Chapter 5

THE INDUSTRIAL SECTOR[1]

5.1 INTRODUCTION

In this chapter we present scenarios for future industrial energy use, based on different assumptions for U.S. energy policies. We start with a reference scenario which is derived from the AEO99 (U.S. DOE, EIA, 1998a) and assumes no policy changes. We then analyze two policy-driven scenarios using the CEF-NEMS model. The CEF-NEMS model does not allow direct modeling of demand side policies in the industrial sector. Hence, extensive changes are made to the model inputs to reflect the actions due to new policies in the policy scenarios, as outlined below and in Appendices A-2 and B-2. The projected changes in inputs are based on analyses by industry, government and academic sources.

A scenario is a way to understand the implications of a possible future through modeling assumptions that reflect this future. By definition, considerable uncertainties exist in all scenario analyses and this is also true for the industrial sector where ever-changing dynamics drive decision-making.

The scenarios presented here reflect our own judgment, based on extensive studies and the input by external reviewers. They do not necessarily reflect the views of the industries that are discussed. The assumptions with respect to technologies and policy results are explicitly described in detail in this chapter and related appendices. We acknowledge that we are not able to analyze all issues that may affect the results. Although we present point estimates, the reader should bear in mind that uncertainties in the assumptions affect the results of the scenarios and that the results are not equally applicable to all companies in an industry. The analytical database for the industrial sector is limited and constrains the ability of modelers to do in-depth analysis in this sector. At the end of this chapter, we explicitly discuss uncertainties and further research required to assess the uncertainties.

5.1.1 Overview of Sector

The industrial sector is extremely diverse and includes agriculture, mining, construction, energy-intensive industries, and non-energy-intensive manufacturing. In 1997, the industrial sector consumed 35 quads of primary energy, accounting for 37% of the primary energy consumed in the U.S. that year. The industrial sector is comprised of 13 key subsectors: agriculture, mining, construction, food, paper, chemicals, glass, cement, steel, primary aluminum, petroleum refining, metals-based durables, and other manufacturing[2]. Fig. 5.1 shows the contribution of each industrial subsector to total industrial primary energy use in 1997. Carbon dioxide emissions from industrial energy use as well as process emissions from cement manufacture were 494 MtC, accounting for 33% of total U.S. CO_2 emissions (U.S. DOE, EIA, 1998a).

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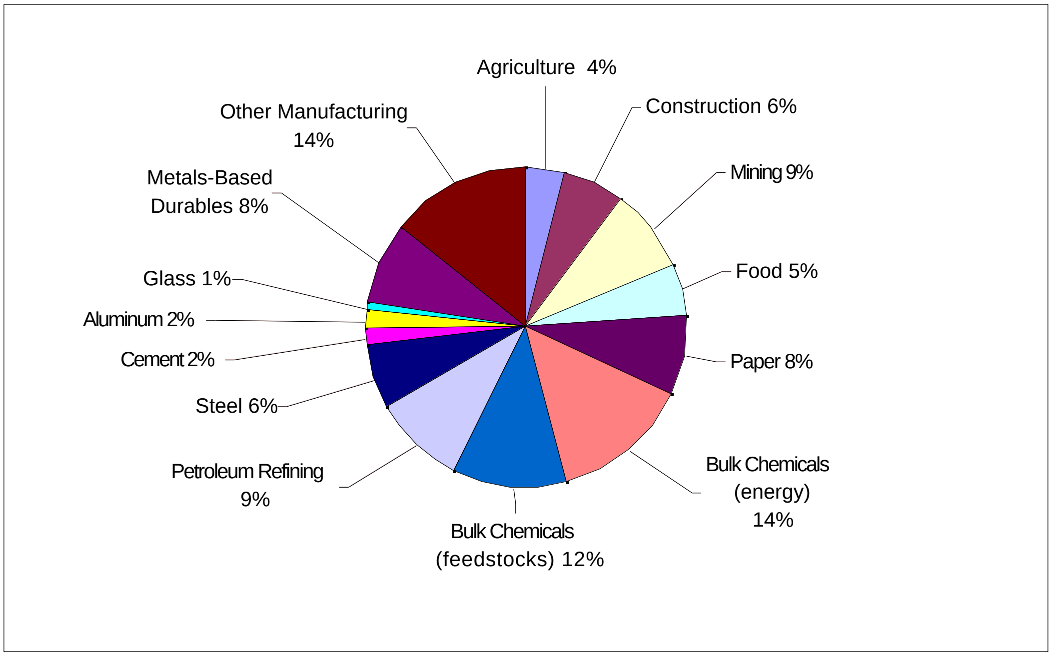
[2] The definitions of the subsectors and an explanation of how they relate to the U.S. Department of Energy's Office of Industrial Technology's Industries of the Future is provided in Appendix A.2. Energy intensive industries include pulp and paper, bulk chemicals, glass, cement, iron and steel, petroleum refining, as well as primary aluminum. Non-energy intensive industries include agriculture, mining, construction, food, metals-based durables, and other manufacturing.

Fig. 5.2 provides a breakdown of the share of CO_2 emissions by industrial subsector. The largest CO_2-producing subsector was also bulk chemicals (energy), followed by other manufacturing, petroleum refining, metals-based durables, mining, steel, construction, food, cement, paper, agriculture, aluminum, and glass, respectively.

The cement subsector is responsible for a higher share of CO_2 emissions than primary energy use due to the process emissions produced during calcination of limestone[3] while producing clinker. Process CO_2 emissions from calcination are added to the cement sub-sector energy-related CO_2 emissions. Other sectors also emit process emissions, which have been partially been accounted for (e.g. chemical industry) or excluded (e.g. limestone use in the steel industry) due to lack of reliable data. The share of CO_2 emissions from the paper sector is lower than the share of energy use, due to the significant consumption of biomass in this sub-sector. We assign zero emissions to the combustion of biomass due to assimilation if biomass is grown in a sustainable way. The share of CO_2 emissions from chemical feedstocks are also lower because a large part of the feedstocks are embodied in the chemical products produced and not directly released to the atmosphere**.**

Fig. 5.1 Primary Energy Use by Industrial Subsectors, 1997



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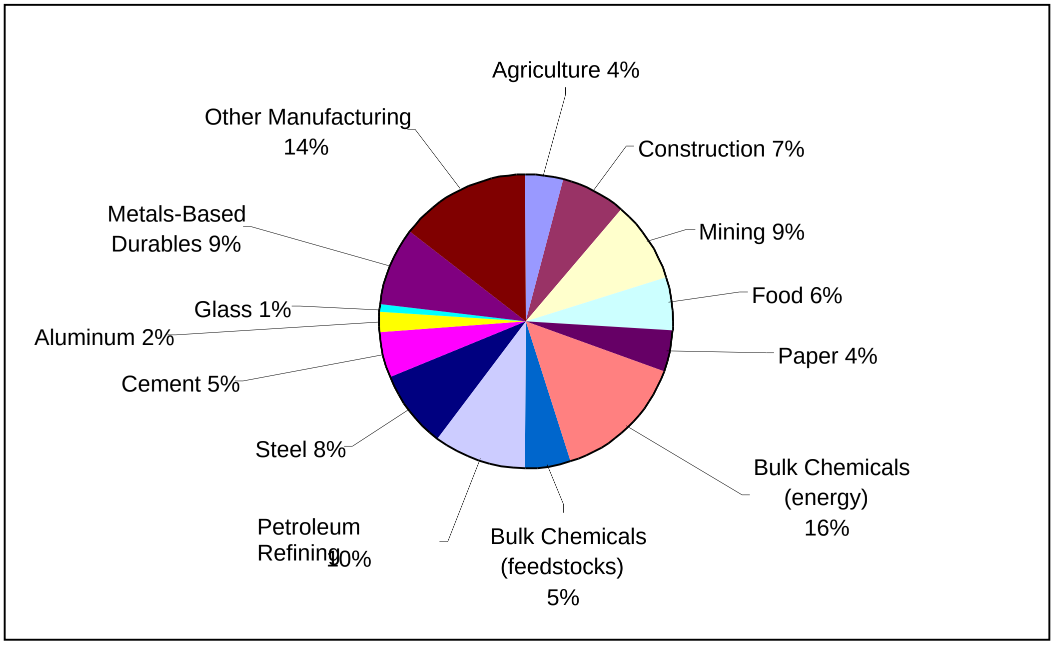
[3] The process emission from clinker production depends on the share of limestone in the raw materials used. The lime-content may vary, and hence the CO2 emission-factor. In this study we follow the IPCC-methodology which estimates the CO_2 emission at 138.3 kgC/tonne clinker (IPCC, 1996), which is equivalent to 125.4 kgC/ton clinker.

