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EXECUTIVE SUMMARY

The industrial sector is a major emitter of GHGs. In industrialized countries, CO_2 accounts for approximately 90% of the CO_2-eq. emissions from the industrial sector[1]. These CO_2 emissions arise from: (1) the use of fossil fuels for energy, either directly by industry for heat and power generation, or indirectly in the generation of purchased electricity and steam; (2) non-energy uses of fossil fuels in chemicals processing and metal smelting; and (3) non-fossil-fuel sources, e.g. cement and lime manufacture. Industrial processes also emit other GHGs, e.g.:

- N_2O and HFCs from chemical processes;
- PFCs from aluminum, magnesium, and semiconductor processing;
- SF_6 from use in electrical switchgear and non-ferrous metals processes, and
- CH_4 and N_2O from food industry waste streams.

In 2002, 36% of global CO_2 emissions from energy use was from the industrial sector (9 Gt CO_2 (2.5 GtC)). Developed nations accounted for 53% of this total; developing nations, 47%. Most of the industrial sector's CO_2 emissions are from energy-intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizers, cement, and paper and pulp. Developing nations currently produce 78% of the world's cement, 58% of fertilizer, and 42% of steel. These shares are projected to continue to increase as a result of continued economic growth in developing nations and on-going structural changes in economies of developed nations. Data on global emissions of non-CO_2 GHGs is incomplete. N_2O emissions from adipic and nitric acid manufacture totalled 129 $MtCO_2$-eq (35 MtC-eq.) in 2000; annual PFC emissions from aluminium manufacture are estimated at 50 $MtCO_2$-eq (14 MtC-eq).

Many options exist for mitigating GHG emissions from the industrial sector, but full use is not being made of them in either industrialized or developing nations. These options can be divided into three categories: sector-wide technology and methods; process-specific technology and methods; and operating procedures.

[1] Data presented in this summary and the trend information (both historical and projected) presented in Section 7.1 includes emissions from petroleum refining. Mitigation technology for petroleum refining is discussed in Chapter 4.

Examples include:

- Sector-wide options include: more efficient electric motor driven systems (use of such systems could reduce emissions by about 100 Mt CO_2 (27.2 MtC)/year in both the EU-25 and the U.S.); fuel switching, including the use of waste materials; and recycling.
- Process-specific options include: the use of the bio-energy contained in food and paper industry wastes; turbines to recover the energy contained in pressurized blast furnace gas; and control strategies to minimize PFC emissions from aluminum manufacture.
- Operating procedure options include: control of steam and compressed air leaks, reduction of air leaks into furnaces, optimum use of insulation, and optimization of equipment size to ensure high capacity utilization.

While full use of existing technology can significantly reduce industrial GHG emissions, *new and lower cost technologies will be needed to meet long term mitigation objectives.* Examples include: development of an inert electrode to eliminate process emissions from aluminum manufacture; use of carbon capture and storage in ammonia manufacture; and use of hydrogen to reduce iron and non-ferrous metal ores.

Industry GHG mitigation decisions, many of which have long-term consequences, will continue to be driven by consumer preferences, costs, competitiveness, and government regulation. A policy environment that encourages the implementation of existing and new mitigation technologies will be beneficial. Policies that reduce the barriers to the adoption of cost-effective, low-GHG emission technology (e.g. lack of information, absence of standards, unavailability of affordable financing for first purchases of modern technology) can be effective.

In many areas of the world, GHG mitigation is not demanded by either the market or government regulation. In these areas, companies can afford to invest in GHG mitigation only to the extent that these investments are compensated by lowered energy or raw material costs, or some similar benefit. Although there is considerable potential for retrofitting existing installations, many industrial facilities last for decades. Today's choices can have long-term consequences.

In addition to the mitigation options discussed above, achieving sustainable development requires the adoption of industrial development pathways that minimize the need for future mitigation. Restructuring of the industrial sector may be required, especially for countries that currently are on a high emissions pathway. Large companies have greater resources, and usually more incentives, to factor environmental and social considerations into their operations than small and medium enterprises (SMEs), but SMEs provide the bulk of employment and manufacturing capacity in many developing countries. Integrating SME development strategy into the broader national strategies for development, is consistent with the sustainable development objectives of poverty reduction and growth in transition and developing countries.

Sustainable development requires balancing environmental, economic, and social justice considerations. Proper choice of GHG mitigation technology can provide this balance. For example, studies in India show that adoption of efficient electrical equipment in the industrial sector leads to higher employment than waiting for additional generating capacity.

Industry is vulnerable to the impacts of climate change, particularly to the impacts of extreme weather. Companies can adapt to these potential impacts by designing facilities that are resistant to projected changes in weather and climate, buying insurance to cover risks to existing facilities, relocating plants to less vulnerable locations, and diversifying raw material sources, especially agricultural inputs. Industry is also vulnerable to the impacts of changes in consumer preference and government regulation in response to the threat of climate change. Companies can respond to these by mitigating their own emissions and developing lower-emission products.

7.1 Introduction

This chapter addresses actions taken to date or that can be taken in the short- and medium-term to mitigate GHG emissions from the manufacturing and process industries[2]. In industrialized countries, CO_2 typically accounts for 90% or more of the CO_2-eq. GHG emissions from the industrial sector (UNFCCC, 2005). These CO_2 emissions arise from three sources: (1) the use of fossil fuels for energy, either directly by industry for heat and power generation or indirectly in the generation of purchased electricity and steam; (2) non-energy uses of fossil fuels in chemical processing and metal smelting; and (3) non-fossil-fuel sources, e.g. cement and lime manufacture. Industrial processes are also emit other GHGs:

- nitrous oxide (N_2O) is emitted as a by-product of adipic acid, nitric acid and caprolactam production;
- hydrofluorocarbons (HFCs) are emitted as by-products of the production of HCFC-22, a refrigerant, and used in refrigeration and foam-blowing;
- polyfluorocarbons (PFCs) are emitted a by-product of aluminium manufacture, and used in magnesium production and semiconductor manufacture;
- SF_6 is emitted in the manufacture, use and, decommissioning of gas insulated electrical switchgear, and used in some non-ferrous metals processes; and
- methane (CH_4) and nitrous oxide (N_2O) can be emitted by food industry waste streams.

Many GHG emission mitigation options have been developed for the industrial sector. They fall into two categories: some are applicable across the entire sector, while others are process- specific. Section 7.2 summarizes mitigation options in matrix form, section 7.3 discusses mitigation options that are applicable across the industrial sector, and section 7.4 discusses process-specific mitigation options. The short- and medium-term potential for both classes of options are discussed in section 7.5, barriers to the application of these options are addressed in section 7.6, and the implication of industrial mitigation for sustainable development is discussed in section 7.7.

Section 7.8 discusses the sector's vulnerability and options for adaptation to climate change. A number of policies have been designed either to encourage voluntary GHG emission reductions from the industrial sector or to mandate such reductions. Section 7.9 describes these policies and the experience gained to date. Reduction of GHG emissions from the industrial sector is often accompanied by co-benefits, particularly the reduction of emissions of local air pollutants. These co-benefits are discussed in section 7.10. As with other sectors, development of new technology is key to the cost-effective control of industrial GHG emissions. Section 7.11 provides a summary of the technology process in the industrial sector. Finally, section 7.12 examines the long-term outlook for GHG emissions reduction from the industrial sector.

7.1.1 Status of the sector

The focus of mitigation efforts in the industry sector has been on energy-intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizer, cement, and paper and pulp, which account for more than half of the sector's energy consumption in most countries (Dasgupta and Roy, 2000;

[2] For purposes of this chapter, industry includes the food processing, and paper, pulp and milling industries, but the growing of food crops and trees are covered in Chapters 8 and 9 respectively. Also, several important industrial processes are covered in other chapters: petroleum refining and the production of biofuels are covered in Chapter 4, and off-site management of industrial wastes is covered in Chapter 10.

Sinton and Fridley, 2000). The food processing industry is also important, because it represents a large share of industrial energy consumption in many non-industrialized countries. Each of these industries is discussed in detail in Section 7.4.

Small- and medium-sized enterprises (SMEs) are structurally important in all countries, and comprise well over 95% of all businesses (APEC, 2005). In India, SMEs have a significant share in the metals, chemicals, food, and pulp and paper sectors. (GOI, 2005). There are 39.8 million SMEs in China, accounting for 99% of the country's enterprises, 50% of asset value, 60% of turnover, 60% of exports, and 75% of employment.

While regulations are moving large industrial enterprises towards the use of environmentally sound technology, SMEs typically do not have the economic or technical capacity to install the necessary control equipment (Chaudhuri and Gupta, 2003; Gupta, 2002). These SME limitations create special challenges for efforts to regulate GHG emissions.

Recent empirical studies show that SMEs contribute to over 55% of GDP and over 65% of total employment in high-income countries, SMEs and informal enterprises, account for over 60% of GDP and over 70% of total employment in low-income countries, while they contribute over 95% of total employment and about 70% of GDP in middle-income countries. SMEs are an important source of export revenues in some developing economies, contributing a larger share of manufactured exports in more industrialized Asian economies, more than 40% in China and 31.5% in India, than the less industrialized African economies, <1% in Tanzania and Malawi. (OECD, 2004).

7.1.2 Development trends

As shown in Figure 7.1.1, the production of energy-intensive industrial goods grew dramatically during the 20th century. This growth is expected to continue as population and GDP increase. Global population, which was 6.2 billion in 2002, is projected to grow to 8.1 billion by 2030 (UNPD, 2005). Real global GDP grew 3.3% annually from 1971 to 2002, and is projected to grow by 3.2% annually from 2002 to 2030 (IEA, 2004).

(INSERT **Figure 7.1.1** here)

Much of the world's energy-intensive industry is now located in developing nations. China is now the world's largest producer of both steel (IISI, 2005) and cement (USGS, 2004). Overall, developing countries accounted for 42% of iron and steel production in 2003 (IISI, 2005), 58% of fertilizer production in 2000 (Swaminathan and Sukalac, 2004), and 78% of cement manufacture in 2003 (USGS, 2004). Since many facilities in developing nations are new, they sometimes include the latest technology and have the lowest specific emissions rates. This has been demonstrated in the aluminium (Navarro et al., 2003), cement (Bureau of Energy Efficiency, 2003), and fertilizer industries (Swaminathan and Sukalac, 2004). However, due to the need to upgrade existing facilities, there continues to be a huge demand for technology transfer to developing nations to achieve energy efficiency and emissions reduction in their industrial sectors.

New rules introduced through the multilateral trade system and foreign buyers require SMEs to comply with higher technical (e.g. technical barriers to trade), environmental (e.g. ISO14000) and labour standards in domestic and export markets. Multinational enterprises seeking out new markets and investments offer capable SMEs the opportunity to insert themselves into global value chains through subcontracting linkages, while those that are unable to do so increasingly face the danger of losing their existing markets. Competition within the developing world for export markets, foreign investment and resources is also intensifying. Against this backdrop of increased global competition, SMEs, SME associations, support institutions and governments in transition and developing countries face the challenge of adjusting and adopting new approaches and inventing new ways of working together to foster SME competitiveness. Integration of SME development strategy in the broader national strategies for sustainable development and/or poverty reduction and growth is under consideration in transition and developing countries (GOI, 2004).

7.1.3 Emissions trends

Global and sectoral data on primary energy use[3], final energy use, and energy-related CO_2 emissions for 1971-2002 (Price, et al., 2005a) are shown in Table 7.1.1. In 1971, the industrial sector used 89 EJ of primary energy, 40% of the global total of 222 EJ. By 2002, industry's share of global primary energy use had declined to 36%. The developing nations' share of industrial CO_2 emissions from energy use grew from 18% in 1971 to 47% in 2002. In 1971, energy use by the industrial sector resulted in emissions of 5.9 Gt CO_2, 44% of a global total of 13.5 Gt CO_2. Total industrial CO_2 emissions are higher when CO_2 emissions from non-energy uses of fossil fuels and from non-fossil fuel sources (e.g. cement manufacture) are included.

(INSERT **Table 7.1.1** here)

Table 7.1.2 shows the results for the industrial sector of the disaggregation of two of the emissions scenarios, A1 and B2, produced for the IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000) into four subsectors and ten world regions (Price et al., 2005a). These projections show a range of energy-related industrial CO_2 emissions from 13 to 20 Gt CO_2 in 2030 for the B2 and A1 scenarios, respectively. In both scenarios the developing countries Latin America, Sub-Saharan Africa, Other Asia, and the Middle East and North Africa have the highest average annual growth rates. Growth in industrial sector CO_2 emissions in the regions of Central and Eastern Europe, Former Soviet Union, and Centrally Planned Asia are envisioned to slow to an average rate of 1.0% to 1.7% in the B2 scenario, and between 2.6 and 2.9% in the A1 scenario for the period 2000-2030. CO_2 emissions are expected to decline or remain relatively stable in the Pacific OECD, North America, and Western Europe regions on both scenarios.

(INSERT **Table 7.1.2** here)

Table 7.1.3 shows projections of non-CO_2 GHG emissions from the industrial sector to 2020 (US EPA, 2006). Globally, emissions are projected to increase by a factor of 2.4, from 480 MtCO$_2$-eq. (130 MtC-eq.) in 1990 to 1160 MtCO$_2$-eq (316 MtC-eq.) in 2020. Regional projections of rates of growth in emissions from 1990 - 2020 range from no-growth in emissions in Central and Eastern Europe and the Former Soviet Union, to a factor of nearly 8 in sub-Saharan Africa, albeit from a very low base.

(INSERT **Table 7.1.3** here)

[3] The values reported here include primary energy consumed in the production of secondary energy sources. Primary energy is the energy embodied in the natural resource (e.g. coal, crude oil, sunlight, uranium) that has not undergone any anthropogenic conversion or transformation (IPCC, 2001a). Secondary energy is the energy contained in products or carriers that results from the transformation or conversion of primary energy, e.g. electricity, petroleum fuels, and various coal products.

7.2 Industrial Mitigation Matrix

A wide range of measures and technologies have the potential to reduce industrial GHG emissions. These technologies can be grouped into categories of energy efficiency, fuel switching, power recovery, etc. Within each category, some technologies, such as the use of more efficient electrical motors, are broadly applicable across all industries; while others, such as the use of black liquor as a biofuel in paper manufacture, are process-specific. Table 7.2.1 presents examples of both classes of technologies for a number of industries. The table is not comprehensive, since many more GHG mitigation technologies have been developed.

(INSERT **Table 7.2.1** here)

7.3 Industrial Sector-wide Technologies and Measures

7.3.1 Energy Efficiency

The energy efficiency of industrial plants depends on three factors: choice and optimization of technology, operating procedures and maintenance, and capacity utilization, i.e., the fraction of maximum capacity at which the process is operating.

Many studies (US DOE, 2004a; IGEN/BEE; n.d.) have shown that large amounts of energy can be saved and CO_2 emissions avoided by strict adherence to carefully designed operating and maintenance procedures. Steam and compressed air leaks, poorly maintained insulation, air leaks into furnaces, and similar problems all contribute to excess energy use. Quantification of the amount of CO_2 emission that could be avoided is difficult, because, while it is well known that these problems exist, the information on their extent is all case-specific. Capacity utilization is one of the determinants of energy and CO_2 emission intensities. Low capacity utilization is associated with more frequent shut-downs and poorer thermal integration, both of which lower energy efficiency and raise CO_2 emissions.

Electric motor driven systems provide the largest potential for improvement of industry-wide energy efficiency. De Keulenaer et al., (2004) report that motor-driven systems account for approximately 65% of the electricity consumed by EU-25 industry. Implementing high-efficiency motor driven systems, or improving existing ones, could save about 30% of this energy consumption, up to 202 TWh per year, and avoid emissions of up to 100 $MtCO_2$ (27.2 MtC) per year. Xenergy (1998) gave similar figures for the U.S., where motor-driven systems account for 63% of industrial electricity use. Use of more efficient electric motor systems could save over 100 TWh per year by 2010, and avoid emissions of 90 $MtCO_2$ (24.5 MtC) per year in the U.S. The efficiency of motor driven systems can be increased by improving the efficiency of the electric motor through reducing losses in the motor windings, using better magnetic steel, improving the aerodynamics of the motor and improving manufacturing tolerances. However, the motor is only one part of the system, and maximizing efficiency requires properly sizing all components, improving the efficiency of the end-use devices (pumps, fans, etc.), reducing electrical and mechanical transmission losses, and use of proper operation and maintenance procedures (De Keulenaer et al., 2004). Additional opportunities for industry-wide energy-efficiency exist in the use of energy-efficient lighting, heating and cooling. These systems have been discussed in Chapter 6.

