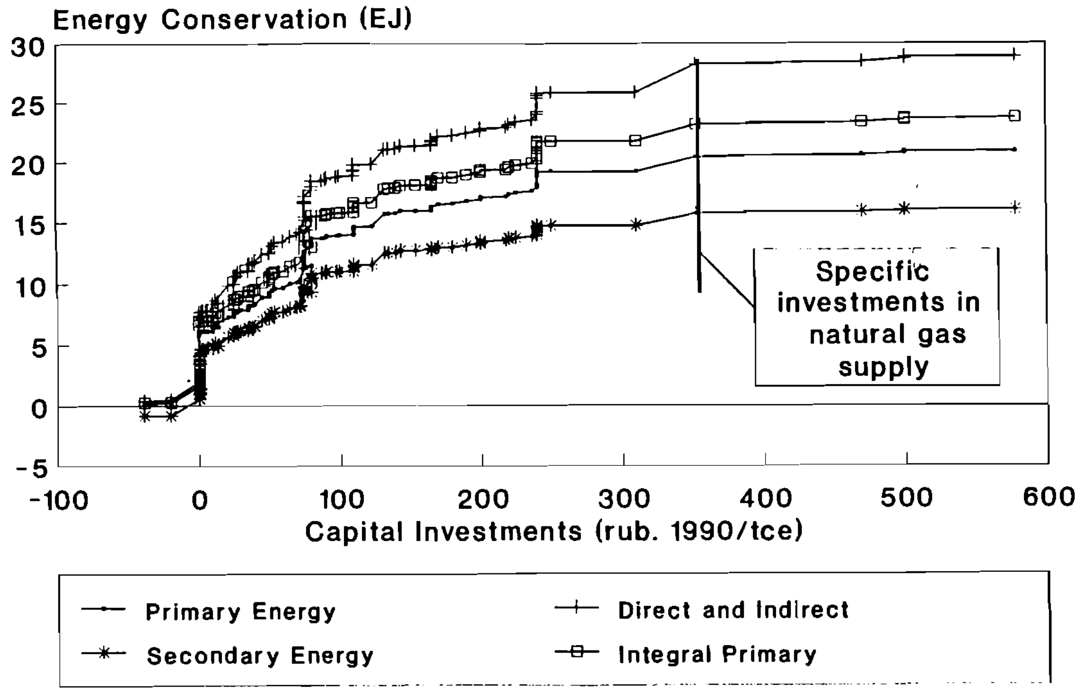

Figure 9. Supply curve of conserved energy for the former USSR. Source: Bashmakov.

translates into 170 GWyr per year (120 mtoe). The share of traditional renewable and biomass energy can even rise to 90 percent in rural areas. In India, 60 percent of the commercial energy used is consumed in the industrial sector. The transport sector accounts for 23 percent of commercial primary energy use, the residential sector for 11 percent and agriculture for 4 percent. While specific energy consumption in industrial and transport sectors is decreasing, the total energy use increases, due to economic growth and the shift from traditional commercial fuels in the residential and agricultural sectors. Compared to OECD countries, both India and China have quite inefficient technologies throughout all sectors. Examples highlighted by Gupta included: one-third of all kerosene consumed in the Indian residential sector is used for lighting purposes. The efficiency of kerosene lamps is 0.7 lumen per watt compared to 11 lumen per watt of incandescent bulbs and 55 lumens per watt of fluorescent lamps. The average Indian refrigerator consumes 60 percent more energy than corresponding appliances in OECD countries and the average air conditioner between 25 and 50 percent. Industrial process efficiencies and energy conversion processes in China and India are also substantially lower than the OECD average (Figure 10). The thermal efficiency of the industrial process heat production in India is only 40 percent if based on coal, in comparison to more than 80 percent in OECD countries; somewhat higher efficiencies between 50 and 60 percent are achieved in China. Compared to OECD countries, the Indian steel industry consumes about 60 percent more energy for the same product and the production of cement clinker is between 35 and 40 percent more energy intensive. Chinese industry is even more energy intensive. Better prospects are provided in the transport sector. Between 1960 and 1985, while rail movements increased by 240 percent and 310 percent in terms of ton and passenger kilometers transported, energy consumption decreased by 33 percent. This is primarily due to the replacement of steam locomotives by diesel and electric traction systems (steam propulsion decreased from 90 percent in 1960 to 1.8 percent in 1985). Besides the use of outdated and inefficient equipment, both India and China face a lack of economies of scale. For example, 70 to 80 percent of Chinese cement clinker is produced in small rotary kilns which use 30 percent more energy than large plants. Moreover, low energy prices are an obstacle for implementing new energy efficient technologies. Gupta mentioned that additional obstacles for efficiency improvements, particularly in India, include capital shortages, scarcity of foreign exchange, large protected domestic markets, labor relations and lack of skilled personnel.

Energy Requirements of Energy Intensive Products (toe/tonne)

Product	China	India
Steel (0.56)	0.95	0.90
Cement clinker (0.08)	0.13	0.11
Thermal power generation (goe/kWh) (240)	278	298

Figure 10. Energy requirements for industrial processes and power generation in China and India, and comparison with OECD average (in parenthesis). Source: Gupta.

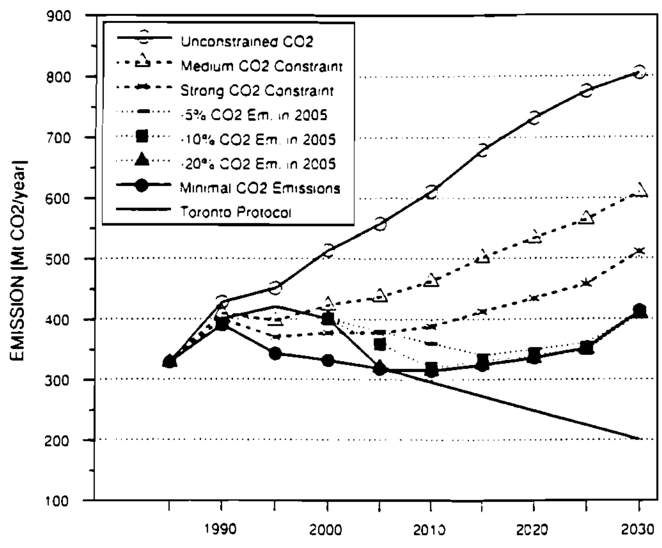

Figure 11. Scenarios of energy-related CO_2 emissions in Italy. Source: Pinchera.

Pinchera showed preliminary results from the MARKAL linear programming model as applied to the Italian energy sector in analyzing future scenarios of CO_2 emissions and policy measures for their reduction. He stressed the low energy and electricity intensity of the Italian economy compared to other OECD countries. At the sectoral level, specific energy consumption in the transport sector is also lower than in most OECD countries. A somewhat different situation was identified in the Italian steel industry, where energy consumption of electric arc furnaces is about 50 percent higher. In the model runs reported by Pinchera, the energy-related CO_2 emissions are projected to increase significantly up to the year 2030, more than doubling 1985 levels (Figure 11). The model run with minimum emissions indicates the feasibility of halving the emissions in 2030. This corresponds to a stabilization of 1990 emission levels, but falls short of the Toronto target.

Discussion

Commenting on the transportation study presented by Pischinger, Yokobori pointed out that current available statistical data is not necessarily tuned to the analytical needs, for lack of consistency or comparability. Michaelis voiced concerns that in view of scientific uncertainties point estimates of the comparative environmental impacts of alternative transportation systems presented by Pischinger might be misleading. Gilli seconded that the comparisons between petroleum fueled and electric road vehicles should rather consider oil-fired electricity instead of a coal-based system.

Blok stressed that industrial energy consumption should be a major objective for efficiency improvement and conservation measures. According to a Dutch study, energy savings between 20 and 40 percent are achievable in many countries. Levine agreed, reporting about successful programs carried out in the US industry. For example, the newest utility demand-side programs showed that the lowest cost per unit energy saved exist in the US industry sector.

Kaya mentioned the necessity of investments by developed countries in developing countries in order to reduce carbon dioxide emissions. He also stressed the importance of studying lifestyle induced carbon dioxide emissions by mentioning as examples the shift from medium-sized to more powerful cars, or the increase of the average size of TV sets towards high resolution TVs. In both cases changing consumer preferences and lifestyles result in increases in energy demand and the resulting emissions.

Session 2 Renewables and Zero-Carbon Options

Most scenarios indicate that global energy demand and its resulting emissions are likely to increase even in those scenarios that include vigorous efficiency improvements. These increases will come primarily from developing countries as a result of population growth and further social and economic development. Hence, supply side measures should also be considered in comprehensive mitigation strategies. Two groups of technological options are available for reducing carbon emissions from energy use: using the natural carbon cycle by replacing the current fossil fuel use with biomass harvested on a sustainable basis (where carbon emissions from fuel use are sequestered by biomass growth of a subsequent rotation cycle), or using zero-carbon energy options such as renewable energies (hydroelectricity, wind and solar energy) and nuclear energy. Common to all of them, with the exception of hydroelectricity and traditional biomass use, is their current relatively modest contribution to the world energy balance, which indicates that in all likelihood it will take many decades for massive market penetration. In addition, further work is needed to demonstrate the technological feasibility and economic viability of the options proposed, or to appropriately respond to concerns voiced on safety and social acceptability. The session was chaired by Meyer Steinberg and included the presentation of seven papers followed by a discussion session.

Hall opened the session, stressing that biomass fuel, if used efficiently, is a low-cost option for carbon substitution and sequestration. Biomass is currently the primary energy source for more than 75 percent of the world population living in developing countries: biomass represents 95 percent of total energy use in Nepal, 80 percent in Kenya, and 30 percent in China and Brazil. Unfortunately, it is used inefficiently in most developing countries. Biomass fuels are usually used in a carbon dioxide neutral way in developed countries such as the USA, Austria, Sweden and Finland with shares of 4, 10, 14 and 17 percent of total energy consumed, respectively. Moreover, energy from biomass can be obtained in many forms, i.e., liquid, electricity or heat. In the middle of the next century, biomass and other renewable sources of energy might contribute over three-fifths of the world's electricity market and two-fifths of the market for fuels used directly, according to a renewable-intensive global energy scenario (RIGES) developed by Johansson *et al.*, and presented by Hall. In the scenario, carbon dioxide emissions could decrease to some 4.2 Gt of carbon by the year 2050, assuming large-scale use of biomass energy from residues, plantations, urban refuse, dung, lumber and pulpwood residues, and forests and cereal production. The required technologies are, to a large extent, existing or would become available in the medium-term. According to Hall, biomass plantations are possible without using fertilizers (except for initial planting) and pesticides. In addition, he argued that the efficient use of biomass energy (electricity and ethanol fuel) is more effective in decreasing atmospheric carbon dioxide than sequestering carbon in trees (Figure 12). Hall stressed that, currently, the most economic use of biomass would be for electricity production. During the last 10 years, 9,000 MWe of biomass-fired electricity generation capacity have been installed in the USA, using mostly agricultural and forestry residues. These facilities meet the stringent air pollution requirements of California. Even hydroelectric companies in Brazil show increasing interest in biomass electricity as a low cost alternative for hydro power. Biomass can also be an interesting option for district heating, as realized by the 15 MWth biomass heating plant near Upsala, Sweden, providing 85 percent of the heat requirement of a settlement with 5,000 inhabitants.

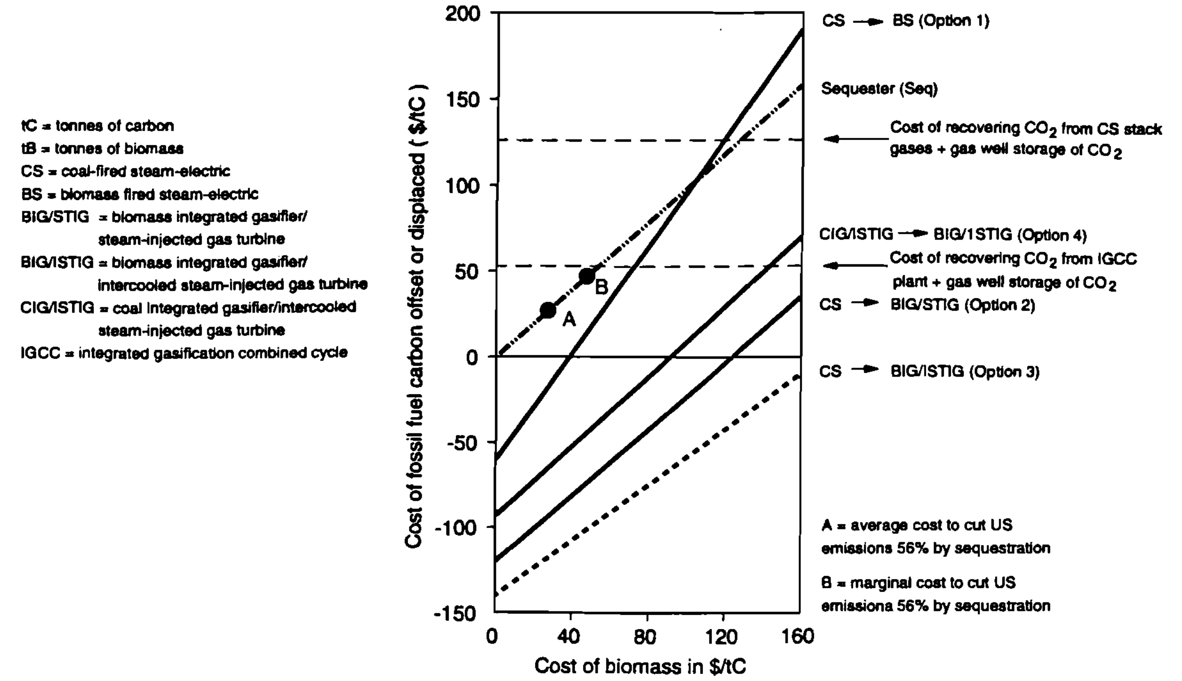

Figure 12. Substituting biomass for coal in power generation vs. carbon sequestering in forests as a function of relative costs of biomass vs. fossil fuel. Source: Hall.