Fig. 5.2 Carbon Dioxide Emissions by Industrial Subsectors, 1997



5.1.2 Technology Opportunities Examples

Various bottom-up studies found cost-effective potentials for energy efficiency improvement varying from 5 to 12% by 2010 (Interlaboratory Working Group, 1997; Energy Innovations, 1997), and up to 20% by 2020 (Energy Innovations, 1997) compared to business as usual, while other studies assumed less potential (U.S.DOE, EIA, 1998b). Many studies identified a wide variety of sector-specific and cross-cutting energy efficiency improvement opportunities (Interlaboratory Working Group, 1997; Aluminum Association, 1997; American Chemical Society, 1996; American Forest and Paper Association, 1994; American Iron and Steel Institute, 1998; Cast Metal Coalition, 1998; Donnelly et al., 1997; National Mining Association 1998a; National Mining Association 1998b). Sector-specific measures include technologies and practices that are unique for a specific process or industrial sector. Cross-cutting measures include technologies that are used more generally (although some applications may be sector-specific) throughout industry, e.g. motors or cogeneration. In this section we describe specific examples of practices and technologies that can be implemented in industry. We focus on measures for three industrial sectors that we have studied in detail (steel, paper, and cement)[4], and one cross-cutting measure (CHP). Barriers may limit the speed of adoption of these technologies (see section 5.3.2).

Innovations in industrial technology aim not only to reduce energy use, but also to improve productivity, reduce capital costs, reduce operation costs, improve reliability as well as reduce emissions and improve working conditions. Hence, many of the technologies discussed below will reduce the production cost-basis of industries, and hence increase competitiveness in a globalizing economy.

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[4] The three sectors were selected on the basis of the modeling characteristics in NEMS, i.e. inclusion of technologies and unit-operations, as well as the availability of data on energy efficiency improvement potentials in these sectors. For the analysis of the three selected sectors we have used 1994 as the base year for the analysis of the baseline, as this was the last year for which the EIA has published the Manufacturing Energy Consumption Survey (MECS) at the time of the study.

Steel Industry. In 1994, steel mills in the U.S. produced 100.5 million tons of steel. Primary energy use for integrated steelmaking was more than three times greater than energy use in secondary (electric arc furnace, EAF) steelmaking, consuming 1364 TBtu compared to 403 TBtu. The primary energy intensity of integrated and secondary steel production in 1994 was 22.3 MBtu/ton and 10.1 MBtu/ton, respectively, for a total sector primary energy intensity of 17.5 MBtu/ton[5]. Total CO_2 emissions from steelmaking in 1994 were 34.4 million metric tonnes C (MtC), with 80% of these emissions from integrated steelmaking. The CO_2 intensity of integrated steelmaking was 0.5 tC/ton of crude steel while the CO_2 intensity for secondary steelmaking was 0.2 tC/ton crude steel, resulting in a total sector CO_2 intensity of 0.4 tC/ton crude steel.

To more carefully analyze the potential for reducing energy use and carbon dioxide emissions from steelmaking in the U.S., we compiled information on the costs, energy savings, and carbon dioxide emissions reductions of a number of technologies and measures. These technologies and measures fall into two categories: state-of-the-art measures that are currently in use in steel mills worldwide and advanced measures that are either only in limited use or are near commercialization (e.g. smelt reduction). We identified nearly 50 energy efficiency measures in the iron and steel industry, including process management systems and gas recovery systems (Worrell et al., 1999). We describe two of the options below: scrap preheating in the electric arc furnace and thin slab casting. Both technologies are used by various steelmakers in the U.S., but still show considerable potential for further adoption leading to increased energy savings in the U.S.

Scrap Preheating. Electricity consumption in EAFs is estimated at an average of 436 kWh/ton, and fuel consumption at 0.14 MBtu/ton of steel (Worrell et al., 1999). Scrap preheating is a technology that can reduce the power consumption of EAFs through using the waste heat of the furnace to preheat the scrap charge. Old bucket preheating systems had various problems, such as emissions, high handling costs, and a relatively low heat recovery rate. Modern systems have reduced these problems and are highly efficient. The energy savings depend on the preheat temperature of the scrap. Various systems have been developed and are in use at sites in the U.S. and Europe, i.e. Consteel tunnel-type preheater, Fuchs Finger Shaft, and Fuchs Twin Shaft. Twin shell furnaces can also be used as scrap preheating systems. All systems can be applied to new construction and to retrofit existing plants. The Consteel process consists of a conveyor belt with the scrap going through a tunnel, down to the EAF through a “hot heel”. Besides energy savings, the Consteel process results in an productivity increase of 33%, reduced electrode consumption of 40% and reduced dust emissions (Jones, 1997a). The FUCHS shaft furnace consists of a vertical shaft that channels the offgases to preheat the scrap. The scrap can be fed continuously (4 plants installed worldwide) or through a so-called system of “fingers” (15 plants installed worldwide). The Fuchs systems make almost 100% scrap preheating possible, leading to potential energy savings of 90-110 kWh/ton (Hofer, 1997)[6]. The energy savings depend on the scrap used and the degree of post-combustion (oxygen levels). The scrap preheating systems lead to reduced electrode consumption, yield improvement of 0.25-2%, up to 20% productivity increase and 25% reduced flue gas dust emissions (reducing hazardous waste handling costs) (CMP, 1997). Electricity use can be decreased to approximately 335-355 kWh/ton using the Consteel process (Herin and Busbee, 1996), without supplementary fuel injection in retrofit situation, while consumption as low as 310-330 kWh/ton has been achieved in new plants (Jones, 1997b). Using post-combustion the energy consumption is estimated to be 310 to 320 kWh/ton and 0.6 MBtu fuel injection (Hofer, 1996). The extra investments are estimated to be $2M (1989) for a capacity of 400,000 to 500,000 ton per year, resulting in specific investments of approximately $4.0 to $5.4/ton for the Consteel process. The annual costs savings are estimated to vary between $1.7/ton and $4.1/ton (Bosley and Klesser, 1991; Hofer, 1997). The simple payback period of installing a scrap preheater is estimated at

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[5] Primary energy is calculated using a conversion rate from final to primary electricity of 3.08, reflecting the difference between an average plant heat rate of 10,500 Btu/kWh and a site rate of 3412 Btu/kWh, including transmission & distribution losses.
[6] This compares to an average electricity consumption of EAFs of 436 kWh/ton steel in 1994 (Worrell et al.,1999).

1 – 2 years for large furnaces. Various U.S. plants have installed a Consteel process, i.e. AmeriSteel (Charlotte, NC), New Jersey Steel (Sayreville, NJ) and Nucor (Darlington, SC), and one plant in Japan. The installation at New Jersey Steel is a retrofit of an existing furnace. Fuchs systems have been installed at North Star (Kingman, AZ), North Star-BHP (Delta, OH), Birmingham Steel (Memphis, TN) and Texas Industries (Richmond, VA). In addition, North Star has ordered another preheater for their Youngstown (OH) plant.

Near Net Shape Casting/Thin Slab Casting. Near net shape casting implies the direct casting of the metal into (or near to) the final desired shape, e.g. strips or sections, and replaces hot rolling. In conventional steelmaking, steel is first cast and stored. The cast steel is reheated and treated in the rolling mills to be reshaped. Near net shape casting integrates casting and the first rolling steps. The current status of this technology is so-called thin slab casting. Instead of slabs of 120-300 mm thickness produced in a continuous casting machine, slabs of 30-60 mm thickness are cast. The cast thin slabs are reheated in a coupled furnace, and directly rolled in a simplified hot strip mill. Pioneered in the U.S. by Nucor at the Crawfordsville and Hickmann plants, various plants are operating, under construction, or ordered worldwide. Originally designed for small scale process lines, the first integrated plants constructed (U.S., Korea) or announced the construction of thin slab casters (Germany, Netherlands, Spain) with capacities up to 1.5 Mt/year. We base our calculation of costs and savings associated with this technology on the CSP-process developed by SMS (Germany) as it represents most of the capacity installed worldwide. Energy savings are estimated to be up to 4 MBtu/ton crude steel (primary energy). The energy consumption of a CSP-plant is 85 kBtu fuel per ton for the reheating furnace and electricity use of 39 kWh/ton (Flemming, 1995). The investments for a large scale plant are estimated to vary between $100/ton and $160/ton product (Anon, 1997a; Anon., 1997b; Schorsch, 1996). Cost savings may vary between $22/ton and $42/ton product (Ritt, 1997; Hogan, 1992; Schorsch, 1996), resulting in a simple payback period of approximately of 3 years. The potential additional capacity of thin slab casting in 1994 was estimated to be 20% of U.S. integrated production and 64% of secondary steel (Worrell et al., 1999).