In view of the low energy efficiency of industries in many developing counties, in particular Africa (UNIDO, 2001), application of industry-wide technologies can yield technical and economic benefits, while at the same time enhance environmental integrity. It has been shown that application of housekeeping and general maintenance can yield energy savings of 10-20%; low cost/minor capital measures (combustion efficiency optimisation, recovery and use of exhaust gases, use of high efficiency electric motors and insulation, etc.) show energy savings of 20-30%; and high capital expenditure measures (automatic combustion control, improved design features for optimisation of piping sizing, and air intake sizing, and use of variable speed drive motors, automatic load control systems, and process residuals) result in energy savings of 40-50% (UNIDO, 2001, Bayaya-Kyahurwa, 2004).

A study (CEEEZ, 2003) of the use of automatic load control devices, meant for controlling the electric current being used by an induction motor in relation to its load, in selected African industries with a total motor capacity of 70,000 kW resulted in a potential saving of 100 ktCO_2-eq. (27 ktC)/yr. Average investment cost was US$ 35 per kW, internal rate of return (IRR) was an attractive 40%, and energy saving ranged between 30%-40%.

Efficient high pressure boilers, which typically operate in the range of 40-80 bars based on the condensing steam extraction turbine (CEST) principle, are now available on the market (Cornlad et al., 2001) and can be used to replace traditional boilers (15-25 bars) using process residual like bagasse in the sugar industry. CEST technology is capable of producing enough electricity for own factory use and for irrigation purposes, with a surplus available for export to the national grid. For example, application of CEST technology with an installed capacity of 60 MW in a 400 t/hr sugar factory could save 400 kt CO_2-eq (110 ktC)/year, and provide a surplus of 40 MW, part of which could be used for irrigating crops, and the rest for export to the national grid (Yamba and Matsika, 2003). Such a facility, at an investment cost of US$ 1710 per kW, yielded an IRR of 12.0%, assuming CO_2 is sold at US$ 5 per tonne, and at an electricity tariff of US$0.04 per kWhr. Similar technology has been installed at Indian sugar factory, increasing the crushing period from 150 to 180 days, and exporting an average of 10 MW to the regional, fossil-fuel based grid, saving an estimated 36 kt CO_2 (10 ktC) per year (Sobhanbabu, 2003).

7.3.2 Fuel Switching, Including Use of Waste Materials

While some industrial processes require specific fuels (e.g. metallurgical coke for iron ore reduction)[4], many industries use fuel directly for steam generation and/or process heat, with the choice of fuel being determined by cost, fuel availability, and environmental regulations. The TAR (IPCC, 2001a) limited its consideration of industrial fuel switching to switches within fossil fuels (replacing coal with oil or natural gas), and concluded, based on a comparison of average and lowest carbon intensities for 8 industries, that such switches could reduce CO_2 emissions by 10-20%. IEA (2004) reports that in 2002, 17% of global industrial energy use was from coal. In their Reference Case, which envisions continuation of the polices in place in mid-2004, IEA sees this share declining to 13% by 2030, but industrial coal usage increasing by 15%. In IEA's Alternative Policy Scenario, which envisions the implementation of energy and environmental policies now under discussion, coal's share of a declining global industrial energy use drops to 12%, with industrial coal usage decreasing by 2% between 2002 and 2030.

A wide variety of industries are using methane from landfills as a boiler fuel. (USEPA, 2005) While there are no technical barriers to broader use of biomass, for most industrial applications biomass is high cost and greater use is unlikely in the short- or medium-term.

[4] Options for fuel switching in those processes are discussed in Section 7.4.

Waste materials (tyres, plastics, used oils and solvents) are being used by a number of industries. The steel industry has developed technology to use such wastes such as plastics (Ziebek and Stanek, 2001) as alternative fuel and raw materials. Pre-treated plastic wastes have been recycled in coke ovens and blast furnaces (Okuwaki, 2004), decreasing CO_2 emissions by reducing both emissions from incineration and the demand for fossil fuels. In Japan, annual use of plastics wastes in steel has resulted in a 0.6 Mt CO_2-eq. emissions reduction (Okazaki et al., 2004).

Incineration of wastes (e.g. tyres, hazardous waste) in cement kilns is one of the most efficient methods to process these wastes (Cordi and Lombardi, 2004; Houillon and Jolliet, 2005). The current use of waste fuels varies widely between countries. The global potential CO_2 emission reduction through increased use of waste fuels is estimated at 12% (Humphreys and Mahasenan, 2002). Cement companies in India are using non-fossil fuels, including agricultural wastes, sewage, domestic refuse and used tyres, as well as wide range of waste solvents and other organic liquids; coupled with improved burners and burning systems (Jain, 2005).

7.3.3 Heat and Power Recovery

Energy recovery provides major energy efficiency and mitigation opportunities in virtual all industries. Energy recovery is an old technique, but large potentials still exist (Bergmeier, 2003). Energy recovery can take different forms, e.g. heat, power and fuel recovery. Fuel recovery options are discussed in the specific industry sectors in Section 7.4. While water (steam) is the most used energy recovery medium, the use of chemical heat sinks, e.g. such as used in heat pumps, organic Rankine cycles, and chemical recuperative gas turbines, allows heat recovery at lower temperatures. Energy-efficient process designs are often based on increased internal energy recovery, making it hard to define the technology and to determine the mitigation potential of energy recovery.

Heat is used and generated at specific temperature and pressures and discarded afterwards. The discarded heat can be re-used in other processes onsite, or used to preheat incoming steam and combustion air. Heat is recovered through the use of heat exchangers. New, more efficient heat exchangers or more robust (e.g. low corrosion) heat exchangers are developed continuously, improving the profitability of enhanced heat recovery. In industrial sites the use of low-temperature waste heat is often limited, except for preheating boiler feed water. Using heat pumps allows recovery of the low-temperature heat for the production of higher temperature steam.

While there is a significant potential for heat recovery in most industrial facilities, it is important to design a heat recovery system that is energy-efficient and cost-effective (i.e. process integration). Various techniques are available to analyze process integration opportunities, of which pinch analysis is the most well known. Developed in the early 1970s it is now an established methodology for continuous processes. The analytical approach to this analysis has been well documented in the literature (Linnhoff, 1993; Smith, 2000; Gundersen, 2002). The approach has now been extended to total site optimization, batch processes, hydrogen and water networks (Smith, 2000; Martin et al., 2000),

The energy savings potential of process integration exceeds that from well-known conventional heat recovery techniques, estimated at 5-10% (Einstein et al., 2001; US DOE, 2002). Even in new designs, process integration finds additional opportunities for energy efficiency improvement. Typically, cost-effective energy savings of 5-40% are found in process integration analyses in almost all industries (Martin et al., 2000; IEA-PI, n.d.). The wide variation makes it hard to estimate the overall potential for energy-efficiency improvement and GHG mitigation. However, Martin et al.. (2000) estimated the potential fuel savings from process integration in U.S. industry to be 10% above the gain for conventional heat recovery systems.

Power can be recovered from processes operating at elevated pressures using even small pressure differences to produce electricity through pressure recovery turbines, as well as from waste heat (e.g. steam turbines and organic rankine cycle). Examples of pressure recovery opportunities are the blast furnace, and fluid catalytic cracker, as well as from natural gas grids (at sites where pressure is reduced before distribution and use). Power recovery from waste heat may include the use of pressure recovery turbines in steam networks instead of pressure relief valves, or organic Rankine cycles from low-temperature waste streams. A recent study in the United States preliminarily explored the potential for power recovery technologies, including pressure recovery turbines, organic rankine cycle and selected others (Bailey and Worrell, 2005). The combined potential of these selected technologies equalled 1-2% of all power produced in the United States, mitigating 21 Mt CO_2 (5.7 MtC).

Cogeneration (Combined Heat and Power) is an important energy recovery technology, where the energy losses in power production are used to generate heat, which is used in industrial processes and for district heating. Cogeneration technology is discussed in detail in Chapter 4. Currently, cogeneration provides about 7% of global power production (Brown, 2004), but has reached over 50% in Denmark (Brown, 2004). Hence, there is still a large potential for expansion of cogeneration. Different studies use different definitions and methods to determine the potential; hence regional estimates may not be comparable. Recent studies found large potentials in many regions and countries. For example, a scenario study for the United States industry found a mitigation potential of almost 150 Mt CO_2 (Lemar, 2001), while the mitigation potential for cogeneration in the European industry is estimated at 334 Mt CO_2 (De Beer et al., 2001). Similar studies have been performed for specific countries, e.g. Brazil (Szklo et al., 2004), although the CO_2 emission mitigation impact is not always specified.

7.3.4 Renewable Energy

The use of biomass is well established in some industries. As discussed in sections 7.4.5 and 7.4.6, the paper and pulp industry uses biomass for much of its energy needs, and the sugar industry in many developing countries uses by-product bagasse to supply not only its own energy needs, but to generate steam and/or electricity for export. The food and jute industries also makes use of solar energy for drying in appropriate climates (Das and Roy, 1994). The African Rural Energy Enterprise Development initiative is promoting the use of solar food driers in Mali and Tanzania to preserve fresh produce for local use and for the commercial market. (AREED, 2000). When economically attractive, other industries use biomass fuels, e.g. the use of charcoal in blast furnaces in Brazil (Kim and Worrell, 2002a). These applications will reduce CO_2 emissions if the biomass is grown sustainably. However, such applications are currently very limited and not projected to grow significantly in the next few decades. Additionally, industry has the option to use solar or wind generated electricity, if it is available. The potential for this technology was discussed in Chapter 4.

7.3.5 Recycling

Recycling of steel in electric arc furnaces accounts about a third of world production. This process typically uses 60-70% less energy and with CO_2 emission reductions being a function of the source of electricity (De Beer, et al., 1998). This technology, and options for further energy savings, are discussed in section 7.4.1.

Recycling aluminium requires only 5% of the energy that primary aluminium production requires. Recycled aluminium from used products (old scrap from the beverage industry, or the transportation or building sectors) is now providing 25% of world demand, and could supply 50% of demand by 2025. The aluminium industry monitors recycling rates, but has not set a target (IAI, 2004). Recycling is also an important energy saving factor in other non-ferrous metal industries, as well as the glass and plastics industries (GOI, various issues).

7.3.6 Carbon Dioxide Capture and Storage, Including Oxy-fuel Combustion

Carbon dioxide capture and storage (CCS) can follow one of two paths: (1) the carbon in a fossil fuel can be reacted with water to yield CO_2 and hydrogen, after which the CO_2 can be captured and the hydrogen used as a fuel, or (2) CO_2 can be captured from the exhaust from fossil fuel combustion. In both cases the captured CO_2 can then be stored geologically in depleted oil and gas fields or in saline aquifers, preventing its release to the atmosphere for very long periods of time. The IPCC Special Report on CCS (IPCC, 2005a) provides a full description of this technology, focusing on its application in electric power generation. However, this technology also has applications in the industrial sector. Large quantities of hydrogen are produced as feedstock for the production of ammonia and other chemicals using a process that generates a CO_2-rich byproduct stream, which is a potential candidate for CCS technology. Blast furnaces also produce a CO_2-rich byproduct stream.

More generally, oxy-fuel combustion can be used to produce a CO_2-rich flue gas, suitable for CCS, from any combustion process. In the past, oxy-fuel combustion has been considered impractical because of the high flame temperature it creates. However, Gross, et al. (2003), report on the development of technology that allows oxy-fuel combustion to be used in industrial furnaces with conventional materials. Oxy-fuel's higher flame temperature improves radiant heat transfer and overall energy efficiency. Tests show up to a 73% reduction in natural gas use compared with a convention air-natural gas furnace. The technology has also been demonstrated using coal and waste oils as fuel. Since much less nitrogen is present in the combustion chamber, NO_x emissions are very low, even without external control, and the system is compatible with integrated pollution removal technology for the control of mercury, sulfur and particulate emissions (Ochs, et al., 2005).

7.3.7 Benchmarking

Companies can use benchmarking to compare their operations against those of other companies to determine whether they have opportunities to improve energy efficiency or reduce GHG emissions. Benchmarking is widely used in industry, but benchmarking programs must be carefully designed to comply with laws ensuring fair competition, and companies must develop their own procedures for using the information generated through these programs.

The governments of The Netherlands and Flanders have used the benchmarking approach as the basis for established energy efficiency covenants with a broad range of their industries. In The Netherlands Energy Efficiency Benchmarking Covenant, companies commit "… to ensure that their energy-intensive facilities comply with the best international energy efficiency standards …" (Government of The Netherlands, 1999). By 2002, this program involved companies using 94% of the energy consumed by industry in The Netherlands. Most of the companies involved in the program were already in the top 10% of energy efficiency world-wide, but 100% participation in the covenant would result in cumulative emissions reductions of 5.7 $MtCO_2$ (1.6 MtC) through 2012 (Government of The Netherlands, 2002). The Flemish covenant, agreed in 2002, uses a similar approach. As of 1 January 2005, 177 companies had joined the covenant, which projects cumulative emissions saving of 2.45 $MtCO_2$ (0.67 MtC) in 2012(Government of Flanders, 2005).

Phylipsen, et al. (2002) critiqued The Netherlands' benchmarking agreement, and conclude that it would avoid emissions of 4-9 $MtCO_2$ (1.1-2.5 MtC) in 2012 compared with a business-as-usual scenario. While these emission reductions are larger than projected by the government, Phylipsen, et al. (2002) conclude that they would be smaller than those achieved by a continuation of the Long-Term Agreements with industry that called for a 2%/year improvement in energy efficiency. These agreements expired in 2000

Most benchmarking programs are developed through trade associations or *ad hoc* consortia of companies, and their details are often proprietary. However, 10 Canadian potash operations published the details of their benchmarking exercise (CFI, 2003), which showed that increased employee awareness and training was the most frequently identified opportunity for improved energy performance.

7.4 Process-Specific Technologies and Measures

7.4.1 Iron and Steel

Steel is by far the most world's important metal, with a total global production of 10575 Mt in 2004. In 2004, the most important steel producers were China (26%), European Union (19%, EU-25), Japan (11%), U.S. (10%) and Russia (6%). The top-10 steel companies produce 28% of the world's steel (IISI, 2005). Two routes are used to make steel. In the primary route (accounting for 67% of global production), iron ore is reduced to iron, which is then processed into steel. In 2004, 756 Mt of iron was produced in almost 50 countries. In the secondary route, accounting for the remaining 33% of world production, scrap steel is melted in electric-arc furnaces to produce crude steel that is further processed. The secondary route uses only 30-40% of the energy used by the primary route, with the CO_2 emissions reduction being a function of the source of electricity (De Beer, et al., 1998).

Total CO_2 emissions of the global steel industry are estimated at 1500-1600 $MtCO_2$ (436 MtC), including emissions from coke manufacture and indirect emissions due to power consumption, or about 6-7% of global anthropogenic emissions. The total is higher for some countries, e.g. steel production accounts for over 10% of China's energy use and about 10% of its anthropogenic CO_2 emissions (Editorial Board of the China Steel Yearbook, 2004). Specific emissions vary widely between countries, from about 1.25 tCO_2 (0.35 tC)/t steel in Brazil to 1.6 tCO_2 (0.44 tC)/t steel in South Korea and Mexico, 2.0 tCO_2 (0.54 tC)/t steel in the U.S. and 3.1-3.8 tCO_2 (0.84-1.04 tC)/t steel in China and India (Kim and Worrell, 2002a). The differences are based on the production routes used, product mix, energy efficiency of the production, carbon intensity of the fuel mix, and carbon intensity of power production. Energy consumption by the steel industry in various regions in 2000 is shown in Figure 7.4.1.

(Insert Figure 7.4.1)

7.4.1.1 Energy Efficiency

Iron and steel production is still a combination of batch processes. Steel industry efforts to improve energy efficiency include enhancing continuous production processes to reduce loss of specific heat and increasing recovery of waste energy and process gases, as well as efficient design of electric arc furnaces e.g. scrap preheating, high-capacity furnaces, foamy slagging, fuel and oxygen injection.

Continuous casting, introduced in the 1970s and 1980s, saves both energy and material. Today, 88% of global steel is cast continuously (IISI, 2005).