Marland presented the results of a model assessing the effectiveness of two competing options for biomass use, i.e., storing carbon in trees or using forest land to produce biomass as an energy source (Figure 13).[4] The most effective strategy for carbon management depends on the current status of the land, the expected growth rate of the forest, the efficiency with which the forest harvest will be used and the time dimension. While forests with high standing biomass and low expected growth rates should be maintained, areas with low standing crop and modest expected growth rates should be covered with new forests in order to accumulate carbon, according to Marland. Planting trees with the long-term objective of carbon storage will be effective only where productivity is low and where harvest is very expensive. However, where higher productivity can be anticipated, net carbon dioxide emissions can be minimized by using the biomass for fossil fuel substitution. Generally, it can be concluded that simply planting trees to store carbon may only be a temporary solution and that planting with the intent of efficient use is the most effective choice in many areas. In all cases, time is of great importance, because given a sufficiently long planning perspective and enough harvest cycles, any small gains per cycle would translate into large absolute differences over the time period characteristic of the global carbon cycle.

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[4] Note that in the hachured region, growth after 50 years cannot replace the carbon stored in the original forest, even when credit is given (as done in Figure 13) for fossil fuel displaced by burning the harvested wood.

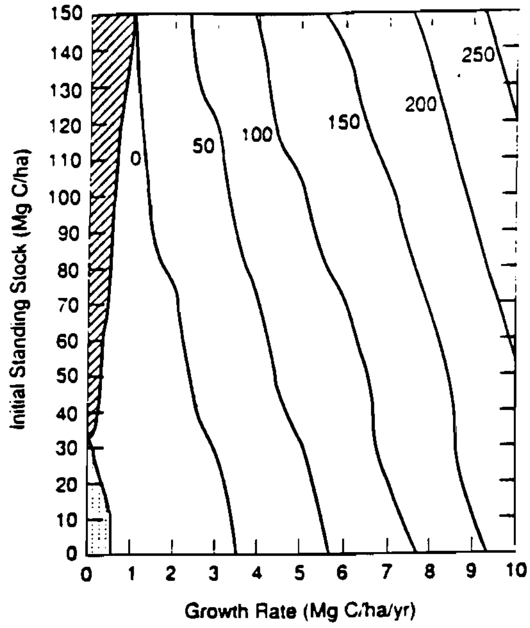

Figure 13. Excess carbon sequestering after 50 years for forest harvest and biomass use over carbon storage in standing stocks (hachured region explained in text), in Mg C ha^{-1} contours. Source: Marland.

Moreira discussed the energy situation in Brazil with particular emphasis on renewable energies. He emphasized that non-commercial use of wood is steadily decreasing while commercial use of both wood and sugarcane are rising (Figure 14). He stressed that Brazil's carbon dioxide problem is primarily related to deforestation. However, there also exists unsustainable use of biomass, such as charcoal production. Less than 20 percent of charcoal production is renewable. He mentioned the increasing significance of biomass fuels outside Brazil, such as the ethanol program in the USA, Paraguay and Argentina. Currently, about 25 percent of all transportation energy in Brazil is derived from ethanol, roughly equal to the share of gasoline; the other 50 percent is based on diesel fuel. The energy output from the alcohol fuel program could still be increased by also using the green top and leaves of the sugar cane plant in addition to the millable stem. In doing so, the yield of currently 80 liters of ethanol and 130 kg of dry bagasse per ton of sugarcane could be increased by another 100 kg of dry biomass, which could be used for energy purposes either for generation of heat or, via a gasification route, converted to electricity.

Sipilä presented a case study of Finland with the scope of reducing carbon dioxide emissions by 20 percent in 2010 and by 40 percent in 2025 compared to the 1988 level. The base scenario projects a 65 percent increase in carbon dioxide emissions from 15 million tons of carbon (54 Mt of carbon dioxide) in 1988 to 24 million tons (89 Mt of carbon dioxide) in 2025 (Figure 15). An important role in the reduction strategy is foreseen for cogeneration plants (CHP) to replace conventional separate electricity generation plants fired with fossil fuels. Sipilä stressed the higher power to steam ratio in CHP, which gives essential economic power production capacity. Biomass fuels are also forecasted to increase from the current level of 17 percent of Finnish primary energy consumption (half of which is derived from the pulp and paper industry). However, in competing with fossil fuels, biomass fuel prices are

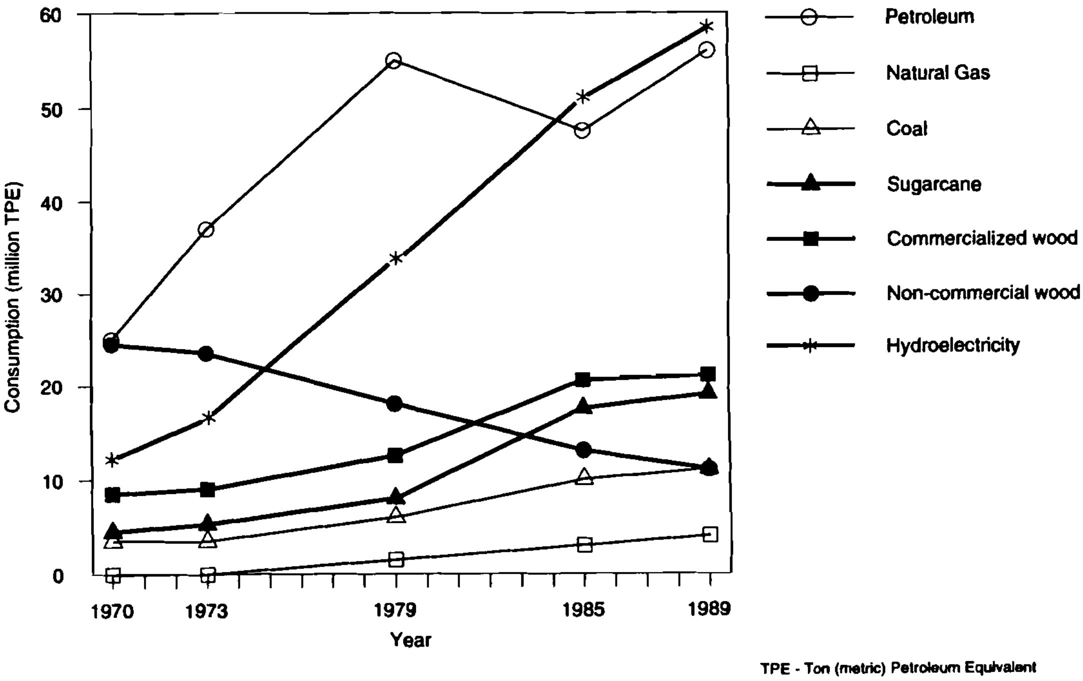

Figure 14. Structure of primary energy consumption in Brazil, 1970-1989. Source: Moreira.

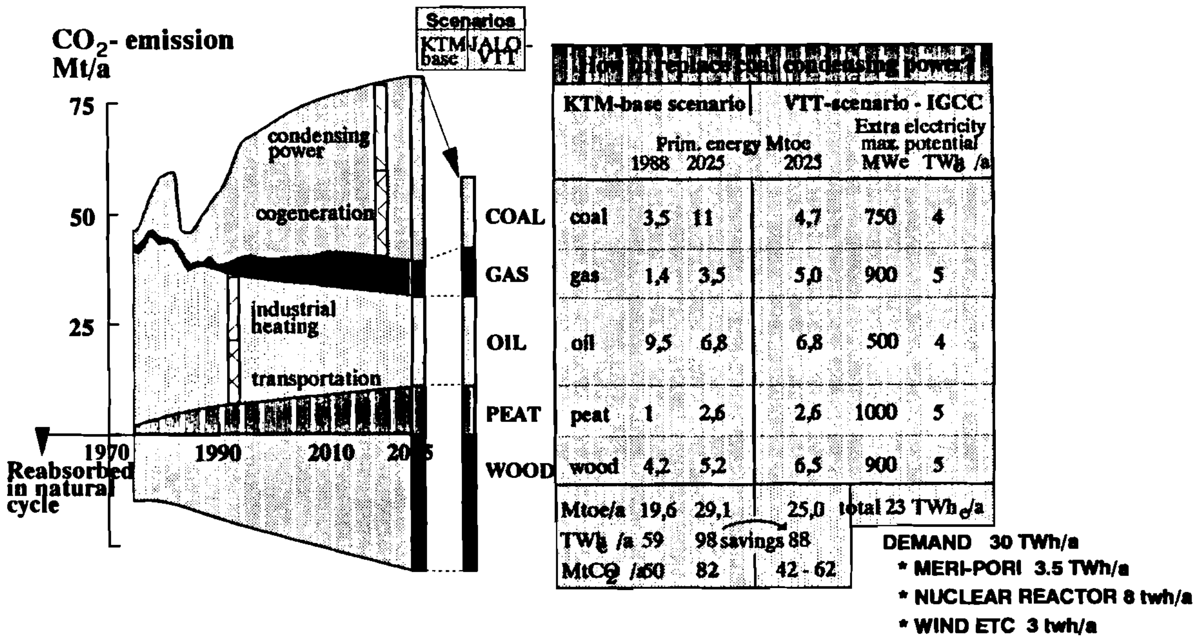

Figure 15. Scenarios of energy-related CO_2 emissions in Finland and their reduction based on enhanced cogeneration and biomass use. Source: Sipilä.

seen as the limiting factor, rather than resource scarcity. Consequently, one possible strategy could involve the co-firing of biomass with coal in fluidized bed combustion boilers, in combined heat and power plants with future IGCC technology, diesel power plants fired with bio-oils and enhanced biomass use as fuel components in the transport sector, e.g., in the form of biodiesel, ETBE or MTBE.

Riedacker stressed, in his presentation, the comparatively larger potential of biomass compared to other forms of renewable energy throughout the world (Figure 16). Riedacker also stressed the necessity for reducing bush fires as a powerful measure for decreasing GHG emissions. This is because a variety of other GHGs are being formed, such as carbon monoxide with a global warming potential five times higher than carbon dioxide. Large

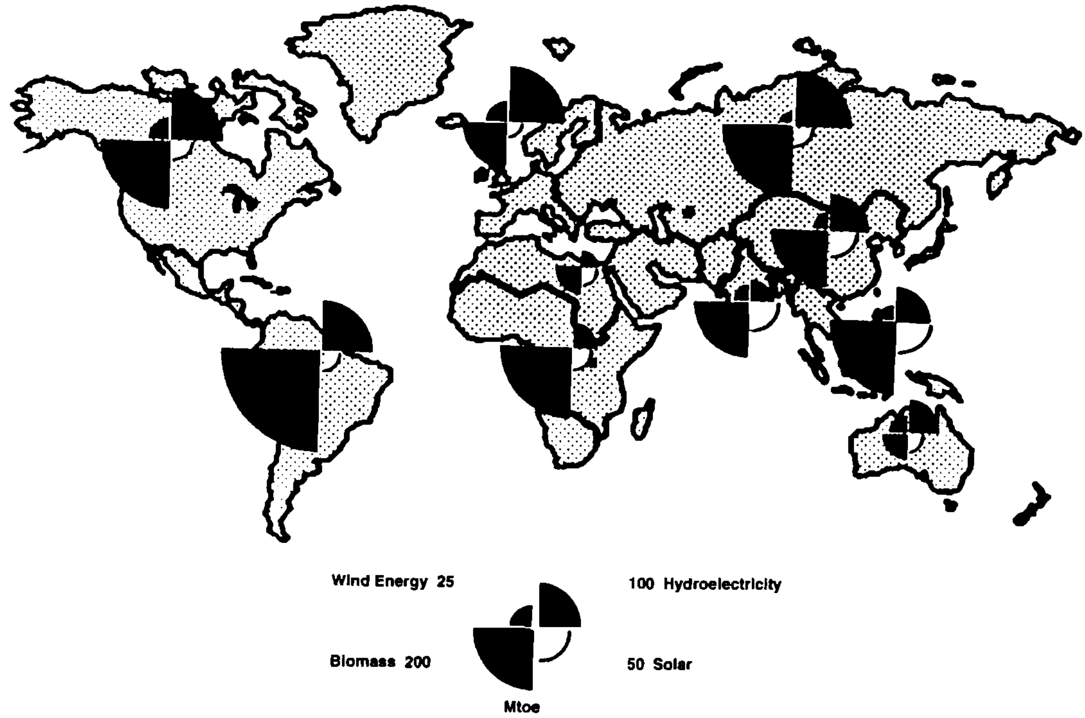

Figure 16. Estimates of renewable energy potentials for major world regions indicating the largest supply potential for biomass. Source: Riedacker (after Dessus *et al.*).

amounts of carbon monoxide and methane are also being released during charcoal production. Consequently, there is a need for modern technologies that convert biomass into non-solid fuels and reduce carbon dioxide emissions drastically. Riedacker also advocated the establishment of a global "Eco-bioenergy Network" (ecologically, economically and globally sound or sounder ways of production and conversion of biomass into energy) to develop an inventory of institutional and technical requirements for implementation of biomass programs and to further advance the exchange of information among different groups.