Pulp and Paper Industry. The manufacture of paper and paperboard is an important element of a modern economy, and is also a highly capital and energy-intensive process. The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard. The processes involved in papermaking include raw materials preparation, pulping (chemical, mechanical, or semi-chemical), bleaching, chemical recovery, pulp drying, and papermaking. In 1994, the U.S. pulp and paper industry consumed 2650 TBtu of primary energy (about 16% of total U.S. manufacturing energy use) to produce 91 million tons of paper (Anglani et al., 1999). The pulp and paper industry's 1994 CO_2 emission is estimated at 30.6 MtC, despite the extensive use of biomass (as a by-product of chemical pulping and wood waste use) which reduces the net CO_2 emissions (Anglani et al., 1999). We identified over 50 technologies and measures that can reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the various process stages of pulp and paper production, varying from improved maintenance to new paper machines (Anglani et al., 1999). We discuss two of these options below: extended nip press and black liquor gasification.

Extended Nip Press. After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners. In an extended nip press (developed and marketed by Beloit Industries, WI), the lower roll is replaced with a device that presses the paper against the roll for about 10 inches (compared to 2 inches in a conventional roll press), allowing for higher pressure loads on the paper without damaging the paper (Lange and Radtke, 1996). This additional pressing allows for greater water extraction (about 5-7% more water removal), resulting in a level of 35% to 50% dryness (Elahi and Lowitt, 1988; Lange and Radtke, 1996). An additional advantage is that on a dryer limited machine, a press can increase yield by up to 25% as well as increase wet tensile strength (Lange and Radtke, 1996). Steam savings estimates range from 15% to 35%, or a reduction in steam demand of 4% for every 1% moisture savings in the press (Elahi and Lowitt, 1998; Lange and Radtke, 1996; Jaccard and Willis, 1996;

de Beer et al., 1994). Extended nip press producers include Beloit's ENP-C and Valmet, and Voith Sulzer Papertechnology (Kincaid et al., 1998). The distribution of the ENP technology has been limited by the presence of a large number of granite rolls in the pressing machines in the industry that can not tolerate high nip loadings (Lange and Radtke, 1996). The press is well suited to newsprint and light weight coated pressing, but less suited to bleached Kraft products due to high densification.

Black Liquor Gasification. Black liquor gasification is used to produce a useable gas from spent pulping solvent. This gas can be used in a traditional boiler, or may in the future be used in conjunction with gas turbines, increasing electricity production dramatically. Black liquor gasification is seen as an important technology area for the pulping industries (AFPA, 1994). There are two major types of black liquor gasification: low temperature/solid phase and high temperature/smelt phase. High temperature gasification takes place above 900°C while low temperature gasification takes place under 750°C. Today, black liquor gasifiers are used as an incremental addition in chemical recovery capacity in situations where the recovery boiler is a process bottleneck. In the future, gasifiers may be able to provide fuel for gas turbines and lime kilns (Nilsson et al., 1995; Lienhard and Bierbach, 1991). Energy savings are the result of producing a higher quality fuel and thereby improving the plant's steam production efficiency. We assume fuel savings of 5.0 MBtu/ton air-dried pulp (Elahi and Lowitt, 1988) while electricity use increases (Nilsson, et al., 1995). A 130 ton per day pulp capacity gasifier costs about $20 million (McCubbin, 1996). This technology is new; there is one commercially operating mill in Sweden and various pilot projects in the U.S. (Georgia-Pacific, Weyerhauser, and Champion) (McCubbin, 1996; Finchem, 1997).

Cement Industry. Annual cement production in U.S averages about 80 Million tons, fluctuating with developments in the construction markets. In 1994, 310 TBtu of fuels were used in the clinker kilns and 36 TWh of electricity were used for cement grinding and other production steps, resulting in total primary energy use of 420 TBtu. In 1994, the U.S. cement industry emitted 19 MtC as carbon dioxide (about 4% of total U.S. manufacturing carbon emissions). Half of the emissions are due to fuel combustion (mainly coal), and half are due to the calcination of limestone. In the cement industry, opportunities exist to substantially reduce the energy intensity and carbon dioxide emissions, both from energy use as well as from limestone calcination in the clinker making process. We have identified about 35 technologies and measures to reduce energy use in cement manufacturing (Martin et al., 1999). Because the cement industry is capital intensive, some opportunities can only be economically implemented when retiring old plants (e.g. new pre-calciner kilns to replace wet or long dry kilns). Other measures can be implemented as retrofits or be used to increase production capacity (e.g. production of blended cements).

Multi-stage Preheater Pre-Calciner Kilns. Older dry kilns may not have multi-stage preheating, leading to higher heat losses. Modern kilns generally have four to six stage preheating and pre-calciners, reducing fuel use to 2.5 MBtu/ton clinker (Cembureau, 1997a; Conroy, 1997; Klotz, 1997; Somani and Kothari, 1997). Installing multi-stage suspension preheaters (i.e. four- or five-stage) may reduce heat losses and thus increase efficiency. The addition of increased pre-heating and a precalciner will generally increase the capacity of the plant, while lowering the specific fuel consumption. Using as many features of the existing plant and infrastructure as possible, special precalciners have been developed by various manufacturers to convert existing plants, e.g. Pyroclon®-RP by KHD in Germany. Generally, the kiln, foundation and towers are used in the new plant, while cooler and preheaters may be replaced. Also, the kiln length may be shortened by 20% to 30% thereby reducing radiation losses (van Oss, 1999). As the capacity increases, the clinker cooler may also have to be adapted in order to be able to cool the large amounts of clinker. The conversion of older kilns is financially attractive when the old kiln needs replacement and a new kiln would be too expensive. Examples of kiln conversions can be found in Germany (Duplouy and Trautwein, 1997) and Italy (Sauli, 1993), and in Eastern Europe. In the U.S. modern clinker kilns incorporate multi-stage preheating and pre-calcining, as found in the Ash Grove plant in Seattle (WA) (Steuch and Riley, 1993) and Holnam's plant at Devils Slide (UT) (Conroy, 1997).

Fuel savings will depend strongly on the efficiency of the existing kiln and on the new process parameters (e.g. degree of precalcination, cooler efficiency), and may vary between 0.4 and 1.2 MBtu/ton clinker (Martin et al., 1999).

Blended Cement. Cement is an inorganic, non-metallic substance with hydraulic binding properties, and is used as a bonding agent in building materials. In the United States, portland cement accounts for about 95% of total production. The production of blended cements involves the intergrinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, volcanic ash) in various proportions. The use of blended cements is a particularly attractive option since the intergrinding of clinker with other additives (supplementary cementitious materials) not only allows for a reduction in the energy used (and associated carbon emissions) in clinker production, but also reduces carbon dioxide emissions from calcination. Blended cements are very common in Europe, with blast furnace and pozzolanic cements accounting for about 12% of total cement production, portland composite cement[7] accounting for an additonal 44% (Cembureau, 1997b). In the U.S., some of the most prevalent blending materials are fly ash and blast furnace slag. A recent analysis of the U.S. situation cited an existing potential of producing 34 million tons of blended cement in 2000 using both fly ash and blast furnace slag, or 36% of U.S. capacity (PCA, 1997). This analysis is based on estimates of the availability of intergrinding materials and a survey of ready-mix companies to estimate feasible market penetration. We assume that the blended cement produced would have, on average, a clinker/cement ratio of 65%. This could result in a reduction in clinker production of 11.9 million tons, when producing 34 million tons of blended cement by 2020. The reduction in clinker production corresponds to specific fuel savings of 0.66 MBtu/ton. The extra energy needed for the drying of the blast furnace slags is offset by reducing the need to bypass kiln exit gases to remove alkali-rich dust (Alsop and Post, 1995). Blended cements lower alkali-silica reactivity thereby allowing a reduction in energy consumption needed due to removal of the alkali dusts. Although electricity consumption is expected to increase a little due to the added electricity consumption to grind the blending materials, this measure results in total fuel savings of 0.76 MBtu/ton cement (Martin et al., 1999).

Cross Cutting: Combined Heat and Power. Electricity and steam are used throughout the industrial sector. Relatively large steam users can be found in the food and chemical industries, as well as in petroleum refining. Steam is often generated in a boiler, while electricity is purchased from a utility. CHP (or cogeneration) has been used in industry to generate the two simultaneously. Modern technologies (e.g. aero-derivative gas turbines) have made CHP more efficient and more economically attractive, especially at smaller scales, than conventional steam turbine systems used in industries with a large steam use, e.g. paper, chemicals. Recent studies (DOE, 1997; Onsite, 1998; Kaarsberg and Elliott, 1998) identified CHP as one of the most important technologies to improve energy efficiency and reduce GHG emissions in the U.S. The primary energy savings from small scale CHP gas turbine units can be about 30% when replacing a conventional coal-fired power plant and about 15% when replacing combined cycles. The savings obtained by condensing and back-pressure steam turbines are considerably smaller. The potentials for CHP vary by sector, and even site, as they depend on site specific technical characteristics (e.g. steam load, demand pattern, heat to power ratio) and on non-technical issues (e.g. regulation, buy back tariffs, standby contracting). Most of the potential sites for new CHP units can be found in the 30 to 75 MW range (Khrushch et al., 1999). The CHP Challenge program of DOE and EPA aims to double the existent CHP capacity by adding over 40 GW of electric CHP capacity, of which most in industry[8].

