Working Paper

Inventory of Greenhouse-Gas Mitigation Measures Examples from the IIASA Technology Data Bank

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WP-92-85
November 1992

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Foreword

The comparative assessment of different strategies for reducing energy-related emissions of greenhouse gases is a major research area within the Environmentally Compatible Energy Strategies (ECS) Project at IIASA. An integral part of this work is the development of a mitigation technology inventory that encompasses a data base called CO2DB. The data base covers the full range of mitigation measures spanning efficiency improvements, conservation, enhanced use of low-carbon fuels, carbon-free sources of energy and other options such as afforestation and enhancement of carbon sinks. The data base includes detailed descriptions of the technical, economic and environmental performance of technologies as well as data pertinent to their commercialization, introduction and diffusion. Additional information includes literature sources, description of salient assumptions and how assessments were made. The primary purpose for the development of the CO2DB is to facilitate the analysis of technological options for reducing the global emissions of greenhouse gases, and in particular for assessing their potentials and costs.

This working paper gives a description of selected technologies from the CO2DB. It also describes some of the most important assumptions behind the technology assessments and gives relevant literature sources. The examples chosen cover the energy system from primary energy production and conversion to energy end-use that results in actual energy services. The paper concludes by giving an example of an energy chain, also called full fuel-cycle analysis, with the associated costs and emissions. This example illustrates possible uses of the CO2DB as a tool for the assessment of mitigation potentials and costs. The data base can facilitate the assessment of carbon dioxide reduction, removal and storage technologies by combining many interrelated technologies together into the energy systems, i.e. to analyze measures throughout the energy chain from primary energy extraction to measures to improve energy. This paper can be used as a technical guide to the technology inventory in conjunction with the manual for the CO2DB software support system (WP-91-31a).

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1. Introduction

The comparative assessment of different strategies for mitigating and adapting to possible global warming is a major area of work within the Environmentally Compatible Energy Strategies (ECS) Project at IIASA. An important product of this work is an integrated data base, CO2DB, with a comprehensive inventory of technological options that might become available globally over long time horizons. The data base covers the full range of technological and economic measures spanning efficiency improvements, conservation, enhanced use of low-carbon fuels, carbon-free sources of energy and other options such as afforestation and enhancement of carbon sinks. The primary purpose of further development of CO2DB and the expansion of the mitigation inventory is to facilitate the analysis of technological options for reducing the global emission of greenhouse gases, in particular for assessing their potentials and costs. This task represents the largest and most important activity of the ECS project.

The inventory of mitigation measures has been implemented as a user-friendly and easily portable PC data base application. It includes those options that have been described in a draft report on *Long-term Strategies for Mitigating Global Warming: Towards New Earth* (Nakićenović *et al.*, forthcoming) and many others taken from the literature. The data base has been specifically designed to provide a uniform framework for the assessment of the ultimate reduction potential of greenhouse gases (GHGs) resulting from the introduction of new technologies over different time frames and in different regions. It includes detailed descriptions of the technical, economic, and environmental performance of technologies, as well as data pertinent to their innovation, commercialization, and diffusion characteristics and prospects. Additional data files contain literature sources and provide space for describing the assessment of data validity and uncertainty ranges.

The purpose of this paper is to present typical examples of the approximately 400 technologies that have been entered into CO2DB and to demonstrate one of its most powerful features, i.e., the possibility of assessing different CO_2 reduction strategies by combining related technologies together to form an "energy chain", sometimes also called the full fuel-cycle analysis. Typically, such a chain includes all steps involved in providing a particular energy service, from primary energy extraction to the end-use conversion. The examples presented here should be understood to be illustrations of the data base content, not as the results of a study analyzing the global greenhouse-gas emission reduction potential, which has been documented in Nakićenović *et al.* (forthcoming). At the same time, our presentation is less uniform than a comparative study of mitigation options. This is most visible in the economic data, where we have used prices in one group of technologies and costs in another. This is less the result of deliberate choice than a reflection of the real data situation. Also, little attempt was made to account for different degrees of optimism shown by the original sources of future performance data. Likewise, this is no guide for the usage of CO2DB on the computer. Messner and Strubegger (1991) provide a full description of the software package and how to use it. This report is based on Version 2 of CO2DB.

The data base software is in the public domain and can easily be made available to other groups, e.g., within the CHALLENGE network which is jointly organized by IIASA and the Institute for Energy Economics and the Rational Use of Energy at Stuttgart University. The aim of the network is to combine different country's studies of GHG reduction strategies to describe and analyze globally comprehensive and consistent scenarios of GHG mitigation.

The examples chosen for this report cover the three major economic sectors: industry, transportation, and residential/commercial. Technologies for steel and cement production, for passenger transport, for lighting, and for refrigeration will be presented and their relative costs and carbon emissions compared.

As an illustration of the data base's ability to calculate chains, we present different combinations of light bulbs and electricity generation systems showing how the choice of an end-use technology influences the economics of power generation.

Appendices summarize the data base formats and all technologies that have been included to date.

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2. End-use Technologies

2.1 Passenger Transportation

2.1.1 Automobiles

For the calculation of annual costs, we assume that the cars considered in this comparison are each driven 15,000 kilometers (approximately 9,300 miles) per year. Vehicle lifetime is assumed to be 12 years. Fuel consumption is defined to reflect driving one-third of the total distance in urban traffic, one-third at a velocity of 90 km (56 miles) per hour, and one-third at 120 km (75 miles) per hour.

Gasoline Car

A passenger car with a 40 kW four-cylinder Otto engine consuming 7.1 liters of gasoline per 100 vehicle kilometers (0.64 MJ/seat-km) with a purchase price (including tax) in Austria of US$(1990) 13,700 (Volkswagen AG, 1991). This vehicle is equipped with a catalytic converter.

Diesel Car

A diesel-powered passenger car with a 47 kW, four-cylinder engine consuming 5.8 liters of diesel per 100 vehicle kilometers (0.53 MJ/seat-km). It costs US$(1990) 15,400 (Volkswagen AG, 1991).

Methanol Car with Otto Engine

According to Heitland *et al.* (1990) the energy consumption of a methanol vehicle with an Otto engine is 84% of a comparable gasoline car which translates into 13.9 liters of methanol per 100 km (0.53 MJ/seat-km). Methanol-powered vehicles are estimated to cost approximately 5% more than a comparable gasoline car, i.e., US$(1990) 14,400 (BMFT, 1984).

Methanol Car with a Diesel Engine

The energy consumption of a methanol vehicle with a diesel engine is 72% of a comparable gasoline car which translates into 12.1 liters of methanol per 100 km (Heitland *et al.*, 1990). This corresponds to 0.46 MJ per seat-km. Like the methanol Otto car, the methanol diesel vehicle is estimated to cost 5% more than a comparable diesel vehicle, i.e., US$(1990) 16,200.

Ethanol Car

Fuel consumption is about 12% less than a comparable gasoline car, resulting in 10.6 liters of ethanol per 100 vehicle kilometers (0.56 MJ per seat-km) when burned in an Otto engine (Geller, 1985). Like the methanol cars, ethanol-powered vehicles are estimated to cost 5% more than a comparable gasoline car, i.e., US$(1990) 14,400.

Compressed Natural Gas (CNG) Car

Natural gas consumption is 0.5 MJ per seat-km. Additional vehicle costs (compared with the 40 kW gasoline engine) of US$ 1,000 are expected due to the 165 bar gas tank (Sperling and DeLucchi, 1989).

Hydrogen Car with Otto Engine

An engine powered with unleaded gasoline can run on hydrogen if some modifications in the engine environment are carried out. Reister and Regar (1992) report about a BMW test vehicle powered with LH2 using 23% less energy that its gasoline powered counterpart. Thus, energy consumption is 0.49 MJ per seat-km. Such a car is estimated to cost 25% more than a comparable gasoline car. This value is taken from a study of Reister and Strobl (1992) who expect a dual-fueled hydrogen car to be 30 to 40% more expensive than a car running exclusively on gasoline.

Hydrogen Car with Fuel Cell

Hydrogen can also be used for powering an electric engine via a fuel cell. In road traffic, fuel cells are expected to have an efficiency around 50%. CO2DB assumes costs of a hydrogen fuel cell car of US$(1990) 120,000. This value is based on the current material costs of a polymer-electrolyte-membrane fuel cell which are approximately US$(1990) 1,500 per kW. (According to Straßer (1992), specific costs could drop to US$(1990) 120 per kW if further research and development is carried out.) Hydrogen is assumed to be stored in liquid form. The engine power output is assumed to be 34 kW and the final energy consumption corresponds to 0.35 MJ per seat-km.

Electric Vehicle with Natrium-Sulfur Battery

Electricity consumption is 13 kWh_{el} per 100 vehicle kilometers (0.12 MJ_{el}/seat-km). The engine has a power output of 34 kW, the maximum velocity is 120 km (75 miles) per hour and the maximum range is 250 km (156 miles). Its price is assumed to be US$(1990) 25,000, including the natrium-sulfur battery if produced by mass production (Sauer, 1991). The battery lifetime corresponds to about 1000 recharging cycles (Reuss, 1991).

Table 2.1 summarizes the data for the cars considered here.

Fuel	*Energy Intensity (MJ/skm)*	*CO_2 Emissions (gCO_2/skm)*	*Inv. Costs (US¢/skm/yr)*	*Var. O+M Costs (US¢/skm)*
Gasoline	0.64	45.6	22.9	0.43
Diesel	0.53	39.1	25.7	0.44
Methanol Otto	0.53	33.9	24.0	0.42
Methanol Diesel	0.46	29.4	27.0	0.42
Ethanol	0.56	43.8	24.0	0.42
CNG	0.50	28.3	24.5	0.42
Liquid H_2	0.49	0.0	28.6	0.42
Liquid H_2, Fuel Cell	0.35	0.0	30-110	0.22
Electricity	0.12	0.0	41.7	0.22

Table 2.1: Energy intensity, carbon dioxide emissions, investment costs, variable operation and maintenance costs of several types of passenger cars. All costs are expressed in US¢(1990).

Variable operating and maintenance (O+M) costs of all cars comprise costs for car maintenance and tires (excluding fuel costs). For cars with internal combustion engines, O+M were derived from the DOT report (1990) and reflect the USA average of gasoline-powered cars. Both types of electric car (conventional battery and fuel cell) are assumed to have half the operating costs of gasoline-powered cars (Mann, 1992). Fixed O+M costs, i.e., insurance, license, and registration fees, are not included here.

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Straßer K., 1992, *Brennstoffzellen für Elektrotraktion*, Wasserstofftechnik III, VDI Berichte 912, VDI Verlag.

Volkswagen AG, *Der neue Golf*, September 1991.

2.1.2 Wide-body Aircraft

The following data for alternatively powered aircraft are based on Lockheed studies on the hydrogen aircraft in the 1970's and early 80's. They have been reported by Brewer (1991) and calibrated to the 1990 level by IIASA's ECS group. All aircraft considered here assume 400 passenger seats, a range of 10,200 km (6,340 miles), and a cruise speed of Mach 0.85. The lifetime of each aircraft is 20 years.

Boeing 747-400

The version 400 of this aircraft type has been operational since 1989 and has an average energy intensity of 0.88 MJ per seat-km (Steiner, 1989). According to Institute of Air Transport (ITA) statistics (1991), its market price was US$ 132.5 million in early 1991.