Sanchez-Sierra emphasized in his presentation that in developed countries most of the carbon dioxide is generated in the energy sector. In the South, however, about two-thirds of carbon dioxide emissions are due to poverty, i.e., deforestation for providing agricultural land. In the Latin American and Caribbean regions, the energy sector generates other airborne pollution besides carbon dioxide, which need to be addressed (Figure 17). Sanchez-Sierra stressed further that the developing countries are facing more pressing problems such as reducing poverty rather than considering mitigation measures against the greenhouse effect. He emphasized the need of a global approach, i.e., a North-South collaboration due to the global issue of these interrelated problems. The Latin American countries have essentially four strategies at their disposal to reduce energy-related GHG emissions, i.e., increased use of hydropower, natural gas, sustainable use of biomass and efficiency improvements. For example, between 1973 and 1990, carbon dioxide emissions per unit of generated electricity were reduced by 27 percent in Latin America by installing hydropower stations. Currently, only 12 percent of the Latin American hydropower potential of 700 GW are exploited.

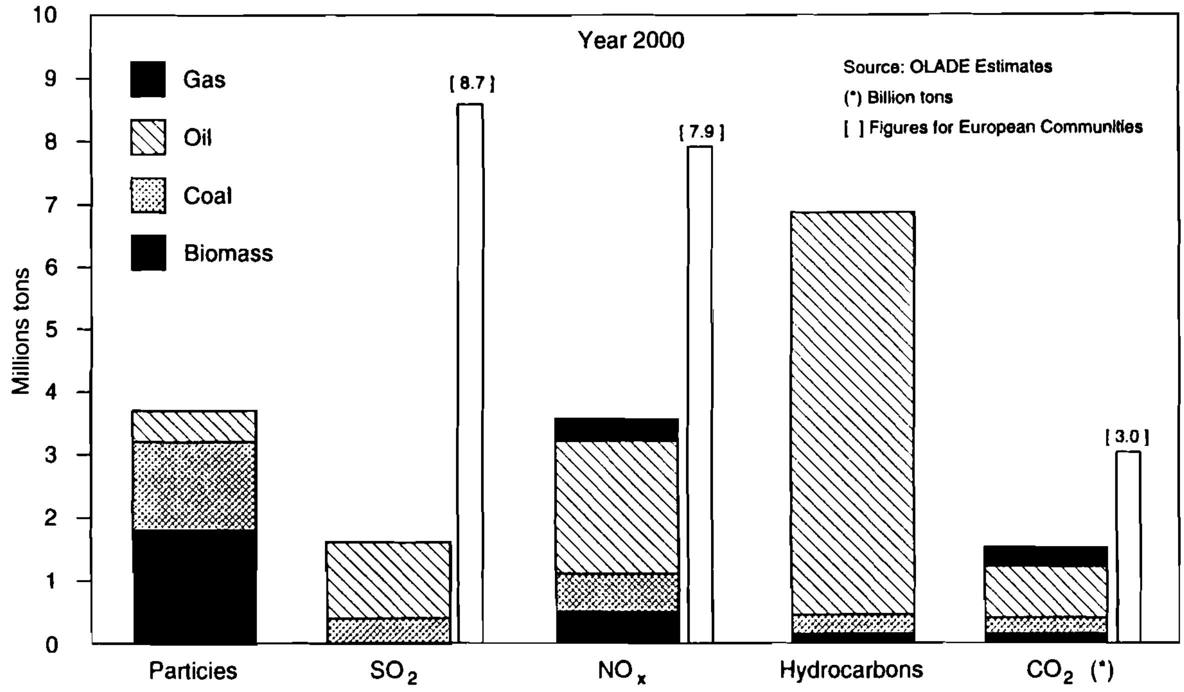

Figure 17. Airborne emissions from energy production and end-use in Latin America on the Caribbean and comparison to EC. Source: Sanchez-Sierra.

Natural gas reserves are sufficient for more than 50 years even at consumption rates higher than the current levels. Although natural gas reserves are concentrated in a few countries (Argentina, Bolivia, Mexico, and Venezuela), there are projects for the interconnection of grids including other countries. The traditional biomass fuels are firewood and charcoal. Thirty percent of the total Latin American population currently depends on firewood. However, the residential use of biomass decreases as urbanization increases. The sustainable use of biomass can play an important role in carbon dioxide mitigation as exemplified by the Brazilian ethanol program (currently being constrained however by low oil prices). Finally, Sanchez-Sierra also emphasized the considerable potential for energy efficiency improvements in the region.

Niehaus stated that nuclear power has no climate impacts and that concerns raised over carbon dioxide release within the nuclear fuel cycle and during the construction of nuclear power plants are unfounded. Such indirect emissions were analyzed 20 years ago. These studies showed that fossil energy requirements are very small, leading to negligible carbc dioxide emissions of nuclear energy. Conversely, if the total number of 420 nuclear plants were replaced by coal-fired power plants, global carbon dioxide emissions would increase by 7 percent. The future of nuclear energy is uncertain and varies from one country to another. Seventy-six reactors are under construction worldwide. Expansion plans are limited in Western countries (except in France which has a 72.7 percent nuclear share in electricity production). However, a few countries such as Sweden, Finland and Italy are going to make decisions or at least are starting to rethink their nuclear policies. A very different situation is given in East Asian countries with active nuclear programs. The most ambitious is Korea which plans to build another 18 reactors by 2006. Figure 18 shows the age distribution of nuclear reactors illustrating that there are more than 20 reactors older than 30 years. This

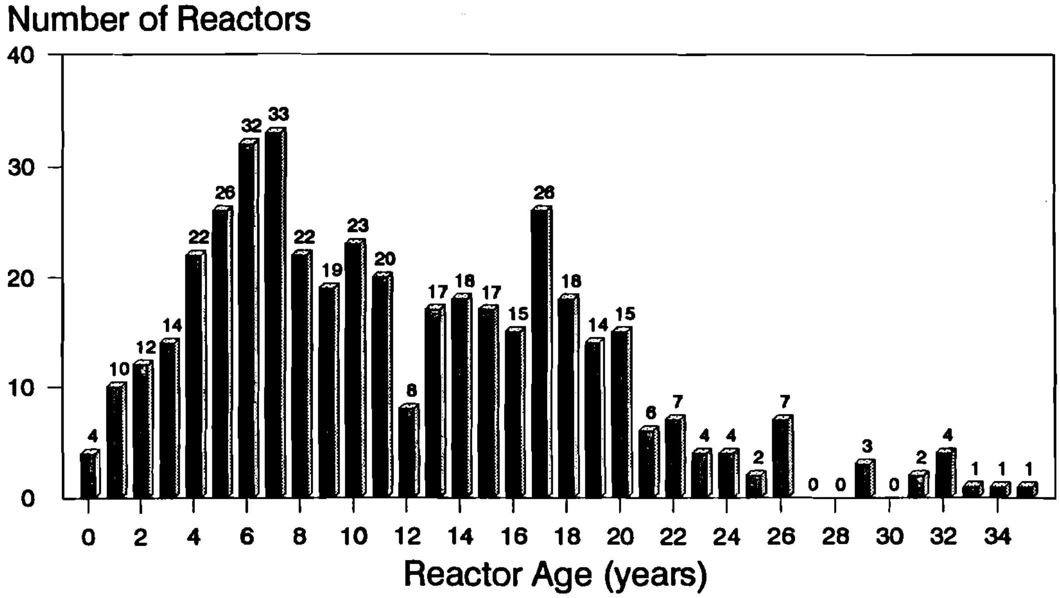

Figure 18. Age distribution of nuclear power plants in operation worldwide. Source: Niehaus.

number will increase to about 70 by 2000. Some of these reactors will probably be backfitted to extend their life spans provided that this would be cost effective; otherwise they will be shut down. Speaking about the current status of nuclear energy production in Eastern Europe and the CIS, Niehaus mentioned a safety analysis among concerned countries and the IAEA for 2 reactor types, i.e., the 10 WWER 440/230 units that are currently in operation and the 15 RBMK units currently in operation, with 4 additional units under construction (3 currently deferred). Niehaus cited the "Senior Expert Symposium on Electricity and the Environment" held in Helsinki on 13-17 May, 1991 that resulted in a document submitted to the Rio summit. The overall conclusion was that nuclear power and renewable energy systems are in the lower spectrum of health risks under the conditions of a routine operation compared to power plants firing coal and oil. Despite the fact that nuclear market potential could be between 40 and 60 GW per year, the future of nuclear power will be determined by a number of factors. Firstly, significant improvements in nuclear safety and secondly, solving the nuclear waste disposal problem, which Niehaus considers as technically feasible, although proper incentives are currently missing. Predictable conditions about commissioning and construction lead times are also required. Finally, Niehaus considers the acuteness of the greenhouse effect as an additional factor that will influence the future of nuclear energy.

Discussion

Steinberg mentioned that biomass plantations scale two dimensionally (i.e., surface area), whereas power and fuel conversion plants scale three dimensionally (i.e., volumetrically). Therefore, larger plants based on larger amounts of biomass feedstocks can decrease costs. Capacities equivalent to 50,000 to 100,000 barrels a day are more economical than smaller plants. Marland argued that reasonable fuelwood plants should be sized between 30 and 50 MWe. According to Hall, the only reason for larger plant scaling would be an integrated system, like the sugarcane industry that produces sugar, alcohol and electricity. This was put into perspective by Sipilä who mentioned that biomass fuels are between 50 and 100 percent more expensive in Scandinavia, including taxes. Therefore they should be integrated in the pulp and paper industry in order to burn waste materials, which reduces costs. The feasible power plant sizes in pulp mills is as high as 60-300 MWth (thermal) in Scandinavia. In Southeastern Europe the amount of biomass needed for a 100 MWth or about 25 MWe (electric) plant is within a radius of 10 km. Moreira emphasized that medium-sized plants might also operate economically. The largest ethanol plant in Brazil has 500 MW installed capacity, which corresponds to an input of 40 thousand tons of sugarcane per day. For this, the sugarcane within a radius between 25 and 30 km has to be harvested economically and transported to the plant.

Hall mentioned the need of 400 to 800 ha per MWe (4,000 to 8,000 m^2 per kWe), depending on productivity and conversion efficiency of biomass. Moreira specified the data for the Brazilian alcohol program with 6 kWth for each ha of the plantation area (around 1,500 m^2 per kWth) under present conditions. With the use of tops and leaves from sugarcane plantations plus efficient gas turbines and biomass gasifiers, it is possible to produce 5 kWe for each ha of the plantation area. Grübler voiced concerns about possible land use conflicts considering energy consumption levels of up to 10 kW per capita (i.e., well over 10,000 m^2 energy biomass land requirements per person) considering that in many Asian countries agricultural land availability is between 1,000 to 2,000 m^2 per person. In addition, competing fertilizer requirements between agriculture and energy biomass production could arise. Hall replied that nitrogen fertilizing is only necessary at the first planting. However, there is a need to recycle ash back onto the fields to restore the nutrient balance. Moreover, there may be competing uses for biomass which have not been discussed up to now, such as the construction and paper and pulp industries. In Hall's scenarios, all biomass grown is used for fossil fuel substitution. Golomb doubted the possibility of using biomass on such a large scale. For example, the city of Boston needs about 2 GWe of electricity, which corresponds to about a quarter of a million ha of the plantation area. However, this area is not available in Massachusetts. Marland replied that biomass makes a contribution rather than providing for a single feedstock for energy needs. Sipilä also mentioned that biomass use in the pulp and paper industry is well establised. Large amounts of electricity can be generated by using the black liquor from paper and pulp plants. Steinberg argued that biomass does not have to be derived exclusively from plantations. The city of New York produces 26 thousand tons of garbage per day, half of which could be used as biomass. Moreira argued that 5.5 percent of U.S. land would be sufficient to produce 1.2 trillion kWh of electricity. For comparison, in Brazil only 1.5 percent of the land is flooded for electricity.