Figure 7.4.2 depicts some of the options for efficiency improvement in the iron and steel industry, and Table 7.4.1, the emission reduction potentials fro the major energy conservation technologies in the steel industry. These potentials were calculated using the methodology developed by Tanaka, et al. (2005). Energy savings depend not only on the application of energy-efficient technology, but also on energy management in steel plants. Okazaki, et al. (2004) estimate that approximately 10% of total energy consumption in steel making could be saved through improved energy and materials management.

(INSERT **Figure 7.4.2** here)
(INSERT **Table 7.4.1** here)

The potential for energy efficiency improvement varies plant to plant and from country to country. The differences can be studied by focusing benchmarking-like studies or penetration rates of key energy-efficient practices and technologies (Tanaka et al.., 2005). Kim and Worrell (2002a) benchmarked the energy efficiency of steel production to the best practice performance in 5 countries with over 50% of world steel production, finding potential CO_2 emission reductions due to energy efficiency improvement varying from 15% (Japan) to 40% (China, India, U.S.). While China has made significant improvements in energy efficiency, reducing energy consumption per tonne steel from 29.3 GJ/tonne in 1990 to 23.0 GJ/tonne steel in 2000[5] (Editorial Board of the China Steel Yearbook, 2004), there is still considerable potential for energy efficiency improvement and CO_2 emission mitigation (Kim and Worrell, 2002a). Planned improvements include greater use of continuous casting and near-net shape casting, injection of pulverized coal, increased heat and energy recovery, and improved furnace technology (Zhou et al., 2003). A recent study estimated the 2010 global technical potential for energy efficiency improvement with existing technologies at 24% (De Beer et al., 2000a) and an additional 5% could be achieved by 2020 using advanced technologies such as smelt reduction and near net shape casting.

Economics may limit the achievable emission reduction potential. A study of the U.S. steel industry found a 2010 technical potential for energy-efficiency improvement of 24%, but the economic potential was limited to 18% (Worrell et al., 2001a), accounting for the full benefits of the energy efficiency measures (Worrell et al., 2003). A similar study of the European steel industry found an economic potential of less than 13% (De Beer et al., 2001). These studies focused mainly on retrofit options. However, potential savings will be realized by a combination of stock turnover and retrofit of existing equipment (Ruth, 1995). A recent analysis of the efficiency improvement of electric arc furnaces in the US steel industry found that the average efficiency improvement between 1990 and 2002 was 1.3%/year, of which 0.7% was due to stock turnover and 0.5% due to retrofit of existing furnaces (Worrell and Biermans, 2005). Future efficiency developments will aim at further process integration. The most important are near net shape casting (Martin et al., 2000), with current applications at multiple plants in the world, and smelt reduction, which integrates ore agglomeration, coke making, and iron production in a single process. While the current blast furnace is very efficient at large scale, at small to medium-scales smelt reduction will offer an energy-efficient alternative (De Beer et al., 1998).

[5] China uses various indicators to present energy intensity, including the comprehensive and comparable energy intensity (see also Price et al.., 2002). The indicators are not always easily comparable to energy intensities from other countries or regions. The above figures use the comparable energy intensity, which is a constructed indicator, making it impossible to compare to those of other studies. Only a detailed assessment of the energy data can result in an internationally comparable indicator (Price et al.., 2002).

7.4.1.2 Fuel Switching

Coal (in the form of coke) is the main fuel in the iron and steel industry because it provides both the reducing agent and the flow characteristics required by blast furnaces in the production of iron. Various steel-making processes produce large volumes of by-products (e.g. coke oven gas, blast furnace gas) that are used as fuel. Hence, a change in coke use will affect the energy balance of an integrated iron and steel plant.

Technology to use oil, natural gas, and pulverized coal to replace coke in iron-making has long been available. Use of this technology has been dictated by the relative costs of the fuels, and the process limitations in iron-making furnaces. Use of oil, and particularly natural gas, could reduce CO_2 emissions from iron-making. More recently, the steel industry has developed technologies that use wastes, such as plastics, as alternative fuel and raw materials (Ziebek and Stanek, 2001). Pre-treated plastic wastes have been recycled in coke ovens and blast furnaces (Okuwaki, 2004). Such recycling contributes to the reduction of CO_2 emissions by reducing emissions from incineration and the demand for fossil fuels. In Brazil, charcoal has been used as an alternative to coke in blast furnaces. While recent data were not available, use of charcoal declined in the late 1990s, as merchant coke became cheaper than charcoal (Kim and Worrell, 2002a).

The production of direct reduced iron (DRI) is an alternative to pig iron. The dominant DRI-production processes use natural gas as fuel, resulting in a lower CO_2 intensity. However, DRI cannot be used in primary steel plants, and is mainly used as an alternative iron input in secondary steelmaking. Currently, DRI production volume is 8% of pig iron production (IISI, 2005).

Longer term, switching to hydrogen in steel production could be a promising option to reduce CO_2 emissions. Theoretically, it is possible to convert iron oxide to iron using hydrogen as a reducer. About 650 Nm^3 of hydrogen is required to produce 1 tonne of iron (De Beer et al., 1998). However, no commercial experience with hydrogen reduction of iron oxides is yet available. If hydrogen were produced by electrolysis from carbon-free sources of energy, or from sustainably grown biomass, CO_2 emissions could be eliminated from this portion of the steelmaking process. Alternatively, if hydrogen were produced from fossil fuels, in conjunction with the carbon capture and storage technology (see Chapter 4), CO_2 emissions could be substantially reduced.

It is technically possible to recover CO_2 from blast furnace gas, but the costs are estimated at $70/ton CO_2 ($250/tC) The potential in 2020 is estimated at 290 Mt CO_2 (79 MtC) or 15% of the estimated emissions in 2020 (De Beer et al., 2000a). Smelt reduction technology would also allow the integration of CO_2 capture and storage into the production of iron.

7.4.1.3 Raw Material Mix

As iron production is the most energy-intensive part of the steel industry, increasing the use of scrap as a feedstock would result in significant energy savings. Scrap use is steadily increasing. In 2004, the global steel industry consumed 406 Mt of scrap to produce steel in primary and secondary steel plants (IISI, 2005). However, as long as the global demand for steel is growing, there will always be a need for iron production. Also, primary steel is certain to remain the preferred material for high-quality products. Despite a global scrap market, there is a potential for increased scrap use in specific regions. Especially on the long term scrap use is likely to increase as more of the currently consumed steel products reach the end of life, and as new melting and refining technologies increasingly allow production of high-quality products. Due to the complexity of steel product categories and qualities the CO_2 mitigation potential of a shift from primary to secondary steel is hard to project (De Beer et al., 2000a).

7.4.2 Non-ferrous Metals

The non-ferrous metals, their global production rates, and CO_2 emissions from electrode and reductant use are shown in Table 7.4.2. Annual production of these metals ranges from roughly 25 Mt for aluminium to a few hundred Kt for metals and alloys of less commercial importance. Compared to some of the world's key industrial materials like cement, steel, or paper, production volumes are fairly low. However, for some of these metals primary production from the ore can be far more energy intensive than for other larger volume bulk materials. In addition, some of the steps during the production phase of these metals can result in the emission of high-GW_p GHGs, e.g. PFCs or SF_6, which can add significantly to CO_2-eq. emissions. Finally, the primary production of these metals tends to be concentrated in only few countries. Thus, the level of national GHG emissions of these countries and their trends are often heavily influenced by the production of these non-ferrous metals.

(INSERT **Table 7.4.2** here)

Generally, the following steps in the production process need to be considered: mining, ore refining and enrichment, primary smelting, secondary smelting, metal refining, and rolling and casting.
For most non-ferrous metals primary smelting from the specific ores tends to be the most energy-intensive, but significant levels of emissions of fluorinated GHGs have also been reported from the refining and casting steps.

7.4.2.1 Aluminium

Global primary aluminium production was 29.2 Mt in 2004 (IAI, 2005), has grown an average of 3% per year over the last 10 years, and based on calculations using the industry's sustainability model, is expected to grow by 3% per year for the next 10 years. Secondary aluminium production (from recycled metal) was approximately 14 Mt in 2004, and is also expected to grow by about 3% per year (Bruggink and Martchek, 2004).

Aluminium metal (Al) is produced by the electrolytic reduction of alumina (Al_2O_3) in a highly energy-intensive process. Energy costs are such an important part of the cost of producing aluminium that smelters are usually located near cheap sources of electricity, typically near large hydroelectric, nuclear, or coal/lignite-fired power plants. In addition to the CO_2 emissions associated with electricity generation, the process itself is GHG-intensive. It involves a reaction between Al_2O_3 and a carbon anode: $2\ Al_2O_3 + 3\ C = 4\ Al + 3\ CO_2$. Additionally, in the smelter pot, Al_2O_3 is dissolved in molten cryolite (Na_3AlF_6). If the flow of Al_2O_3 to the anode is disrupted, a phenomenon known as an anode effect will occur. Cryolite will react with the anode to form perfluorocarbons (PFCs), CF_4 and C_2F_6 (IAI, 2001). CF_4 has a GW_p of 5700 and C_2F_6, which accounts for about 9% of the mix, has a GW_p of 11,900 (IPCC, 2001c). These emissions can be significantly reduced by careful attention to operating procedures and more use of computer-controlled operations that minimize disruptions in Al_2O_3 flow. Beyond this, major reductions in emissions can be achieved by switching from older cell technology (e.g. Vertical Stud Södeberg (VSS) or Side Worked Prebake (SWPB)) to more advanced technologies (e.g Centre Work Prebake (CWPB) or Point Feed Prebake (PFPB)).

SF_6 (GW_p = 22,200 (IPCC 2001c)) has been used for stirring and degassing of molten aluminium in secondary smelters and foundries (Linde, 2005). The process is not very common because of cost and technical problems (UBA, 2004). Current level of use is unknown.

Currently, the main potentials for further CO_2-eq. emissions reduction are a further penetration of state-of-the art smelter technology and process control plus an increase of recycling rates for old-scrap (IEA GHG, 2001). Research is proceeding on development of an inert anode that would eliminate anode-related CO_2 and PFC emissions from Al smelting. A commercially viable design is expected by 2020 (The Aluminum Association, 2003).

7.4.2.2 Magnesium

Magnesium is produced in fairly low volumes, but its production is very energy intensive. Its growth rates have been high due to an expanding use of this light weight metal in the transportation industry. In addition SF_6 is quite commonly used as cover gas for the die casting of magnesium. USEPA (2001) estimated that in 2000 about 16 Mt CO_2-eq. (4.4 MtC-eq.) were emitted globally from SF_6 use in die casting. Very likely this by far outweighs energy related emissions from the production of magnesium. According to an EU-study (Harnisch and Schwarz, 2003) the majority of these emissions can be abated at low costs (<1 € / t CO_2-eq. (<3.67 €/tC-eq.) through the use of the traditional cover gas SO_2, which is toxic and corrosive, or of more advanced fluorinated cover gases with low global warming potentials. Significant parts of the global magnesium industry located in Russia and China still use SO_2 as a cover gas. The International Magnesium Association, which represented 44% of global magnesium production in 2002, has committed to phasing out SF_6 use by 2011 (Ottinger Schaefer et al., 2005).

7.4.2.3 Total Emissions and Reduction Potentials

Table 7.4.3 gives an overview of the key emission sources in the non-ferrous metal industry. Respective values are lower bounds. Total annual GHG gas emissions from the non-ferrous metal industry were at least 560 Mt CO_2-eq. (150 MtC-eq.) in 2000 (IEA GHG 2001). The GHG abatement options for the production of most non-ferrous metals are still fairly uncertain. In the past, non-ferrous metal industries, other than aluminium, have been considered as too small or too complex in respect to applied raw material, production technologies and product qualities, to be systematically assessed for reduction options.

(INSERT **Table 7.4.3** here)

7.4.3 Chemicals and Fertilizers

The chemical industry is highly diverse, with thousands of companies producing tens of thousands of products in quantities varying from a few kilograms to thousand of tonnes. Because of this complexity, reliable data on energy use and GHG emissions are not available, even in the U.S., which has the world's largest chemical industry (Worrell et al., 2000a). The majority of the CO_2-equivalent emissions from the chemical industry are in the form of CO_2, from both fuel combustion and process by-products. The largest CO_2 emission sources are the production of ethylene and other petrochemicals, ammonia for nitrogen-based fertilizers, and chlorine. Despite the high value of its products, pharmaceutical manufacture uses relatively little energy, most of which is used for the buildings that house industry facilities (Galitsky and Worrell, 2004). In addition, some chemical processes create other GHGs as by-products, e.g. N_2O from adipic acid, nitric acid and caprolactam manufacture, and HFC-23 from HCFC-22 manufacture.

Reducing energy use has been a chemical industry goal for many years. The chemical industry makes use of many of the sector-wide technologies described in Section 7.3. Much of the petro-chemical industry is co-located with petroleum refining, creating many opportunities for process integration and co-generation of heat and electricity. Galitsky and Worrell (2004) identify separations, chemical synthesis, and process heating as the major energy consumers in the chemical industry, and list examples of technology advances that could reduce energy consumption in each area, e.g. improved membranes for separations, more selective catalysts for synthesis, and greater process integration to reduce process heating requirements. Longer-term, biological processing offers the potential of lower energy routes to chemical products (See Section 7.12.1.1).

7.4.3.1 Ethylene

Ethylene, which is used in the production of plastics and many other products, is produced by steam cracking hydrocarbon feedstocks, from ethane to gas oil. Hydrogen, methane, propylene, and heavier hydrocarbons are produced as by-products. The heavier the feedstock, the more and heavier the byproducts, and the more energy consumed per tonne of ethylene produced (Worrell et al., 2000a). Ren, et al. (2006) report that steam cracking for olefin production is the most energy consuming process in the chemicals industry, accounting for emissions of about 180 $MtCO_2$/year, but that significant reductions are possible. Cracking consumes about 65% of the total energy used in ethylene production, but use of state-of-the-art technologies (e.g. improved furnace and cracking tube materials, co-generation using furnace exhaust) could save up to about 20% of total energy. The remainder of the energy is used for separation of the ethylene product, typically by low temper-ature distillation, and compression. Up to 15% total energy can be saved by improved separation and compression techniques (e.g. absorption technologies for separation). Catalytic cracking also offers the potential for reduced energy use, with a savings of up to 20% of total energy. This savings is not additive to the energy savings for improved steam cracking (Ren, et al., 2006). Processes have been developed for converting methane in natural gas to olefins as an alternative to steam cracking. However, Ren, et al.. (2005) conclude that the most efficient of these processes uses more than twice as much primary energy as state-of-the-art steam cracking of naphtha.

7.4.3.2 Fertilizer Manufacture

Swaminathan and Sukalac (2004) report that the fertilizer industry consumes about 1.2 percent of world energy consumption and is responsible for about the same share of global GHG emissions. More than 90 percent of this energy is used in the production of ammonia. However, as the result of energy efficiency improvements, modern ammonia plants are designed to use about half the energy per tonne of product than those designed in 1960s. As shown in Figure 7.4.3, the design energy consumption has dropped from over 60 GJ per tonne ammonia in the 1960s to 28.4 GJ per tonne ammonia in the latest design plants, approaching the thermodynamic limit of about 19 GJ per tonne of ammonia. Benchmarking data indicate that the best-in-class performance of operating plants ranges from 28.0 to 29.3 GJ per tonne ammonia (Chaudhary, 2001; PSI, 2004). Since the newest plants tend to have the best energy performance, and much of the recent fertilizer industry construction is in developing nations, which now account for 58 percent of ammonia production. Regional difference in energy performance are mostly determined by feedstock (natural gas vs heavier hydrocarbons) and age of the ammonia plant (PSI, 2004, Phylipsen, et al., 2002).

(INSERT **Figure 7.4.3** here)

Scope for further improvement in the energy efficiency of new plants is becoming limited. Ammonia plants that use natural gas as a feedstock have an energy efficiency advantage over plants that use heavier feedstocks, but today almost 80 percent of global ammonia capacity is based on natural gas. Retrofit of old plants is feasible and offers a potential for improved efficiency. Verduijn and de Wit (2001) concluded that the energy efficiency of large single train ammonia plants, the bulk of existing capacity, could be improved at reasonable cost to levels approaching newly designed plants, provided that the upgrading is accompanied by an increase in capacity.