Liquid-hydrogen Aircraft

This aircraft is powered by liquid hydrogen and has a projected energy use of 0.64 MJ per seat-km. Its principal exhaust gas is water vapor of which it emits 80% more (per seat-km) than a B747-400. Brewer (1991) projects investment costs to be 2.5% lower than a conventional aircraft[1]. CO2DB therefore assumes a price of US$ 129.1 million. CO2DB's introduction date for this type of aircraft is 2020.

LNG Aircraft

According to Brewer (1991), the performance of an aircraft fueled by liquid natural gas is expected to fall between that of a conventional jet and a liquid hydrogen aircraft. The energy intensity is 0.72 MJ per seat-km. Investment costs are projected to be 8% higher than for a conventional aircraft. Therefore, a price of US$ 143.1 million has been assumed. CO2DB's introduction date for this type of aircraft is 2015.

[1] Note the difference between the fuel-cell and hydrogen combustion technology. The much higher material costs of low-temperature fuel cells make the hydrogen cars of the previous section much more expensive than conventional cars. Since aircraft use hydrogen combustion engines, and since hydrogen airplanes are expected to have more favorable technical characteristics (less weight, requiring less thrust), investment costs are even lower here than those of conventional aircraft.

Aircraft	*Energy Intensity (MJ/skm)*	CO_2 *Emissions* (gCO_2/skm)	*Water Vapor* (gH_2O/skm)	*Inv. Costs*[1] *(US¢/skm/yr)*	*Fixed O+M Costs (US¢/skm/yr/yr)*
B747-400	0.88	62.3	25.5	8.32	0.46
LH2	0.64	0.0	46.3	8.11	0.43
LNG	0.72	40.7	30.6	8.99	0.47

(1) assuming that each aircraft is airborne for 50% of its service lifetime.

Table 2.2: Energy intensity, carbon dioxide emissions, water vapor emissions, investment costs, fixed operation and maintenance costs, for three types of aircraft. All costs are given in US$(1990). The aircraft are a Boeing 747-400, a liquid-hydrogen powered 400 passenger aircraft, and an LNG-powered 400 passenger aircraft.

Fixed operating and maintenance costs account for crew, insurance, and maintenance. They were derived using data from major American airlines and correspond to a B747-400 in the first quarter of 1990 (ITA, 1991). Corresponding data for alternatively fueled aircraft are derived form Brewer (1991) and calibrated to current levels.

References

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2.1.3 Railways

The costs of railway systems considered here include the costs of infrastructure. Thus, they cannot be compared directly with the passenger cars and aircraft examined in the previous sections. The vehicle lifetime is 35 years in all cases (EBI, 1992).

Shinkhansen

The first high-speed ground transportation line was introduced in 1964 between Tokyo and Osaka with a maximum speed of 210 km (131 miles) per hour. A Shinkhansen train consists of 16 wagons totaling 1500 passenger seats. The final-energy intensity is about 0.18 MJ per seat-km (Kamada, 1977). For better comparability, our data refer to a hypothetical track in the USA.

Train à Grande Vitesse (TGV)

The first TGV lines began operation in 1981 from Paris to Lyon with a maximum speed of 270 km (169 miles) per hour and a seat capacity of 368. Since 1989, the TGV Atlantique connects Paris with Western France using trains that travel at a maximum speed of 304 km (188 miles) per hour and have a seat capacity of 485 (Lacôte, 1992). The energy consumption is 0.31 MJ per seat-km for the TGV Sud-Est (to Lyon) and 0.28 MJ per seat-km for the TGV Atlantique, respectively. For better comparability, our data refer to a hypothetical track in the USA.

Intercity Express (ICE)

The intercity express was introduced in Germany in 1991. Its maximum speed is between 250 and 300 km (156 and 188 miles) per hour, depending on the guideway. An ICE with 12 wagons (645 seats) has an energy consumption of 0.21 MJ per seat-km at velocities between 250 and 300 km per hour (Jänsch, 1990).

Magnetic-levitation Trains (Maglev)

Several Maglev projects have been investigated, but no commercial operating system exists right now. We present here two sets of data describing the Transrapid system, one for the USA and one for Germany. Cost data for the two data sets vary by up to a factor of 1.8. Due to magnetically levitated transport, the only resistances are related to the magnetic field and aerodynamic drag which results in lower operation and maintenance costs.

(a) USA

The following data are based on an ANL study of integrating high-speed ground transportation systems in the USA (ANL, 1989). The study examines scenarios with a

Shinkhansen-type connection between Los Angeles and San Diego, and with a TGV-type and a Transrapid system between Los Angeles and Las Vegas. Unit investment costs include the vehicles, guideway, and power delivery. Vehicles typically account for less than 20% of the total investment costs. The operating costs include the guideway, vehicle maintenance, and miscellaneous items such as insurance, ticketing, and vehicle crews. Energy costs are excluded.

(b) Germany

The data described here are based on a study of a proposed line between Hamburg and Hannover with two stops in-between (KAT, 1989). The distance of 147 km (92 miles) is covered in 29 minutes (including both stops), corresponding to an average velocity of 300 km (186 miles) per hour. The system considered here includes 11 Maglev trains (328 seats each), the guideway, and stations at costs of US$(1990) 1.91 billion. Electricity consumption is 0.36 MJ per seat-km. Vehicle lifetime is assumed to be 35 years in all cases.

Train	*Avg.Speed (km/h)*	*Energy Intensity (MJ/skm)*	*Inv. Costs (US¢/skm/yr)*	*Fixed O+M Costs (US¢/skm/yr/yr)*
Shinkhansen, USA	204	0.18	83	1.81
TGV, USA	257	0.31	68	1.62
Maglev, USA	296	0.36[(1)]	60	1.00
ICE, Germany	250	0.31	n.a.	n.a.
Maglev, Germany	304	0.36	118	2.06

[(1)] Contradictory data were found in the ANL report; this value reflects the German data.

Table 2.3: Average speed, energy intensity investment costs and fixed operation and maintenance costs for different high-speed trains. All costs are given in US¢ (1990).

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2.2 Residential/Commercial Technologies

2.2.1 Lighting

Light as useful energy can be measured in lumen hours. Here we show investment costs of different lighting systems, derived from the purchase prices of light bulbs. Costs and emissions per unit of service delivered will be shown in Section 3.

The *incandescent light bulb* is the most wide-spread in actual use; the contained gas is nitrogen. Lamp efficiencies can be improved by 10% by using a filament tube with a high-pressure halogen inside an outer enclosure, i.e., a *halogen lamp*.

Fluorescent lamps are up to four times more efficient than incandescent light bulbs. Older types (phosphor lamps) emitted broadly throughout the spectrum, high-efficiency phosphor lamps achieve improved efficacy and color rendering. Costs per lumen are thus substantially reduced. Three different phosphor coatings exist, i.e., Standard (S), Double Coat (DC) and Tri-phosphor (TP).

(a) USA

Table 2.4 summarizes the most important characteristics of commercial light bulbs (McGowan, 1989).

Type of Lamp	*Watts*	*Lumen/Watt*	*Lifetime (1000 hours)*	*Inv. Costs (US¢/lum.)*
Incandescent	60	14.5	1	0.09
Halogen	90	19.4	2	0.23
H-eff. Phosphor (S)	40	78.7	20	0.07
H-eff. Phosphor (DC)	40	81.3	20	0.13
H-eff. Phosphor (TP)	40	81.9	20	0.26
Compact Fluorescent	15	46.7	9	0.90

Table 2.4: Performance and investment costs (calculated from purchasing prices) of several types of lamps. Costs are given in US¢ (1990).

(b) Austria

Type of Lamp	*Watts*	*Lumen/Watt*	*Lifetime (1000 hours)*	*Inv. Costs (US¢/lum.)*
Incandescent	60	14.5	1	0.14
Halogen	50	19.4	2	0.50
Compact Fluorescent	15	60.0	9	3.35

Table 2.5: Performance and investment costs (calculated from purchase prices) of several kinds of lamps. Costs are given in US¢ (1990). Source of cost data: own market research.

(c) India

According to the Mitigation Panel of the U.S. National Academy of Science, the retail price of a compact fluorescent lamp might rise to 5 US¢(1990) per lumen due to high import fees (NAS, 1991).

References

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National Academy of Sciences (NAS), 1991, *Policy Implications of Greenhouse Warming*, Report of the Mitigation Panel, National Academy Press, Washington, D.C., 1991.

2.2.2 Refrigerators

Five different types of 200 liter refrigerators without a freezer compartment were examined, and the data for Denmark are summarized in Table 2.6 (Norgard, 1989). The lifetime of each refrigerator is assumed to be 10 years.

Type of Refrigerator	*Energy Consumption (kWh/liter yr)*	*Incremental Investment Costs (US$/liter)*
Average used in 1973	2.75	0
Average used in 1988	1.75	0
Average sold in 1988	1.35	0
Best available in 1988	0.45	0.16
Advanced Efficiency	0.25	0.29

Table 2.6: Energy consumption and incremental costs of several refrigerators. Costs are given in US$ (1990).

2.2.3 Freezers

Danish data for five 250 liter chest freezers with an internal temperature of —18°C are summarized in Table 2.7 (Norgard, 1989). Freezers with the best available technology in 1988 consumed just one-quarter of the energy an average freezer used in 1973. A further 50% increase in insulation thickness has the potential of reducing energy consumption to 100 kWh per year.

Type of Freezer	*Energy Consumption (kWh/liter yr)*	*Incremental Investment Costs (US$/liter)*
Average used in 1973	2.80	0
Average used in 1988	2.00	0
Average sold in 1988	1.60	0
Best available in 1988	0.72	0.12
Advanced Efficiency	0.40	0.21

Table 2.7: Energy consumption and incremental costs of several freezers. Costs are given in US$ (1990).

References

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2.3 Industry

In 1990, the steel and cement industries released 30% of the total industrial carbon dioxide (Nakićenović *et al.*, forthcoming). We have therefore chosen these two sectors for the discussion in the following section.

2.3.1 Steel Production

In steel plants, three-quarters of the total energy input is used for pig iron production. For this reason, we restrict the description to those technologies that produce liquid steel. All steel plants considered here produce 530 tons of liquid steel per hour. Assuming a capacity factor of 90%, annual steel output is 4.2 million tons. All facilities have a lifetime of 30 years. The hot-metal ratio, i.e., the ratio of liquid steel to total steel oven charge (essentially consisting of liquid steel and scrap) is assumed to be uniformly 75%. In one case only, an electric arc furnace is considered with a charge of 100% scrap. Costs are related to OECD countries; fuel costs are excluded.

Conventional Steel Plant

The conventional plant consists of coke ovens, a sinter plant, a blast furnace, and a basic-oxygen furnace. Coal accounts for more than 95% of the primary energy inputs. The blast furnace operates oil-free and has a capacity of 400 tons of liquid iron per hour. Coke consumption is 550 kg per ton of liquid iron, corresponding to a coal input of 700 kg in the coke ovens. All electricity inputs of steel plant are produced internally. A volume of 35 m^3 (STP) of oxygen and 30 tons of water are required for the production of one ton of liquid steel. Carbon dioxide emissions are equal to 1.8 tons per ton of liquid steel. Investment costs for such plants can differ substantially, depending on the available infrastructure. On the basis of several publications, i.e., S&E (1987), Azimi and Lowitt (1988), the International Iron and Steel Institute (1982), VOEST Alpine (unpublished), and Mannesmann (unpublished), we have estimated investment costs of US$ 280 per ton of liquid steel annual capacity.