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[7] Portland composite cement consists of 65% clinker, 30% additives, and 5% filler, as defined by the European cement standard ENV197-2.

[8] Although we assess the potential for cogeneration in this study, we have not yet been able to integrate the cogeneration results into the scenarios. Hence, we report separately on the cogeneration results in section 5.5.4.

5.2 BUSINESS-AS-USUAL SCENARIO

In the CEF-study we have adopted the economic scenarios as used by the EIA for the AEO99. We adopt the energy consumption data of the AEO99 reference case for the business-as-usual scenario for all industrial sub-sectors except for paper, cement, steel, and aluminum, the first three of which we analyzed in detail. For the paper, cement, and steel sectors, our estimates of physical energy intensities by process differed from those in the NEMS model; thus for these three sectors, we modified the NEMS baseline energy intensities (referred to as Unit Energy Consumption, UEC) and the annual rate of improvement in the UECs over time (referred to as Technology Possibility Curves, TPCs).

For the business-as-usual scenario for the paper, cement and steel sub-sectors, we modified the UECs and TPCs for both existing and new equipment based on a number of recent analyses (Worrell et al., 1999; Anglani et al., 1999; Martin et al., 1999). A detailed description of these modifications is provided in Appendix A.2. In addition, we revised the 1994 new plant UECs for the aluminum sector, based on current energy use in Hall-Heroult cells of 13.2 MWh (Ravier, 1986). We also changed the retirement rates for all sub-sectors, to reflect actual lifetimes of installed equipment. Although NEMS does not treat equipment lifetime endogenously, it is possible to define the retirement rate for process equipment. Table 5.1 provides retirement rates and associated plant lifetimes for the AEO99, and the CEF-scenarios for each industrial subsector. Retirement rates for industrial technologies in the AEO99 scenario seem to be low, when compared to other sources (BEA, 1993; Jaccard and Willis, 1996), or assessments of technical and economic lifetimes of technologies. Retirement rates for paper, cement, and steel are based on detailed assessments of equipment ages and future developments in these sectors. For example, the retirement rates in the steel industry were assessed on the basis of the age of current U.S. plants. The oldest working blast furnace in the U.S. in 1997 was 67 years old, followed by two other blast furnaces that were 50 years old, while the average age is estimated at 29 years (Worrell et al., 1999) (see Table 5.1, Basic Oxygen Furnaces)[9].

Table 5.1 Retirement Rates and Plant Lifetimes for Industrial Subsectors for AEO99 Reference Case, and CEF Scenarios

	Retirement (%/yr)		**Lifetime (year)**	
Sector	**AEO99**	**CEF**	**AEO99**	**CEF**
Agriculture	2.0	2.5	50	40
Mining	2.0	2.5	50	40
Construction	2.0	2.5	50	40
Food	1.7	2.1	59	47
Paper	2.3	2.3	43	43
Bulk Chemicals	2.3	2.5	43	40
Glass	1.3	1.4	77	70
Cement	1.2	2.0	50	50
Steel				
Basic Oxygen Furnaces	1.0	1.5	100	67
Electric Arc Furnaces	1.5	1.8	67	56
Coke Ovens	1.5	1.8	67	56
Other Steel	2.9	2.9	34	34
Primary Aluminum	2.1	2.3	48	43
Metals-Based Durables	1.5	1.9	67	53
Other Manufacturing	2.3	2.5	43	40

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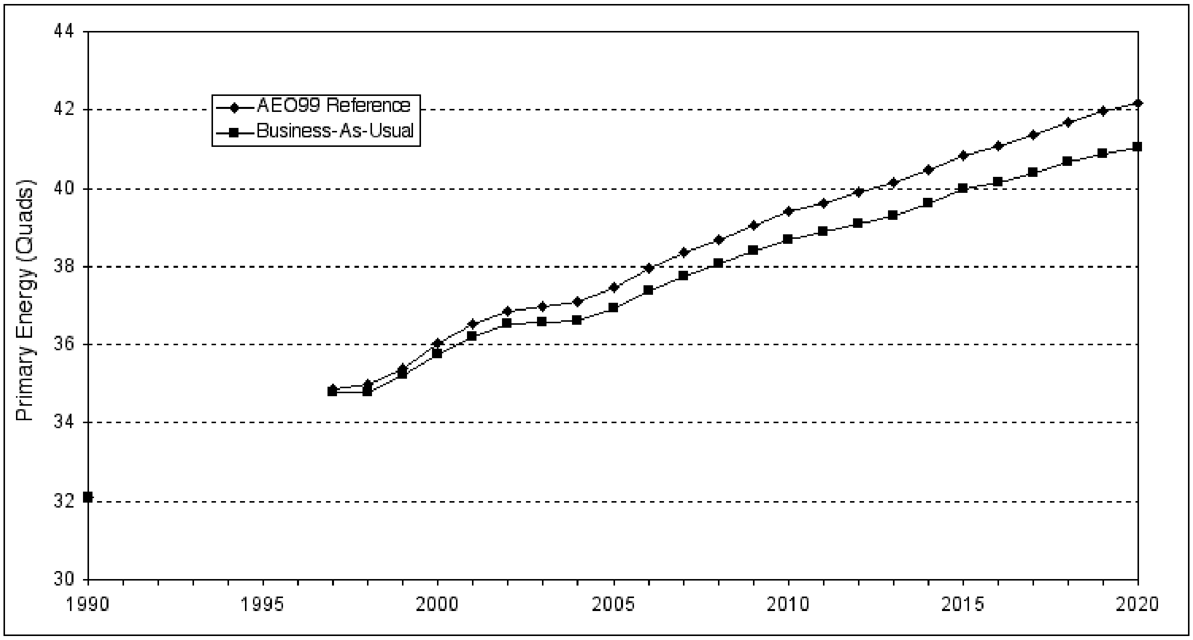
[9] Plants are often re-built during the lifetime, so it is difficult to determine the actual age of equipment. Generally, it reflects the age of the major construction. A blast furnace shell may have been built 50 years ago, it is re-lined every 7 to 8 years, and equipment may be replaced or added, increasing capacity and improving energy efficiency.

Fig. 5.3 shows the difference between the AEO99 reference case and our business-as-usual scenario that not only incorporates our adjustments in the paper, cement, steel, and aluminum sub-sectors, but also includes model feedback effects in other sectors. In 2020, our business-as-usual scenario projects primary energy use of 41.0 Quads, slightly lower than the 42.2 Quads projected by the AEO99 reference case.

Fig. 5.3 Comparison of AEO99 Reference Case and Business-As-Usual Scenario



5.3 POLICY IMPLEMENTATION PATHWAYS

5.3.1 Definition of Pathways

We analyze two policy implementation scenarios – a moderate scenario based on establishment of voluntary agreements with industry that set moderate annual energy efficiency improvement commitments and an advanced scenario setting higher voluntary energy efficiency improvement commitments. Voluntary sector agreements between government and industry are used as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions because an integrated policy accounting for the characteristics of technologies, plant-specific conditions, and industrial sector business practices is needed. Policies and measures supporting these voluntary sector agreements should account for the diversity of the industrial sector while at the same time being flexible and comprehensive, offering a mix of policy instruments, giving the right incentives to the decision maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures. Industry is extremely diverse, and even within one sub-sector large variations in the characteristics may be found. Non-energy intensive industries and agriculture consist of thousands of stakeholders[10]. While, voluntary sector agreements are used as the structure of energy efficiency policy throughout industry, such a policy instrument may be less effective in these sectors. Various instruments which support the

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[10] Voluntary agreements are typically used with limited sets of companies. In The Netherlands there is a voluntary agreement with a large number of stakeholders, i.e. agriculture in The Netherlands with 8000 companies. In this case the association has signed on behalf of all its members.

voluntary sector agreements, both at the federal level and state level, are put in place in the policy scenarios to reach the very diverse stakeholders.

Evaluation of voluntary industrial sector agreements in The Netherlands showed that the agreements helped industries to focus attention on energy efficiency and find low-cost options within commonly used investment criteria (Korevaar et al., 1997; Rietbergen et al., 1998). Although the agreements themselves proved to be successful and cost-effective (Rietbergen et al., 1998), various support measures were implemented within the system of voluntary agreements. It is difficult to attribute the energy savings to a specific policy instrument; rather, it is the result of a comprehensive effort to increase implementation and development of energy-efficient practices and technologies in industry by removing or reducing barriers. This emphasizes the importance of offering a package instead of a set of individual measures, which may give the idea of competing measures or instruments rather than a concerted action.