The largest potential for reducing GHG emissions from state-of-the-art ammonia plants is the application of the carbon dioxide capture and storage (CCS) technology discussed in Chapter 4. Hydrogen production, which creates a CO_2-rich stream, is a necessary step in the manufacture of ammonia. Most studies of CCS technology identify ammonia production as a potential candidate for early introduction of CCS technology. The IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC, 2005b) estimates the cost of CO_2 capture from ammonia plants at $5-55/net tCO_2 ($20-200/tC). The Special Report also provides information on the costs of transportation and geological storage, as well as on the challenges in applying this technology.

7.4.3.3 Chlorine Manufacture

The TAR (IPCC, 2001a) reported on the growing use of more energy efficient membrane electrolysis cells for chlorine production. There have been no significant developments affecting GHG emissions from chlorine production since the TAR.

7.4.3.4 N_2O Emissions from Adipic Acid, Nitric Acid and Caprolactam Manufacture

Based on a GW_p of 296 for N_2O, global N_2O emissions from the manufacture of adipic acid (used as a feedstock for a variety of chemical products) were estimated at 55 Mt CO_2-eq. (15 MtC-eq.) in 2000, and are projected to grow to about 74 Mt CO_2-eq. (20 MtC-eq.) in 2020, with developed nations accounting for about 53% of emissions in both 2000 and 2020. Global N_2O emissions from the manufacture of nitric acid were estimated at 110 Mt CO_2-eq. (30 MtC-eq.) in 2000, and are projected to grow to 130 Mt CO_2-eq. (35 MtC-eq.) in 2020, with developed nations accounting for about 65% of emissions in both 2000 and 2020 (USEPA, 2003). Delhotal, et al. (2005) report that thermal destruction can eliminate 96 percent of the N_2O emitted from adipic acid manufacture, and catalytic reduction can eliminate 89 percent of the N_2O emitted from nitric acid manufacture. Costs are less than US$ 1.5/tCO_2-eq. (US$ 5.5/tC-eq.) using a 20% discount rate and a 40% corporate tax rate, and mitigation potential is approximately 187 Mt CO_2-eq. in 2020. No data was found on global N_2O emission rates from caprolactam (used in the manufacture of nylon) production. IPCC (2006) gives N_2O emission factors of 9 and 14.5 kg/t caprolactam for modern plants and older plants, respectively, and indicates that these emissions can be controlled to a high degree by non-specific catalytic reduction.

7.4.3.5 HFC-23 Emissions from HCFC-22 Manufacture

Up to 4% HFC-23 (GW_p = 12,000 (IPCC, 2001c)) is produced as a byproduct of HCFC-22 manufacture. HCFC-22 has been used as a refrigerant, but this use is ending in developed countries and will eventually end in developing countries. However, production of HCFC-22 for use as a feedstock in the manufacture of fluoropolymers is expected to grow, leading to increasing emissions through 2015 in the business-as-usual case. Capture and destruction by thermal oxidation is a highly effective option for reducing HFC-23 emissions at a cost of < $US 0.20 per tCO_2-eq. (<$US 0.75 per tC-eq.) (IPCC/TEAP, 2005).

7.4.4 *Minerals*

7.4.4.1 Cement

Cement is one of the most important construction materials and is produced in nearly all countries; relatively low price and high density of cement limit ground transportation. Cement consumption is closely related to construction activity and general economic activity. Global cement production grew from 594 Mt in 1970 to 1950 Mt in 2004, with the vast majority of the growth occurring in developing countries, especially China. In 2003 developed countries produced 421 Mt (22% of world production) and developing countries 1521 Mt (78%) (USGS, 2005).

Global cement consumption is growing at about 2.5%/year. While a group of 12 multinational companies controls nearly 75% of production in developed countries, regional and local players dominate most of the industry in Asia including China and India (Jain, 2005). China has almost one half of world's cement capacity and dominates current world cement production, manufac-turing 850 Mt in 2004. India is second largest producer, with capacity of 152 Mt (Jain, 2005) and production of 110 Mt in 2004 (USGS, 2005).

The production of clinker, the principal cementious material in cement, emits CO_2 from the calcinations of limestone. Cement production is also highly energy-intensive production process, consuming about 2% of the global primary energy. The major energy uses are fuel for the production of clinker and electricity for grinding raw materials and the finished cement. Various processes are used in clinker and cement making with varying energy intensities. Carbon-intensive fuels, e.g. coal, dominate in clinker making, hence the cement industry is a major source of CO_2 emissions. Worrell et al. (2001b) estimated total emissions from cement production in 1994 at 1126 $MtCO_2$, of which 52% were process emissions from clinker production and 48% from energy use. Based on average emission intensities (see below) the total emissions in 2003 are estimated at 1587 Mt CO_2 (432 MtC) to 1697 $MtCO_2$ (462 MtC), or about 5% of global CO_2 emissions.

The average intensity of CO_2 emissions of global cement production is estimated by Worrell et al.. (2001b) at 814 kg CO_2 (222 kg C)/t cement, while another study estimated the emission intensity at 870 kg CO_2 264 kg C)/t in the year 2000 (Humphreys and Mahasenan, 2002). Emission intensities vary by region from a low of 700 kg CO_2 (190 kg C)/ton cement in Western Europe and 730 kg CO_2 (200 kg C) in Japan and South Korea, to a high of 900, 930, and 935 kg CO_2 (245, 253, and 255 kg C) per ton cement in China, India and the United States, respectively (Humphreys and Mahasenan, 2002; Worrell et al., 2001b). Emission intensities have decreased over time, as evidenced by detailed studies of Canada (approx. 0.9%/year since 1990), the US (approx. 0.3% between 1970 and 1999) and Mexico (approx. 1%/year) (Nyboer and Tu, 2003; Worrell and Galitsky, 2003; Sheinbaum and Ozawa, 1998). A decomposition analysis of CO_2 emission trends in four major cement-producing countries showed that energy efficiency improvement and reduction of clinker content in cement were the main factors contributing to emission reduction, while the carbon intensity of fuel mix in all countries increased slightly. The differences in emission intensity are due (in order of contribution) to differences in the clinker content of the cement produced, energy efficiency, carbon intensity of the clinker fuel, and carbon intensity of power generation (Kim and Worrell, 2002b). The substantial differences in emission intensity suggest that there is potential for emission reduction in the cement industry.

In India, 94% of capacity is based on modern, energy-efficient dry process technology. The industry has introduced precalciners, multistage suspension pre-heaters, cyclones, improved burners, and high efficiency clinker cooling systems (Sathaye et al., 2005b). Decomposition analysis (Dasgupta and Roy, 2002) shows that the reduction in energy intensity since 1995-96 has led to a reduction in emissions from the industry despite the increase in output.

CO_2 emission mitigation can be achieved through reduction of the emissions due to energy use and those due to the calcination of limestone (by reducing the clinker content of cement). The combined technical potential of these opportunities is estimated at 30% globally, and varying between 20 and 50% for different regions (Humphreys and Mahasenan, 2002; Kim and Worrell, 2002b).

Energy efficiency improvement has historically been the main contributor to emission reduction. Benchmarking and other studies have demonstrated a substantial technical potential for energy efficiency improvement remains, varying between 0% to 40% for various countries (Kim and Worrell, 2002b; Worrell et al.., 1995). Countries with a high potential still use outdated technolo-gies, like the wet process clinker kiln. Studies for the US identified 30 opportunities in every production step in the cement-making process and estimated the economic potential for energy efficiency improvement in the US cement industry at 11%, reducing emissions by 5% (Worrell et al., 2000b; Worrell and Galitsky, 2004). The cement industry is capital intensive and equipment can have a long lifetime, limiting the economic potential on the short term.

The use of blended cement offers another potential reduction in cement industry carbon intensity. Standard Portland cement contains 95% clinker, resulting in a high carbon intensity, as the production of clinker is responsible for the process emissions and most of the energy-related emissions. In blended cement, clinker is replaced by alternative cementious materials, e.g. blast furnace slag, fly ash from coal-fired power stations, and natural pozzolanes, resulting in lower CO_2 emissions (Josa et al., 2004). Current applications of blended cement varies widely from country to country, being relatively high in Europe and low in the U.S. and U.K. Blended cement is consi-dered a major opportunity for emission reduction by the cement industry, and the potential is estimated at more than 7% of CO_2 emissions (Humphreys and Mahasenan, 2002; Worrell et al., 1995). Alternatives for limestone-based cement are also being investigated (Gartner, 2004; Humphreys and Mahasenan, 2002), but have not yet been proven economically for large scale application. For example, geopolymers have been applied in niche markets (Humphreys and Mahasenan, 2002).

Carbon capture and storage has been investigated for the cement industry due to the high concentration of CO_2 in the flue gas. Preliminary calculations suggest that it is possible to reduce CO_2 emissions by 65-70%, at costs varying between 50 and 250 US$/t$CO_2$ (Anderson and Newell, 2004). The cement industry has no practical experience with this technology (Worrell et al., 2001b).

7.4.4.2 Lime

Generally lime refers both to high-calcium and dolomitic forms containing magnesium. Lime is produced by burning limestone or dolomite in small-scale, vertical or large-scale, rotary kilns. While in most industrialized countries the industry is concentrated in a small number of larger corporations, in most developing countries lime kilns are typically small operations using local technology. However, even in industrialized countries independent small-scale vertical kilns operate (e.g. Greece). Pulp and sugar mills may have captive lime production to internally regenerate lime. Lime is mainly used in a small number of industries (especially steel, but also chemicals, paper and sugar), mining, as well as for flue gas desulfurization. There are no detailed statistics on global lime production, but Miller (2003) estimated global production at 120 Mt, excluding regenerated lime. The largest producers are China, United States, Russia, Germany, Mexico and Brazil.

CO_2 emissions are due to the decarbonization of limestone and magnesium carbonate, fuel combusted in the process, and indirect emissions from generation of the electric power consumed in the process. In efficient lime kilns about 60% of the emissions are due to decarbonization of the raw materials. No estimates of global CO_2 emissions due to lime production are available. In Europe process emissions are estimated at 750 kg CO_2/t lime (IPPC, 2001). Regeneration of lime in pulp and sugar mills does not necessarily lead to additional CO_2 emissions, as the CO_2 is from biomass sources (Miner and Upton, 2002). Emissions from fuel use vary with the kiln type, energy efficiency and fuel mix. Energy use varies between 3.6 and 7.5 GJ/t lime in the European Union (IPPC, 2001), 7.2 GJ/t in Canada (CIEEDAC, 2004) and for lime kilns with US pulp mills (Miner and Upton, 2002), and up to 13.2 GJ/t for small vertical kilns in Thailand (Dankers, 1995). In Europe, fuel-related emissions are estimated at 0.2 – 0.45 tCO_2/t lime. (IPPC, 2001). Electricity use for lime production varies between 40 and 140 kWh/t lime, depending on the type of kiln and the required fineness of the lime (IPPC, 2001).

Emission reductions are possible by use of more efficient kilns (Dankers, 1995; IPPC, 2001) and through improved management of existing kilns, using similar techniques as the cement industry (see section 7.4.4.1). Emission reductions (5-10% of total emissions) are possible by energy efficiency measures at payback periods of three years or less (CLI, 2001; Worrell and Galitsky, 2003). Switching to low-fossil carbon fuels can further reduce CO_2 emissions. The use of solar energy has been investigated for small-scale installations (Meier et al.., 2004). It may also be possible to reduce the consumption of lime in various processes. For example, Vaccari et al.. (2005) reviewed alternative processes to replace lime in the sugar industry.

7.4.4.3 Glass

Glass is produced by melting raw materials (mainly silica, soda ash and limestone), and often cullet (recycled glass), in glass furnaces of different sizes and technologies. Typical furnace designs include: cross-fired or end-fired with regenerative air preheat, recuperative heat recovery and fuel-oxygen firing (EU-BREF Glass, 2001). The industry is capital intensive, furnaces have a life time of up to 12 years, and there are a limited number of technology providers. Natural gas and fuel oil are the main fuels used by the glass industry.

Reliable international statistics on glass production are not available. The global glass industry is dominated by the production of container glass and flat glass. According to industry estimates the global production of container glass was 57 Mt in 2001 (ISO, 2004); production of flat glass was 38 Mt in 2004 (Pilkington, 2005). The production volumes of special glass, domestic glass, mineral wool and glass fibers are each smaller by roughly an order of magnitude.

The energy intensity of continuous glass furnaces in Europe and the US was found to range from about 4 to 10 GJ/t of container glass and 5 to 8.5 GJ/t of flat glass (Beerkens and van Limpt, 2001). Values depend on the size and technology of the furnace and the share of cullet used. The energy consumption for batch production can be significantly higher and typically ranges from 12.5 to 30 GJ of product (Römpp, 1995). Assuming that globally half of this energy is provided by natural gas and half by fuel oil, and a global average of 7 GJ/t of product, yields an emission factor of 450 kg energy related CO_2/t of product. Globally, energy used in the production of container and flat glass results in the emission of approximately 40-50 MtCO_2 per year. Emissions from the decarbonisation of soda ash and limestone can contribute up to 250 kg CO_2/t of product depending on the specific composition of the glass and the amount of cullet used.

Short to mid-term emission reduction potential is estimated to be 30-40%, reflecting the range of efficiencies reported by Beerkens and van Limpt (2001). Main mitigation options in the industry include: improved process control, increased cullet use, increased furnace size, use of regenerative heating, oxy-fuel technology, batch and cullet pre-heating, reduction of reject rates (Beerkens and van Limpt, 2001) and the use of natural gas instead of fuel oil. The scope for the use of biomass is limited, and potential new break-through technologies are not in sight.

7.4.4.4 Ceramics

The range of commercial ceramics products is large, including bricks, roof and wall and floor tiles, refractory ceramics, sanitary ware, tableware and cookware, and other products. In terms of volume the production of bricks and tiles dominate. The main raw materials used in the brick industry include clay and kaolin. Production technologies and respective energy efficiencies vary tremendously from large industrial operations to cottage and artisan production, which are still very common in many developing countries. The main fuels used in modern design industrial kilns are natural gas and fuel oil. Specific energy consumption strongly varies for different products and kiln designs. The EU-BREF Ceramics (2005) reports specific energy consumptions for modern industrial brick production ranging from 1.4 to 2.4 GJ/t of product. In developing countries small scale kilns - mainly to produce bricks - using inexpensive manual labor are often used. Wood, agricultural residues, and coal (FAO, 1993) are the main fuels used, with specific energy consumptions of 0.8 to 2.8 GJ/t of brick for the small- to mid-size kilns, and 2 to 8 GJ/t of brick for the very small-scale kilns used by the cottage industry and artisans (FAO, 1993). It should be noted that specifications for bricks produced in different types of kilns differ strongly, e.g., solid, hollow or perforated bricks. Industrial, as well as small-scale producers, utilize, to a certain extent, the energy contained in the organic fraction of clay and shale as well as in pore forming agents (e.g. saw dust) added to the clay in the production process. CO_2 emissions from the calcination of carbonates contained in clay and shale typically contribute 20-50% of total emissions.

Reliable international statistics on the production of ceramics products are not available. The annual per capita consumption of bricks, tiles and other ceramic products in t per capita per year is estimated at 1.2 in China (Naiwei, 2004); 0.4 in the EU (EU-BREF Ceramics, 2005), 0.1 in the U.S. (USGS, 2004), and 0.25, 0.12, and 0.05 for Pakistan, India and Bangladesh (FAO, 1993). This suggests that the global production of ceramic products exceeds 2 Gt/year, leading to the emission of more than 400 $MtCO_2$ (110 MtC) per year from energy use and calcination of carbonates. Additional research to better understand the emission profile and mitigation options for the industry is needed

GHG mitigation options include the use of more efficient kiln design and operating practices, fuel switch away from coal into fuel oil, natural gas and biomass, and partial substitution of clay and shale by alternative raw materials such as fly ash. Mitigation options also include the use of alternative building materials like concrete or wood, as well as the use of bricks made from concrete or lime and sand. However, informed decisions will consider emissions over the whole life cycle of the products including their impact on the energy performance of the building. It is also worth noting, that the current choices of building materials and kiln technologies are deeply related to local traditions, climate, and the costs of labor, capital, energy and transportation as well as the availability of alternative fuels, raw materials and construction materials.

7.4.5 Paper, Pulp and Milling

The paper and pulp industry is a substantial consumer of energy and generator of CO_2 emissions. However, the paper and pulp industry in OECD countries has promoted energy conservation, and the TAR (IPCC, 2001a) reported a continuous downward trend in primary energy use per unit of production from 1970 to 1992. This trend has continued. At the same time, production of paper products has increased with economic growth over the past decade, resulting in an increase of absolute emissions of CO_2.