Conventional Steel Plant with Additional Energy-saving Technologies (Conventional+EST)

Energy can be recovered in virtually every production phase. Plant performance can be upgraded by implementing devices for hot gas recovery, such as a blast furnace top pressure recovery turbine with an energy-saving potential of roughly 250-300 MJ per ton of crude steel. Moreover, the basic oxygen furnace operates with a net energy surplus if flue gas is recycled. In addition, energy-saving devices can be implemented at the coke and sinter plant, reducing coal consumption by about 10% compared with its predecessor. Investment increases to US$(1990) 300 per annual ton of liquid steel. (IISI, 1982; Maier *et al.*, 1986).

Direct-reduction Plant and Electric Arc Furnace (DRI+EAF)

Various direct-reduction processes exist of which about 90% use a gaseous reductant and only 10% use coal (Steffen and Lüngen, 1988). CO2DB contains two direct-reduction plants, both based on a study by Heinrich *et al.* (1990). One of the plants is based on natural gas, the other plant uses coal as the reductant and energy source. Each plant is connected with an electric arc furnace. The *natural-gas based plant*, DRI(NG)+EAF, consumes about 10 GJ of natural gas and 665 kWh of electricity per liquid ton of steel. Investment costs are estimated to be US$(1990) 165 per ton of liquid steel. The *coal-based process*, DRI(C)+EAF, requires 10.9 GJ of coal and 665 kWh of electricity. Investment costs increase to US$(1990) 200 per ton of liquid steel.

Direct Iron Ore Smelting Processes (DIOS)

In the direct smelting process the ore is prereduced with a reduction gas (this step corresponds essentially to the direct reduction process). In a second stage, however, the sponge iron is melted either with coal (e.g., in the COREX process) or electricity (plasmamelt process) (Ottow *et al.*, 1989).

Coal-based DIOS and Basic Oxygen Furnace (DIOS+BOF)

Currently, much attention is drawn to the direct smelting COREX process. The first commercial plant became operational in December 1989 with a capacity of 300,000 tons of pig iron per year. The COREX process reduces iron ore "by the way": the export gas, 1500 — 1800 m^3 per ton of pig iron with a lower heating value of 7,000 kJ/m3 (35% CO, 20% H_2 and 45% CO_2; sulphur content less than 70 ppm), can be used in other steel plant facilities or sold for electricity generation (for the calculations here, the credit of the export gas is assumed to be US$(1990) 30 per ton of liquid steel produced). If linked to a basic-oxygen furnace, the net energy consumption per unit of liquid steel is about 12 GJ, and oxygen consumption is 500 m^3. All electricity is assumed to be produced within the plant. The COREX process offers a great economic advantage over the conventional process since cheap, low-quality coal can be used. Investment costs are US$(1990) 215 per ton of liquid steel (Pühringer *et al.*, 1991; Steinmetz *et al*, 1986).

Electricity-based DIOS Process and Basic-oxygen Furnace (DIOS(el)+BOF)

The plasmamelt process requires between 50 and 100 kg coke and 200 kg of coal per ton of pig iron. Most of the energy consumed is electricity (1040 kWh). Obviously, low-cost electricity is an economic prerequisite for plasmamelting. However, globally, only one plasma melter is operating in a modified process in Sweden with a very low capacity of 8 tons per hour (Ottow *et al.*, 1988). CO2DB contains a plasma melter which is connected to a basic-oxygen furnace.

Electric Arc Furnace Smelting 100% Scrap (EAF)

The electric arc furnace smelts a burden of 100% steel scrap or mixtures of scrap with sponge iron or — to some extent — liquid pig iron. Typically, 75% of the energy input is electricity, the remainder consisting of natural gas, oxygen, carbon, etc. The energy consumption of electric arc furnaces is about 600 kWh_{el} per ton of liquid steel. This comparatively low energy requirement is due to the energy embodied in steel scrap. Investment costs are about US$(1990) 100 per annual ton of liquid steel (Azimi and Lowitt, 1988).

Iron Reduction with Hydrogen and Electric Arc Furnace (DRI(H_2)+EAF)

Hydrogen can be used as a reductant of iron. This process can be realized by either a direct reduction process or a direct smelting process. The primary emission is water vapor, carbon dioxide emissions are practically zero. CO2DB contains a direct reduction process . As a first-order estimate, energy consumption and costs are identical to the process based on natural gas.

References

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Heinrich P., Knop K., Madlinger R., 1990, *Stand und Entwicklungspotential der Direktreduktion mit dem HYL-III-Verfahren*, Stahl und Eisen 110, No.8.

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VOEST Alpine (1992), personal communication.

Plant Type	*Primary Energy (GJ/tls)*	*Electricity (kWh/tls)*	*CO_2 Emissions ($tonCO_2/tls$)*	*Inv. Costs (US$/tls/yr)*	*Fixed O+M Costs (% of Inv.)*	*Variable O+M Costs (US$/tls)*
Conventional	17.9	0	1.8	280	11	100
Conventional+EST	16.0	0	1.6	300	11	100
DIOS(C) + BOF	22.8 (12)	0	1.4	215	10	100
DIOS(el) + EAF	7.7	1040	0.8 — 1.8	n.a.	n.a.	n.a.
DRI(NG) + EAF	10.0	665	0.5 — 1.2	165	10	100
DRI(C) + EAF	10.9	665	1.1 — 1.7	200	10	100
DRI(H_2) + EAF	10.0	665	0.0	165	10	100
EAF	0.2	600	0.0 — 0.6	100	9	140

Table 2.8: Primary energy intensity, externally produced electricity consumption, carbon dioxide emissions, investment costs, fixed operation and maintenance costs (labor, maintenance), and variable operation and maintenance costs (iron ore, alloys, scrap, electrodes, etc.) per ton of liquid steel (tls). The figures are for the following plants: a conventional steel plant, a conventional steel plant with additional energy saving technologies, a direct iron ore smelting process with a basic-oxygen furnace (DIOS(C)+BOF), a plasma melter with an electric arc furnace (PLASMA+EAF), a direct reduction plant fired with natural gas with an electric arc furnace DRI(NG)+EAF, a coal-based direct reduction plant with an electric arc furnace (DRI(C)+EAF), a hydrogen-based direct reduction plant with an electric arc furnace (DRI(H_2)+EAF), and an electric arc furnace smelting scrap (EAF).

2.3.2 Cement Production

Essentially two different processes for cement production exist, the dry and the wet process. The latter permits more homogenization of kiln feed and requires less ground raw materials than the former. Moreover, plant design is simpler. The difference in energy consumption is considerable. The wet process requires about 5.0-6.0 GJ per ton of clinker, the dry process 3.4-5.0 GJ. Using a pre-heater, the energy consumption of the dry process can be reduced to 3.1-4.2 GJ per ton of clinker (Locher and Kropp, 1989). In comparison, US energy intensity per ton of cement was 4.1 GJ and 133 kWh of electricity in 1988. The theoretical minimum is 1.75 GJ per ton of clinker (Tresouthick and Mishulocich, 1991).

Table 2.9 gives an overview of several cement production technologies and fuels. Costs reflect the OECD average (Maier *et al.*, 1986); energy costs are excluded. Note that energy intensity is related to one ton of cement, consisting of 95% clinker and 5% gypsum.

References

Locher F.W. and Kropp J., 1989, Cement and Concrete, *Ullmann's Encyclopedia of Industrial Chemistry*, Vol.A5, VCH Verlagsgesellschaft mbH.

Maier M. *et al.*, 1986, *Rationelle Energieverwendung durch neue Technologien Band 2,* Praxiswissen aktuell, Verlag TUV Rheinland.

Tresouthick S.W. and Mishulocich A., 1991, *Energy and Environmental Considerations for the Cement Industry, Energy and Environment in the 21st Century*, MIT Press, Cambridge, Massachusetts.

Process Type	*Fuel*	*Primary Energy (GJ/ton)*	*CO_2 Emissions ($kgCO_2/ton$)*	*Inv. Costs (US$/ton/yr)*	*Fixed O+M Costs (% of Inv.)*	*Variable O+M Costs (US$/ton)*	*LT (yr)*
Wet	Coal	6.6	1352	depreciated	4	15	30
Dry	Coal	5.4	1239	250	4	15	30
Dry-PH	Coal	4.1	1116	263	4	15	30
Dry-HE	Coal	3.7	1079	268	4	15	30
Dry-HE-CS	Coal	7.0	10	375	4	15	30
Dry	Nat.Gas	5.4	1036	250	4	15	30
Dry-HE	Nat.Gas	4.1	964	268	4	15	30

Table 2.9: Characteristic quantities for cement production processes. In all cases, clinker content is assumed to be 95% per ton of cement. The process types are as follows: wet process, dry process, dry process with pre-heater (dry-PH), high efficiency dry process (dry-PH; including pre-heater, rolling mills, and computer control) and high efficiency dry process with carbon scrubbing (dry-HE-CS). It is assumed that the electricity source corresponds to the fossil fuel used. CO_2 emissions include 770 kg CO_2 per ton of clinker generated during calcination.

3. Fuel and Power Production

3.1 Hydrogen Production

Steam Reforming of Natural Gas

The plant described here represents a large-scale facility producing 100,000 m^3 of hydrogen per hour. Before entering the tubular reformer, natural gas is desulfurized and blended with water vapor. The synthesis gas leaves the reformer, is cooled down and enters the shift converter. In a pressure swing absorption unit waste gases are separated from hydrogen.

The following data have been taken from Scholz (1992).

Input:	Natural Gas, m^3 (STP)/h:	42,880 at 40 bar
	Water, t/h:	58
	Air, m^3/h:	188,500
Output:	Hydrogen, m^3 (STP)/h:	100,000 at 30 bar
	Electricity, MW:	15
	Waste Water, t/h:	11.3
	Waste Gas, m^3 (STP)/h:	239,930
	CO_2, %	18.14
	CO, ppm	80
	CH_4, ppm	100
	NO_X, ppm	50
	N_2, %	62.19
	SO_2, ppm	< 1 ppm
	O_2, %	1.23
	H_2O, %	18.42
Costs:	Investments, million US$(1990):	84.1
	Fixed O+M, % of Investments:	7
	Variable O+M, US¢(1990)/kWh:	0.05

Electrolysis of Water

Electrolyser Inc., Toronto is the only manufacturer of uni-polar cells. The advantage of this cell type is its robustness. Since the cells are arranged in parallel, they can be easily maintained or renewed, if necessary, without interruption of the process (Häussinger *et al.*, 1989). The following data are from the producer (Electrolyzer Corporation, 1990).

Input:	Electricity, MW_{el}:	430
	Purified Feedwater, t/h:	1
	Cooling Water, t/h:	24
Output:	Hydrogen (99.9%), m^3 (STP)/h:	1000 at 1.013 bar
	Oxygen (99.7%), m^3 (STP)/h:	500
Costs:	Investments, million US$(1990):	1.42
	Fixed O+M, % of Investments:	4

Fuel Type	*Output ($1000m^3$/h)*	*Effic. (%)*	*CO_2 Emissions (gCO_2/MJ)*	*NO_X Emissions (gNO_X/MJ)*	*CH_4 Emissions (gCH_4/MJ)*	*Inv. Costs (US$/kW)*
Natural Gas	100	81.2	85.5	0.017	0.02	280
Electricity	1	65.1	0.0	0.0	0.0	474

Table 3.1: Two hydrogen production processes, one based on coal and one based on natural gas. All costs are given in US$(1990).

References

Electrolyzer Corporation LTD. (EC), 1990, *Electrolytic Hydrogen Plants*, Publication TECL EHP0187, Canada.