Sipilä reported that the first biomass fueled gas turbine, a 30 MWth demonstration system, constructed by Bioflow AB, will be operational in 1993 in Sweden. Hall mentioned a Global Environment Facility (GEF) project in North East Brazil to integrate a gasifier with General Electric gas turbines. This plant has a capacity of 30 MWe and will be operational in 1995. Steinberg added that there are, currently, intense studies about integrated gasifier combined cycle plants (IGCC) underway. Seifritz proposed to compare carbon dioxide avoidance costs in industrialized countries with land costs of tropical forests in developing countries. If the latter are cheaper per unit of carbon dioxide taken up or avoided, then land should be purchased. This suggestion was rejected by Hall, who pointed out that there is possibly more than 20 million ha of surplus agricultural land in Europe. In addition, agriculture in the European Community is being subsidized by over 40 billion dollars per year. Moreover, cheap land purchase in tropical forests is in reality limited, due to the need for protecting the forest from fellage. Levine asked about strategies for efficiency improvements of domestic biomass combustion. Sanchez-Sierra responded that most of the biomass burning is due to the extension of agricultural areas and therefore the question is linked more to social development and less to energy use. Gupta reported about a project in India that involved distribution of two million cooking stoves free of charge to households in rural areas. These stoves had efficiency levels of about 20 percent compared to 8 percent with traditional cooking methods. However, 60 percent of the stoves were used as storage containers rather than for cooking due to a variety of reasons: the design was more complicated compared to the previous ones, the old cook stoves had been used for heating the room as well as for cooking and the previous models were portable, allowing cooking outside in a courtyard so that women could sit together while cooking. The new stoves could not fulfill these multiple functions. This particular example illustrates the importance of understanding the proper social dimension of the use of particular end-use devices, a precondition for the analysis of the possible diffusion of energy efficient end-use appliances. Grubb emphasized that solar energy for heating water is highly economical in countries such as Israel and Greece. Moreover, costs of currently expensive solar cells are projected to decline significantly in the future. Besides, wind energy is economical in some countries such as Denmark where there are high wind speeds and high electricity prices. All of these technologies should be examined because they have a considerable potential for reducing carbon dioxide emissions, especially as their future economics are likely to improve. Johann, representing the Greenpeace view, stressed that more attention should be paid to lifestyle issues in addition to the efficiency improvements and the shift from fossil fuels towards renewable fuels. He considered an increase in nuclear power for fossil fuel replacement irresponsible, after accidents such as Chernobyl.

Mintzer asked about carbon dioxide emissions related to fuel enrichment and long-term waste disposal in a nuclear-dominated future. Niehaus replied that the energy for constructing a nuclear power plant and supporting the fuel cycle (including enrichment) is recovered within three to four months of reactor operation. The corresponding carbon dioxide emissions are less than one percent of the amount that nuclear reactors are avoiding, compared to coal-fired power plants. This might be somewhat different in a rapid growth scenario, but the maximum global nuclear growth potential is at most 60 GWe per year, i.e., 50 percent more than during the mid-1980s. Waste disposal would also require very little energy, even over extremely long time horizons.

Session 3 Clean Fossils, Carbon Removal and Storage

This session, chaired by Michael Jefferson, was opened by a summary of the main conclusions from the World Energy Council (WEC) Madrid Congress, followed by six papers and discussion. The conclusions from the WEC Congress with respect to fossil fuel availability also provided a good introduction to this Session. The WEC concluded that for the period up to 2020 there are ample reserves of fossil fuels available. Beyond that time horizon, the Commission Report expresses also concerns about continuing oil and natural gas availability and upward pressures on energy prices due to increased dependency on energy imports, lengthening supply lines and higher exploration and production costs. According to the WEC, ultimate recoverable fossil reserves exceed 6,000 TWyr (4,400 Gtoe) and contain about 4,300 of Gt carbon. This compares with 760 Gt of carbon currently in the atmosphere. From this perspective and from the current dominance of fossil fuels in the global primary energy supply, fossil fuels will continue to play an important role throughout the 21st century, which could result in emissions far exceeding the assimilative capacity of the global biosphere. Hence, the issue of clean fossil fuels and of possible carbon sequestration and disposal from fossil fuel use are important elements of GHG mitigation strategies.

The session was opened by the Chairman with a summary of the main conclusions from the WEC Congress. Jefferson referred, in particular, to the draft report of the WEC Commission, "Energy for Tomorrow's World". The draft report contains three possible future global energy demand and supply cases. In the reference case, global primary energy demand is projected to increase to close to 19 TWyr/yr (13.3 Gtoe). In the "enhanced economic development" case, rapid economic development would lead to a doubling of current primary energy demand to 24.4 TWyr by 2020, even assuming that energy intensity reduces at about the fastest rates achieved over the last 15 years. Even more ambitious is the "Ecologically Driven" case in which energy demand would be below 16 TWyr/yr as a result of even more vigorous reductions in energy intensity. In addition, the case assumes development of new renewable forms of energy, which could lead to a stabilization of energy-related carbon emissions at a level of 6 Gt of carbon by 2020 compared to 8.4 Gt in the reference case and 11.3 in the "enhanced economic development" case. Turning to the conclusions of the WEC Congress, Jefferson referred to three specific areas. First of all, in the conclusions and recommendations, the first item is the high risk of deteriorating local, regional and global environmental conditions unless vigorous countermeasures are taken. Secondly, no one has set remedies for global environmental problems, but given potential risks and continuing uncertainties of climate change, a precautionary strategy must be adopted with a balance of minimum regret measures and further studies. This must be based on increased efficiency in the production and use of clean energy and the development of non-carbon fuel sources. In addition, more effective measures to promote energy efficiency and conservation are urgently needed. The sources of fiscal measures that would be required to achieve such goals remain for further consideration, not because the WEC was opposed to taxes, but because it would want to make sure (e.g., via "earmarking") that they would meet the purposes they were supposed to be required for. And it seems wise that the governments and international institutions themselves gave much more attention to how to adapt to the consequences of climate change should pessimistic forecasts prove to be right. The conclusions and recommendations of that part of the WEC Congress recognized that energy provision and use, and their related GHG emissions, may well be an important factor contributing to enhanced global warming, if this hypothesis is well-founded. For the majority of the population today and the expected 8 billion living on this globe in 2020, however, overcoming poverty and local and regional environmental impacts are higher priorities than the potential impacts of global warming. It has to be stated that this must not be taken as a reason to underestimate or to neglect the potential dangers coming from global warming. The WEC therefore supports a combined approach to the problems of global warming by (a), improving the scientific basis in particular with respect to a better understanding of the sources of GHGs and their role and interactions within global geo-chemical cycles and (b), precautionary measures with an emphasis on energy efficiency improvements and exploring all opportunities for clean energy supplies. Precautionary measures, their range and speed of implementation, must be kept within the parameters of the actual state of science and must take into consideration economic growth and development as well as the limited availability of financial resources. The WEC offers its active participation and constructive contribution to the ongoing work of the Intergovernmental Panel on Climate Change. In view of energy and environmental interest, non-governmental and governmental institutions must no longer work separately, but should join forces much more closely than in the past.

Jones examined the Australian government's interim planning target to reduce GHG emissions to 20 percent below their 1988 levels by 2005. About 45 percent of Australia's carbon dioxide emissions are released from coal power plants. In addition, the growth rate of energy consumption is higher than in most other developed countries, due to high population growth and immigration rates. Six different scenarios have been examined for Australia. The three most important are "business-as-usual", "no regrets" and "interim target". In the "business-as-usual" scenario, energy consumption increases by 36 percent between 1990 and 2005, corresponding to an increase in carbon dioxide emissions from 76 to 104 Mt of carbon. A regionalized MARKAL model has been used for this analysis. The technologies for mitigating GHG emissions ranged from conventional ones to biomass fuels for transport, wind and solar thermal plants for electricity production. The results showed that the reduction target could be met and that most of the changes would occur in the electricity generation sector. While primary energy consumption remains approximately constant in the scenario, carbon dioxide emissions are reduced by 26 percent through a rapid and massive shift from coal towards natural gas, hydro, wind and solar technologies. However, costs would be quite high (Figure 19); the change of the energy system would result in a reduction of the gross national product by two percent. The "no regrets" strategy (meaning that GHG emissions are limited, where such a reduction can be economically justified for other reasons) results in an increase in primary energy by 21 percent and in carbon dioxide emissions by 17 percent between 1990 and 2005.

Blok gave an overview of the present status of carbon dioxide recovery and possibilities for terrestrial disposal. In the Netherlands' R&D program, three IGCC plants were examined. In addition, the study examined a coal power plant with a retrofitted chemical absorption unit and a natural gas combined cycle plant with a chemical absorption unit. All of the plants analyzed (Figure 20) have a power output between 450 and 600 MWe. The lowest efficiency drop of all coal based plants from 42.5 percent to 36.4 percent was achieved by the IGCC process with physical absorption. The efficiency of the natural gas combined cycle plant with a chemical absorption unit also dropped by about 6 percentage points, from 52 percent to 44.9 percent. These two options represent also the lowest and the highest cost per ton of carbon dioxide recovered, i.e., US$ 62 per ton of carbon for the IGCC plant and US$ 147 per ton

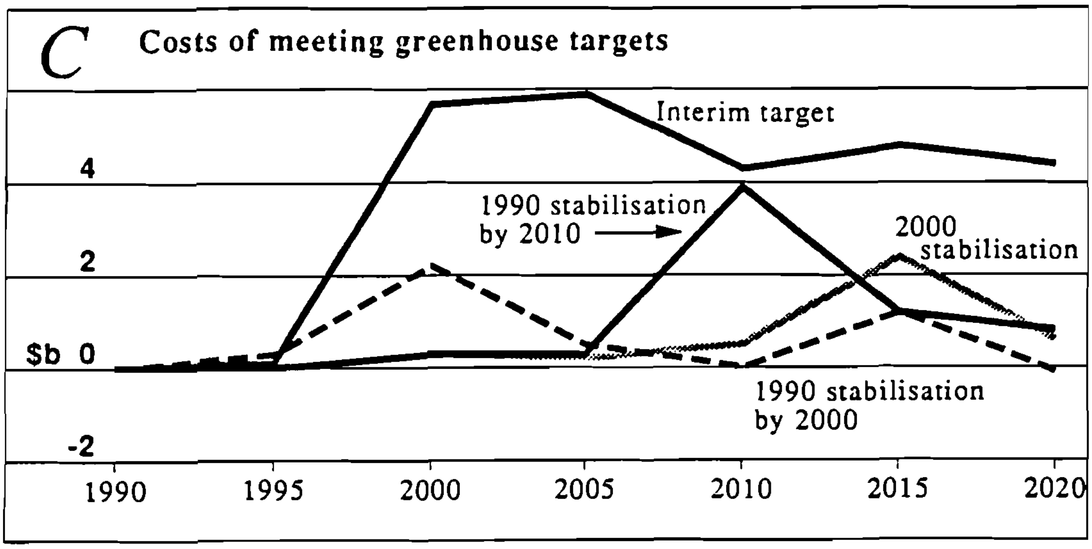

Figure 19. Costs of meeting various GHG emission targets in Australia (Aus$ billion). Source: Jones.

Type of plant - method of recovery	IGCC - CO_2/O_2- combustion (Texaco)	IGCC - CO_2/O_2- combustion (Shell)	IGCC - shift & physical absorption (Texaco)	Pulverized coal - chemical absorption (retrofit)	Natural gas Combined cycle - chemical absorption
Net electric power (MW)	520	520	500	450	600
Net conversion efficiency (%)	34.8	36.0	36.4	29.7	44.9
Degree of CO_2 recovery (%)	99	96	82	87	77
Specific CO_2 emissions (g/kWh)	5	30	140	105	86
Base plant figures:					
Net conversion efficiency (%)	42 - 43				52
Specific CO_2 emissions (g/kWh)	800				390

Figure 20. Techno-economic overview of various technologies for carbon recovery from fossil fuel power plants. Source: Blok.

of carbon for the natural gas combined cycle. Blok mentioned that other studies attained higher cost figures (up to twice as high). Improvements can be expected in optimizing amine absorption processes, applying gas absorption membranes, optimizing heat integration of carbon dioxide separation in IGCC plants, and in the search for more efficient physical absorbers. Blok then gave a brief assessment of subterranean storage in natural gas fields with an estimated global storage capacity of 90 Gt of carbon on the basis of proved reserves and 400 Gt of carbon on the basis of ultimately recoverable reserves. Storage potential in oil fields was estimated to be smaller (about 40 Gt of carbon on the basis of proved reserves) while the storage capacity in aquifers appears quite high with some 90 Gt of carbon or even more. However, subterranean carbon dioxide disposal is also linked to environmental risks such as accidents with carbon dioxide handling, carbonate chemistry (possible reservoir weakening in the case of a carbonate matrix), leakages in the case of clay drying of aquifer top layers, (salty) water displacement of higher layers, among others.

Halsnæs reported on the UNEP greenhouse gas abatement costing studies with the scope of improving economic data for comparing national strategies for GHG emission abatement. There exists a close cooperation between the participating countries, Brazil, Venezuela, India, Zimbabwe, Senegal, Egypt, Thailand, Denmark, the Netherlands and France. She mentioned many problems related to forecasting, for example, the industrial energy intensity of developing countries, the energy demand in different sectors to be consistent with macroeconomic models, fuel prices and future ecological policies adopted in developing countries.