It is possible to estimate future potential of GHG reduction in developed and developing countries by investigating the factors influencing past reductions in energy intensity. In this section, we identify three representative factors: use of biomass fuels, energy saving, and recycling of paper products; and describe their potential to reduce CO_2 emissions.

7.4.5.1 Use of Biomass Fuels

The production of paper and pulp produces wood waste, bark, sawdust, black liquor[6], and sludge as by-products, all of which can be used as biomass fuels. The industry is thus one of the main producers and consumers of biomass fuels. These biomass fuels can be carbon neutral, i.e., the same amount of CO_2 as emitted from these fuels is absorbed into the new forest growth, if sustainable forest management is practiced. Combustion of paper sludge rather than landfill disposal provides an additional reduction in GHG emissions because landfill of paper sludge will result in methane emissions, and more CO_2-eq. emissions than combusting the same amount of sludge. Since the increase in oil prices of the 1970s, the paper and pulp industry in many countries has increased the use of biomass fuels, reducing the CO_2 intensity of the industry.

Typically, bark, wood wastes, and black liquor are combusted in boilers to generate steam, which is used in the pulping and papermaking processes (in integrated plants), as well as for power generation. Advanced technology gasifies the black liquor and wood residues allowing for increased power generation, which has the potential to make pulp mills power exporters and the paper and pulp industry carbon neutral, depending on the efficiency of the process, and whether the trees used were grown sustainably (Farahini, 2004).

7.4.5.2 Emission Reduction Potential

The technical potentials for CO_2 emissions reductions by region in the paper and pulp industry were estimated using the methodology developed by Tanaka, et al. (2005). These projections are shown in Table 7.4.4. However, we should note the following structural factors that lead to the differences in the specific emissions for each country:

- production process (e.g., paper/pulp, mechanical/chemical pulp);
- fuel mix, including biomass and waste (e.g., used paper/plastics) and use of combines heat and power;
- Raw materials (domestic or imported wood, non-wood pulp).

These factors would have to be taken into account before the economic potential for CO_2 emission reduction could be assessed.

(INSERT **Table 7.4.4** here)

[6] In chemical pulping process used to make higher quality paper products, woodchips are digested in a mixture of sodium hydroxide and sodium sulphide or sulphite. After a few hours the fibres are separated from the spent pulping liquor (so-called black liquor). The black liquor retains 35-60% of the incoming wood, making it a biomass fuel. (Nilsson et al..,1995).

7.4.6 Food and Beverage

The food and beverages industry has a variety of products/processes including sugar, edible oils from different sources (e.g. peanuts, coconut, palm, cotton), starch, fruits and vegetables canning, bakeries and breweries, and meat processing. Most of these products constitute major commercial commodities, particularly for developing countries. Some of these commodities are quite energy-intensive (e.g. sugar, starch, breweries).

The sugar cane industry is one of the largest food industries with about 1670 mills situated mostly in developing countries (India, Pakistan, South East Asia, China, Southern Africa, and Latin America) (Sims, 2002). World sugar cane production from these sources is over 1.2 Gt per year (Banda, 2002). Edible oils are another significant product with export potential supporting most developing countries economies. For example, Malaysia, the world's largest producer and exporter of palm oil, has 3.5 million hectares of its land under palm oil production (UNDP, 2002), whilst Sri Lanka, the world's fourth producer of coconut oils, covers over a 0.4 million hectares for its cultivation (Kumar, et al., 2003).

Corn refining, including wet corn milling, has been the fastest growing market for U.S. agriculture over the past twenty years (CRA, 2002). Wet milling of corn produces starch, ethanol, sweeteners such as high fructose corn syrup, feed products, vegetable oil and other byproducts. Within food processing, corn wet milling is the most energy-intensive industry, using 15% of the total energy in the U.S. food industry (EIA, 2001). Over 100 technologies and measures for improving energy efficiency of corn wet milling have been identified (Galitsky et al.., 2003).

7.4.6.1 Production Processes, Emissions and Emission Intensities

The main production processes for the food industry are almost identical, involving preparatory stages including crushing, processing/refining, drying and packaging. Most produce process residuals, which typically go to waste. Food production requires electricity, process steam and thermal energy, which in most cases are produced from fossil fuels. Most food industry processes produce large volumes of wastewater with a high concentration of organic material. This waste-water is a serious problem for normal waste treatment plants due to its varying composition and unbalanced nutrients. Pre-treatment of the wastewater in a digester is normally required before it can be discharged into a sewer system (UNDP, 2002). The major GHG emissions from the food industry are CO_2, from the combustion of fossil fuels (diesel, heavy fuel oil, coal) in boilers and furnaces, and CH_4 (GW_p=23) from wastewater systems due to anaerobic reactions occurring in the ponds.

Although unit factory emissions from the food industry are low, their cumulative effect is significant in view of large numbers of such factories in both developed and developing countries. Energy intensities of such factories vary depending on the nature of operations. For example, typical energy intensities are estimated at about 11 GJ/t for edible oils, 5 GJ/t for sugar, and 10 GJ/t for canning operations (UNIDO, 2002). The largest source of emissions is CH_4 from wastewater treatment. For example, in the palm oil industry in Malaysia (UNDP, 2002), 62% of a total of 90 kt CO_2-eq.(25 ktC-eq.) per year are generated from open lagoons, with the balance from grid electricity sources. A similar trend was noted in the starch industry in Thailand (Cohen, 2001), where out of a total of 370 kt CO_2-eq.(101 ktC-eq.) per year, 88% were from wastewater treatment, 8% from combustion of fuel oil, and 4% from grid electricity.

7.4.6.2 Mitigation Opportunities

There are many opportunities for the food industry to be self-sufficient in generating electrical power and significantly reducing process steam and thermal energy requirements, leading to a sustainable production path with reduced local and global environmental effects. A mixture of driving forces now exists, which can propel these industries towards attainment of such a sustainable path. The sugar industry, which is a major worldwide industry, is facing many problems. Sugar prices are extremely volatile and preferential prices for sugar will eventually be removed under the World Trade Organisation rules (Jolly, 2004). The sugar industry also faces difficulties due to saturated markets in the industrialised countries and competition from other sweeteners. For the sugar industry to be sustainable and competitive, there is increased need for it to diversify its products portfolio by investing in products such as ethanol and surplus electricity generation (Cornlad, et al., 2001).

The need for competitiveness as a result of globalisation is also being felt in other food-based industries such as the coconut and starch industries (Kumar, 2003; Cohen, 2001) and bakery industry (Kannan, et al., 2003). These industries are taking advantage of improved energy management practices combining engineering skills with housekeeping.

Virtually all the countries in the world have environmental regulations, although of varied stringency, which require installations including the food industry to limit final effluent BOD (Biochemical Oxygen Demand) in the wastewater before discharge into waterways. Such measures are compelling industries to use more efficient wastewater treatment systems. The recently introduced EU-directive requiring Best Available Techniques (BAT) on environmental permit conditions in the fruit and vegetable processing industry (Dersden, et al., 2002) will compel EU industry in this sector to introduce improved wastewater purification processes thereby reducing fugitive emissions due to anaerobic reactions.

Various technologies and processes are available in the market place, which can be applied in the near- and medium-term in the food industry to reduce GHG emissions. These include good housekeeping and improved management, as well as improvements in both cross-cutting systems (e.g. boilers, steam and hot water distribution, pumps, compressors and fans) and process-specific technologies. Important technologies include improved process controls, more efficient process designs, and process integration (Galitsky, et al., 2001), cogeneration to produce enough electricity for own use and surplus for export (Cornlad, 2001), and anaerobic digestion of residues to produce biogas for electricity generation and/or process steam (UNDP, 2002). Following the example of Brazil, in India, the sugar industry has diversified into cogeneration of power and production of fuel ethanol. Cogeneration began in 1993-94, and as of 2004 reached 680 MW. Full industry potential is estimated at 3500 MW. In 2001, India instituted a mixed fuel programme requiring use of a 5% ethanol blend, which will create an annual demand for 500 M litres of ethanol (Balasubramaniam, 2005).

7.4.6.3 Potential for Mitigation

A study on the application of traditional boilers with improved combustion and CEST in the Southern African sugar industry showed that by 2010, the sugar factories under consideration could be self sufficient in electricity generation with surpluses of 135MW for use for irrigation purposes and 1620 MW for export to the national grid (Yamba and Matsika, 2003). Application of CEST technologies, the study showed, will reduce GHG emissions by 8 Mt CO_2-eq. (2.2 MtC-eq.)/year by the year 2010, and also improve financial performance of such industries from an Internal Rate Return (IRR) of 13.9% and Net Present Value (NPV) of US$32.7 million under business-as-usual operation to 15.3% IRR and US$ 51.6 million NPV when CEST technologies are applied to normal sugar operations (Deborah, et al., 2001).

A similar study for Australia (Sims, 2002) indicated that if all 31 of the country's existing sugar mills were converted to CEST technology, they would have the potential to generate 20 TWh/year of electricity, and assuming that they replaced coal-fired electricity generation, reduce emissions by 16 $MtCO_2$ (4.4 MtC)/year. Gasifying the biomass and using it in combined cycle gas turbine could double the CO_2 savings (Cornlad, 2001).

Proposed CDM projects in the Malaysian palm oil industry (UNDP, 2002), and the Thai starch industry (Cohen, 2001) demonstrate that use of advanced anaerobic methane reactors to produce electricity would yield a GHG emission reduction of 56-325 kt CO_2-eq. (15-90 MtC-eq.)/year. Application of improved energy management practices in the coconut industry (Kumar, et al., 2003) and bakery industry (Kannan, et al., 2003) showed significant saving of between 40-60 % in energy consumption for the former and a modest saving of 6.5 % for the latter. In the long term, use of residue biomass generated from the food industry in state-of-the-art Biomass Integrated Gasifier Combined Cycle (BIG/CC) technologies, once they become commercially available, will significantly improve electricity generation and GHGs savings by a factor of two (Yamba and Matsika, 2003; Cornlad, et al., 2001) over the CEST technologies.

7.4.7 Other Industries

This section covers a selection of industries with significant emissions of high GW_p gases. The manufacture of semiconductors, liquid crystal display and photovoltaic cells can result in the emissions of PFCs, SF_6, NF_3, and HFC-23 (IPCC, 2006). The technology available to reduce these emissions from semiconductor manufacturing, and the World Semiconductor Council (WSC)'s commitment to reduce PFC emissions by at least 10% by 2010 from 1995 levels are discussed in the TAR (IPCC, 2001a). Ottinger Schaefer, et al. (2005)report that emission levels from semiconductor manufacture were about 40 $MtCO_2$-eq (11 MtC-eq) in 2000, and that significant growth in emissions will occur unless the WSC commitment is implemented globally and strengthened after 2010. The potential for mitigation of emissions from the production of liquid crystal displays and photovoltaic cells needs further research.

The production of medium and high voltage electrical transmission and distribution equipment using SF_6 resulted in emission of about 5 MtCO2-eq (1.4 MtC-eq) in 2000 (Ottinger Schaefer et al., 2005). Production is currently mainly located in Europe and Japan. Respective emissions from this source are estimated to have declined in Europe since the mid-1990s despite a 60% growth in production, 1995-2003. This is mainly due to targeted training of staff, and improved gas handling and test procedures at the production sites (Wartmann and Harnisch, 2005). Emissions of SF_6 at the end-of-life of electrical equipment are growing in relevance but are covered in Chapter 10.

A third group of industries that emits hydrofluorocarbons (HFCs) includes those manufacturing rigid foams, refrigeration and air conditioning equipment, and aerosol cans, as well as industries using fluorinated compounds as solvents or for cleaning purposes. This group of industries previously used ozone depleting substances (ODS), which are subject to declining production and use quotas defined under the Montreal Protocol. As part of the phase out of ODS, many of them have switched to HFCs as replacements, or intend to do so in the future. Mitigation options include improved containment, training of staff, improved recycling at the end-of-life, the use of very low GW_p alternatives, and the application of not-in-kind technologies. A detailed discussion of use patterns, emission projections, and mitigation options for these applications can be found in the

IPCC/TEAP Special Report on Protecting the Ozone Layer and Safeguarding the Climate (IPCC/TEAP, 2005). Ottinger Schafer et al. (2005) estimated emissions from production of HFCs at 1.5-15 $MtCO_2$-eq (0.4-4 MtC-eq) in 2000, and projected growth to 8-80 $MtCO_2$-eq (2.2-22 MtC-eq) by 2020. Solvent and cleaning uses of HFCs are fully emissive despite containment and recycling measures. Based on projections by Ottinger Schafer et al. (2005), these application will dominate industry emissions and could contribute up to 80 $MtCO_2$-eq by 2020.

7.4.8 Cross-Industry Options

Some options for reducing GHG emissions involve more than one industry, and may increase energy use in one industry to achieve a greater reduction in energy use in another industry or for the end-use consumer. For example, the use of granulated slag in Portland cement may increase energy use in the steel industry, but can reduce both energy consumption and CO_2 emissions during cement production by about 40%. Approximately 300 kg of blast furnace slag are generated for every tonne of iron produced. Granulated slag becomes blast furnace cement when pulverized and mixed with clinker, reducing the clinker content of the cement. Production of clinker is the most energy- and carbon-intensive step in cement manufacture. Slag content can be as high as 60% of the cement, replacing an equivalent amount of clinker (Cornish and Kerkhoff, 2004). Light weight materials (high tensile steel, aluminium, plastics, composites) often require more energy to produce than the heavier materials they replace, but their use in vehicles will reduce transportation sector energy use, leading to an overall reduction in global energy consumption.

7.5 Short- and Medium-term Mitigation Potential

One of the major goals of this report is to develop estimates of the potential for and cost of GHG emission mitigation. Unfortunately, the literature reviewed to date provides insufficient information for developing such estimates for the industrial sector. (We are seeking additional literature references.) Table 7.5.1 shows estimates of the potential to reduce industrial CO_2 emissions, globally and by sector, to 2030. Only one reference (IEA, 2004) provides a global estimate of potential in 2030, but that reference does not provide a cost estimate. There are a number of estimates of potential for specific regions and industries, but too few to construct a bottom-up estimate of global potential. Cost information is far more limited, with estimates for only two countries, Mexico and South Africa.

(INSERT **Table 7.5.1** here)

A larger amount of information is available for non-CO_2 gases. Delhotal, et al. (2005) report that thermal destruction can eliminate 96 percent of the N_2O emitted from adipic acid manufacture, and catalytic reduction can eliminate 89 percent of the N_2O emitted from nitric acid manufacture. Costs are less than US$ 1.5/tCO_2-eq. (US$ 5.5/tC-eq.) using a 20% discount rate and a 40% corporate tax rate, and mitigation potential is approximately 187 Mt CO_2-eq. in 2020. IPCC (2006) reports that 90% of N2O emissions from caprolactam manufacture can be controlled by non-selective catalytic reduction, but does not provide either cost or total abatement potential.

Ottinger Schaefer, et al., 2005, provide marginal abatement cost curves (MACs) for 2010 for HFCs, PFCs and SF6 from a variety of sources using a 4% discount rate and 0% tax rate. Considering only emissions from the sectors covered by this chapter (aluminium, magnesium, HCFC production, electrical transmission and distribution gear and solvent use), in 2010, mitigation of approximately 18 $MtCO_2$-eq. (5 MtC-eq.) can be achieved at no net cost, and approximate 140 MtCO2-eq. (38 MtC-eq.) can be mitigated at a cost of \$20/tCO_2-eq. The MACs are insensitive to cost above

\$20/tCO_2-eq., except in the case of solvent use, where at approximately \$30/tCO_2-eq., an additional 18 MtCO_2-eq. can be mitigated.

No global data were found on mitigation cost or potential for CH_4 emissions from the food industry.

7.6 Barriers to Industrial GHG Mitigation

In many areas of the world, GHG mitigation is neither demanded nor rewarded by the market or government. In these areas, companies can afford to invest in GHG mitigation only to the extent that their investments are compensated by lowered energy or raw material costs, or some similar benefit.

Even though a broad range of cost-effective GHG mitigation technologies exist, a variety of barriers prevent their fully realisation in either developed or developing countries. Another barrier is the ability of industrial organizations to access and absorb the available information on these technologies. Access to information tends to be more of a problem in developing nations, but all companies, even the largest, have limited technical resources to interpret and translate the available information. The success of the voluntary information sharing programs discussed in Section 7.9.2 is evidence of the pervasiveness of this barrier.