Häussinger P., Lohmüller R., and Watson A.M., 1989, Hydrogen, *Ullmann's Encyclopedia of Industrial Chemistry*, Vol.A14, VCH Verlagsgesellschaft mbH.

Scholz W.H., 1992, Verfahren zur großtechnischen Erzeugung von Wasserstoff und ihre Umweltproblematik, Linde, *Berichte aus Technik und Wissenschaft 97/1992.*

3.2 Methanol Production

Modern industrial methanol manufacturing consists of a three-step process: synthesis gas production, methanol synthesis, and distillation. The feedstock is natural gas. The technical data for a methanol plant have been taken from Schnurnberger (1986), data about cost and plant size correspond to a project in Venezuela (*Oil and Gas Journal*, 1991).

Input:	Natural Gas, m^3 (STP)/h:	85,680
	Electricity, kW_{el}:	1.06
Output:	Methanol, t/h:	76.5
	Waste Water, t/h:	10.7
	Waste Gas, m^3 (STP)/h:	14,306
Costs:	Investments, million US$(1990):	290
	Fixed O+M, % of Investment:	4.5

References

Oil and Gas Journal, 1991, March 18, p135.

Schnurnberger W., 1986, Wasserstoff als Rohstoff, in: *Wasserstoff als Energieträger*, Winter C.J., Nitsch J. (eds.), Springer Verlag.

3.3 Electricity Generation

3.3.1 Renewables

Hydropower

In its study on energy and climate, the Enquiry Commission of the German Parliament (1990) describes the following data for run-of-river hydropower stations. It was commercially available in 1985, the technical lifetime is 50 years, the time availability is 80%, and the capacity factor is 55%. Construction time is two years in both cases.

Capacity	0.1-10 MW	>10 MW
Investment Costs, US$(1990)/kW	3480	2480
Fixed O+M Costs, US$(1990)/kW/yr	42	30

Wind Energy

(a) USA

The following table indicates 1988 cost data and the potential for their future reduction in the USA (Department of Energy, 1990). The system lifetime is assumed to be 30 years in all cases. All costs are given in 1990 currency. Data are based on average wind velocities of 5.5 m/s.

Year	*Investment Costs (US$/kW)*	*O+M Costs (c/kWh)*	*Capacity Factor (%)*
1988	1215	1.9	20
2000	1025 — 1080	1.1 — 1.3	30 — 28
2010	920 — 1040	0.9 — 1.0	33 — 29
2020	865 — 990	0.6 — 0.9	34 — 30
2030	810 — 920	0.6 — 0.9	35 — 31

Table 3.2: Projected performance of wind-derived electricity in the USA based on 1988 figures.

(b) Germany

The Enquiry Commission of the German Parliament (1990) estimates the prospects of German wind technology as follows. The data are based on a rated power output of 200 kW, time availability of 95%, capacity factor of 20 to 28%, and wind speeds between 4.5 and 5.5 m/s. All costs are given in 1990 currency. Investment costs include infrastructure.

Time	*Inv. Costs (US$/kW)*	*Fixed O+M Costs (US$/kW/yr)*	*Variable O+M Costs (US¢/kWh)*
2000	1120	45	0.05
2020	1070	45	0.05

Table 3.3: Projected performance of wind-derived electricity in Germany.

(c) Denmark

The following average data for eight Danish windfarms currently operating with a total installed capacity of 42.7 MW is derived from Bernstein (1992).

Number of Units	240
Average Unit Size, kW	178
Investment Costs, US$(1990)/kW	1200
O+M Costs, US$(1990)/kW/yr	19.2
Capacity Factor, %	22.8
Technical Availability, %	92
Lifetime, yr	20

Photovoltaics

The Solar Energy Research Institute has projected the performance of photovoltaic (PV) systems located in the USA as follows (Department of Energy, 1991):

Year	*Investment Costs (US$/kW)*	*O+M Costs (¢/kWh)*	*Capacity Factor (%)*
1988	7560	0.5	25.0
2000	2510 — 3780	0.2	27.5
2010	1755 — 2270	0.2	27.5
2020	1240 — 1510	0.2	27.5
2030	1005 — 1270	0.1	27.5

Table 3.4: Projected performance of photovoltaic electricity in the USA based on 1988 figures.

References

Bernstein M.A., 1992, *Costs and Greenhouse Gas Emissions of Energy Supply and Use*, The World Bank.

Department of Energy, 1990, *The Potential of Renewable Energy, an Interlaboratory White Paper*, prepared for Office of Policy, Planning and Analysis, U.S.Department of Energy.

Enquiry Commission of the German Parliament, 1990, *Energie und Klima, Band 3, Erneuerbare Energien*, Economica Verlag.

3.3.2 Fossil Fuel Power Plants

Coal-fired Plant

Hendriks *et al.* (1989) provide data of a pulverized-coal power plant with a steam boiler. The capacity is 600 MW_{el} and the efficiency is 40%. The investment costs are US$(1990) 1088/kW and O+M costs are US$(1990) 40/kW/yr. Carbon dioxide emissions are 0.85 kg/kWh.

Coal-fired Plant with Chemical Carbon Scrubbing

The carbon dioxide concentration in the exhaust gas can be reduced in a chemical absorption process using a monoethanolamine (MEA) solution. In comparison with the coal plant just described, net capacity drops to 440 MW_{el} and the efficiency to 29.3%. Investment costs increase to US$(1990) 1980/kW and O+M costs to US$(1990) 94/kW/yr. Carbon emissions are 0.08 kg/kWh, a reduction of 90% (Hendriks *et al.*, 1989).

Coal-fired Plants in Developing Countries

To show cost differences between countries, we present the following regional data for coal power plants according to Bernstein (1992). Costs are given in US$(1990). Since no thermal efficiencies are given in the original, no carbon emissions could be calculated.

Country	*Inst.Cap.* *(MW_{el})*	*Unit Avail.* *(%)*	*Life Time* *(yr)*	*Inv.Costs* *(US$/kW)*	*O+M Costs* *(US$/kW/yr)*
Costa Rica	47.3	70	30	1334	158
Jamaica	61	66	30	1401	27
Thailand	225	75	25	1233	28
India	3×200	41	30	1172	177[2]
India	2000[1]	68	30	607	51[2]
Philippines	2×300	70	30	1043	20

[1] 5×200 MW + 2×500 MW
[2] includes interest paid during construction

Table 3.5: Installed capacity, technical availability, lifetime, investment costs, and operation and maintenance costs of coal power plants in several developing countries.

Gas Turbine Plants

Bernstein (1992) reports the following data, originating from the National Power Cooperation in the Philippines.

Capacity	30 MW
Capacity Factor	70%
Thermal Efficiency	30%
Lifetime	20 years
Investment Costs	391 US$(1990)/kW
O+M Costs	10 US$(1990)/kW/yr

Combined-cycle Plant, Philippines

The same source, Bernstein (1992), describes a combined-cycle (CC) plant, also for the Philippines.

Capacity	300 MW
Capacity Factor	70%
Thermal Efficiency	46%
Lifetime	20 years
Investment Costs	577 US$(1990)/kW
O+M Costs	9.7 US$(1990)/kW/yr

Combined-cycle Plant, Netherlands

Hendriks *et al.* (1989) studies the performance of a 600 MW_{el} combine-cycle natural-gas power plant with additional energy input into the steam cycle. The efficiency is reported as 48%, investment costs are US$(1990) 680/kW, and O+M costs US$(1990) 16/kW/yr. Carbon dioxide emissions are 0.40 kg/kWh.

Natural Gas-fired Power Plant with Chemical Carbon Scrubbing

If the natural gas-fired power plant is equipped with a monoethanolamine-based carbon scrubber, net capacity is reduced to 520 MW_{el} and plant efficiency drops to 41.6%. Investment costs increase to US$(1990) 1020/kW and O+M costs to US$(1990) 35/kW/yr (Hendriks *et al.*, 1989). Carbon emissions are reduced to 0.04 kg/kWh which translates into a carbon dioxide reduction of 90%.

Integrated Gasifier Combined-cycle Plant (IGCC)

The system consists of a gasifier, a particulate and sulfur removal system, a combustion turbine burning synthesis gas, and a steam turbine powered by the waste heat of the gas turbine exhaust and gasifier. An example of such a plant is given by Hendriks *et al.* (1989): net power output is 711 MW_{el}, the efficiency is 43.6%, investment costs are US$(1990) 1120/kW, and annual operation and maintenance costs are US$(1990) 44/kW/yr. Carbon dioxide emissions are 0.76 kg/kWh_{el}.

Integrated Gasifier Combined-cycle Plant (IGCC) with Physical Carbon Scrubbing

The same IGCC plant can be equipped with a carbon scrubber (Hendriks *et al.*, 1989). Using a physical absorption process with a selexol solvent, the following changes in performance are expected. Net power output will drop to 621 MW, efficiency to 38.1%, investment costs will rise to US$(1990) 1573/kW, and annual operation and maintenance costs will be US$(1990) 58/kW/yr. Carbon dioxide emissions are 0.091 kg/kWh_{el}, a reduction of 88%.

IGCC Power Plants in India

Bernstein (1992) lists cost data for several IGCC power plants under construction or in operation in India. Costs are given in US$(1990). The unit availability is 80% and the lifetime in 30 years in all cases.

Inst. Cap. (MW_{el})	*Inv. Costs (US$/kW)*	*Gasification Process*
496.2	2509	Texaco
564.4	2201	Shell
577.2	1529	KRW
585.7	1578	Moving Bed

Table 3.6: Installed capacity, investment costs, and type of gasification process for Indian IGCC plants.

3.3.3 Fuel Cells

A fuel cell is an electrochemical cell which converts the chemical energy of a fuel directly to electrical energy. Hydrogen and hydrogen-rich synthesis gases derived from natural gas or coal are used as fuel. Air or oxygen serve as the oxidant. While low-temperature fuel cells are used in spacecraft and prototype motor vehicles, high-temperature fuel cells are envisaged for stationary power generation.

The Molten-carbonate Fuel Cell (MCFC)

Molten carbonate fuel cells operate at temperatures of 650°C. The electrolyte is made of molten salts. Clean hydrocarbons can be fed directly into the cell where they are converted to hydrogen, carbon dioxide, and carbon monoxide. Internal reforming of the synthesis gas results in hydrogen and carbon dioxide. Hydrogen is oxidized by carbonate ions to water vapor that drives the shift process.

Nitrogen oxide emissions are almost entirely eliminated due to the electrochemical scrubbing characteristics of the MCFC cathode, through which all of the stack gases would exit (Appleby and Foulkes, 1989). Meanwhile, continuous operating times of close to 10,000 hours have been recorded. Current test programs are set to demonstrate 40,000 hours of reliable electricity production.

Solid-oxide Fuel Cells (SOFC)

These operate at temperatures close to 1000°C. They use a solid electrolyte, a mixture of yttria and zirconia. Therefore, there are no problems related to liquid-fuel handling and corrosion. The fuel gas is hydrogen or a hydrogen-rich synthesis gas. Since oxygen is the only oxidant, no recirculation of carbon dioxide is required. Consequently, SOFCs are technically much simpler than MCFCs.