Golomb stressed that the ocean represents a huge natural reservoir for carbon dioxide disposal, since it covers 70 percent of the earth's surface and has an average depth of 3,800 meters. Even if all anthropogenic carbon dioxide emissions were pumped into the ocean, the increment of the carbon content would only be one-hundredth of a percent per year. Most important, the deep ocean below the surface layer is highly unsaturated with carbon dioxide (0.1 kg of carbon dioxide per cubic meter) and can absorb 400 times more, constituting a vast storage potential. The problems of deep ocean disposal of carbon dioxide are of technical, economic and political nature. Moreover, public resistance could be expected. Carbon dioxide has to be injected below the thermocline in an approximately 1,000 meters depth where residence times are estimated to be some hundred years; injection depths of less than 1,000 meters would cause a rapid diffusion back to the atmosphere. Carbon dioxide can be released in the deep ocean as a gas, solid or liquid. The most efficient disposal mode in terms of transportation and processing is in liquid form. The off-shore pipeline injection is the most economical disposal mode, however, the maximum depth for pipelaying is constrained to 650 meters to date and to 1,000 meters in the near future. Other disposal strategies might be considered, such as releasing carbon dioxide in a shallower layer where prevailing currents carry the release plume downward, mixing carbon dioxide and seawater in a confinement vessel (Figure 21) that sinks down, releasing carbon dioxide in a depth where carbon dioxide hydrates are likely to be formed and would continue to sink to the ocean floor. Moreover, carbon dioxide could be solidified and released from a ship (however, half of the dry ice would melt en route and the carbon dioxide would return to the atmosphere). Transport and injection costs are estimated to be equal or greater to the carbon dioxide removal costs at power plants. While global effects of carbon dioxide injection are considered to be negligible, local effects on aquatic life around the discharge plume might take place. The oxygen deficient and turbulent plume around the injection point might have adverse effects on mesopolagic organisms, the resulting pH (that might become as low as 3) could also be detrimental to living organisms. Part of the released carbon dioxide may form solid hydrate flakes that sink to the bottom and bury benthic organisms.

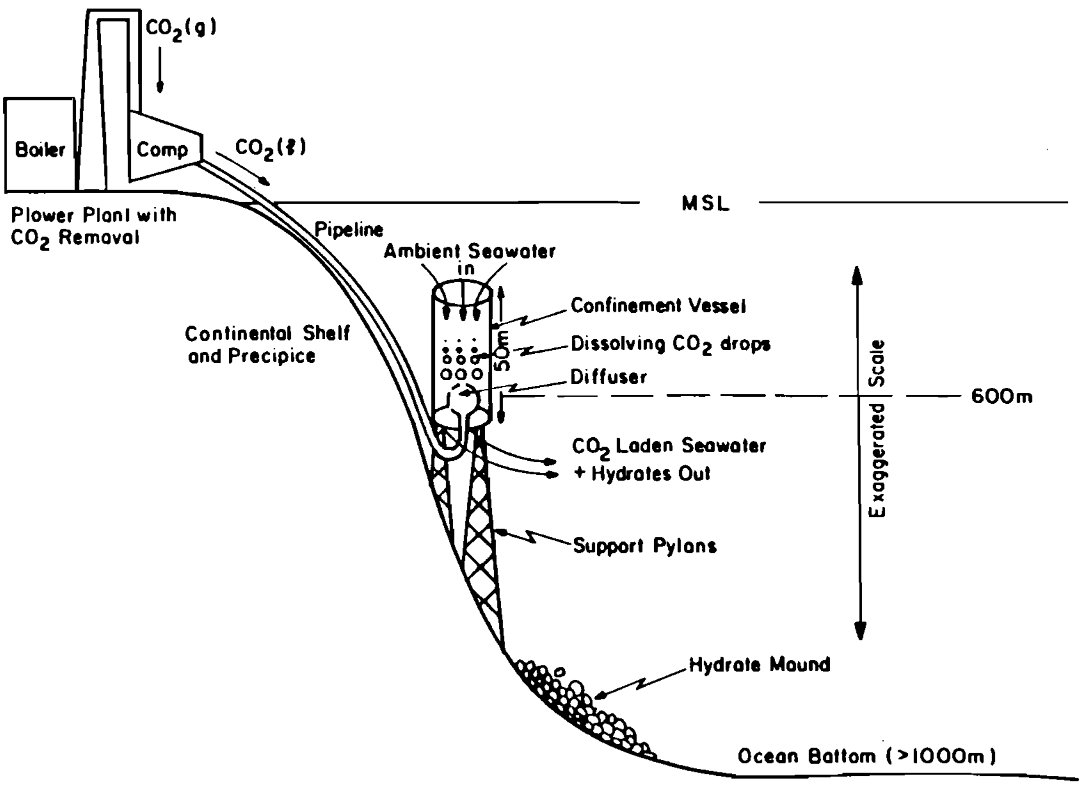

Figure 21. Scheme of CO_2 release system with confinement vessel suggested for deep ocean disposal of sequestered CO_2. Source: Golomb.

Rogner emphasized that about 3,000 Gt of fossil fuel based carbon can be extracted at low cost, i.e., less than US$ 20 per barrel of oil equivalent (1990 US dollars). To put this resource volume into an environmental perspective, current energy-related carbon emissions are close to 6 Gt per year, indicating that most of this fossil carbon should be left in the ground untapped. Consequently, switching towards carbon-free energy sources will have to be completed long before the stock of fossil resources is approaching depletion. The switching to non-fossil energy sources, however, has to be preceded by technological change at the end-use level where the bulk of carbon emissions occur. Rogner stressed that hydrogen is the ideal substitute for carbon containing end-use fuels, especially in the transportation sector. Efficiency considerations favor electrochemical conversion technologies, e.g., fuel cells that convert hydrogen into electricity and are not subject to Carnot efficiency constraints. Hydrogen fuel cells suitable for stationary and non-stationary applications offer conversion efficiencies in the order of 60 to 70 percent. Figure 22 displays techno-economic parameters for various transportation technologies under realistic load conditions. Fuel cell-equipped vehicles are not range constrained such as battery powered vehicles. With regard to emissions, the only fuel cell by-product is water. Although non-fossil energy sources will ultimately be required for hydrogen production, in the interim, hydrogen will be derived from fossil fuels (steam reforming of natural gas, primarily). The benefits of steam-reformed hydrogen are: (1) overall reduction of carbon emissions without compromising on energy service supply; (2) central carbon production (as opposed to thousands of tail-pipes) which eventually opens the possibility for carbon removal and disposal.

	Units	Diesel 1990	Gasoline 1990	Solid Polymer Fuel Cell	
				1990	2nd generation
Power	kW H_2	70	85	34	45
Capital cost [1]	US$(90)/kW	50	45	5,500 [2]	400 [2]
Variable O&M cost [3]	US$(90)/km	0.012	0.013	0.020	0.007
Efficiency	%	19.5	17	43	51
Fuel use	MJ/km (l/km)	2.31 (6.5)	3.22 (10.0)	1.78	1.50
Cost (excl. fuel) [3]	US$(90)/km	0.043	0.048	1.70	0.169
Carbon emissions [4]	kg_{CO2}/km	0.175	0.231	0	0

[1] Includes IC engine or fuel cell, generator and ancilleries
[2] Includes battery for spiking
[3] Based on 15,000 km per year
[4] Emissions caused by vehicle only

Figure 22. Techno-economic parameters for various transportation technologies including fuel cells. Source: Rogner.

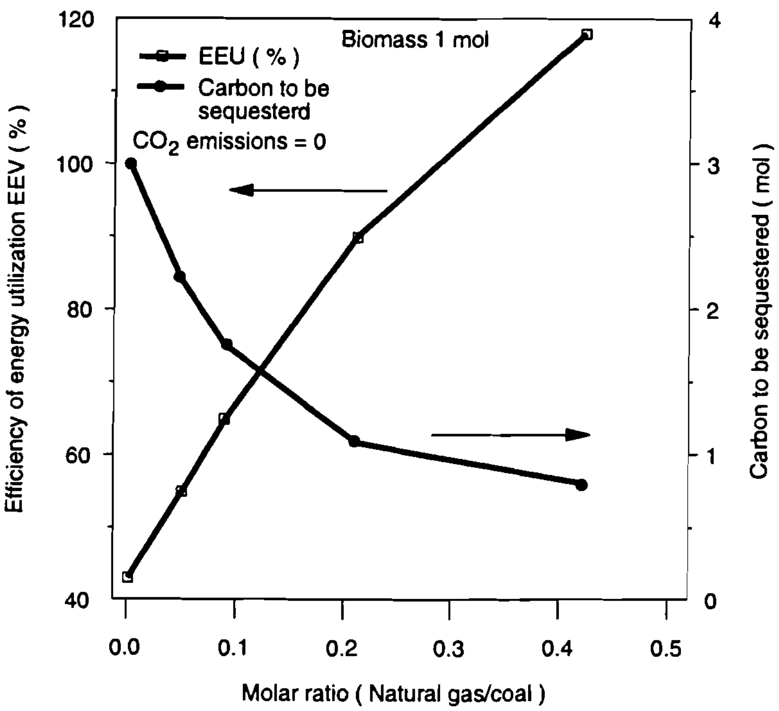

Figure 23. Mole ratio (natural gas/coal) for hydrocarb process for zero CO_2 emission. Source: Steinberg.

Steinberg and Yamada introduced the hydrocarb process which consists of two steps, the hydrogasification of a carbon containing feedstock (fossil fuels or biomass) and the thermal decomposition of methane. The net energy balance is positive and the excess hydrogen can be used as an energy carrier. Alternatively, hydrogen can be combined with CO to form methanol in a catalytic step as a coproduct to carbon. The carbon is stored and could be burnt if the greenhouse effect turns out not to be as threatening as it seems to be now. If biomass is used alone as a feedstock, the hydrocarb process decomposes the ligno-cellulose to carbon, hydrogen and water. This process is able to store the carbon contained in biomass as elementary carbon but provides only 3 percent of the biomass energy as hydrogen. If combining biomass with natural gas as feedstock (1 mole ligno-cellulose and 0.3 mole natural gas) the reaction co-product is methanol in addition to carbon. Similarly, biomass can also be used in conjunction with oil or coal or co-processed with mixtures of coal and natural gas. Figure 23 indicates the energy utilization efficiency and the amount of carbon to be sequestered as a function of the molar ratio of natural gas to coal while maintaining zero carbon dioxide emission at all times. Yamada presented results from an economic evaluation of the hydrocarb process (Figure 24), ranging from US$ 50 up to US$ 300 per ton of carbon. According to Yamada, the costs are comparable to those of IGCC plants with carbon dioxide removal and storage in natural gas fields or in the deep ocean.

	Case 1 (B-C)	Case 2 (B-C-N)	Case 3 (B-N)
Investment cost (US$$10^9$)	3.1	2.3	2.0
CO_2 removal cost[1] at 20%/yr[2]	130	30	10
(US$/t-C)	(200)[3]	(70)[3]	(50)[3]
at 40%/yr[2]	320	160	130
(US$/t-C)	(420)[3]	(220)[3]	(170)[3]
Area for plantation at 0.8 kg-C/m^2.yr (in km^2)	4000	4400	4500

B-C = Biomass and coal
B-C-N = Biomass and coal and natural gas
B-N = Biomass and natural gas
[1] CO_2 removal cost = methanol price - raw material costs - annual fixed costs (cf. footnote 2) based on unit CO_2
[2] Annual fixed costs = assumed at 20% and 40% of investment costs, respectively
[3] Product yield = 0.8

Figure 24. Economic assessment of various applications of the hydrocarb process. Source: Yamada.

Discussion

Golomb emphasized that global effects of carbon dioxide disposal in the deep ocean are negligible due to the very small incremental concentrations of carbon dioxide. Locally serious effects to living organisms might, however, appear. There is a need for further study of local effects, e.g., via small scale releases with subsequent monitoring over 3 and 5 years. However, those risks are certainly smaller compared to the ones from climate change. No serious technical problems should exist for the construction and installation of confinement vessels. Current marine technology allows operation to depths of 650 meters. To put this into perspective, the oil pipe from Tunisia to Italy was laid at a depth up to 600 meters. Golomb argued for a strategy along the mitigation marginal cost curve, meaning to start with energy conservation and efficiency improvements, then with carbon dioxide recovery and terrestrial disposal. Ocean disposal should be considered the last resort.