A third barrier is competition for financial and technical resources within companies. In those parts of the world where GHG mitigation is not a legal requirement, projects to reduce GHG emissions must compete for technical and financial resources against projects to advance all of the other company goals. Projects to increase capacity or bring new products to the market typically have priority, especially in developing countries, where markets are growing rapidly, and where a large portion of industrial capacity is in SMEs. Energy efficiency and other forms of GHG mitigation technology can provide attractive rates of return, but they tend to increase initial capital costs, which can be a barrier, particularly in developing countries where capital availability is limited. If the technology involved is new to the market in question, even if it is well-demonstrated elsewhere, the problem of raising capital may be further exacerbated (Shashank, 2004).

7.7 Sustainable Development Implications of Industrial GHG Mitigation

Although no universally accepted practical definition of sustainable development yet exists, the concept has evolved to integrate economic, social and environmental aims. The key is a better understanding of relevant policy linkages.

GHG emissions mitigation policies induce increased innovation that can reduce the energy and capital intensity of industry. But this could come at the expense of other even more valuable productivity-enhancing investments or learning-by-doing efforts (Goulder and Schneider, 1999). The effects of industrial development policies on GHG emissions need not always be climate-friendly. If policies are successful in stimulating economic activity, they also likely will stimulate increased energy use. The only way the policy could then mitigate GHG emissions is if the carbon-intensity of economic activity decreased by more than the increase in the scale of activity. In OECD countries both structural change and the intensity effect could mitigate GHGs (Schipper, et al., 2000; Liskas, et al., 2000). For developing countries like India (Dasgupta and Roy, 2003), China (Zhang, 2003), Korea (Choi and Ang, 2001; Chang, 2003), Bangladesh (Bain, 2005), and Mexico, for industry sector in general and energy intensive industries in particular, the energy and carbon intensity of production activities has decreased due to energy conservation and fuel switching. However, economic activity has increased more rapidly, resulting in higher overall carbon emissions. Detailed surveys for these countries are available in APERC, 2002, and Dasgupta, 2005.

Environmental constraints to development are acutely felt in the industrial sector in relation to both production and consumption of manufactured goods. Environmental effects of industrial production fall within the purview of the industrial sector alone. Industrial technology and its continuous innovative change if properly shaped by market and policy incentives makes an important contribution to solving the environmental sustainability problem. Although social development appears to be less closely linked to industry, it is strongly impacted by industrial development. There seem to be at least three ways (UNIDO, n.d.) in which industry helps to achieve the goals of social development

(1) Industry's substantial contribution to fund social development programmes.
(2) Creation of employment. Social indicators of industrial sustainability are all related to employment. Studies (Sathaye, et al., 2005a, Phadke, et al., 2005) have shown that in developing countries like India electricity efficient technology adoption can lead to relative higher employment and income generation.
(3) Promotion of various aspects of social integration through general thrust towards modernization, integration of women by way of productive employment. Many developed (Sutton, 1998) and developing countries are pursuing approach to greening by encouraging companies to achieve dematerialisation, habitat restoration, recycling, commitment to social responsibility. In India commitment of energy intensive industries on human-capital formation and on worker health and safety, reflect response to sustainability demands (GOI, 2005). The Indian steel industry has adopted, along with the strict energy conservation and audit measures, a sustainable development objective of meeting its corporate social responsibility goals (Jindal Power and Steel, Ltd., 2005).

Green purchasing is the practice of applying environmental criteria to the selection of products or services. Green purchasing has been relatively common among larger companies for the past decade. A 1995 survey of 1000 purchasers of office equipment and supplies showed that 80% of them were taking part in environmental initiatives within their companies. In another survey of 256 U.S. manufacturing firms, half indicated that suppliers were key players in their pollution prevention strategies. Some leading industrial companies organize workshops for their suppliers on to how to meet their standards, and conduct environmental audits of their suppliers' facilities. (Hamner and del Rosario, 1997)

In many cases, the local environment may be improved through fuel switching and energy conservation that reduces emissions from fossil fuels. As a generalization, large companies have had greater resources, and usually more incentives, to factor environmental and social considerations into their operations than small and medium enterprises (SMEs). Nevertheless, many SMEs have played their part in advancing a sustainable development agenda. For example, there have been advancements where such enterprises are part of coordinated supply chain or industrial park initiatives, or where they have participated in research and innovation (Dutta, et al., 2004) in sustainable goods and services.

7.8 Interaction of Mitigation Technologies with Vulnerability and Adaptation

The TAR chapter on adaptation contained no specific references to industry, and the chapter on human settlements, energy, and industry contained only one paragraph on the vulnerability of industry to climate change, which concluded: "Very little is known concerning the effects of warming on industry, and most information remains highly speculative.” (IPCC, 2001b). However, that paragraph does mention that industry could be affected by government climate policies or by changes in consumer behaviour resulting from climate change.

Industry, like all other human activities, is affected by weather and climate, particularly by weather extremes. However, large industrial enterprises are probably less vulnerable to these extremes than most other human activities because their facilities tend to be built to withstand the most extreme conditions anticipated at the time of their construction. Such facilities are also more likely to carry insurance to provide financial protection against weather-related damage. SMEs often lack these protections and are likely to be more vulnerable than large enterprises. Also, because of their financial and technical resources, large industrial organizations typically have a significant adaptive capacity for addressing vulnerability to weather extremes. SMEs typically have fewer financial and technical resources and therefore less adaptive capacity.

Many industrial facilities are large users of water, and a reduction in water availability could be a serious impact of climate change.

Industrial enterprises of all sizes are also vulnerable to changes in government policy and consumer preferences. While the specifics of government climate policies will vary greatly, all will have one fundamental objective: constraining GHG emissions. And while consumers may become more sensitive to the GHG impacts of the products and services they use, it is almost certain that they will continue to seek the traditional qualities of low cost, reliability, etc. The challenge to industry will be to continue to provide the goods and services on which society depends in a GHG-constrained world.

Industry can respond to the potential for increased government regulation or changes in consumer preferences in two ways: by reducing its own GHG emissions or by developing new, lower GHG emission products and services. To the extent that industry does this before required by either regulation or the market, it is demonstrating the type of anticipatory, or planned, adaptation advocated in the TAR (IPCC, 2001b). Industry is undertaking three types of programs in anticipation of the need to operate in a GHG-constrained world, GHG measurement and reporting systems, developing GHG management systems, and research and development on new technology.

GHG Measurement and Reporting Systems. It is axiomatic that measurement is a critical first step in the management of any process parameter. The most broadly used GHG emissions measurement protocol in the industrial sector is the Greenhouse Gas Protocol developed by the World Resources Institute and World Business Council for Sustainable Development (WRI/WBCSD, 2004). The Protocol defines an accounting and reporting standard that companies can use to ensure that their measurements are accurate and complete. Several industries (e.g. aluminium, cement, chemical, and paper and pulp) have developed specific calculation tools to implement the Protocol. Other calculation tools have been developed to estimate GHG emissions from office-based business operations and to quantify the uncertainty in GHG measurement and estimation (WRI/WBCSD, 2005). Understanding the sources and magnitudes of its GHG emissions gives industry the capability to develop business strategies to adapt to government and consumer requirements as they develop.

GHG Management Systems. Quality management systems were first promoted by Edward Deming in the 1950s (Deming, 1986), and codified in 1978 in the ISO 9000 standards, which were updated as ISO 9000:2000 (ISO, 2000). This approach was extended to environmental issues in 1996 in the ISO 14001 standard (ISO, 1996). Many companies are following this approach, though not necessarily the ISO standards, to build adaptive capacity for GHG emission reduction. At a 2004 American Petroleum Institute/U.S. Department of Energy Conference, ChevronTexaco reported on its management system for evaluating GHG impacts during the of design of capital projects, Exxon-Mobil reported on its Global Energy Management System, and Suncor reported on its development of a GHG management system covering all of its operations (API, 2005). The GHG emissions reduction opportunities identified by these management systems are evaluated using normal business criteria, and those meeting the current business or regulatory requirements are adopted. Those not adopted represent an adaptive capacity that could be used should business, government, or consumer requirements change.

Many studies have indicated that the technology required to reduce GHG emissions and eventually stabilize their atmospheric concentrations is not currently available (Jacoby, 1998; Hoffert, et al., 2002; Edmonds, et al.,2003). While these studies concentration on energy supply options, they also indicate that significant improvements in end-use energy efficiency will be necessary. Much of the necessary research and development is being carried out in public-private partnerships. One such partnership is the U.S. Department of Energy's Industrial Technologies Program, which has as its primary goal "… to invest in high-risk, high-value research and development that will reduce industrial energy requirements while stimulating economic productivity and growth." (US DOE, n.d.). Under this program a number of industries have developed technology roadmaps, laying out the new technology they will need to meet the array of challenges they face, including control of GHG emissions. For example, the aluminium industry's roadmap defines the technological need to reduce energy use and to develop inert anodes that will eliminate the potential for PFC emissions (The Aluminum Association, 2003). Similar programs exist in other regions (NEDO, 2005) and in individual industrial sectors (US DOE, n.d.). These programs provide adaptive capacity for industry by creating the technology needed to meet potential government regulation or changed consumer preference.

7.9 Effectiveness of and Experience With Policies

7.9.1 Kyoto Mechanisms (CDM and JI)

The Kyoto Protocol created the *Clean Development Mechanism (CDM)* to allow Annex I countries to obtain GHG emission reduction credits for projects that reduced GHG emission in non-Annex I countries, provided that those projects contributed to the sustainable development of the host country (UNFCCC, 1997). Private sector involvement was specifically permitted by the Protocol, which allowed credits to be earned beginning in 2000. The 2001 Marrakech Accords on implementation of the Kyoto Protocol called for a prompt start for the CDM (UNFCCC, 2001). While industrial companies have expressed considerable interest in and support for the CDM, progress on its implementation has been slow. The first CDM project was approved in November, 2004, and as of June, 2006, only XXX projects have been approved. Even industrial groups such as IETA (International Emissions Trading Association), which are highly supportive of the CDM have expressed concern about the complexity of the CDM, which discourages its integration into normal business processes, and the elements of regulatory subjectivity involved in assessing additionality (IETA, 2004).

The concept of *Joint Implementation (JI)*, GHG-emissions reduction projects carried out jointly by Annex I countries or business from Annex I countries, is mentioned in the UNFCCC, but amplified in the Kyoto Protocol. However, since the Kyoto Protocol does not allow JI credits to be transferred before 2008, progress on JI implementation has been slow. Both CDM and JI build on experience gained in the pilot-phase Activities Implemented Jointly (AIJ) program created by the UNFCCC in 1995 (UNFCCC, 1995).

7.9.1.1 Regional Differences

As of the beginning of 2005, Africa lagged behind other regions in the implementation of mitigation strategies under UNFCCC arrangements such as AIJ and the Kyoto Protocol mechanisms. Out of a total of 50 AIJ projects, only two were in Africa. None of the 20 projects recently approved under The Netherlands carbon purchase programme, CERUPT, were in Africa. Further, out of over 40 baseline methodologies submitted to the CDM Executive Board, of which eleven have been approved and six have progressed as Project Design Documents, only one on landfill project in South Africa is under active consideration (CDM for Sustainable Africa, 2004).

Yamba and Matsika (2004) identified policy, technical, financial and legal barriers inhibiting the exploitation of CDM in sub-Saharan Africa. Policy barriers identified include limited awareness of the benefits of CDM to business, and of CDM objectives and its cycle by government and the private sector. Other barriers include non-ratification of the Kyoto Protocol, and no fully established Designated National Authorities (DNAs). Technical barriers include limited awareness on the availability of energy-saving technologies and processes, and sometimes lack of knowledge of appropriate technologies for potential CDM projects. Limited human resources in the development of bankable business proposals and CDM projects, and CDM's requirements on additionality are additional major constraint. Of the barriers identified, financial issues pose the greatest challenges; in particular, the low market value of carbon credits (about US$ 5 per tonne in early 2005) and high CDM transaction costs do not encourage industry participation. Additionally, lack of financial resources from local CDM investors is another major inhibiting factor. Legal barriers include limited, and sometimes no, awareness at government and private sector levels, of the Kyoto Protocol, or the legal issues in the development of CDM projects.

CDM project identification and potential estimation has attracted much attention over the past few years in India and other developing countries. The Government of India has identified energy efficiency in the power sector and the steel industry as priorities for Indian CDM projects. As of December, 2004, 44 CDM projects have been proposed for India , including biomass-based cogeneration and energy efficiency, but only 3 project have been approved (GOI, 2005). This delay and low success rate has diminished hopes about the ability of CDM to encourage technology transfer. Some countries that are actively participating in CDM (e.g., Brazil, Costa Rica, Argentina, and Uruguay) are actually at the lower end of the priority list. (Silayan, 2005).

7.9.2 Voluntary GHG Programs and Agreements

7.9.2.1 Government-initiated GHG Programs and Agreements

Government-initiated GHG programs and agreements are found in many countries. These programs typically focus on energy-efficiency improvement or reduction of energy-related GHG emissions, although there are also examples of programs directed toward reduction of non-CO_2 GHG emissions. (APERC, 2003; Galitsky, et al., 2004; WEC, 2004).

Government-initiated *information* programs provide information on energy-efficient technologies and practices through industrial energy audit or assessment reports, benchmarking, case studies, fact sheets, reports and guidebooks, tools and software, websites, working groups, conferences and trade shows, and demonstrations of commercial and emerging technologies (Galitsky, et al., 2004, WEC, 2004). *Energy and GHG emissions management* programs provide standardized energy management systems, energy awareness promotion materials, industry experts, training programs, GHG emissions reporting or registries, and verification and validation assistance for companies to help

them to track and report energy use or GHG emissions reductions (Galitsky, et al., 2004). *Financial assistance* programs include loans, subsidies, and tax abatement (credits, deductions, or accelerated depreciation) related to purchased of energy-efficient equipment, along with subsidized assessments or audits of industrial facilities (WEC, 2004). For example, in order to motivate the industrial sector to take up energy conservation seriously, the Government of India has introduced fiscal incentives that ranged from offering 100 % depreciation allowances to cut on import duties for specific items to offering energy audit subsidy schemes through various agencies (GOI, 2005).
Awards and recognition provide positive publicity related to energy efficiency or GHG emission reduction (Galitsky, et al., 2004). *Energy efficiency standards* for industrial equipment such as motors and pumps are used to specify mandatory minimum energy consumption levels for specific types of equipment (APERC, 2003, CLASP, 2005).

Target-setting, where companies or industrial sectors determine a goal for energy-efficiency improvement, is done through a process of establishing visions and roadmaps as well as through voluntary agreements (VAs). VAs can be classified as unilateral commitments by industry, private agreements between industry and stakeholders, voluntary programs developed by government that individual firms can join, and agreements negotiated between industry and government (OECD Environment Directorate and IEA, 2003). Negotiated agreements that include explicit targets are the most effective type of VA (UNFCCC, 2002). As a part of negotiated agreements, companies or industry organizations set targets for reducing energy use or GHG emissions in exchange for government support including the types of programs described above. Negotiated agreements typically cover a period of five to ten years, so that strategic energy-efficiency investments can be planned and implemented. There are also VAs covering process emissions in Australia, Bahrain, Brazil, Canada, France, Germany, the Netherlands, New Zealand, Norway, Japan, the UK, and the U.S. (Bartos, 2001; EFCTC, 2000; USEPA, 1999)

VAs for energy efficiency improvement and reduction of energy-related GHG emissions by industry have been implemented in industrialized countries since the 1990s. A number of these national-level agreement programs are now being modified and strengthened, while additional countries, including some recently industrialized and developing countries, are adopting such agreements in an effort to increase the energy efficiency of their industrial sectors (Price, 2005).

Experience with VAs has been mixed, with some programs, such as the French Voluntary Agreements on CO_2 Reductions, appearing to just achieve business-as-usual savings (Chidiak, 2002; OECD, 2002). However, the more successful programs have seen significant energy savings (Bjørner and Jensen, 2002), even doubling historical autonomous energy efficiency improvement rates (Rietbergen et al.., 2002) and are cost-effective (Phylipsen and Blok, 2002). In addition, these agreements have important longer-term impacts including changes of attitudes and awareness of managerial and technical staff regarding energy efficiency, addressing barriers to technology adoption and innovation, creating market transformation to establish greater potential for sustainable energy-efficiency investments, promoting positive dynamic interactions between different actors involved in technology research and development, deployment, and market development, and facilitating cooperative arrangements that provide learning mechanisms within an industry (Delmas and Terlaak, 2000; Dowd et al., 2001). The most effective agreements are those that are legally binding, set realistic targets, include sufficient government support – often as part of a larger environmental policy package, and include a real threat of increased government regulation or energy/GHG taxes if targets are not achieved (Bjørner and Jensen, 2002; Karup and Ramesohl, 2002; Price, 2005).