System	*Net Cap. (MW)*	*Eff. (%)*	*LF (%)*	*LT (yr)*	*Inv. Costs ($/kW)*	*Fixed O+M ($/kW/yr)*	*Variable O+M (¢/kWh)*
MCFC(C)	650	50.5	75	30	1650	16.5	1.05
MCFC(NG)	200	52.9	75	30	1150	15.0	1.00
SOFC(C)	165	49.7	75	30	1240	12.4	0.90
SOFC(NG)	165	54.2	75	30	860	11.2	0.85

Table 3.7: Net capacity, thermal efficiency, load factor, lifetime, investment costs, fixed operating and maintenance costs, and variable operation and maintenance costs of a molten carbonate fuel cell and a solid oxide fuel cell. Each fuel cells is powered with coal (C) or natural gas (NG).

References

Appleby A.J. and Foulkes F.R., 1989, *Fuel Cell Handbook*, Van Nostrand Reinhold, New York, USA.

Bernstein M.A., 1992, *Costs and Greenhouse Gas Emissions of Energy Supply and Use*, The World Bank.

Hendriks C.A., Blok K., and Turkenburk W.C., 1989, The Recovery of Carbon Dioxide from Power Plants, *Climate and Energy*, Kluwer Academic Publishers, The Netherlands.

3.3.4 Nuclear Electricity Generation

Light Water Reactors

(a) USA

Investment costs of a 1100 MW light water reactor in the USA were $3,060 per kW at the end of the 80's. Total O+M costs averaged 1.24 US¢(1990)/kWh in 1985, if based on a plant life of 30 years and a capacity factor of 70%. The EPRI target for investment costs is US$(1990) 1870 per kW due to an expected higher construction labor productivity, shorter construction period, streamlined licensing process, etc. (Williams and Larson, 1989). Fuel costs are 1.02 US¢(1990)/kWh.

(b) Germany

The Enquiry Commission of the German Parliament (1990) expects the future performance of light water reactors as follows.

Commercial Availability, Year	2000	2020
Net Capacity, MW	1258	1390
Investment Costs[(1)], US$(1990)/kW	1648	1493
Fixed O+M Costs, US$(1990)/kW/yr	40.8	36.9
Variable O+M Costs, US¢(1990)/kWh	0.05	0.05
Time for Construction, yr	5	5
Technical Lifetime, yr	35	35
Time Availability, yr	80	80
Technical Availability, yr	80	80

[(1)] including decommissioning costs

(c) Japan

The management handbook of Japanese Electric Utilities (Tokyo Electric Power Company, 1991) includes data for an existing and a future light water reactor.

Commercial Operation, Year	Today	1997
Net Capacity, MW	1067	1311
Gross Capacity, MW	1100	1356
Investment Costs, US$(1990)/kW	2210	2070
Fixed O+M Costs, US$(1990)/kW/yr	49.4	49.4
Decommissioning Costs, US¢(1990)/kWh	0.117	0.117
Fuel Cost, US¢(1990)/kWh	0.87	0.87
Construction Time, yr	5	4
Lifetime, yr	30-40	40
Time Availability, %	70	n.a.
Technical Availability, %	80	n.a.

References

Enquiry Commission of the German Parliament (GEC), 1990, *Energie und Klima Band 5, Kernenergie*, Economica Verlag.

Tokyo Electric Power Company (TEPCO), 1991, *Management Handbook of Japanese Electric Utilities*.

Williams R.H. and Larson E.D., 1989, *Expanding Roles for Gas Turbines in Power Generation, Electricity, Efficient End-Use and new Generation Technologies, and their Planning Implications*, Lund University Press.

4. Chain Calculations

A powerful instrument for the systems analysis of mitigation measures is the ability of CO2DB to combine individual technologies to form energy chains. Each technology has well-defined inputs and outputs. If the input to one technology is matched by the output of another, these two technologies can be linked. In this way, if a series of technologies describing a complete system from primary energy extraction to end-use is combined into a chain, total quantities (costs, emissions, energy consumption) can be calculated. In this section, we show several chains related to lighting.

4.1. Lighting

To study alternative lighting methods, we compare conventional lighting, as represented by incandescent bulbs, and the prevailing pattern of electricity generation, with new technologies. To do this efficiently, we have included a dummy technology in CO2DB describing the actual power generation mix of the U.S. in the year 1990, i.e., 53% coal, 4% oil, 11.6% natural gas, and 31.4% zero-carbon fuels. The average conversion efficiency was 36.3%, and average carbon dioxide emissions were 0.54 kg CO_2 per kWh. We assume electricity generation costs of 3.5 US¢/kWh, reflecting the U.S. average (National Academy of Sciences, 1991). Thus, our reference chain consists of this power generation mix, coupled with an incandescent 60 Watt light bulb (ILB) providing an output of 870 lumen (as described in Section 2.2.1). This lighting system consumes 1.9 kWh primary energy per lumen year (lmyr) emitting 0.39 kg CO_2. Total costs are 4.2 US¢(1990) per lumen year.

To analyze the performance of alternative systems providing the same service, we vary the front end of our original energy chain using the data for a coal power plant, a combined-cycle (CC) power plant fired by natural gas, a coal power plant with a chemical carbon scrubber, and a nuclear power plant. The variability on the end-use side is represented by replacing ILBs by compact fluorescent light bulbs (CFLs). The results of CO2DB's chain calculations are shown in Figures 4.1—4.3.

The results show that the exclusive use of coal power plants would reduce primary energy consumption by about 10%. At the same time, CO_2 emissions would increase by 50% and costs would remain approximately constant.

In an energy system based primarily on natural gas, a dominant role might be played by CC power plants. In comparison with our reference system, a gas-fired CC plant decreases CO_2 emissions and primary energy intensity by 24% each. This strategy also results in a decrease in costs of more than 30%.

A bigger decrease of carbon dioxide emissions can be achieved by retrofitting coal power plants with carbon scrubbers. In our example, CO_2 scrubbers reduce emissions by more than 65% compared with the reference case. However, primary energy intensity and costs increase by 25% and 40%, respectively.

A hypothetical, all-nuclear electricity generation system eliminates the carbon emissions of our lighting system altogether, incurring costs that are a few percent higher in comparison with the reference system.

The impact of using compact fluorescent light bulbs instead of conventional incandescent bulbs on carbon emissions is comparable with introducing carbon scrubbers into the reference system, i.e., it reduces emissions by more than 60% to 0.12 $kgCO_2$/lmyr. This strategy also results in by far the lowest primary energy consumption. Despite the almost four-fold lamp costs compared with the incandescent bulb, total costs decrease by 25%.

To illustrate how costs of technologies can vary substantially between different regions, we show three identical lighting systems (each consisting of a compact fluorescent lamp, electricity transmission and distribution, electricity generated in a pulverized-coal power plant, and coal-mining) for the U.S.A, Austria, and India in Figure 4.4. While the costs of electricity generation and transmission are kept constant, the costs of light bulbs and coal-mining differ. Compared with the U.S.A., total costs are more than 35% and 70% higher in Austria and India, respectively.

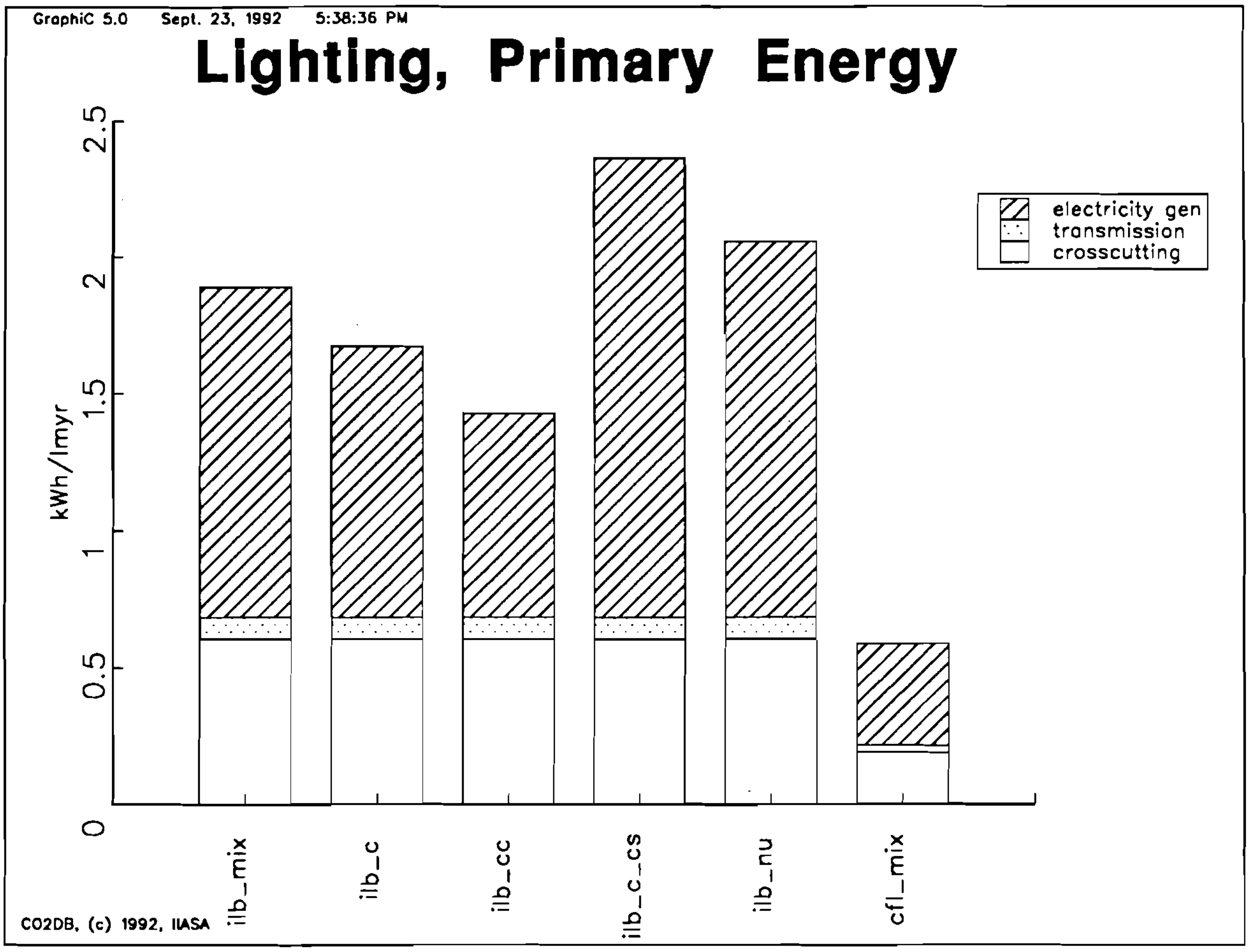

Figure 4.1 Primary energy consumption of six lighting chains.

ilb	...	incandescent light bulb
cfl	...	compact fluorescent lamp
mix	...	electricity transmission and distribution, average U.S. electricity generation energy use.
c	...	electricity transmission and distribution, pulverized-coal power plant.
cc	...	electricity transmission and distribution, natural gas powered combined cycle plant.
c_cs	...	electricity transmission and distribution, pulverized-coal power plant with a chemical carbon dioxide scrubber.
nu	...	electricity transmission and distribution, nuclear power plant.