Seifritz compared the acceptability of carbon dioxide injection into the deep ocean with the acceptability of nuclear energy. He mentioned the possibility of disposing dry ice from ships into the ocean as a disposal method. According to his calculations more than two-thirds of the carbon dioxide per unit dry ice can be brought down to a depth of 3,000 meters in order to be dissolved and to sink further. Another solution would be terrestrial storage of carbon dioxide. Seifritz proposed to construct a well insulated "dry ice repository" with a radius of 200 meters (storing 50 million tons of carbon dioxide). This storage system could be installed close to a power plant and would delay the release of carbon dioxide to the atmosphere. Half of the carbon dioxide is released after 800 years, but the whole contents of the repository would diffuse after 4,000 years. This strategy of releasing carbon dioxide within a time span much longer than the characteristic time constant of carbon dioxide in the atmosphere of about 250 years results in smoothing atmospheric carbon dioxide peak concentrations. The energy consumption for carbon dioxide separation and dry ice production corresponds to 25 percent of the heating value of coal (1.3 Wyr per mole of dry ice). Hall agreed to the attractiveness of this suggestion from a biological point of view, due to the small releases of carbon dioxide which are welcome to biological systems.

Rogner emphasized that in the long run, nuclear, solar and other renewable energy sources will be used for hydrogen production. However, without the necessary adjustments of the end-use infrastructure to accommodate hydrogen, there appears to be no immediate need for societies to commit themselves to the use of either socio-politically sensitive or techno-economically uncertain zero carbon energy sources. In the interim, hydrogen could be produced from natural gas. Rogner mentioned a project in Vancouver, Canada, where a transit bus has been equipped with fuel cell stacks. Road testing will commence in January 1993. Hydrogen will be stored as a compressed gas. The average efficiency of the fuel cells used for this project are expected to range between 45 and 48 percent. If road testing meets expectations, several buses are planned to be completed in time for the 1994 Commonwealth Games to be held in Victoria, Canada.

Steinberg stressed that the hydrocarb process would focus investments in an energy storage system of elementary carbon. This energy could be used over the long run. On the other hand, if power plants are retrofitted with carbon scrubbers and carbon dioxide is injected into the ocean, money will be spent for a disposal system rather than for energy storage.

Jones mentioned that in Australia, the electricity generation system is considered to offer the most cost effective potential for large carbon dioxide emission reduction. Nuclear energy is currently not considered as an option by the Australian government. Jones reported that wind energy is currently used on a very small scale only, despite the huge share of renewable energy in his own scenarios.

Blok stressed that Selexol absorption is superior to membrane separation of carbon dioxide and hydrogen due to the higher degree of pureness of carbon dioxide and the lower energy consumption. Membrane technology turned out to be attractive only in a case of separation of hydrogen and carbon monoxide, where both product streams are fed to different gas turbines.

Session 4 Technology Assessment and R&D Priorities

In this session, chaired by Keiichi Yokobori, a total of ten presentations and the ensuing discussion focused on integrative issues of technology assessment. Whereas, (indeed in many individual areas) technological options and/or resulting policies can be identified to lower carbon dioxide emissions from the energy sector (cf., the previous three sessions), the key question is how these different options are going to be compared, how their ultimate potentials and costs can be evaluated, but also how to quantify their possible benefits in addition to GHG reduction. The required methodological framework should aim for documentation of the underlying data and implicit assumptions used in such a technology assessment, rather than to aim necessarily for a (perhaps premature) consensus of the optimal policy mix to encounter the risks of climate change. Fully documented technology inventories, linked with detailed engineering AND macroeconomic cost models will be instrumental for such studies at the global, regional and national level to evaluate realistic scenarios of future GHG emissions and assess technological options and related policy instruments for mitigation. A proper assessment of related statistical requirements should also be called for in this context.

Katscher reported about the ongoing German IKARUS (Instruments for Greenhouse Gas Reduction Strategies) project, perhaps the most ambitious national GHG mitigation analysis project currently performed. IKARUS aims at the development of a comprehensive database and associated computer models to support analysis of mitigation options of climatically relevant gases from the German energy system (Figure 25). In addition, a research project addresses issues of verification of possible protocols to the Climate Convention. Besides carbon dioxide, the IKARUS database accounts for methane, non-methane volatile organic compounds, carbon monoxide, sulphur dioxide, nitrous oxides, dinitrous oxides, chloroflourocarbons and stratospheric water vapor. A PC based linear program model

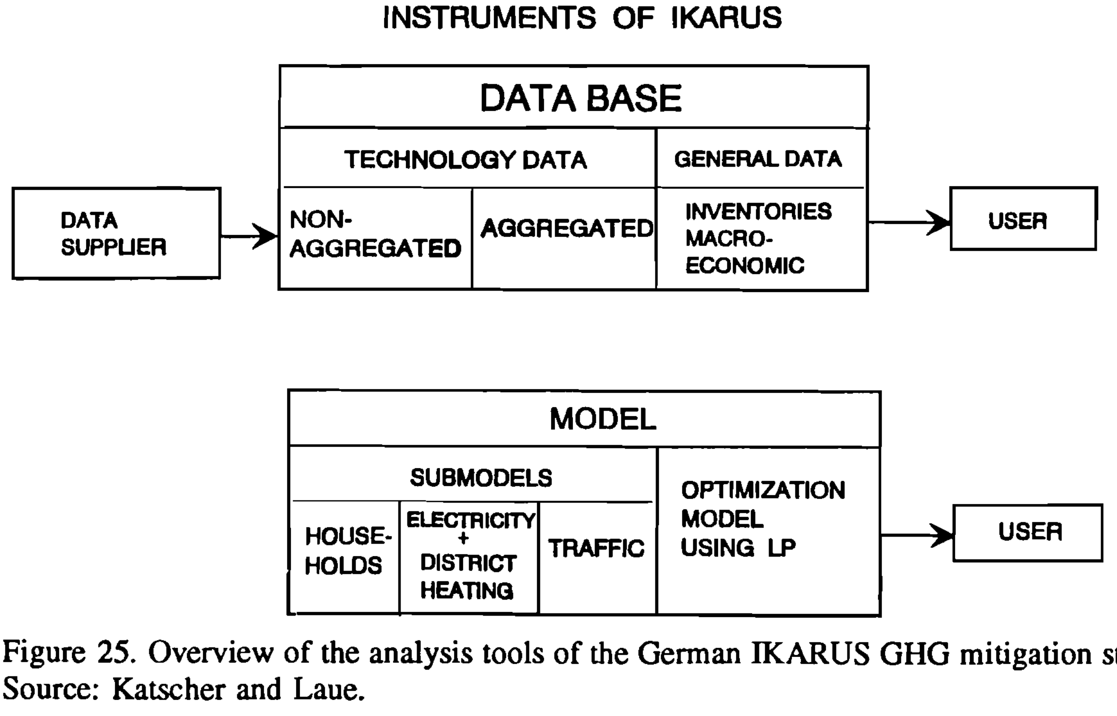

Figure 25. Overview of the analysis tools of the German IKARUS GHG mitigation study. Source: Katscher and Laue.

reproduces the energy flow in Germany and incorporates more than 2,500 energy technologies with special emphasis on energy saving techniques. The model optimizes technology configurations with minimum costs for a given user-defined reduction target for three reference years: 1989, 2005 and 2020. The menu guided PC-based database contains technical, economic, emissions, structural, and other socioeconomic data for the reference years. It is intended to be used as a general information system and as an input database for the models. The data account for the primary energy sector, energy conversion and the end-use sector consists of households and small consumers, industry, transport and cross-sectional technologies. The system is designed for high portability in order to enable different groups to share a common methodological tool in their analyses of GHG mitigation strategies. As such, the system is designed to enable comparisons and documentation of differences between various strategies suggested and analyzed by different groups in both analytical and policy communities. Work in 1992 focused on the test implementation of the model and database, on initial computer runs and database queries. In 1993, models will be tuned and the database completed.

Grübler reported on the IIASA database of carbon dioxide reduction technologies, the CO2DB. The database has been established for two reasons, i.e., improving data access and consistency (by generating more transparency of underlying assumptions, e.g., on costs or emission factors used for various technologies) and to allow comparative assessments of entire technological systems (ranging from primary energy extraction to the end-use device) by calculating the performance of whole energy chains in terms of emissions, primary energy requirements and costs. Finally, the database provides input descriptions for a linear programming model of the energy system, operating at the global, world regional or national level (the energy supply planning model MESSAGE developed at IIASA, or for similar kinds of models). The CO2DB covers technological, economic, environmental and resource characteristics of GHG mitigation options. Besides carbon dioxide, practically all emissions can be examined. The CO2DB also contains additional information on the market potential and diffusion rates of technologies, i.e., when, where and how fast a new technology could penetrate the energy market. This information reflects promoting factors or constraints for the introduction and growth of new technologies. Data variations such as regional differences in resource availability and costs, scientific uncertainty, and possible future developments are included by means of subtables which can be opened for each technology. Grübler demonstrated some results of energy chain calculations using the CO2DB, presenting carbon dioxide emissions, primary energy use and costs of delivering the energy service lighting (Figure 26). This analysis gives insights into judging technology performance and provides indications of possible tradeoffs of various mitigation strategies (e.g., fuel switching versus energy end-use efficiency improvements, or combinations thereof). At present, the CO2DB contains over 400 technologies. During 1993 its coverage is planned to be extended to up to 1,000 technologies with emphasis on improving the representation of technologies important particularly for developing countries and on resource requirements like materials, labor and land. Grübler emphasized the importance of parallel projects developing inventories of GHG mitigation technologies as each of these efforts can respond best to the requirements of their corresponding institutions and enable, also, preservation of the diversity of opinions in technology assessments of GHG mitigation options. Documentation of underlying data in the form of databases, however, can shed transparency into the scientific debate and offer at the same time possibilities for collaboration.

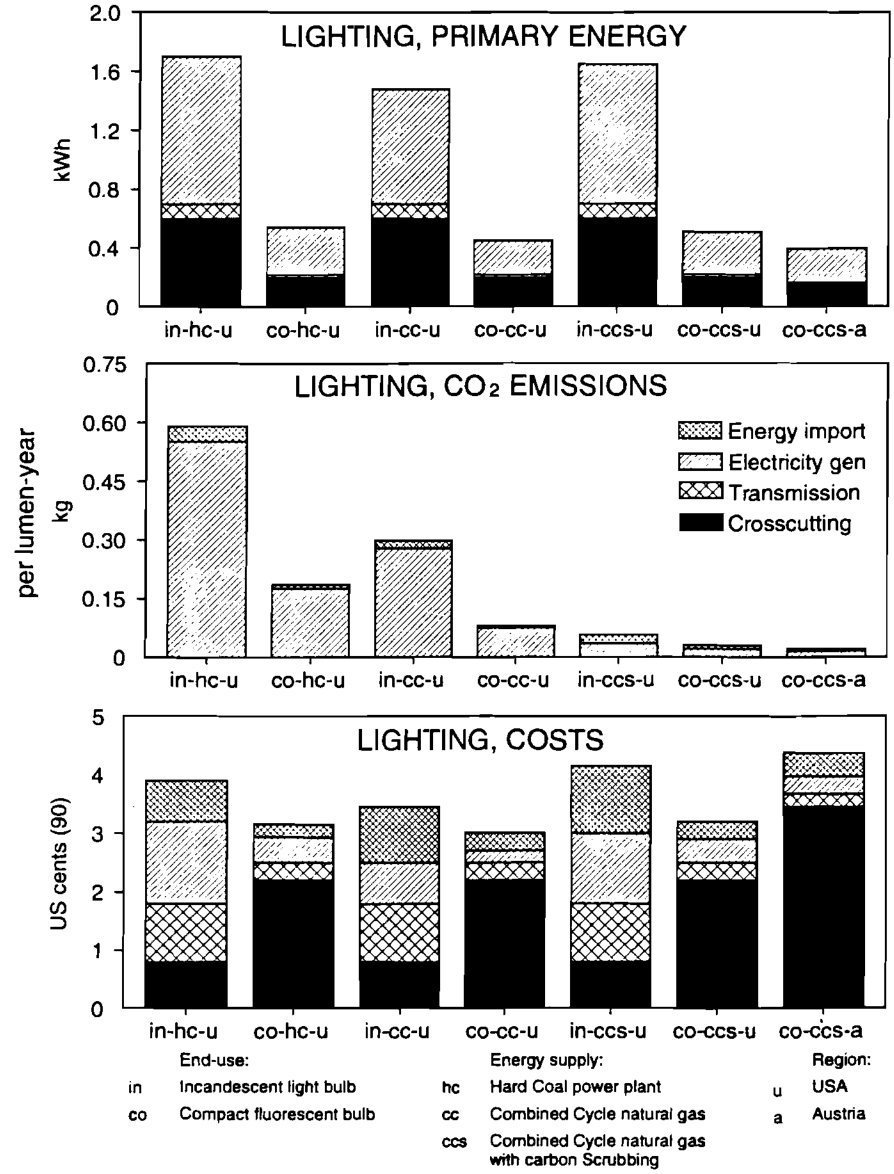

Figure 26. Primary energy requirements, carbon emissions and costs of various energy chains delivering lighting service (per lumen-yr). Source: Grübler based on the IIASA CO2DB.