Table 5.2 outlines the various policies and programs that fall under the umbrella of voluntary industrial sector agreements in this analysis and describes how they are expanded under the moderate and advanced scenarios. These include expansion of a number of existing programs, such as the Industrial Assessment Centers and the Climate Wise Program, as well as establishment of new programs such as labeling for chlorine-free paper. For all programs, we increased funding by roughly 50% in the moderate scenario and roughly 100% in the advanced scenario. Table 5.3 identifies which programs influence each of the industrial sub-sectors that we focus on in this assessment. A brief description of the policies and programs used in this analysis is provided below. Appendix B.2 describes the goals of the individual programs, and what contribution they are assumed to have on reducing energy use or greenhouse gas emissions, and how they are linked to the CEF-NEMS modeling. The goals are estimated using different methodologies, which makes it difficult to compare or to evaluate.

The effects of increased program efforts are difficult to assess. Cost-effectiveness may improve due the increased volume, but may also be less effective as programs reach smaller energy users or lead to implementation of less-effective measures. The interaction of various measures deployed simultaneously is difficult to estimate ex-ante, or even ex-poste (Blok, 1993; Stein and Strobel, 1997). It is often more difficult to assess the impacts of individual programs than the estimated impact of a set of policies. For this study, we group individual programs into four categories: information dissemination, investment enabling, regulations, and research, development and demonstration.

Table 5.2 Policies and Programs for Reducing Energy Use and Greenhouse Gas Emissions from the Industrial Sector Under the Moderate and Advanced Scenarios

Policy/Program	Moderate Scenario	Advanced Scenario
Voluntary Industrial Sector Agreements		
Voluntary Industrial Sector Agreements	Voluntary programs to reduce GHG emissions (CO2 and non-CO2) in energy-intensive and GHG-intensive industries, for specific industrial process or buildings.	Voluntary programs to reduce GHG emissions (CO2 and non-CO2) in all industries, including benchmarking.
Voluntary Programs		
Expanded Challenge programs Motor and Compressed Air Challenge	Increased effort to assist in overall motor system optimization through increased education, technical assistance, training, and tools. Increased promotion of use of adjustable-speed drives.	Increased promotion of overall motor system efficiency and use of adjustable-speed drives by offering greater financial incentives.
Steam Challenge	Outreach, training, and development of assessment tools is increased.	Expanded to include outreach to smaller boiler users and to develop automated monitoring and controls.
CHP Challenge	Financial incentives, utility programs promoting CHP, and expanded removal of barriers (e.g. permitting) are added.	Program expands to include increased outreach, dissemination, and clearing-house activities
Expanded ENERGY STAR Buildings and Green Lights	Development of best practices management tools and benchmarking information. Floorspace covered by program increases by 50%.	Best practices management tools and benchmarking information expanded and more extensively marketed. Floorspace covered by program increases by 100%.
Expanded ENERGY STAR and Climate Wise program	Increased efforts in the currently addressed sectors and program expansion to include glass, steel, and aluminum, as well as selected light industries.	Program expanded to include light industries, agriculture, construction, and mining.
Expanded Pollution Prevention Programs	Expanded effort leads to increased recycling in the steel, aluminum, paper, and glass industries.	Number of partners grows to 1600 by 2020 (from 700 in 1997).
Information Programs		
Expanded Assessment Programs	Number of industrial assessment centers increases from 30 to 35 and number of assessments per center increases from 30 to 36 per year. Expanded to include business schools and community colleges. Added emphasis on increased follow-up.	Number of industrial assessment centers increases to 50 and number of assessments per center increases to 40 per year. Comprehensive energy plans for each audited facility added.
Product Labeling and Procurement	Development of labels for two products.	Labeling expanded to other products (e.g. glass bottles). Marketing of labels is increased and government procurement policies are revised to include labeled products.

Investment Enabling Programs		
Expanded State Programs State Industrial Energy Efficiency Programs	Current state level programs are expanded to include information dissemination, audits, demonstration programs, and R&D. Participation grows from less than half of the states to 30 states.	Programs expanded to include all 50 states.
Clean Air Partnership Fund	Expanded use of integrated approaches for complying with CAA. Expanded demonstration of new technologies.	GHG emissions reduction projects given higher priority.
Expanded ESCO/utility programs Standard performance contracting (line charge)	Expansion of line charges to 30 states and increased efforts to target small industrial customers.	Expansion of line charges to 50 states and further increased efforts to target small industrial customers.
Financial incentives Tax incentives for energy managers	Provides tax rebates of 50% of the salary of an energy manager to 5000 medium and large energy-using industries by 2020.	Tax rebates provided to 10,000 medium and large energy using-industries by 2020.
Tax rebates for specific industrial technologies	Increased rebates focus on implementation of advanced technologies.	Increased rebates focus on implementation of advanced technologies. Increased funding leads to accelerated adoption of these technologies.
Investment tax credit for CHP systems	Tax credit extended from 2003 to 2020, leading to expansion of CHP as well as third party producers at industrial sites.	Tax credit extended from 2003 to 2020, leading to expansion of CHP as well as third party producers at industrial sites.
Regulations		
Motors Standards and Certification	Mandates upgrade of all motors to EPACT standards by 2020. Extends standards to all motor systems and enforces 100% compliance. Promote national motor repair standard.	Extends standards to all motor systems and enforces 100% compliance. Mandates national motor repair standard.
State Implementation Plans/Clean Air Partnership Fund	Identifies control measures and regulations to adopt and enforce the control strategies.	Identifies control measures and regulations to adopt and enforce the control strategies.
Research & Development Programs		
Expanded Demonstration Programs	Demonstration programs expanded in currently addressed sectors and extended to mining and construction sectors. Number of demonstration programs increased from 10 to 15 per year.	Extent of demonstration programs further expanded in all sectors and incorporated into state demonstration programs. Number of demonstration programs increases to 18 per year.
Expanded R&D programs Industries of the Future	Increased R&D efforts in all industries currently in program.	Increased R&D efforts in all industries currently in program and expansion to a number of smaller “other manufacturing” industries.
Other OIT R&D programs	Program R&D efforts increased in all areas related to improving industrial sector energy efficiency.	Industrial sector energy efficiency R&D efforts further increased.
Domestic Carbon Dioxide Emissions Trading System	N/A	

Table 5.3 Policies to Reduce Greenhouse Gas Emissions in the Industrial Sector

	POLICIES					
	Voluntary Agreements	**Expanded Assessment Programs**	**Expanded Challenge Programs**	**Expanded Labeling Programs**	**Expanded Climate Wise Program**	**Expanded Pollution Prevention**
SCENARIO	Both	Both	Both	Both	Both	Both
END USE SECTORS						
Agriculture		X	X	X	X	
Mining	X	X	X		X	
Construction		X	X	X	X	
Food	X	X	X	X	X	
Paper	X	X	X	X	X	X
Chemicals	X	X	X		X	
Glass	X	X	X	X	X	X
Cement	X	X	X	X	X	
Iron and Steel	X	X	X	X	X	X
Aluminum	X	X	X	X	X	X
Metals-Based Durables	X	X	X		X	
Other Non-Intensive	X	X	X		X	
	POLICIES					
	Expanded State Programs	**Expanded ESCO/Utility Programs**	**Financial Incentives**	**Expanded R&D Programs**	**Expanded Demonstration Programs**	**Carbon Trading System**
SCENARIO	Both	Both	Both	Both	Both	Advanced
END USE SECTORS						
Agriculture	X		X	X	X	X
Mining	X		X	X	X	X
Construction	X		X		X	X
Food	X	X	X		X	X
Paper	X	X	X	X	X	X
Chemicals	X	X	X	X	X	X
Glass	X	X	X	X	X	X
Cement	X	X	X	X	X	X
Iron and Steel	X	X	X	X	X	X
Aluminum	X		X	X	X	X
Metals-Based Durables	X	X	X	X	X	X
Other Non-Intensive	X	X	X	X	X	X

Voluntary Industrial Sector Agreements. Voluntary agreements are “agreements between government and industry to facilitate voluntary actions with desirable social outcomes, which are encouraged by the government, to be undertaken by the participants, based on the participants’ self-interest” (Story, 1996). A voluntary agreement can be formulated in various ways; two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such voluntary industrial agreements.

In this study, the voluntary industrial sector agreements are defined as a commitment for an industrial partner or association to achieve a specified energy efficiency improvement potential over a defined period. The level of commitment, and hence specified goal, varies with the moderate and advanced scenario. The number and degree of supporting measures also varies with the two scenarios, where we expect the increased industrial commitment to be met with a similar increased support effort by the federal and state government. The effectiveness of voluntary agreements is still difficult to assess, due to the wide variety and as many are still underway. Ex-poste evaluations are therefore not yet available. We estimate the effect on the basis of various efforts undertaken. Voluntary industrial agreements in Japan and Germany are examples of self-commitments, without specific support measures provided by the government. Industries promised to improve energy efficiency by 0.6% to 1.5% per year in those countries (IEA, 1997a; Stein and Strobel, 1997). As the targets are set by sub-sector, only intra-sector structural changes are included in the targets, while inter-sector structure changes are excluded. The voluntary industrial agreements in The Netherlands have set an efficiency improvement goal of 2% per year (Nuijen, 1998; IEA, 1997b), excluding intra- and inter-sector structural change. Industries participating in the voluntary agreements in The Netherlands receive support by the government, in the form of subsidies for demonstration projects and other programs (Rietbergen et al., 1998). The voluntary agreements in The Netherlands were strongly encouraged by the government. They were also attractive to industry, as they allowed the development of a comprehensive approach, provided stability to the policy field, and were an alternative to future energy taxation (Van Ginkel and De Jong, 1995), or regulation through environmental permitting. For more details on voluntary industrial agreements, see Newman (1998); Rietbergen et al., (1998); Nuijen (1998); Mazurek and Lehman (1999). Voluntary industrial agreements may be less effective in light industries, which typically have a large number of different companies. However, voluntary agreements may work well with some of the large companies that dominate production and energy use in this sector. In The Netherlands Philips Electronics participates in an individual voluntary industrial agreement, as it solely dominates the metals durables industry.