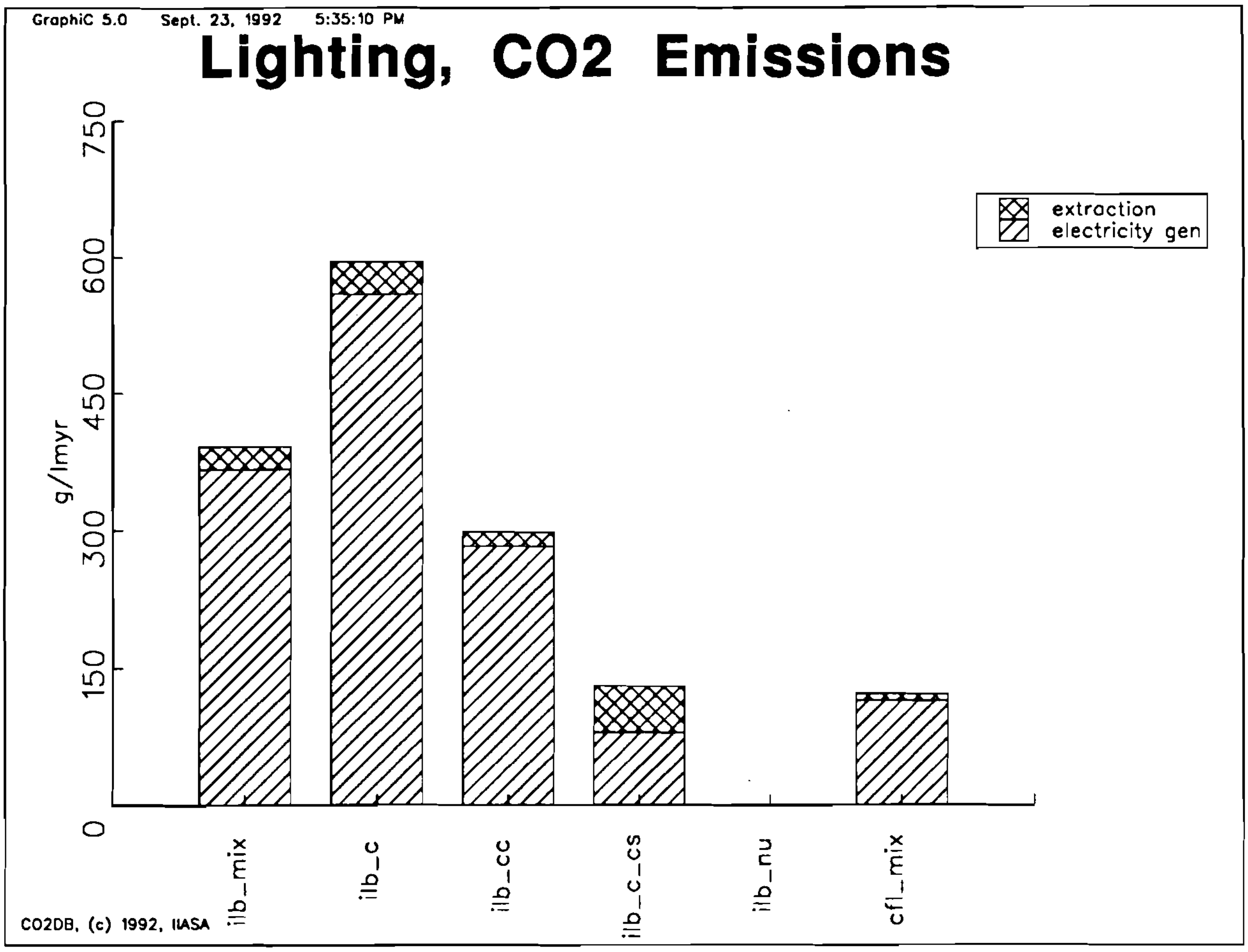

Figure 4.2 Carbon dioxide emissions of six lighting chains.

ilb	...	incandescent light bulb
cfl	...	compact fluorescent lamp
mix	...	electricity transmission and distribution, average U.S. CO_2 emissions from electricity generation and fuel extraction.
c	...	electricity transmission and distribution, pulverized-coal power plant, coal mining.
cc	...	electricity transmission and distribution, natural gas powered combined cycle plant, natural gas extraction.
c_cs	...	electricity transmission and distribution, pulverized-coal power plant with a chemical carbon dioxide scrubber, coal mining.
nu	...	electricity transmission and distribution, nuclear power plant.

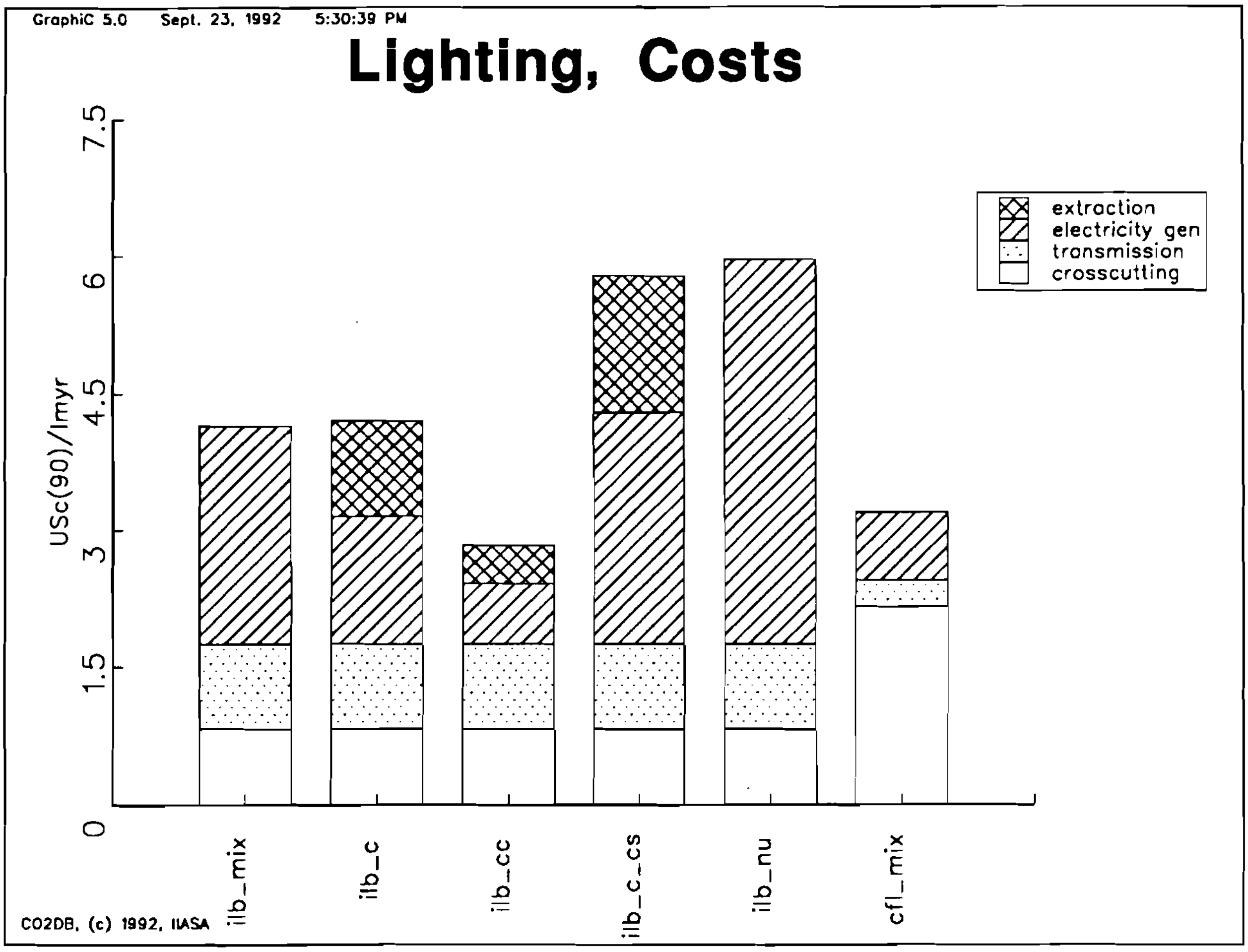

Figure 4.3 System costs of six lighting chains.

ilb	...	incandescent light bulb
cfl	...	compact fluorescent lamp
mix	...	electricity transmission and distribution, average U.S. costs of electricity generation and fuel extraction.
c	...	electricity transmission and distribution, pulverized-coal power plant, coal mining.
cc	...	electricity transmission and distribution, natural gas powered combined cycle plant, natural gas extraction.
c_cs	...	electricity transmission and distribution, pulverized-coal power plant with a chemical carbon dioxide scrubber, coal mining.
nu	...	electricity transmission and distribution, nuclear power plant.

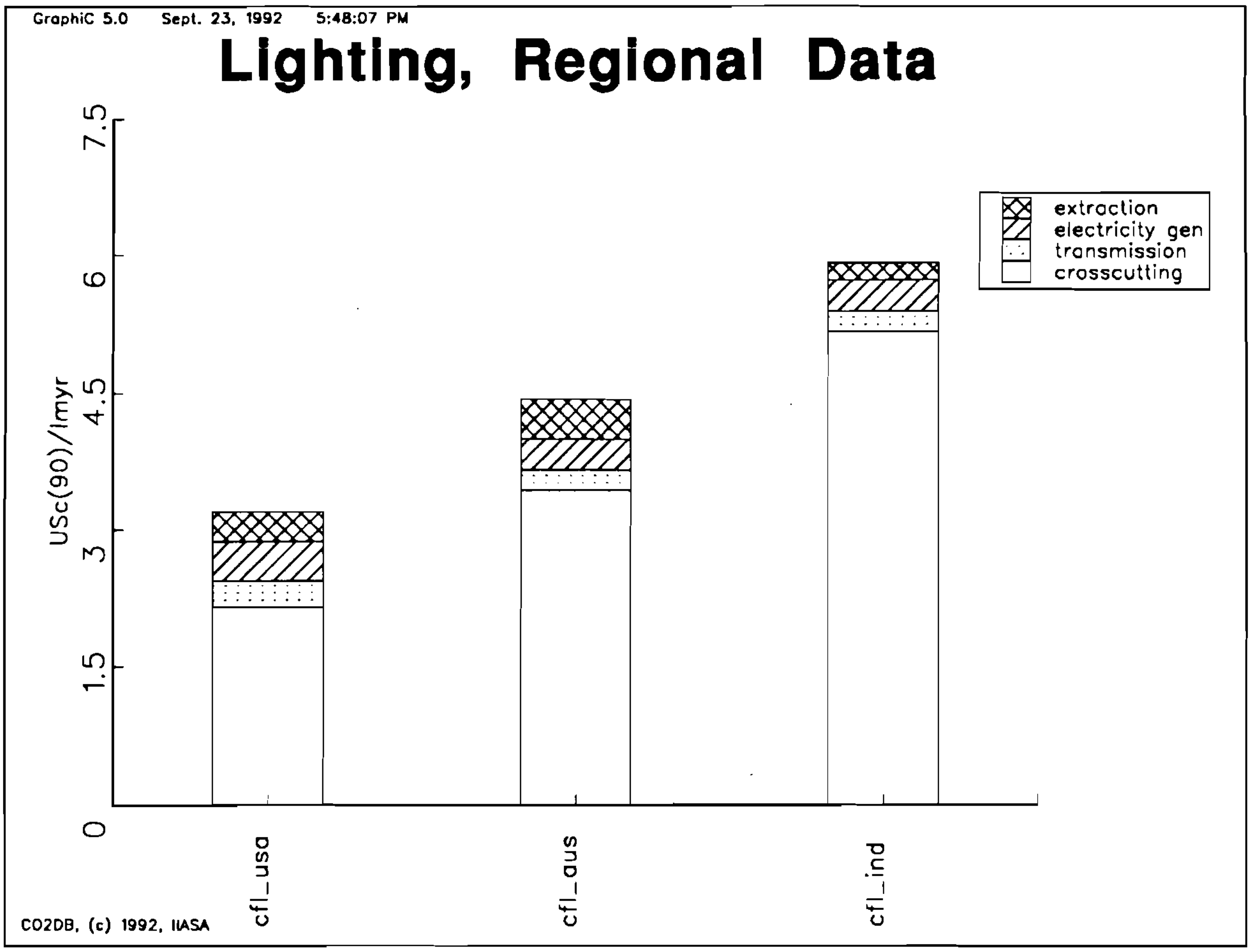

Figure 4.4 Compact fluorescent lamp, electricity transmission and distribution, electricity generated in a pulverized coal power plant and coal mining in the U.S.A, Austria and India.