After a brief introduction by Kaya, Fujii presented results of their joint "New Earth 21" global energy model which has been developed to analyze carbon emission scenarios up to the year 2050. Three final energy demand scenarios ranging between 10 and 15 TWyr/yr fuel and 2.4 to 5.3 TWyr/yr electricity in the year 2050 in combination with four carbon tax scenarios were analyzed (Figure 27). Two of the taxes are constant over time (US$ 100 and 200 per ton of carbon), whereas two are phased in taxes starting at US$ 30 and 60 per ton of carbon in 1990, and ending at US$ 180 and 360 per ton of carbon respectively in 2050. At present, the model does not yet contain energy conservation technologies, but considerable attention has been given to carbon dioxide removal and disposal in depleted natural gas wells, aquifers and the deep ocean. Nuclear energy was assumed to increase from about 350 GWe in 1990

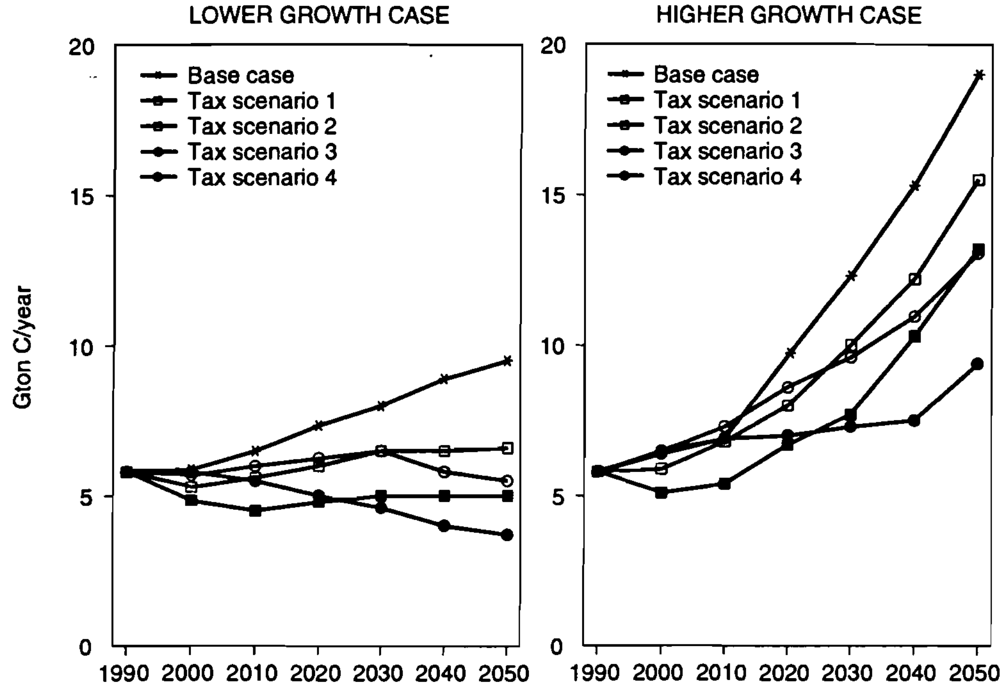

Figure 27. (Net) carbon dioxide emissions for three global energy demand and four carbon tax scenarios analyzed with the New Earth 21 Model. Source: Kaya and Fujii.

to 500 GWe in 2010 in order to remain at this level up to the year 2050. The market penetration of biomass and other renewables is also comparatively low in all scenarios; therefore, the dominance of fossil fuels in the global energy supply continues to prevail well into the next century. Carbon emissions are between 10 and 19 Gigatons of carbon by the year 2050 in the low and high cases without a carbon tax respectively. The latter scenario corresponds to a three-fold increase to the 1990 level emissions. The model shows that a monotone decrease in global carbon dioxide emissions can be achieved with the higher phased-in carbon tax (reaching US$ 360 per ton of carbon by the year 2050). In this scenario carbon emissions are around 3 to 4 Gigatons by the year 2050. Drastic reductions in carbon dioxide emissions can only be achieved technologically with carbon dioxide recovery and subsequent disposal. The subterranean disposal of carbon dioxide is identified as an attractive option; however, this strategy faces limited capacity. Ocean disposal appears as an economic solution in the model calculations, provided deposition costs are less than US$ 100 per ton of carbon.

King reported on the ongoing technology assessment work and resulting policy research issues from the perspective of the World Bank. He discussed the role of international development institutions, the importance of technology assessment and of technology demonstration projects and ensuing research priorities. According to King, the main criteria for demonstration of the feasibility of "greenhouse friendly" technologies in developing countries are institutional and financial, as well as cost effectiveness (e.g., minimum incremental costs per ton of carbon dioxide avoided). Typical examples of global environmental projects are uses of coal bed methane, flare gas, energy conservation measures and sustainable uses of renewable energy. King identified a huge scope for low cost GHG reduction in developing countries which should be financed first, such as energy conservation. However, energy pricing policies may drive a big wedge between economic and financial prices, particularly of efficiency improvement projects. Moreover, there are GHG reduction options with negative incremental costs (i.e., with cost savings). Such projects, however, pose two dilemmas from the perspective of a donor agency. The first one is whether donors can justify grants for projects with negative costs (these - from the perspective of the donor agencies - should be done by the countries themselves anyway) or whether they should just concentrate on expensive projects, ignoring the "free lunches". The second issue is how to encourage countries to change their policies (just financing their incremental cost, i.e., providing compensation, would not provide incentives for this.) According to King, short-term research priorities for technology assessment are for methodologies for calculating incremental costs of projects and sectoral response measures, and for information on costs of alternative energy sources and their associated data uncertainties. Longer-term research priorities are for estimating incremental GHG abatement/avoidance costs across sectors and countries and over long time horizons; for developing cost allocation rules (e.g., in case of joint products); and for studying the efficiency issues of future protocols of the Climate Convention.

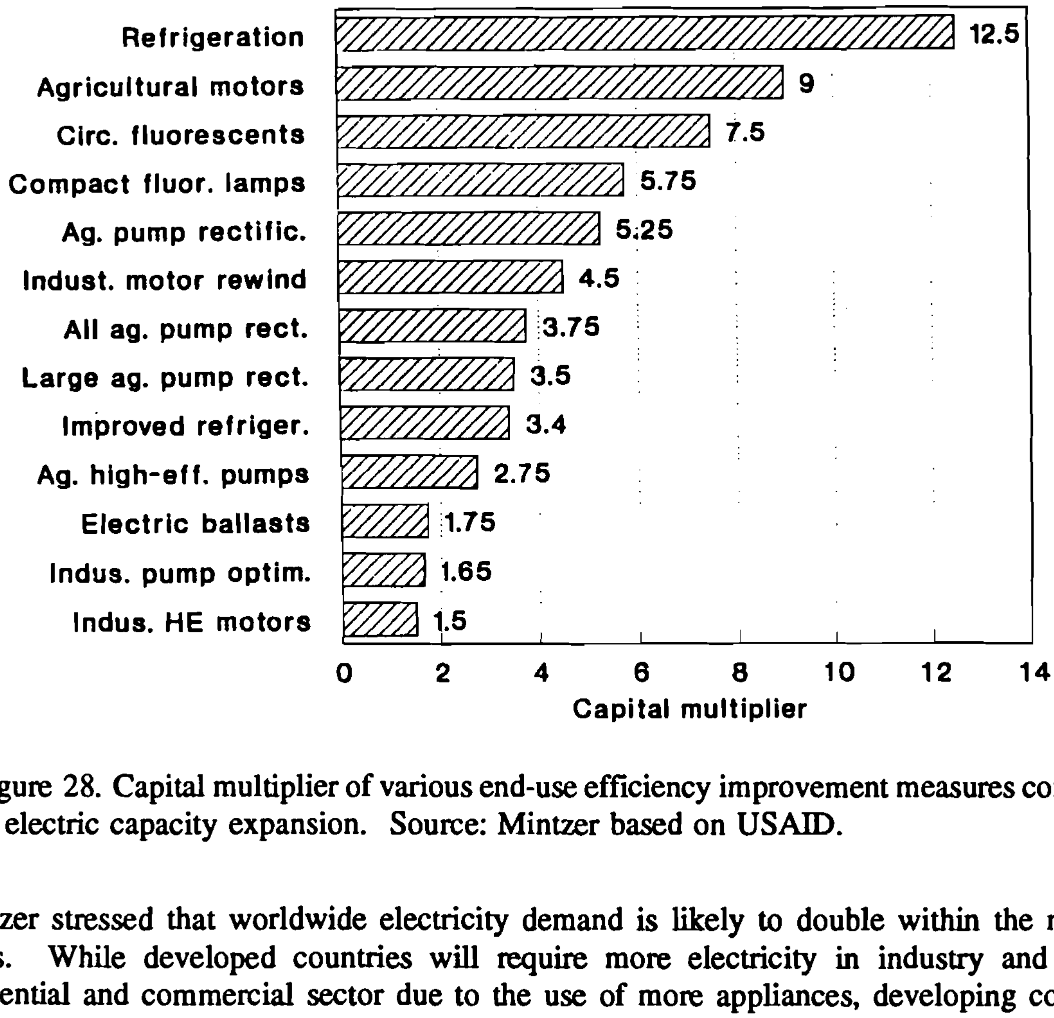

Figure 28. Capital multiplier of various end-use efficiency improvement measures compared to electric capacity expansion. Source: Mintzer based on USAID.

Mintzer stressed that worldwide electricity demand is likely to double within the next 20 years. While developed countries will require more electricity in industry and in the residential and commercial sector due to the use of more appliances, developing countries require more electricity for satisfying their basic needs such as electrification of rural areas and increasing urbanization. Mintzer emphasized that the basic problem is related to the general development strategy, i.e., how to meet economic development objectives with minimum damage to human communities and natural ecosystems rather than to the greenhouse effect. Currently, developing countries have to face a triple bind; capital shortages make it impossible to fulfill supply expansion plans in many countries; declining institutional performance (financial and technical performance of utilities) makes it impossible to deliver adequate electricity services for sustained economic growth, and increasing concerns about environmental degradation complicate expansion plans. Mintzer concluded that improving energy efficiency is the key to survival. The challenge is to plan technological options in a proper institutional and social context, selecting, in particular, technologies with high rates of return and large capital multipliers, i.e., projects where investments in energy savings are up to one order of magnitude cheaper compared to delivering the same energy service via capacity expansion (Figure 28). Partnerships between developed and developing countries should design technologies together to achieve optimum compatibility and share costs for technology development. In addition, obstacles such as institutional barriers, market failures, reluctance to policy changes, etc. have to be overcome.

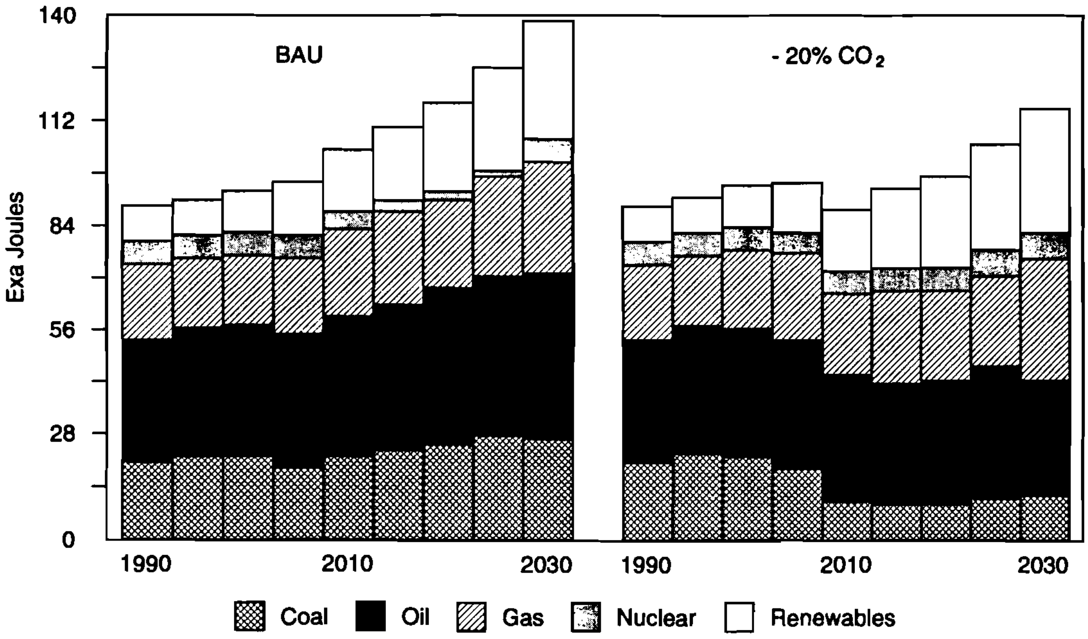

Figure 29. Primary energy consumption in BAU and -20% CO_2 scenarios for the USA. Source: Hamilton.

Hamilton stressed the importance of a careful analysis of mitigation strategies with the help of formal energy models prior to commitments for policy action. As an example of such a model he presented the linear programming model MARKAL. Currently, this engineering type of model is being linked to a macro-economic growth model. The MACRO model incorporates feedback effects of changes in energy technologies options on the level of economic activity and the effect of changes in energy prices on energy demand and on other sectors of the economy. Hamilton illustrated the usefulness of the modeling framework with a case study on the impacts of a 20% reduction of energy-related carbon dioxide emissions in the USA (Figure 29).