The U.S. has instituted a program known as Climate VISION, which calls upon energy-intensive industries to commit to voluntary goals for reducing energy use and GHG emissions. Under this program, members of the American Iron and Steel Institute, who represent nearly three-fourths of U.S. steel production capacity, have committed to achieving a 10% increase in energy efficiency by 2012 from 1998 levels. The American Chemistry Council, which represents 90% of U.S. chemical industry production, has agreed to an overall GHG intensity reduction target of 18% by 2012 from 1990 levels. Other industries have made similar commitments. (US DOE, 2003).

7.9.2.2 Company or industry-initiated GHG programs and agreements

Numerous companies are participating in GHG emissions reporting programs as well as making commitments to reduce energy use or GHG emissions through individual corporate programs, non-governmental organization (NGO) programs, and industry association initiatives.

Beginning in the late 1990s, a number of individual companies initiated in-house energy or GHG emissions management programs and made GHG emissions reduction commitments (Margolick and Russell, 2001). Examples include DuPont’s pledge to reduce GHG emissions by 65% and hold energy use constant compared to a 1990 baseline (DuPont, 2002), BP’s target to reduce GHG emissions by 10% in 2010 compared to a 1990 baseline (BP, 2003), United Technologies Corporation’s goal to reduce energy and water consumption by twenty-five percent as a percent of sales by the year 2007 using a 1997 baseline (Rainey and Patilis, 2000) and Hewlett-Packard’s commitment to reduce PFC emissions by 10% from 1990 levels by 2005 (Hewlett Packard, 2002).

Often these corporate commitments are formalized through GHG reporting programs or registries such as the World Economic Forum Greenhouse Gas Register where 13 multi-national companies disclose the amount of GHGs their worldwide operations produce (WEF, 2005) and through NGO programs such as the Pew Center on Global Climate Change’s Business Environmental Leadership Council (Pew Center on Global Climate Change, 2005), the World Wildlife Fund’s Climate Savers Program (WWF, 2005), as well as programs of the Chicago Climate Exchange (CCX, 2005).

Industrial trade associations provide another platform for organizing and implementing GHG mitigation programs. The International Aluminium Institute initiated the Global Aluminium Partnership for Sustainability which established 9 sustainable developing voluntary objectives and 22 performance indicators and which provides technical services to member companies in their quest to reach these goals (Chase, 2004). The World Semiconductor Council (WSC), comprised of the national semiconductor industry associations of the United States, Japan, Europe, Republic of Korea, and Chinese Taipei, established a target of reducing PFC emissions by at least 10% below the 1995 baseline level by 2010 (Bartos, 2001). The World Business Council for Sustainable Development (WBCSD) started the Cement Sustainability Initiative in 1999 with ten large cement companies. The Initiative conducts research related to actions that can be undertaken by cement companies to reduce GHG emissions (Battelle Institute/WBCSD, 2002) and outlines specific member company actions (WBCSD, 2002).

There are few evaluations of the effectiveness of such company- or industry-initiated programs or agreements. An evaluation of the Germany industry’s self-defined global warming declaration found that achievements in the first reporting period appeared to be equivalent to business-as-usual trends (Ramesohl and Kristof, 2001). Questions have been raised as to whether such initiatives, which operate outside of a regulatory or legal framework, often without standardized monitoring and reporting procedures, just delay the implementation of government-initiated programs without delivering real emissions reductions (OECD, 2002). Companies that participate in the WBCSD Cement Sustainability Initiative, however, have been shown to have superior financial performance compared to the total stock market (Kommunalkredit Dexia, 2004).

The steel industry has committed to voluntary reductions in energy use in several countries (see Section 7.7.2). Japanese steelmakers committed to a voluntary action program to mitigate climate change with the goal of a 10% reduction in energy consumption in 2010 against 1990. In FY 2003, they accomplished 6.4% reduction in CO_2 emissions against 1990, through improvement of blast furnaces, upgrade of oxygen production plants, installation of regenerative burners, and other steps (Nippon Keidanren, 2004).

The members of the International Aluminium Institute (IAI), which now are responsible for more than 70% of the world's primary aluminium production, have undertaken a Global Aluminium Sustainable Development Initiative. This initiative includes commitments for the industry as a whole to an 80% reduction in PFC emissions intensity and a 10% reduction in smelting energy intensity by 2010 compared to 1990. IAI data (IAI, 2005) show a reduction in CF_4 emissions intensity from 0.54 to 0.14 kg/tonne Al, and a reduction in C_2F_6 emissions intensity from 0.057 to 0.017 kg/tonne Al between 1990 and 2003, with best available technology having a median emission rate of only 0.05 kg CF_4/tonne in 2000. IAI, 2004 showed a 6% reduction in smelting energy use between 1990 and 2001. Overall, PFC emissions from the electrolysis process dropped from 7.5 to 3.8 kg CO_2-eq. per tonne Al metal produced. The steps taken to control these emissions have been mainly low or no-cost, and have commonly been connected to smelter retrofit, conversion, or replacements (Harnisch et al., 1998; IEA GHG 2000).

Many chemical companies have entered voluntary agreements to reduce their energy use. By 2003, the Japanese chemical industry had reduced its CO_2 emissions intensity by 9% compared with 1990 levels (Nippon Keidanren, 2004), but due to increased production, overall CO_2 emissions were up by 10.5%.

7.9.3 GHG Financial Instruments

Financial instruments are used to stimulate investment in energy-saving measures by reducing investment cost. Important types of financial instruments include: grants and subsidies, favourable loans, and fiscal incentives. Fiscal incentives include measures to reduce taxes on energy-efficient equipment, accelerated depreciation, tax credits and tax deductions. Many developed and developing countries have financial schemes available to promote energy saving in industry (Price et al., 2005b).

According to a WEC survey 28 countries provide some sort of grant or subsidy for industrial energy efficiency projects; most subsidies were found in European countries (WEC, 2004). Subsides can be fixed amounts, a percentage of the investment (with a ceiling), or proportional to the amount of energy saved. In Japan the New Energy and Industrial Technology Development Organisation (NEDO) pays up to one-third of the cost of each high performance furnace. NEDO estimates that the project will result in energy savings equalling 5% of Japan's final energy consumption by 2010 (WEC, 2001). Favourable loans are loans offered at lower than the market rate to investors in energy efficient techniques. The Korean Energy Management Corporation (KEMCO) provides long-term and low interest loans to certified companies. (IEA, 2005). According to WEC (2004), soft loans are less popular than subsidies in the countries surveyed.

Fiscal measures are also frequently used to stimulate energy savings in industry. Some examples are:

- In The Netherlands, the Energy Investment Deduction (Energie Investeringsaftreck, EIA) stimulates investments in low-energy capital equipment and renewable energy by means of tax deductions (deduction of the fiscal profit of 55% of the investment) (IEA, 2005).
- In France, investments in energy efficiency are stimulated through lease credits. In addition to financing equipment, these credits can also finance associated costs such as construction, land and transport (IEA, 2005).
- The UK's Enhanced Capital Allowance Scheme allows businesses to write off the entire cost of energy-savings technologies specified in the "Energy Technology List" during the year they make the investment (HM Revenue & Customs, n.d.).
- Under Singapore's Income Tax Act, companies that invest in qualifying energy-efficient equipment can write-off the capital expenditure in one year instead of three. (NEEC, 2005).
- In the Republic of Korea, a 5% income tax credit is available for energy-efficiency investments (UNESCAP, 2000).
- Romania has a program where imported energy-efficient technologies are exempt from customs taxes and the share of company income directed for energy efficiency investments is exempt from income tax (CEEBICNet Market Research, 2004).

Evaluations show that financial incentives for industry actually lead to energy savings and corresponding greenhouse gas emission reductions. They create a larger market for energy efficient technologies. A drawback of financial incentives is that the schemes often also are used by investors who would have carried out the investment even without the incentive. Possible solutions to improve cost effectiveness are to restrict schemes to specific target groups and/or techniques (selected list of equipment, only innovative technologies), or use a direct criterion of cost-effectiveness (WEC, 2001; De Beer, et al., 2000b).

7.9.4 Regional and National GHG Emissions Trading Programs

The UK has imposed a Climate Change Levy on fossil fuels. Industrial companies can negotiate emissions reduction targets through agreements that, when met through efficiency measures and optional participation in the UK emissions trading scheme, which has been in place since March 2002, if those efficiency measures fall short of the target, will result in rebate of 80% of the levy. The program puts special emphasis on direct emissions and indirect emissions of the industrial sector and excludes direct emissions from the energy generation. Companies' performance against their targets is measured and verified annually (UK-DEFRA, 2004). Participants can sell excess allowances or save them for later use. In some cases direct participants' levels of emissions in the year before the start of the scheme were substantially below their baseline (NOA, 2004).

In January 2005, the European Union Greenhouse Gas Emission Trading Scheme (EU ETS) was launched as the largest multi-country, multi-sector GHG emission trading scheme world-wide (EC, 2005). For the initial phase of the scheme, from 2005-2008, each member state decided upon the total quantity of allowances it will allocate and the allocation of those allowances to the operator of each installation. The second phase lasts five years, from 2008 to 2012, parallel to the Kyoto Protocol first commitment period. Besides electricity and heat producers the following energy-intensive sectors are covered in the proposed EU trading scheme: mineral oil refineries and coke ovens, iron and steel production, cement and lime kilns, glass and ceramic producers, pulp and paper production, and all combustion installations with thermal input greater than 20 MW_{th}.

The inclusion of all large combustion installations means that the majority of installations in the chemical industry and the aluminium sector also are included. Each installation has to surrender allowances according to its annual, externally verified emissions report based on the harmonised rules of the EU Monitoring and Reporting Guidelines (OJ, 2004). The EU ETS will apply for approximately 12,000 installations, collectively responsible for around 1,680 Mt CO_2 (460 MtC) annually, that represent a 46% of the CO_2 emissions of the enlarged EU-25 (Kruger and Pizer, 2004). The number of companies affected by the Directive is obviously smaller, as large companies have many plants covered by the trading scheme. Two comprehensive assessments have analysed the first observed and likely future impacts of the EU-ETS on the industrial sector in the EU (IEA, 2005; Egenhofer, et al., 2005). Key issues identified relate to the harmonisation of methods for national allocation of emission allowances to the different industrial sectors in relation to the energy sector, the impact of increased power prices on the energy intensive industries, and compliance costs for small and medium sized enterprises.

7.9.5 Energy and Technology Policies

Some of the energy technologies needed by energy-intensive industries require enormous amount of investment and long period of time to construct capital equipment (Yamaji, 1999), e.g. town gas pipelines, power plants and grids. The huge amount of capital equipment and long replacement period involved make the investment risk prohibitively high for private companies, even if some innovative energy carriers or technologies are available. Government is expected to lower financial risk and promote the investment through technology policy, which includes diverse options: budget allocation for R&D on innovative technologies, subsidy or legislation to stimulate specific environmental technologies, or regulation to suppress unsustainable technologies.

Energy policy can have many objectives that impact on mitigation. For example, national energy strategy or technology policy objectives in some countries include energy security, environmental protection, and economical development (U.S. National Energy Policy Development Group, 2001). Specific goals can include: stable, secure energy supply; more severe environmental regulation; introduction of environmentally sound technologies for environmental protection; and deregulation in energy systems. The general goal is a balance consistency between energy security, environmental protection, and economical development.

The Indian 2001 Energy Conservation Act is expected to yield benefits in terms of reduced GHG emission. A Bureau of Energy Efficiency has been established for energy efficiency regulation, prescribe standards, set up energy conservation fund etc.

7.9.6 Sustainable Development Policies

The Commission on Sustainable Development 13th session (CSD-13) in April 2005 focused on concrete policy options to provide a supportive environment for new business formation and the development of small enterprises, including policies to:

- reduce information barriers for energy efficiency technology for industries,
- capacity building programmes for industry associations, and
- stimulating technological innovation and change to reduce dependency on imported fuels, to improve local air pollution or to generate local employment.

India's 10th Five Year Plan explicitly mentions sustainable development as goal of development (GOI, 2005; GOI, 2002) and reflects government's commitment to Millennium development goals. The Spatial Environmental Planning Programme of the Ministry of Environment and Forests has been conceptualized for ensuring protection of environment and resources through planned and sustainable development. The programme commenced in fourteen volunteering states with district-wise assessment for siteing of industries. The programme was initiated under a environmental management capacity building technical assistance project funded by the World Bank during 1997-2003. The programme has now been extended for the tenth five year plan and following activities for industrial sector have evolved under this programme: (1) Zoning atlas for siteing of industries, and (2) industrial estate planning and development of eco-industrial estates. To ensure environmental sustainability the 2001 Energy Conservation Act mandated a Bureau of Energy Efficiency to ensure energy efficiency, conservation and use of renewables. The energy saving potential for energy-intensive industries has been estimated at 5000 GWh. SME development has been taken up as sustainable growth strategy in India (GOI, 2005).

7.9.7 Air Quality Policies

There are many effective opportunities to reduce GHG emission and, at the same time, achieve substantial reductions in local air pollutants. Several examples important for the industry sector have been reported (STAPPA/ALAPCO, 1999):

- switching to natural gas-fired steam generation at an existing coal- or oil-fired unit,
- reducing electricity consumption via improved end-use efficiency,
- thin slab casting (reducing material and energy losses) and scrap preheating in the iron and steel industry,
- use of blended cements, which will reduce the clinker needs, and
- process integration and cogeneration in the petroleum refining and chemical industry.

In general air quality and climate change are treated as separate issues in national and international policies, even though most practices and technologies that will reduce GHG emissions will also cause a net reduction of emissions of air pollutants. However, air pollutant reduction measures may not necessarily reduce GHG emissions (STAPPA/ALAPCO, 1999) as many require the use of additional energy.

There are attempts to integrate industrial policies on air pollution and climate change. In Europe, the National Emission Ceilings (NECs) is a important regulation for the air quality, and the EU Emission Trading Scheme is important for the reduction of GHG emissions. In the Netherlands the requirements of the NECs will be fulfilled by a NO_x emission trading system. This system will be implemented through the same legal and administrational infrastructure as the European CO_2 emission trading system (Dekkers, 2003).

At European level the IPPC Directive 96/61/EC lays down a framework requiring Member States to issue operating permits for certain industrial installations. The Directive applies to new or substantially changed installations with effect from October 1999 and no later than October 2007 for existing installations. These permits must contain conditions based on best available techniques (BAT) to achieve a high level of protection of the environment as a whole. To improve information exchange BAT reference documents (BREFs) are made available which Member States are required to take into account when determining best available techniques generally or in specific cases (EIPPCB, n.d.). These BREFs contain information on achievable energy efficiency standards in addition to achievable emission levels of air pollutants.

7.9.8 Waste Management Polices

The impact of waste management policies on GHG from the industrial sector can be very important: Such policies include the reduction of energy use in industry because of the re-use of products (e.g. of refillable bottles), as well as the use of recycled materials in industrial production processes. Recycled materials significantly reduce the specific energy consumption of the production of paper, glass, steel, aluminium and magnesium. The amount, quality, and price of recycled materials is largely determined by waste management policies. These policies can also influence the design of products - including the choice of materials, with its implications on production levels and emissions. Several prominent examples can be found in the packaging sector. Lifecycle assessment methods can help to quantify the net effect of these policies on emissions across the affected parts of the economy (Smith et al., 2001).

Another important influence of waste policies on industrial GHG emissions are their influence on the availability of secondary ("waste") fuels and raw materials for industrial use. These fuels and raw materials originate from wastes which could otherwise have been treated otherwise or exported from the country. A recent example is the "EU Landfill Directive" (EU-OJ, 1999), which limits the maximum organic content of wastes acceptable for landfills. As a result, a massive re-structuring of the waste sector is currently taking place in Europe. It makes available substantial amounts of waste containing significant biomass fractions. Typically there is competition between the different uses for these wastes: dedicated incineration in the waste sector, co-combustion in power plants, or combustion in industrial processes, e.g. cement or lime kilns. The EU-ETS provides additional economic incentives to use secondary fuels with significant biomass content as substitutes for fossil fuels. In order to provide additional inexpensive disposal routes, several countries have set incentives to promote the use of various wastes in industrial processes. The impact of switching from a fossil fuel to a secondary fuel on the energy efficiency of the process itself is commonly negative, but is often compensated by energy savings in other parts of the economy. Mineral wastes, such as fly-ash or blast-furnace slag, can have several competing use alternatives in the waste, construction, and industrial sectors. The production of cement, brick and stone-wool offers energy saving use options for these material in industry. For secondary fuels and raw materials, lifecycle assessment methods help to quantify the net-emission reductions across all affected parts of the economy.