References

National Academy of Sciences (NAS), 1991, *Policy Implications of Greenhouse Warming*, Report of the Mitigation Panel, National Academy Press, Washington, D.C., USA.

APPENDIX A — Overview of CO2DB

CO2DB is a data bank for energy-conversion technologies in the context of the problem of global warming. In addition to the normal features of information storage and retrieval, CO2DB provides a number of analysis tools. The present version of the data bank puts special emphasis on carbon dioxide, although other greenhouse gases (and even other emissions) can be handled with CO2DB too. To an extent, such data have already been included.

CO2DB accepts information on the following types of technology characteristics and parameters:

1. General description of the technology,
2. Technical data,
3. Economic data,
4. Emission data,
5. Labor and material requirements,
6. Regional information, and
7. Literature sources.

This information is grouped into tables, and all tables for a given technology are linked to the General Description table. Thus, cost data for different reference years or for different regions can be included in one general technology description. Likewise, more than one literature source can be stored in parallel subtables.

All relevant variables in CO2DB can be defined in several units. Energy units are, e.g., barrels of oil equivalent (boe), gigajoules (GJ), or kilowatt-hours (kWh). For the presentation of calculation results, all monetary and energy quantities are converted to a common unit which can be chosen by the user.

CO2DB also provides tools for the analysis of the information it contains, i.e., it facilitates the preparation of printed reports of selected technologies and the calculation of the characteristic parameters of energy-conversion chains. Such energy-conversion chains may be defined interactively by selecting the technologies that participate in an energy-conversion process. Appendix B illustrates both features.

For energy conversion chains, CO2DB calculates the overall specific energy use per unit of final output, pollutant emissions, and costs. These outputs may be defined in energy terms (final or useful energy) or as energy services such as seat-kilometers (for passenger transport) or lumen-hours (for lighting).

Version 2.0 of CO2DB provides an additional feature useful in the evaluation of energy chains: equivalent chains can be displayed (printed) in one graph or one table for comparison. The graphs evaluating the lighting chains (in Section 4) were produced with the help of these features.

To date, CO2DB contains descriptions of approximately 400 technologies. The basic strategy for collecting this information has been to cover the broad spectrum of present estimates for controversial technologies. This is especially true for renewable technologies such as photovoltaics, where estimates of technical and economic performance for the coming decades cover a wide range. Another dimension of diversification in CO2DB concerns the regional and temporal aspects. Technology descriptions in CO2DB cover technological evolution over the next 50 years, and they differentiate between world regions. This regional diversification is partly achieved by generating several subtables for one technology. One group of examples of such regionalized data describes resource extraction technologies.

The following tables give an overview of the present contents of CO2DB. Table A.1 classifies the technologies according to their position in the energy-conversion chain, i.e., according to the type of energy produced: primary, secondary, final and useful energy, or energy service. This table includes only technologies that are related to energy conversion, i.e., it excludes "technologies" such as afforestation which have been included because of their relevance for GHG reduction, but which are not necessarily producing energy output.

Energy Output	No.
final energy	23
useful energy	57
energy service	85
Total	370

Table A.1: Technology classification by position in the energy chain.

Table A.2 summarizes the energy-related technologies by sector. The sectors include energy conversion (such as electricity generation, refineries, and methanol production), energy transport, and end-use. The ''crosscutting'' sector includes end-use technologies that cannot be attributed to just one sector, like electric motor drives, lighting, or heat pumps.

Sector	No.
extraction	32
energy import	9
physical treatment	5
chemical conversion	14
electricity generation	119
co-generation	11
district heat production	9
hydrogen production	8
transmission/distribution	19
residential & commercial	49
industry sector	38
transport sector	31
crosscutting	26
Total	370

Table A.2: Technology classification by sector of technology.

Finally, in Table A.3 the energy-conversion technologies are classified according to the fuel produced.

Sector	No.
Coal and Lignite	7
Oil and Refinery Products	22
Natural Gas, CNG and LNG	22
Biomass	9
Nuclear Fuels	2
Electricity	128
District Heat	17
Hydrogen and LH2	13
Synthetic Fuels	8
Total	228

Table A.3: Technology classification by fuel produced.

APPENDIX B — Technology Descriptions

The technologies described in Section 4 of this document are presented as CO2DB reports in this appendix. For each table generally described in appendix A, we include one printed table here — except when they are empty. The information presented in the printed reports corresponds to the contents of the data bank and also to the screen that can be viewed with CO2DB. Messner and Strubegger (1991) describe all potential data items of CO2DB.

Here, we describe the following technologies:

Conventional incandescent lamp, 60W (technology No 151)
COMPAX fluorescent lamp, 15W (No 152)
Conventional incandescent light bulb, 60W, Austria (No 141)
COMPAX fluorescent lamp, 15W, Austria and India (No 140)
U.S. power generation mix, 1990 (No 248)
Pulverized-coal-fired power plant (No 260)
Pulverized-coal-fired power plant with CO2 recovery (No 261)
Existing and future LWR, Japan (No 284)
Natural-gas-fired combined cycle power plant (No 262)

Table I: General Data

1) Tech. name: Conventional incandescent lamp, 60W		
2) Identification: cil60	3) Technology No: 151	
4) Technical availablility:	5) Commercial availability:	
6) Data collected by: Sabine Messner		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: crosscutting	Type: efficiency impr.	
Output: services	Input: final	
10) Description file:		
11) Hard copy no: sm5, #16		
12) Notes: 60W conventional light bulb 120 Volt design		

Table II: Technical Data (energy forms)

ID: tec_151_1			
1) Unit size: 60		Unit: Watt [MI]	
2) Construction time: [yr]		3) Plant life: 0.33 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 34.25 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
electr.	Input	1	Wh
light	Output	14.5	lm h
7) Notes: Plant life: 1000 operating hours, average utilization: 3000 h/yr -> plant life=0.33 yr			

Table III: Economic Data (per main input)

ID: eco_151_inp		
1) Currency: US $	2) Year: 1988	
Type of costs	Quantity	Unit
3) Investment:	1.2	c/W
4) Fixed O+M:		
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:		
8) Total (excl. fuel):		
9) Total (incl. fuel):	18.9	c/kWh
10) Notes: $5 for replacing lamp (total investm: 0.77$/lamp) tot cost excl repl: 6.88 $/m lm h, tot: 13.06$/m lm h		

Table VII: Literature

ID: lit_151_1
1) Book: Electricity - Efficient End-Use and New Generation Technologies, and Their Planning Implications
2) Chapt.: Energy-efficient lighting
3) Author: Terry McGowan
4) Publ.: Lund University Press
5) Type of publ.: book
6) Year of publication:
7) IIASA access: B21909
8) Access:
9) Notes:

Table I: General Data

1) Tech. name: COMPAX fluorescent lamp, 15W		
2) Identification: cfl15	3) Technology No: 152	
4) Technical availablility:	5) Commercial availability:	
6) Data collected by: Sabine Messner		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: crosscutting	Type: efficiency impr.	
Output: services	Input: final	
10) Description file:		
11) Hard copy no: sm5, #17		
12) Notes: Electromagnetic ballast compares with conventional incandescent lamp, 60W (cil60)		

Table II: Technical Data (energy forms)

ID: tec_152_1			
1) Unit size: 15		Unit: Watt [MI]	
2) Construction time: [yr]		3) Plant life: 3 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 34.25 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
electr.	Input	1	Wh
light	Output	46.7	lm h
7) Notes: plant life: 9000h operating hours, average utilization: 3000h/yr -> plant life=3yr			

Table III: Economic Data (per main input)

ID: eco_152_1		
1) Currency: US $	2) Year: 1988	
Type of costs	Quantity	Unit
3) Investment:	85	c/W
4) Fixed O+M:		
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	8	c/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):	28.2	c/kWh
10) Notes: $5 for replacing lamp (investment cost: 12.75$/lamp) tot cost excl repl.: 4.98 $/m lm h, total: 6.04$/m lm h		

Table VII: Literature

ID: lit_152_1
1) Book: Electricity - Efficient End-Use and New Generation Technologies, and Their Planning Implications
2) Chapt.: Energy-efficient lighting
3) Author: Terry McGowan
4) Publ.: Lund University Press
5) Type of publ.: book
6) Year of publication:
7) IIASA access: B21909
8) Access:
9) Notes:

Table I: General Data

1) Tech. name: Conventional incandescent light bulb, 60 W, Austria		
2) Identification: id141	3) Technology No: 141	
4) Technical availablility: 1990	5) Commercial availability: 1990	
6) Data collected by: Andreas Schaefer		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: crosscutting	Type: conventional tec.	
Output: services	Input: final	
10) Description file:		
11) Hard copy no:		
12) Notes: Cost of conventional 100W light bulb in Austria Technical characteristics from McGowan 89		

Table II: Technical Data (energy forms)

ID: tec_141_1			
1) Unit size: 60		Unit: W [MI]	
2) Construction time: [yr]		3) Plant life: 0.33 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 34.25 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
electr.	Input	1	Wh
light	Output	14.5	lm h
7) Notes:			

Table III: Economic Data (per main input)

ID: eco_141_1		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:	0.02	$/W
4) Fixed O+M:		
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	0.1404	$/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes:		

Table VII: Literature

ID: lit_141_cst
1) Book:
2) Chapt.:
3) Author:
4) Publ.:
5) Type of publ.:
6) Year of publication:
7) IIASA access:
8) Access:
9) Notes: IIASA Research of Austrian Market in 1992: Cost

Table VII: Literature

ID: lit_141_tecd
1) Book: Electricity - Efficient End-Use and New Generation Technologies, and Their Planning Implications
2) Chapt.: Energy-efficient lighting
3) Author: Terry McGowan
4) Publ.: Lund University Press
5) Type of publ.: book
6) Year of publication:
7) IIASA access: B21909
8) Access:
9) Notes: Technical performance

Table I: General Data

1) Tech. name: COMPAX fluorescent lamp, 15W, Austria and India		
2) Identification: id140	3) Technology No: 140	
4) Technical availablility: 1990	5) Commercial availability: 1990	
6) Data collected by: Andreas Schaefer		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: crosscutting	Type: conventional tec.	
Output: services	Input: final	
10) Description file:		
11) Hard copy no:		
12) Notes: Cost data for Austrian lamp: market research Indian lamp: NAS 1991 technical performance acc. to McGowan 1989		

Table II: Technical Data (energy forms)

ID: tec_140_1			
1) Unit size: 15	Unit: W [MO]		
2) Construction time: [yr]	3) Plant life: 9000 [h]		
4) Techn. avail.: [ ]	5) Av./mnt. time: 100 [%]		
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
electr.	Input	1	Wh
light	Output	60	lm h
7) Notes: Technical data from McGowan 1989			