Webster reported about the IEA greenhouse gas R&D program which focuses on carbon dioxide emissions from using fossil fuels, particularly in the generation of electricity. The

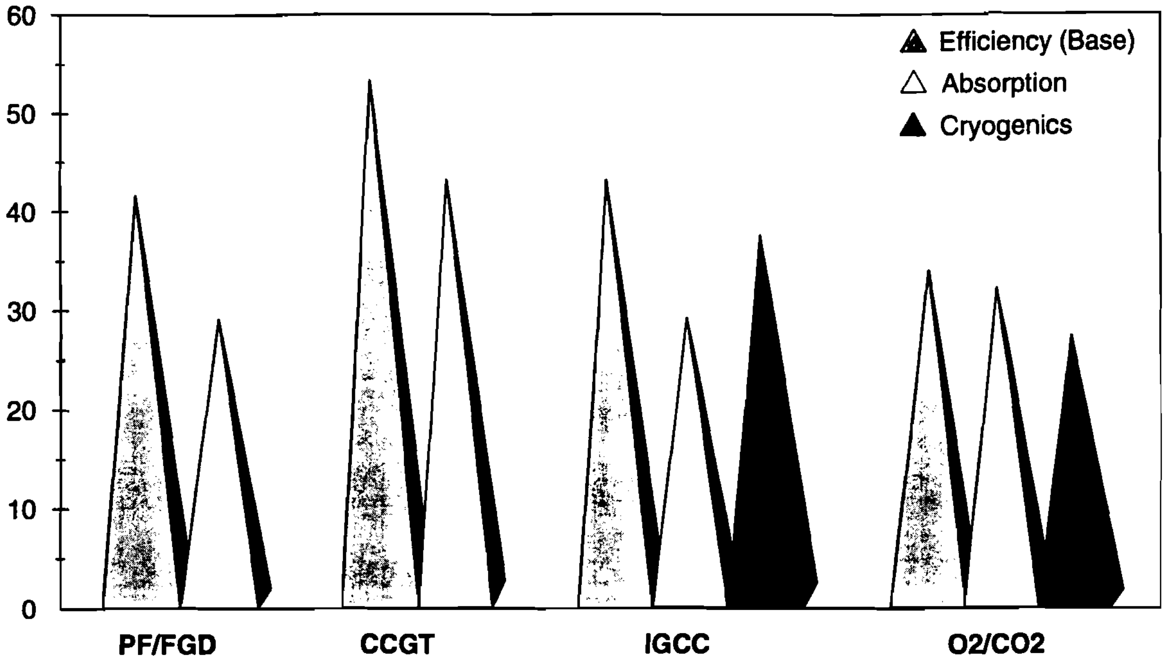

Figure 30. Changes in power plant efficiencies (in %) with different CO_2 removal technologies. Source: Webster.

R&D program is structured into four components: technological and economic assessments, information dissemination, economic studies and proposals. Technical assessments are being performed for electricity generation, carbon dioxide recovery systems and carbon dioxide transport and disposal. Webster presented the first results from the techno-economic assessment work on carbon dioxide recovery from fossil power plants (Figure 30), confirming results presented earlier in Session III on clean fossil technologies and carbon removal.

Moisan reported on scenarios of GHG reduction in France by the year 2010. Due to the large share of nuclear energy in the electricity generation, carbon dioxide emissions currently account for only 32 percent of all GHG emissions (Figure 31). Methane emissions account for about 28 percent, followed by CFCs with 19 percent. The transportation sector is responsible for half of the GHG emissions in France. Two scenarios have been analyzed within a time frame up to the year 2010. A "business-as-usual" (BAU) scenario and an "environment" scenario (based on realistic actions for mitigating GHG emissions such as elimination of landfill emissions, active reforestation, etc.). In the BAU scenario, the total GHG emissions in France stabilize (even slightly decrease) up to the year 2010. In the "environment" scenario, GHG emissions are reduced from the current 324 million tons of carbon equivalent to 246 million tons, i.e., by 24 percent. Most of these reductions are projected to come from a reduction in CFCs and methane emissions, as well as from reforestation. Conversely, it is interesting to note that in the "environment" scenario carbon dioxide emissions rise by some 12 percent over the 1990 to 2010 time horizon. Therefore, although it will be easier to mitigate emissions of other gases, carbon dioxide will become the main issue, justifying consideration of least-regret strategies, energy efficiency improvement policies in particular.

		2010	
GHG emissions[1]	1990	Business-as-usual	Environment
CO_2	103	127	115
CO-NMHO	39	23	21
NO_x	13	17	11
NO_2O	16	16	14
CH_4	90	83	73
CFC	63	46	12
Total emissions	324	312	246
Reforestation	-13	-16	-33
Total net	311	296	213

[1] GWP (direct and indirect effects) considered, 20 year time horizon: CO=7, HC=31, NO_x=30, N_2O=270, all others=IPCC, 1992 Supplement.

Figure 31. Current GHG emissions in France and scenarios up to 2010. Source: Moisan.

Discussion

Katscher mentioned that biomass use and related technologies are included in the IKARUS database; however, land use changes are not considered at present. Laue emphasized that one important issue for development of the IKARUS database was that the contained data can be used by a variety of users with their own model.

Grübler explained that both existing technologies and future designs demonstrated are included in the IIASA CO2DB with an emphasis on those technologies with a significant GHG mitigation potential. Special literature files give more specific information on technologies contained in the database. Both biomass and afforestation options are included in the IIASA CO2DB.

Kaya emphasized that the "New Earth 21" model is still under development and that energy conservation measures, being one of the most promising technologies, will be included in the future.

King stressed that technological change might significantly reduce GHG emissions in developing countries in the long run. In the short run, policy options should concentrate on implementing existing energy saving technologies which, however, is not currently happening or only to a small degree. King emphasized that many economic projects do exist which could lead to lower GHG (and other pollutant) emissions which are not currently being implemented. On the one hand, there could be a policy problem for a number of donors to implemented. On the one hand, there could be a policy problem for a number of donors to finance such projects, which are economical, on a pure grant basis. On the other hand, it would not be desirable to finance exclusively non-economical projects when such economic opportunities go unfunded.

Mintzer emphasized that the principal problem is managing the evolution of the development of economies rather than managing GHG emissions alone. Emphasis should therefore be on meeting the demand growth for goods and services while minimizing long-term environmental damage. Compared to this more principal issue, the abatement of GHG emissions appears as an incremental problem.

General Discussion

Niehaus emphasized the need to consider, in detail, GHG mitigation strategies in terms of their micro- and macro-economic effects. Besides considering impacts on employment, growth of gross national product, etc., he urged, in particular, that attention be paid to the implications of various scenarios on the relations between developed and developing countries. The latter might see the efforts of developed countries on GHG abatement only as an impediment to their own much needed economic and social development.

Niehaus also questioned the timeliness and relevance of research on verification, as was mentioned, for instance, as part of the German IKARUS project. Katscher stressed the importance of verified data with respect to international conventions. Data of GHG emissions for carbon dioxide and even more so for other GHGs are difficult to collect and to verify (also in industrialized countries). However, it is important to attempt to gather these data in order to get a feeling for their accuracy and uncertainty ranges. Nakićenović added that while the issue of verification is important, it constitutes the last step of the analysis cycle. He stressed the need of getting GHG emission inventories at least within the current uncertainty ranges first. The next step should be the development of a country specific strategy for reducing GHG emissions; verification might be the last link in the chain. Putting this issue also into political context, Mintzer emphasized the need for a strategy to find out whether countries fulfill their commitments. In turn, Hamilton stressed that before making any commitment, countries should know the impact of reduction efforts on the energy system and their economies. For such evaluations, formal modeling tools are instrumental.

Spencer mentioned the uncertainties of the future evolution of energy systems and of the economy at large. Large uncertainties persist with respect to the future evolution of prices, technologies and demands. Therefore it becomes very difficult for modelers to look beyond 15 years into the future. For example, the natural gas combined cycle power plant cannot be a single global answer due to the uncertainty of natural gas resource availability and prices. Grübler agreed to the regional importance of natural gas. However, in general, he argued for a perspective of abundance rather than one of traditional resource scarcity. In fact, from an environmental perspective, already known energy reserves and resources threaten to surpass the assimilative capacity of the biosphere. Therefore, efficient use of clean fossil fuels such as natural gas should receive particular attention. In Nigeria, for example, carbon dioxide emissions from flaring (wastage) of natural gas exceed the carbon dioxide emissions generated by natural gas consumption for energy purposes proper. Spencer was critical of a further expansion of natural gas use due to losses from production and transport systems which would have a significant impact on GHG emissions as concluded by a study recently completed by EPRI. While Grübler agreed that leakage rates need to be considered carefully, he emphasized, however, that leakage rates are not inevitable, as they can be controlled by appropriate monitoring and technology.

Moisan emphasized that the main problem is incorporating technological change into the models, especially over the long-term, rather than to focus on the methodological discussion on the issue of macroeconomic versus engineering type technology models. While on the supply side, forecasts within a time period of 30 years correspond approximately to the pace of technological change in this area, demand side technologies develop much faster. Mintzer emphasized that each model corresponds best to a certain task. While bottom-up models are well suited for simulating specific engineering developments over the short to medium-term, top-down models are good for simulating macroeconomic effects, such as changing the general price level. The solution might be to link both model types together. Mori stressed the importance of uncertainty for planning concrete options and raised the question of how uncertainty is going to be treated in different models. Hamilton mentioned that one of the major uncertainties is related to costs of new technologies which, however, can be treated well within models. Kaya explained that uncertainty might be approached by making many computer runs with modest changes of input parameters, but such sensitivity analysis is, however, constrained by both money and time. Mintzer mentioned that an even more dramatic uncertainty is associated with discontinuity and surprises. Therefore, we should deal with the questions of how to use the models under this point of view and what would be the responses to such discontinuous events.

Levine stressed the importance of better representation of the demand side, which with a linear programming model cannot be dealt with easily. Voss responded by mentioning that the largest limitation of the models is to making proper use of them and not their level of representation. The greatest value to be gotten out of a model is to identify the necessity of a strategy from today's perspective, and not to get insight into future conditions. From such a perspective, the importance of uncertainties could also decrease. Kaya pointed out that the major result from a model should be to give insight into the kinds of technologies that should be developed, rather than to limit policy instruments exclusively to carbon taxes.

IPCC/EIS-IIASA International Workshop on Energy-Related Greenhouse Gases Reduction and Removal 1-2 October 1992 to be held at IIASA, Laxenburg, Austria

Sponsoring Organizations:

Energy & Industry Subgroup, Intergovernmental Panel on Climate Change (IPCC/EIS)
International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
Global Industrial & Social Progress Research Institute (GISPRI), Tokyo, Japan
Aeon Group Environment Foundation, Tokyo, Japan
Asahi Glass Foundation, Tokyo, Japan
SECOM S&T Foundation, Tokyo, Japan

PROGRAM

Thursday, October 1

08:30 Registration

09:00 Welcome Address, Peter E. de Jánosi, IIASA Director

09:10 Introductory Address, Keiichi Yokobori, IPCC/EIS Co-chair

09:30 Workshop Background and Overview, Nebojša Nakićenović, IIASA

10:00 Coffee Break

SESSION I: ENERGY END-USE AND CONSERVATION

Chairperson: Y. Kaya

Panel: Y. Ogawa, M. Levine, R. Pischinger, L. Michaelis, Yu. Kononov, I. Bashmakov, S. Gupta, G.C. Pinchera

10:30 Overview and Presentations by Panelists

12:00 General Discussion

13:00 Lunch

SESSION II: RENEWABLES AND ZERO-CARBON OPTIONS

Chairperson: M. Steinberg

Panel: D. Hall, G. Marland, J. Moreira, K. Sipilä, A. Riedacker, G. Sanchez-Sierra, R. Niehaus

14:30 Overview and Presentations by Panelists

16:00	Coffee Break (Computer demonstration: MESSAGE III by M. Strubegger)
16:30	General Discussion
18:00	Reception and Buffet Dinner

Friday, October 2

SESSION III: CLEAN FOSSILS, CARBON REMOVAL AND STORAGE

Chairperson: M. Jefferson

Panel: B. Jones, K. Blok, K. Halsnaes, D. Golomb, H.-H. Rogner, M. Steinberg, K. Yamada

09:00	Overview and Presentations by Panelists
10:30	Coffee Break
11:00	General Discussion
12:00	Lunch

SESSION IV: TECHNOLOGY ASSESSMENT AND R&D PRIORITIES

Chairperson: K. Yokobori

Panel: W. Katscher, A. Grübler, Y. Kaya/Y. Fujii, K. King, I. Mintzer, L. Hamilton, I. Webster, F. Moisan

13:30	Overview and Presentations by Panelists
15:30	Coffee Break (Computer demonstration: IIASA CO2 DB by S. Messner)
16:00	General Discussion
17:00	Buses to Vienna and Airport
17:00	Informal Reception (for those who are staying longer)
18:30	Bus and taxis to Vienna

**IPCC/EIS-IIASA International Workshop
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