7.10 Co-benefits of Industrial GHG Mitigation

The TAR explained that "co-benefits are the benefits from policy options implemented for various reasons at the same time, acknowledging that most policies resulting in GHG mitigation also have other, often at least equally important, rationales." (IPCC, 2001a) A general discussion of co-benefits is presented in Chapter 11. Here we focus on co-benefits of *industrial* GHG mitigation options that arise due to reduced emissions and waste (which in turn reduce environmental compliance and waste disposal costs), increased production and product quality, improved maintenance and operating costs, an improved working environment, and other benefits such as decreased liability, improved public image and worker morale, and delaying or reducing capital expenditures (see Table 7.10.1) (Pye and McKane, 2000; Worrell et al., 2003).

(INSERT **Table 7.10.1** here)

Significant co-benefits arise from reduction of emissions, especially local air pollutants. A study in Shanxi, China estimated that improvements to industrial boilers and adoption of co-generation of heat and electricity had local health benefits, such as increased life expectancy, reduced outpatient and emergency room visits, reduced lost work days, and reduced asthma attacks, valued between US$24 and US$33 per t CO_2 reduced. The mitigation options had costs of US$9.2 to US$-30 per t CO_2, resulting in overall net negative costs when the health impacts and energy cost reductions were considered (Aunan et al., 2004). Another study found that the costs associated with responding to air pollution (both mitigation policy implementation and health-related costs) could be significantly reduced in the U.S., EU, China, and India if climate change and air quality policies were aligned, and that the most attractive options are technical measures to increase energy efficiency (Kok and de Coninck, 2004).

Regarding other co-benefits of industrial GHG mitigation, a review of 41 industrial motor system optimization projects implemented between 1995 and 2001 found that 22 resulted in reduced maintenance requirements on the motor systems, 14 showed improvements in productivity in the form of production increases or better product quality, 8 reported lower emissions or reduction in purchases of products such as treatment chemicals, 6 projects forestalled equipment purchases, and others reported percentage increases in production or decreases in product reject rates (Lung et al., 2003). Motor system optimization projects in China are seen as an activity that can reduce operating costs, increase system reliability, and contribute to the economic viability of Chinese industrial enterprises faced with increased competition (McKane et al., 2003).

A review of 54 emerging energy-efficient technologies, produced or implemented in the U.S., EU, Japan and other industrialized countries for the industrial sector, found that 20 of the technologies had environmental benefits in the areas of "reduction of wastes" and "emissions of criteria air pollutants." The use of such environmentally-friendly emerging technologies is often most compelling when it enables the expansion of incremental production capacity without requiring additional environmental permitting. In addition, 35 of the technologies had productivity or product quality benefits (Martin et al., 2000).

Quantification of the co-benefits of industrial technologies is often done on a case-by-case basis. One evaluation identified 52 case studies from projects in the U.S., Netherlands, UK, New Zealand, Canada, Norway, and Nigeria that monetized non-energy savings. These case studies had an average simple payback time of 4.2 years based on energy savings alone. Addition of the quantified co-benefits reduced the simple payback time to 1.9 years (Worrell et al., 2003). Inclusion of quantified co-benefits in an energy-conservation supply curve for the U.S. iron and steel industry doubled the potential for cost-effective savings (Worrell et al., 2001a; Worrell et al., 2003).

Difficulties associated with quantifying co-benefits include the fact that not all benefits are easily quantified in financial terms (e.g. increased safety or employee satisfaction), there are variations in regulatory regimes vis-à-vis specific emissions and the value of their reduction, and there is a lack of time series and plant-level data on co-benefits. Also, there is a need to assess not only co-benefits, but also negative impacts that may be associated with some technologies, such as increased risk, increased training requirements, and production losses association with technology installation (Worrell et al., 2003).

7.11 Technology Research, Development, Deployment and Diffusion

Many industrial processes require much more energy than the thermodynamic ideal, suggesting a large potential for energy-efficiency improvement and GHG emission mitigation. However, this does not mean that the technology is available to capture these efficiency gains. Technology development is therefore an essential step in producing significant reductions in GHG emissions. Studies have demonstrated that new technologies are being developed and entering the market continuously, and that new technologies offer further potential for efficiency improvement and cost reduction (Worrell et al., 2002).

While this chapter has tended to discuss technologies only in terms of their GHG emissions mitigation potential and cost, it is important to realize that successful technologies also must meet a host of other performance criteria, including cost competitiveness, safety, and regulatory requirements;

and win consumer acceptance. While some technology is marketed as energy-efficient, other benefits may drive the development and diffusion of the technology, as evidenced by a case study of impulse drying in the paper industry, in which the driver was productivity (Luiten and Blok, 2004). This is understandable given that energy cost is just one of the drivers for technology development.

Innovation and technology transfer are interactive and iterative processes, involving many different parties. In a globalizing economy and industrial sector, environmentally-sound technologies are increasingly facing the same barriers and challenges for implementation around the world. An effective process for technology transfer will require interactivity between various innovators, adaptors and users of technology. The interactive and dynamic character of technology transfer stresses the need for innovative and flexible approaches, through long-term partnerships between various stakeholders, including public-private partnerships (Worrell et al., 2000b).

Technology research, development, deployment and diffusion are carried out by both governments (public sector) and companies (private sector). Ideally, the roles of the public and private sectors will be complementary. Flannery (2001) argued that it is appropriate for governments to identify the fundamental barriers to technology and find solutions that improve performance, including environmental, cost and safety performance, and perhaps customer acceptability; but that the private sector should bear the risk and capture the rewards of commercializing technology. Case studies of specific successful energy-efficient technologies, i.e. shoe press in papermaking (Luiten and Blok, 2003a) and strip casting in the steel industry (Luiten and Blok, 2003b), have shown that a better understanding of the technology and the development process are essential in the design of effective government support of technology development. The government can play also an important role in cultivating “champions” for technology development, as well to “anchor” energy and climate as an important continuous driver for technology development (Luiten and Blok, 2003a).

Recent analyses in energy R&D show that public and private energy R&D budgets of OECD countries have declined in past decades, while historical analysis has shown that patents and R&D spending have a close correlation (Margolis and Kammen, 1999). Compared to other sectors, the R&D intensity[7] of the energy sector is very low. Moreover, in IEA countries only 17% of the public energy R&D budget is spent on energy-efficiency, while 51% is spent on nuclear and fossil-fuel technology (IEA, 2005).

7.11.1 Public Sector

7.11.1.1 Domestic Policies

Governments are often more willing than companies to fund higher-risk technology research and development. This willingness is articulated in the U.S. Department of Energy’s Industrial Technologies Program role statement: “The program’s primary role is to invest in high-risk, high-value research and development that will reduce industrial energy requirements while stimulating economic productivity and growth” (US DOE, 2004b). The Institute for Environment and Sustainability of the EU’s Joint Research Centre has a similar mission, albeit focusing on renewable energy (Joint Research Centre, n.d.a), as does the program of the Japanese government’s New Energy and Industrial Technology Development Organization (NEDO, 2005).

Flannery (2001) focused on the research, development, and initial deployment portions of the technology process, but it is well-established that governments can play an important role in technology

[7] R&D intensity is the amount spend on R&D per monetary unit of product value produced.

diffusion by disseminating information about new technologies and by providing an enabling environment in which energy-efficient technologies are implemented. The effectiveness of policies to support technology diffusion should be based on an understanding of the drivers for technology diffusion. For example, a case study of electric arc furnaces in the US steel industry has demonstrated that retirement and stock turnover accounted for 2/3 of observed change in energy intensity, while retrofit of existing technology accounted for 1/3 of observed change (Worrell and Biermans, 2005). A wide array of policies has been used and tested in the industrial sector in industrialized countries, with varying success rates (Galitsky et al., 2004; WEC, 2004). No single instrument will reduce all of the barriers to technology diffusion; an integrated policy accounting for the characteristics of technologies, stakeholders, and regions addressed is needed.

Selection of technology is a crucial step in any technology adoption. Information programs are designed to assist energy consumers in understanding and employing technologies and practices to use energy more efficiently. Information needs are strongly determined by the situation of the actor. Therefore, successful programs should be tailored to meet these needs. Energy audit programs, which exist in numerous countries, are a more targeted type of information transaction than simple advertising. The U.S. Department of Energy's Industrial Assessment Center program is a well-known example of an audit program. The program performs audits in small and medium-sized enterprises. About 42% of the suggested measures are implemented by audited companies (Muller and Barnish, 1998).

Programs or policies that promote or require reporting and benchmarking of energy consumption have been implemented in many countries (Sun and Williamson, 1999; Galitsky et al., 2004). Reporting facility energy use has been shown as an effective means of raising management awareness of internal energy consumption trends, while benchmarking energy use provides a means to compare the energy use of one company or plant to that of others producing the same products. Reporting and benchmarking programs have been established in Canada, Denmark, Germany, The Netherlands, Norway, the U.K., and the U.S. (Sun and Williamson, 1999). In addition to such national programs, specific industrial sectors such as the petroleum refining and ethylene industry have benchmarking programs.

Many of the voluntary programs discussed in Section 7.9.2 include information exchange activities to promote technology diffusion at the national level and across sectors. For example, for 2002, the U.S. Industrial Technologies Program claimed energy savings of approximately 0.3 EJ as the result of diffusion of more than 90 technologies across the U.S. industrial sector. Reductions in CO_2 emission were not given for 2002, but scaling the energy savings information to the cumulative carbon emissions data provided indicates a 2002 CO_2 emission reduction in the order of 19 Mt (US DOE, 2004b). EU programs, e.g. Lights of the Future and the Motor Challenge Programme (Joint Research Centre, n.d.b), have similar objectives, as do programs in other regions.

7.11.1.2 Foreign or International Policies

In contrast to agricultural research, development and diffusion (RD&D) programs, which assume a need for domestic research because of geographic specificity, industrial RD&D programs assume that technologies are easily adapted across regions with little innovation. The majority of industrial RD&D is still generated in the industrialized world, and has been slow to diffuse into developing countries. A recent study (Evenson, 2002) suggests that the presence of a domestic research and development program in a developing country increase the county's ability to adapt and adopt new technologies. Preliminary analysis seems to suggest that newly industrialized countries are becoming more active in the generation of scientific and technical knowledge, although there is no accurate information on the role of technology development and investments in scientific knowledge in developing countries (Amsden and Mourshed, 1997).

Internationally, there are a growing number of bilateral and multilateral technology RD&D programs to address the slow and potentially sporadic diffusion of technology across borders. International RD&D collaboration can be an effective means of technology transfer. A December, 2004 U.S. Department of State Fact Sheet lists 20 bilateral agreements with both developed and developing nations (U.S. Dept. of State, 2004), many of which include RD&D elements.

Multilaterally, the UNFCCC has resulted in the creation of two technology diffusion efforts, the Climate Technology Initiative (CTI) and the UNFCCC Secretariat's TT:CLEAR technology transfer database. CTI was established in 1995 by 23 IEA/OECD member countries and the European Commission, and as of 2003 has been recognized as an IEA Implementing Agreement. Its focus is the identification of climate technology needs in developing countries and countries with economies-in-transition and filling those needs with training, information dissemination and other support activities (CTI, 2005). TT:CLEAR, which started-up as a prototype in September, 2001, is a more passive technology diffusion mechanism that depends on users accessing the data base and finding the information they need. A recent survey of TT:CLEAR's effectiveness (UNFCCC, 2004) attracted a relatively low number of respondents (303 individuals from 81 countries, out of approximately 600 users) who expressed general satisfaction with the system, but made numerous suggestions for improvement. A weakness of the survey was that only 39% of the respondents were from developing nations, the target audience for the system.

Additionally, UNFCCC meetings have included an on-going discussion of the barriers to technology transfer, which led to the creation on the Expert Group on Technology Transfer (EGTT), in an effort to focus on overcoming these barriers (UNFCCC, 2001). EGTT has promoted a number of activities including workshops on enabling environments and innovative financing for technology transfer. Ultimately, the Kyoto Protocol's CDM and JI should act as powerful tools for the diffusion of GHG mitigation technology, but as detailed in Section 7.7.1, progress in the implementation of these mechanisms has been slow.

7.11.2 Private Sector

In September, 2004, the IPCC convened an expert meeting on industrial technology development, transfer and diffusion, which had as one of its objectives of identifying the key drivers of these processes in the private sector (IPCC, 2005a). The meeting concluded that the key drivers for private sector involvement in the technology process were:

Competitive advantage – companies develop technology to create or maintain a competitive advantage in open markets.
Consumer acceptance – companies respond to consumer demand. Environmental stewardship is one of the factors that defines consumer demand.
Country-specific characteristics – the willingness of companies to deploy technology in a specific country is a function of its economic and political infrastructure as well as its natural resource endowment. The scale of facilities in a specific country will also affect the type of technology that can be deployed. Large facilities can often afford more sophisticated technology than small facilities.
Intellectual property rights (IPR) – Since companies invest in the development of technology to create competitive advantage, protection of IPR is critical to their achieving that advantage. Countries with strong IPR protection are more desirable locations for the deployment of new technology.

Regulatory framework – While protection of IPR is a critical issue, it is not the only regulatory issue of concern for technology deployment. Issues include: government incentives; government policies on GHG emissions reduction; energy security and economic development; rule of law; and investment certainty.

The meeting concluded that each of these drivers could either be stimulants or barriers to the technology process, depending on their level, e.g. a high level of protection for IPR would stimulate the deployment of innovative technology in a specific country while a low level would be a barrier.

7.12 Long-term Outlook, System Transitions, Decision-making, and Inertia

7.12.1 Long-term Technologies

7.12.1.1 Biological Processing

Theoretically many industrial organic chemicals can be manufactured from biomass. In the petrochemical industry simple hydrocarbons undergo reaction in order to incorporate functionality, based on O and N. Biomass components are often functionalised, thus in many cases reactions to incorporate functionality are not required. This potentially represents reduction in the energy requirement for chemical processes.

An example is the use of ammonia to incorporate nitrogen. Globally about 130 Mt of ammonia are produced (UYSEG, n.d.) consuming about 30 GJ/tonne (Heaton, 1996), a total of 3.9 EJ/year. Ammonia is used in the production of acrylonitrile, which is used in the manufacture of amines and some plastics, and has a production volume of about 4 Mt/year. (The Innovation Group, 2002; Weissermel and Arpe, 1993) Acrylonitrile, from the reaction of propylene with ammonia, requires a process energy of about 6 GJ/tonne (Brown, 2003). Thus, depending on route, about 24PJ/yr is used in acrylonitrile manufacture purely for nitrogen incorporation. Using a biomass component as a feedstock for acrylonitrile manufacture would reduce process energy requirements by eliminating the need to incorporate nitrogen and the use of ammonia. Research is underway on the use of leguminosae, which uses symbiosis to bind atmospheric nitrogen in desirable functionalities, to produce nitrogen-containing organic chemicals with a significant reduction in the use of fossil resources. Commercialization of this technology is not expected before 2030.

Research is also underway on biological processing in the minerals industry.

7.12.1.2 Hydrogen

Hydrogen, produced from either fossil fuels in conjunction with carbon capture and storage, or from non-fossil energy sources, can provide a low or zero GHG emission energy carrier. The production and distribution of hydrogen is discussed in Chapter 4. Here we discuss potential industrial end uses hydrogen.

Hydrogen can replace carbon as a reducing agent in the smelting of metals. Use of hydrogen in the production of iron was discussed in Section 7.4.1. If hydrogen were generally available, it also could be used by industry as a fuel. Research on the use of hydrogen as a fuel is underway. BP is studying the use of hydrogen in gas turbines to generate electricity in remote areas. (API, 2003). Alternatively, industry could use hydrogen in fuel cells to efficiently generate electricity. While this approach would require much less change in end-use technology, it is dependent on the development of cost effective, durable fuel cell technology.

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