Experience with industrial sector voluntary agreements exists in the U.S. for the abatement of CFC and non-CO_2 GHG emissions. For example, eleven of twelve primary aluminum smelting industries in the U.S. have signed the Voluntary Aluminum Industrial Partnership (VAIP) with EPA to reduce perfluorocarbon (PFC) emissions from the electrolysis process by almost 40% by the year 2000 (U.S. EPA, 1999b). Similar programs exist with the chemical, magnesium and semi-conductor industries, as well as voluntary methane emission abatement programs with the coal, oil and natural gas industry. New voluntary efforts include landfill operators and agriculture.

Voluntary Programs. The policy scenarios include expanded programs modeled after current policy programs, i.e. Challenge technology delivery programs, Energy Star Buildings and Green Lights, Climate Wise and specific pollution prevention programs.

- Expanded Challenge Programs
  - *Motor Challenge and Compressed Air Challenge.* The U.S. Department of Energy’s Motor Challenge program was created in 1993 to promote voluntary industry/government partnerships to improve energy efficiency, economic competitiveness, and the environment. The main goal of the program is to work in partnership with industry to increase the market penetration of energy-efficient industrial electric motor-driven systems. A key element in the Motor Challenge strategy is to encourage a "systems approach" to industry’s selection, engineering, and maintenance of motors, drives, pumps, fans, and other motor-driven equipment (Scheihing et al., 1998). The program focuses its resources on the key industrial sectors that are participating in DOE’s Industries of the Future (IOF) strategy, as well as the water supply and wastewater sectors. The current Motor Challenge program focuses on eight energy- and waste-intensive sectors: forest products, steel, aluminum, metal casting, chemicals, glass, mining, and agriculture, and is targeting large plants in these industries (Scheihing et al., 1998). Starting in 1999, the Motor Challenge program has been expanded to include provision of enhanced technical assistance on steam and compressed air systems (U.S. DOE, 1999). The moderate and advanced scenarios call for increased funding for increased educational efforts and technical assistance. The program will increase its efforts to promote adoption of adjustable speed drives. Financial incentives will be added in the advanced scenario.

- *Steam Challenge.* The Steam Challenge program, a public-private initiative launched in April of 1998, was developed by DOE-OIT in partnership with the Alliance to Save Energy (ASE) and leading providers of energy-efficient steam technologies. The goal of Steam Challenge is to provide targeted information and technical assistance to help industrial customers retrofit, maintain, and operate their steam systems more efficiently and more profitably. Participation in Steam Challenge is open to steam system operators and managers, developers and distributors of steam systems equipment, and steam trade and membership organizations (U.S. DOE, OIT, 1999c). Increased funding in the moderate and advanced scenarios provides for expanded outreach, training, development of assessment tools, and development of automated monitoring and controls.

- *CHP Challeng.*[11]. DOE and EPA recently announced a target of doubling combined heat and power (CHP) capacity (including industrial, commercial, and federal facilities) in the United States by 2010. It seeks to open a national dialogue on CHP technologies to raise awareness of the energy, environmental, and economic benefits of CHP, and to promote innovative thinking about ways to accelerate the use of CHP (Laitner et al., 1999). State and regional officials will be key participants in this CHP Challenge. Future plans include a series of seminars with state officials, regional workshops, and a national CHP conference for policymakers and CHP practitioners to promote collaborative solutions (U.S. DOE, OIT, 1999d). Educational materials also are being prepared for state legislators and environmental groups. The CHP Challenge will coordinate with other government and industry programs to leverage ongoing activities relevant to CHP—for example, by working with the Federal Energy Management Program (FEMP) and facilities management agencies to expand the use of CHP technologies in government facilities. The Challenge also will assess related DOE technology demonstrations in advanced turbines, fuel cells, and combustion and heat recovery equipment (U.S. DOE, OIT, 1999d). Increased funding in the moderate and advanced scenarios allows for increased barrier removal, outreach, dissemination, evaluation assistance, and clearinghouse activities.

- ENERGY STAR Buildings and Green Lights
  The U.S. Environmental Protection Agency's ENERGY STAR programs help to eliminate information barriers and improve efficiency in investments in the buildings component of industrial energy use, which is especially important in light industries. ENERGY STAR programs are voluntary partnerships between EPA, the U.S. Department of Energy, product manufacturers, local utilities, and retailers to develop and market energy-efficient products (see also above). Partners help promote energy-efficient products by labeling them with the "ENERGY STAR" logo, which may be used as a marketing tool, and educating consumers about the benefits of energy efficiency. Participating companies are provided with access to information on products and practices to improve their efficiency. EPA will continue to add products to the list of those that qualify for the ENERGY STAR label (U.S. EPA, 1999b). The Green Lights program, a voluntary pollution prevention program sponsored by EPA and part of the ENERGY STAR program, aims at improving the efficiency of lighting systems. Green Lights partners agree to install energy efficient lighting where profitable as long as lighting quality is maintained or improved. Future expansion of ENERGY STAR will focus on initiatives that are more valuable to the industrial sector—for example, providing best practices management tools to industrial facilities and, if possible, developing and providing benchmarking information to help industries assess and compare their energy usage, and ultimately save energy (Lupinacci-Rausch, 1999). We assume that industrial building floorspace included in the ENERGY STAR Buildings and Green Lights programs increases by 50% under the moderate scenario and doubles under the advanced scenario.

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[11] We have assessed the potential for industrial cogeneration for the different policy scenarios (see section 5.5.4 for results). However, the cogeneration results have not yet been integrated in the overall results, reported in section 5.5.

- Expanded ENERGY STAR and Climate Wise Program
  U.S. Environmental Protection Agency sponsors various government-industry partnership initiatives, e.g. ENERGY STAR and Climate Wise, designed to stimulate the voluntary reduction of greenhouse gas emissions among participating manufacturing companies by providing technical assistance and helping organizations identify the most cost-effective ways to reduce greenhouse gas emissions. In the Climate Wise program companies submit an Action Plan that identifies specific cost-effective energy efficiency and pollution prevention measures. Companies then quantify and report their energy savings and emission reduction numbers annually. In return, participants in the Climate Wise program receive assistance in identifying actions that both save energy and reduce costs, have access to technical assistance, and receive public recognition for their efforts (e.g., through signing ceremonies, media briefings, articles in business journals) (U.S. EPA, 1999a, U.S. EPA, 1999b). Program expansions and funding are increased by 50% in the moderate scenario and doubled in the advanced scenario. The moderate scenario incorporates additional partners while the advanced scenario incorporates new manufacturing sectors, both scenarios contributing to the savings in existing and new plant equipment.

- Expanded Pollution Prevention Programs
  Although not directly aimed at energy use or GHG emissions, the WasteWise program may reduce energy use and GHG emissions through pollution prevention and increased recycling of energy intensive materials. The WasteWise program targets the reduction of municipal solid waste, such as corrugated containers, office paper, yard trimmings, packaging, and wood pallets. Participants, which range in size from small local entities to large corporations, sign on to the program for a 3-year period and commit to reduce waste, establish reduction goals, and monitor progress of waste reduction projects and activities. The U.S. EPA has also created the Design for the Environment (DfE) Program to build on the "design for the environment" concept pioneered by industry. Under this program, EPA encourages businesses to incorporate environmental considerations into the design and redesign of products, processes, and technical and management systems, as well as environmentally procurement programs (U.S. EPA, CPD, 1999; U.S. EPA, OCFO, 1999). Increased funding in the moderate and advanced scenarios is expected to lead to reductions in material demand, increased diversion of wastes to recycling instead of landfilling, and overall changing consumption and production patterns in the primary materials industries.

Information Dissemination Programs. Information dissemination programs include assessment programs and labeling programs, as well as elements of the “Challenge” programs, the Climate Wise program, and pollution prevention programs (see above).