Table III: Economic Data (per main output)

ID: eco_140_aus		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:	3.35	c/lm
4) Fixed O+M:		
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	14.04	c/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes: Costs for Austria: own research		

Table III: Economic Data (per main output)

ID: eco_140_ind.		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:	5	c/lm
4) Fixed O+M:		
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	58	c/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes: Costs for India acc. to NAS 1991 and IEA 1992		

Table VII: Literature

ID: lit_140_aus
1) Book:
2) Chapt.:
3) Author:
4) Publ.:
5) Type of publ.:
6) Year of publication:
7) IIASA access:
8) Access:
9) Notes: Austria: IIASA Research of Austrian Market in 1992 for cost data

Table VII: Literature

ID: lit_140_ind.
1) Book: Policy Implications of Greenhouse Warming; Report of the Mitigation Panel
2) Chapt.:
3) Author:
4) Publ.: National Academy Press, Washington, D.C.
5) Type of publ.: Report
6) Year of publication: 1991
7) IIASA access:
8) Access:
9) Notes: India: Cost data

Table VII: Literature

ID: lit_140_tecd
1) Book: Electricity - Efficient End-Use and New Generation Technologies, and Their Planning Implications
2) Chapt.: Energy-efficient lighting
3) Author: Terry McGowan
4) Publ.: Lund University Press
5) Type of publ.: book
6) Year of publication:
7) IIASA access: B21909
8) Access:
9) Notes: Technical performance data

Table I: General Data

1) Tech. name: U.S. power generation mix, 1990		
2) Identification: id248	3) Technology No: 248	
4) Technical availablility: 1990	5) Commercial availability:	
6) Data collected by: Andreas Schaefer		
7) Data quality:		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: electricity gen.	Type: conventional tec.	
Output: secondary	Input: primary	
10) Description file:		
11) Hard copy no:		
12) Notes: Technology representing power generation mix in 1990 in the U.S. Includes conversion efficiency, CO2 emissions and generation costs (no technical and economic technology information)		

Table II: Technical Data (energy forms)

ID: tec_248_1			
1) Unit size:		Unit: [ ]	
2) Construction time: [yr]		3) Plant life: [ ]	
4) Techn. avail.: [ ]		5) Av./mnt. time: [ ]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
total	Input	1	
electr.	Output	0.363	
7) Notes: Average efficiency, uses 53% coal, 4% oil, 11.6% gas and 31.4% carbon-free sources			

Table III: Economic Data (per main output)

ID: eco_248_1		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:		
4) Fixed O+M:		
5) Variable O+M:	3.5	c/kWh
6) Decommissioning:		
7) Fuel costs:		
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes: variable O+M costs reflect U.S. average generation cost (NAS 1991)		

Table IV: Environmental Data

ID: env_248_1			
1) Pollutant	in/out	Quantity	Unit
CO2	MO	540	g/kWh
2) Notes:			

Table VI: Miscellaneous data

ID: app_248_1		
8) Prod.		
8) Resrch		
8) Prereqs		
8) Country U.S.		
5) Type of limit:	Quantity	Unit
6) Existing capacity		
7) Existing installations		#
8) Notes:		

Table VII: Literature

ID:	lit_248_1
1) Book:	Policiy Implications of Greenhouse Warming Report of the Mitigation Panel
2) Chapt.:	
3) Author:	
4) Publ.:	National Academy Press, Washington, D.C.
5) Type of publ.:	report
6) Year of publication:	1991
7) IIASA access:	
8) Access:	
9) Notes:	

Table I: General Data

1) Tech. name: Pulverized coal fired power plant		
2) Identification: pulv_hc_ppl	3) Technology No: 260	
4) Technical availablility:	5) Commercial availability:	
6) Data collected by: Sabine Messner		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: electricity gen.	Type: conventional tec.	
Output: secondary	Input: primary	
10) Description file:		
11) Hard copy no:		
12) Notes: Pulverized coal fired steam power plant as basis for evaluation of CO2 scrubbing by chemical absorption		

Table II: Technical Data (energy forms)

ID: tec_260_1			
1) Unit size: 600		Unit: MW [MO]	
2) Construction time: [yr]		3) Plant life: 25 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 68.5 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
hard coal	Input	1	
electr.	Output	0.41	
7) Notes: Efficiency based on low heating value			

Table III: Economic Data (per main output)

ID: eco_260_1		
1) Currency: US $	2) Year: 1988	
Type of costs	Quantity	Unit
3) Investment:	1000	$/kW
4) Fixed O+M:	35	$/kW/yr
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	2	$/GJ
8) Total (excl. fuel):		
9) Total (incl. fuel):	3.5	c/kWh
10) Notes: O+M Costs calculated to fit to total cost		

Table IV: Environmental Data

ID: env_260_1			
1) Pollutant	in/out	Quantity	Unit
CO2	MI	2.933	ton/kWyr
2) Notes: Emission of CO2 based on German Enquete			

Table VII: Literature

ID: lit_260_1
1) Book: The Recovery and Disposal of Carbon Dioxide
2) Chapt.:
3) Author: Kornelis Blok, Chris Hendriks
4) Publ.: University of Utrecht, NL
5) Type of publ.: presentat
6) Year of publication: 1991
7) IIASA access:
8) Access:
9) Notes: Presented at IIASA, March 19 - 21 1991

Table I: General Data

1) Tech. name: Pulverized coal fired power plant with CO2 recovery		
2) Identification: hc_ppl_rec	3) Technology No: 261	
4) Technical availablility:	5) Commercial availability:	
6) Data collected by: Sabine Messner		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: electricity gen.	Type: conventional tec.	
Output: secondary	Input: primary	
10) Description file:		
11) Hard copy no:		
12) Notes: CO2 recovery by chemical absorption from coal steam power plant		

Table II: Technical Data (energy forms)

ID: tec_261_1			
1) Unit size: 440		Unit: MW [MO]	
2) Construction time: [yr]		3) Plant life: 25 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 68.5 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
hard coal	Input	1	
electr.	Output	0.29	
7) Notes:			

Table III: Economic Data (per main output)

ID: eco_261_1		
1) Currency: US $	2) Year: 1988	
Type of costs	Quantity	Unit
3) Investment:	1800	$/kW
4) Fixed O+M:	65	$/kW/yr
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	2	$/GJ
8) Total (excl. fuel):		
9) Total (incl. fuel):	5.9	c/kWh
10) Notes: US$ 32 per ton of CO2 avoided		

Table IV: Environmental Data

ID: env_261_1			
1) Pollutant	in/out	Quantity	Unit
CO2	M1	0.2933	ton/kWyr
2) Notes: CO2 reduced by 90%			

Table VII: Literature

ID: lit_261_1
1) Book: The Recovery and Disposal of Carbon Dioxide
2) Chapt.:
3) Author: Kornelis Blok, Chris Hendriks
4) Publ.: University of Utrecht, NL
5) Type of publ.: presentat
6) Year of publication: 1991
7) IIASA access:
8) Access:
9) Notes: Presented at IIASA, March 19 - 21 1991

Table I: General Data

1) Tech. name: Existing and future LWR, Japan		
2) Identification: id284	3) Technology No: 284	
4) Technical availablility: 1990	5) Commercial availability: 1990	
6) Data collected by: Andreas Schaefer		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: electricity gen.	Type: conventional tec.	
Output: secondary	Input: primary	
10) Description file:		
11) Hard copy no:		
12) Notes: Cost and performance estimates for existing and future light water reactors in Japan		

Table II: Technical Data (energy forms)

ID: tec_284_1990			
1) Unit size: 1067		Unit: MW [MO]	
2) Construction time: 5 [yr]		3) Plant life: 30 [yr]	
4) Techn. avail.: 80 [%]		5) Av./mnt. time: 70 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
fission e.	Input	3	
electr.	Output	1	
7) Notes: Plant life: 30-40 years			

Table II: Technical Data (energy forms)

ID: tec_284_1997			
1) Unit size: 1311		Unit: MW [MO]	
2) Construction time: 4 [yr]		3) Plant life: 40 [yr]	
4) Techn. avail.: 80 [%]		5) Av./mnt. time: 70 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
fission e.	Input	3	
electr.	Output	1	
7) Notes:			

Table III: Economic Data (per main output)

ID: eco_284_1990		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:	2210	$/kW
4) Fixed O+M:	49.4	$/kW/yr
5) Variable O+M:	0.117	c/kWh
6) Decommissioning:		
7) Fuel costs:	0.87	c/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes: Decommissioning Costs of USc .117/kWh are added as variable O+M costs		

Table III: Economic Data (per main output)

ID: eco_284_1997		
1) Currency: US $	2) Year: 1990	
Type of costs	Quantity	Unit
3) Investment:	2070	$/kW
4) Fixed O+M:	49.4	$/kW/yr
5) Variable O+M:	0.117	c/kWh
6) Decommissioning:		
7) Fuel costs:	0.87	c/kWh
8) Total (excl. fuel):		
9) Total (incl. fuel):		
10) Notes: Decommissioning Costs of USc .117/kWh are added as variable O+M costs		

Table VII: Literature

ID: lit_284_1
1) Book: Management handbook of Japanese Electric Utilites
2) Chapt.:
3) Author:
4) Publ.: Japan Atomic Industrial Forum
5) Type of publ.:
6) Year of publication: 1991
7) IIASA access:
8) Access: Yasushi Taguchi
9) Notes:

Table I: General Data

1) Tech. name: Natural gas fired combined cycle power plant		
2) Identification: ngcc	3) Technology No: 262	
4) Technical availablility:	5) Commercial availability:	
6) Data collected by: Sabine Messner		
7) Data quality: ready		
8) Invention:	Innovation:	Prototype:
1. Comm.:	1% share:	50% share:
Phase:		
9) Sector: electricity gen.	Type: conventional tec.	
Output: secondary	Input: primary	
10) Description file:		
11) Hard copy no:		
12) Notes: Natural gas fired combined cycle power plant as basis for evaluation of CO2 scrubbing by chemical absorption		

Table II: Technical Data (energy forms)

ID: tec_262_1			
1) Unit size: 600		Unit: MW [MO]	
2) Construction time: [yr]		3) Plant life: 25 [yr]	
4) Techn. avail.: [ ]		5) Av./mnt. time: 68.5 [%]	
6) Energy inputs and outputs			
Name	in/out	Quantity	Unit
nat_gas	Input	1	
electr.	Output	0.48	
7) Notes:			

Table III: Economic Data (per main output)

ID: eco_262_1		
1) Currency: US $	2) Year: 1988	
Type of costs	Quantity	Unit
3) Investment:	625	$/kW
4) Fixed O+M:	5	$/kW/yr
5) Variable O+M:		
6) Decommissioning:		
7) Fuel costs:	3.2	$/GJ
8) Total (excl. fuel):		
9) Total (incl. fuel):	3.2	c/kWh
10) Notes:		

Table IV: Environmental Data

ID: env_262_1			
1) Pollutant	in/out	Quantity	Unit
CO2	MI	1.734	ton/kWyr
2) Notes: Emissions of CO2 based on German Enquete			

Table VII: Literature

ID: lit_262_1
1) Book: The Recovery and Disposal of Carbon Dioxide
2) Chapt.:
3) Author: Kornelis Blok, Chris Hendriks
4) Publ.: University of Utrecht, NL
5) Type of publ.: presentat
6) Year of publication: 1991
7) IIASA access:
8) Access:
9) Notes: Presented at IIASA, March 19 - 21 1991