- Expanded Assessment Programs
  The U.S. Department of Energy Office of Industrial Technology’s Industrial Assessment Center (IAC) program is an energy efficiency improvement initiative that also supports waste reduction and improvements in productivity for small and medium sized manufacturing firms[12]. There are now 30 universities operating IACs across the country. Since its inception in 1976, these centers have performed more than 8,000 assessments and provided 53,000 recommendations since 1976; about 42% of the suggested investments have been implemented (STAPPA/ALAPCO, forthcoming). The energy audits and assessments are performed by teams from engineering schools at Universities across the country, who help manufacturers identify opportunities to improve productivity, reduce waste, and save energy. Most clients of the IAC centers are currently in food processing and metals

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[12] The IAC Program defines small and medium sized enterprises as having gross annual sales of $75 million or less, consume energy at a cost of $1.75 million per year or less, or employ no more than 500 people.

manufacturing, due to the higher presence of small and medium sized enterprises in these sectors. Historically, IAC assessments have identified the most retrofit opportunities in lighting, HVAC and building envelopes, heat recovery and containment, compressors, and motors in small and medium sized enterprises (U.S. DOE, OIT, 1999b). Under the moderate and advanced scenarios, funding is increased so that additional IACs are established. Due to integration with both business schools and local community colleges, the number of assessments also increases and the work of the centers is expanded to include development of comprehensive energy plans for the audited industries. Developing such corporate energy plans to implement and maintain energy-efficient practices will focus industries on sustained efforts, modeled after programs run at various companies.

- Product Labeling and Procurement
  Consumer information to encourage demand for environmentally benign products, e.g. eco-labeling, is a step towards more sustainable production that is taken in many countries. For example, the “Blue Angel” program has been in existence since 1977 in Germany, and is used for a wide array of products. The “Blue Angel” program labels products like unbleached, recycled paper, as well as many other common products (e.g. computers, paint). The “Green Seal” in the U.S. is a similar, but independent non-governmental, effort. The labeled products generally have a lower environmental impact than competing products, and often result in energy savings due to the use of less energy-intensive materials or recycled materials. To maintain objectivity standardized and independent procedures are needed. The design of the testing procedures may take a few years. Corporate and governmental procurement programs of labeled products are also established as 'market-pull' instruments. The federal government has established procurement programs for energy consuming equipment (FEMP). The described effort would expand the program to other products, e.g. cement for public construction projects. Under the moderate scenario, we assume the development of a federal eco-labeling program for development of a label for unbleached, recycled paper and for performance-based cement standards. Under the advanced scenario, the program will be expanded to various products.

Investment Enabling Programs. Investment enabling programs include state programs, ESCO/utility programs, and financial incentives.

- Expanded State Programs
  - *State Industrial Energy Efficiency Programs.* Currently many states and regional bodies have local industrial innovation and competitiveness programs (NIMAP, 1999), of which a number specifically aim at industrial energy efficiency improvement. In this description we excluded utility or ESCO programs (see description under ESCO programs, below). Approximately 300 regional or state programs exist. Successful examples of energy programs can be found in e.g. Iowa, New York, Texas, and Wisconsin. The Energy Center of Wisconsin focuses on demonstration projects. The NYSERDA (New York State Energy Research and Development Authority) program in New York focuses more on industrial R&D, while the LoanSTAR program in Texas focuses on demonstrating energy retrofit technologies. The Iowa Energy Center focuses on agriculture and audits. The programs are active in information dissemination, auditing, demonstration, and R&D of industrial technologies. Recently, OIT has also started an effort to expand the IOF program to the state level. States Industries of the Future (SIOF) has activities in 50 states in various stages of development, and focus points (depending on the interests of local industries). Increased funding in the moderate and advanced scenarios will accommodate expansion of technology demonstration and practices across sub-sectors, auditing, active dissemination, and integration with other industrial innovation and environmental policies.

  - *Clear Air Partnership Funds.* There are various ways to comply with the provisions of the Clean Air Act. Harmonized strategies to reduce air pollutant emissions that also reduce GHG emissions can be developed in all sectors, including the industrial sector (STAPPA/ALAPCO, 1999). Air pollution control measures are developed by state and local regulators and are described in a State Implementation Plan (SIP). A SIP contains plans for inventories of emissions, modeling of efforts needed to attain or maintain a specified emission level, a list of control measures, and regulations to adopt and enforce the control strategies (see Regulations, below). The Clean Air Partnership Fund will provide financial incentives to reduce air pollution and GHG emissions simultaneously. The GHG emission reduction will depend strongly on the measures that are implemented to reduce pollutant emissions, and are likely to vary by region (STAPPA/ALAPCO, 1999). While the moderate and advanced scenarios follow the same timeline as the baseline scenario, start of implementation of measures by the year 2000, increased funding makes integrated approaches more attractive for industries and allows new technology demonstrations without the current risk of non-compliance.

- Expanded *ESCO/Utility Programs*
  Following deregulation, 19 states have introduced public benefit charges. The revenue from the public benefit charges will be used to fund projects in energy efficiency, R&D, renewable energy sources, as well as to subsidize low-income households. The charge and the spending pattern will vary by state (Kushler, 1998; Kushler, 1999). We assume that the revenues will mainly be used to expand the work of Energy Service Companies (ESCOs) through standard performance contracting (Eto et al., 1998). Historically, utility demand-side management program performance has varied widely, and depends on factors like marketing, targeting of approaches, program procedures, level of financial incentives, and availability of technical assistance (Nadel, 1990). Utility programs seem to have mainly been targeted to larger customers. A recent analysis of bidding programs for commercial/industrial energy savings showed typical costs from $0.054 to $0.08 per kWh-saved (Goldman and Kito, 1994). For the business-as-usual scenario, we use a typical cost of $0.06/kWh-saved. Under the moderate scenario, we assume public benefit charges are used in 20 states by the year 2000 and expanded to 30 states by 2005. We assume that the typical costs in the moderate scenario will be $0.065 per kWh-saved, due to increased efforts targeting small industrial consumers. For the advanced scenario, the programs will have slightly higher typical costs of $0.07/kWh-saved, as it is more difficult to reach a larger group of customers.

- Financial Incentives
  - *Tax Rebates for Specific Industrial Technologies.* As part of the U.S. climate change proposal, President Clinton announced support for $6.3 billion in funding over 5 years for additional R&D efforts and tax cuts to stimulate energy efficiency and other technologies that reduce greenhouse gas emissions. The financial incentives and R&D expenditures would spur development and commercialization of advanced technologies and leverage larger private sector investments. Specific technologies that have been discussed for the tax rebate program include black liquor gasification, direct steelmaking technologies, and advanced aluminum cells. Other potential tax incentive initiatives in the industrial sector could include improved aluminum smelting technologies and major chemical production processes. These incentives could be made available for up to ten years, assuming that they are initiated in 1999 or 2000 (Elliott, 1999). Under the moderate and advanced scenarios, the expanded program will be aimed at the implementation of advanced technologies. In the early years this will include industrial cogeneration, roller kilns, autothermal reforming, black liquor gasification, near net shape casting. After 2005 it could also include advanced technologies, now under demonstration or development, e.g. smelt reduction, advanced (catalytic) membrane applications, and impulse drying. The higher funding level in the advanced scenario is expected to accelerate uptake of these technologies within the analysis period of the study.

- *Investment Tax Credit for CHP Systems.* This policy would establish an 8% investment credit for qualified CHP systems with an electrical capacity in excess of 50 kilowatts or with a capacity to produce mechanical power in excess of 67 horsepower (or equivalent combination of electrical and mechanical energy capacities). A qualified CHP system would be required to produce at least 20 percent of its total useful energy in the form of thermal energy and at least 20 percent of its total useful energy in the form of electrical or mechanical power (or a combination thereof). In the moderate scenario it is expected that the tax credit scheme is maintained at the 2000-2002 level throughout the scenario period (2020). In the advanced scenario it is expected that the tax credit scheme is started at a level of $100 Million for the period 2000-2005, and maintained at a higher level of $200 Million from 2005 till 2020. The investment credit remains at 8% for qualifying CHP units. After 2005, higher credit levels are available for advanced cogeneration systems, including advanced turbines, gas turbines for industrial furnaces, high efficiency systems using waste gases, and for industrial applications of fuel cells. The program is maintained throughout the modeled period, and is expected to contribute to the expansion of CHP in industry, as well as third party (merchant) producers at industrial sites.

Regulations

- Motors Standards and Certification.
  The moderate scenario mandates upgrade of all motor systems to EPACT standards by 2020,and extends standards to all motors not currently governed by EPACT, although the effect of the latter may be limited (Xenergy, 1998). It also includes improved rewind practices by promoting a national repair standard (EASA-Q) and the institution of certification and licensing of rewind shops by 2004. Specifications for motor purchases are supplied and energy-efficiency requirements are increased to EPACT standards (by extending standards to all motors not currently governed by EPACT). The advanced scenario extends standards to all motor systems and enforces 100% compliance by 2020, improves rewind practices and mandates national repair standard (EASA-Q) into law by 2004, and mandates certification and licensing of rewind shops by 2004.

- State Implementation Plans/ Clear Air Partnership Fund
  State Implementation Plans outline air pollution control measures to comply with the provisions of the Clean Air Act. These SIPs include a list of control measures and regulations to adopt and enforce the control strategies (STAPPA/ALAPCO, 1999). This regulatory element of the Clean Air Act SIPs augments the harmonized strategies to reduce air pollutant emissions and GHG emissions that are described above under Investment Enabling Programs.

Research, Development, and Demonstration Programs. New technologies that could have the largest impact in the period after 2010 include black liquor gasification (paper), impulse drying (paper), smelt reduction (steel), membranes (chemicals, food), heat pumps (chemicals, food), inert anodes (aluminum), new grinding technologies (non-metallic minerals, mining), process control and equipment (all sectors) high efficiency and high temperature CHP including gas turbines and fuel cells (DOE National Laboratory Directors, 1998; Interlaboratory Working Group, 1997; Blok et al.,1995). Expanded R&D efforts are likely to generate future energy savings over the modeled timeframe depending on the timing and scheduling of the R&D (Breger, 1997).

- Expanded Demonstration Programs
  Demonstration programs, such as the U.S. Department of Energy's National Industrial Competitiveness through Energy, Environment, and Economics (NICE[3]), improve industry energy efficiency, reduce industry's costs, and promote clean production. Grants support innovative technology deployment that can significantly conserve energy and energy-intensive feedstocks, reduce industrial wastes, prevent pollution, and improve cost competitiveness. The NICE[3] program currently focuses on the following industries (# of projects): agriculture (1), aluminum (6), chemicals

(13), forest products (10), glass (2), metal casting (4), petroleum (3), steel (8), other industries: electroplating/galvanizing (4), electronics (2), food (4), general manufacturing (10), printing (1), textiles (3) (U.S. DOE, OIT, 1999a). These programs are expanded under the moderate and advanced scenarios, with the increased funding leading to demonstration programs in additional industrial sub-sectors, incorporated into state programs, and providing more information dissemination services.

➢ Expanded R&D Programs

In this study we model the impact of R&D policies by assuming increasing availability of new technologies in the moderate and especially in the advanced scenario. In the advanced scenario the policies to increase energy efficiency will provide incentives to direct R&D efforts increasingly to energy and resource efficiency. The technologies mentioned above will affect the trends in efficiency of new technologies in all industrial sectors gradually (reflecting the trends in S-curves for technology development and penetration). R&D developments may also affect the costs and potential energy savings from retrofit of existing technologies, but less pronounced than for new technologies.

- *Industries of the Future.* The U.S. Department of Energy, Office of Industrial Technologies, Industries of the Future (IOF) strategy—creating partnerships among industry, government, and supporting laboratories and institutions to stimulate technology research, development, and deployment—is being implemented in nine energy- and waste-intensive industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. The IOF strategy is based on the preparation of documents outlining each industry's vision for the future, along with technology “roadmaps” identifying the technologies that will be needed to reach that industry's goals. Potential technologies are assessed and selected for funding by DOE and the industries (U.S. DOE, OIT, 1999e). Industries of the Future programs are expanded in the moderate and advanced scenarios, leading to increased research and development of future technologies and savings in new plant equipment.

- *Other OIT R&D Programs.* The Office of Industrial Technologies currently funds basic research in the areas of Enabling Technologies and Distributed Generation. The Enabling Technologies include engineered ceramics/continuous fiber ceramic composites, advanced industrial materials, combustion systems, and sensors and control technologies. The Distributed Generation programs focus on industrial power generation and industrial distributed generation (U.S. DOE, 1999). In cooperation with the DOE Office of Fossil Energy, OIT supports the development and demonstration of high-efficiency gas turbines primarily designed for industry. Funding increases under the moderate and advanced scenarios lead to expanded program R&D efforts in all areas related to improving industrial sector energy efficiency.

Accelerated R&D in 2010-2010 Period

The policies and programs discussed above were originally designed for the period 2000-2010. It is assumed that similar policies will be maintained throughout the period 2010-2020. In addition, the results of accelerated R&D policies will impact energy efficiency improvement potentials after 2010. R&D will likely increase the potential for energy efficiency improvement, while reducing the costs for new technology. R&D is not expected to have profound effects in the analysis period up to 2010. However, R&D can substantially contribute to decreasing the costs of new technologies as well as promoting the development of new technologies designed to reduce energy use and carbon emissions between 2010 and 2020. It is difficult to model technologies under development in the same detail as commercially available technology.

Domestic Carbon Dioxide Emissions Trading System

In the advanced scenario a carbon trading system is assumed to be implemented, which would lead to a estimated value of carbon permits of 50$/ton C (see section 3.2.1.3).

5.3.2 Barriers Addressed

Voluntary industrial agreements, along with the associated package of industrial sector policies and programs outlined above, are designed to address a number of barriers to investment in energy efficiency and greenhouse gas emissions reduction options including willingness to invest, information and transaction costs, profitability barriers, lack of skilled personnel, and other market barriers. Table 5.4 outlines the programs and policies we use to support voluntary industrial agreements in this analysis and the barriers they address.

Willingness to Invest. The decision-making process to invest in energy efficiency improvement, like any investments, is shaped by the behavior of individuals or of various actors within a firm. Decision-making processes in firms are a function of its rules of procedure (DeCanio, 1993), business climate, corporate culture, managers' personalities (OTA, 1993) and perception of the firm's energy efficiency (Velthuijsen, 1995). The literature suggests that the fewest barriers to energy efficiency investment exist in the industrial sector, where managers are thought to be motivated by cost minimization (Golove, 1994). The behavior has been categorized in a study by EPRI in the U.S., which determined nine "types" of managers (EPRI, 1990), depending on industrial development type and management characteristics. In markets with strong growth and competition, efficiency with respect to energy and other inputs is necessary to survive. In contrast, stagnating markets are poor theatres for innovation and investment, and instead rely on already depreciated equipment to maintain low production costs. A survey of 300 firms in The Netherlands showed that a favorable market expectation was perceived as an important condition for investing in energy efficiency improvement. In markets where increased energy costs can still be recovered in the product price, firms do not have the incentive to invest in energy efficiency improvements. In the same survey it also appeared that firms often perceived themselves as energy efficient, even though profitable potentials for energy efficiency improvements were still found (Velthuijsen, 1995). Energy awareness as a means to reduce production costs does not seem to be a high priority in many firms, despite a number of excellent examples in industry worldwide. By including energy efficiency as a component of waste minimization, firms have identified more opportunities for savings (see box) (Nelson, 1994).

Company Programs

Dow Chemical in Louisiana introduced an annual waste reduction contest in 1981 among employees at the Plaquemine-site (LA). This contest has continued to find significant, highly cost-effective energy and materials savings projects each year, implying that even well managed firms do not automatically optimize their use of resources. Each year more profitable energy conservation and waste reduction projects are identified in an annual contest with rate of returns far over 100%. The additional efficiencies found at Dow Chemical suggest that great potential exists to improve the efficiency and reduce the emissions of the industrial sector, if organizational and other internal barriers can be overcome (Nelson, 1994).

Information & Transaction Costs. Cost-effective energy efficiency measures are often not undertaken as a result of lack of information or knowledge on the part of the consumer, lack of confidence in the information, or high transaction costs for obtaining reliable information (Reddy, 1991; OTA, 1993; Velthuijsen, 1995; Sioshansi,1991; Levine et al.,1995; Ostertag, 1999). Information collection and processing consumes time and resources, which is especially difficult for small firms. Many firms and individuals are uninformed regarding the possibilities for buying efficient equipment (Reddy, 1991), because energy is just one of many criteria in acquiring equipment. The information needs of the various actors are defined by the characteristics of the investors leading to a need for a diversified set of information sources. Public agencies and utilities play an important role in providing this information.

Financial Barriers. A large number of standard accounting procedures are available for firms to determine the economic feasibility and profitability of an investment. Surveys showed that many investors use instruments such as simple payback period, rate of return or net present value to evaluate energy efficiency projects. When energy prices do not reflect the real costs of energy, then consumers will necessarily invest less in energy efficiency unless such investments have additional benefits. Energy prices, as a component of the profitability of an investment, are also subject to large fluctuations. The uncertainty about future energy prices, especially in the short term, seems to be an important barrier (Velthuijsen, 1995). The uncertainties often lead to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate (Hassett and Metcalf, 1993; Sanstad et al., 1995). An important reason for high hurdle rates is capital availability. Capital rationing is often used within firms as an allocation means for investments, leading to even higher hurdle rates, especially for small projects with rates of return from 35 to 60%, much higher than the cost of capital (~15%) (Ross, 1986). DeCanio (1993) has shown that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital to the firm. On the energy supply side the costs of capital are much lower, leading to imperfections of the capital market. Utilities and investors in power supply typically operate with longer payback periods (Levine et al., 1994). These capital market imperfections lead to bias against end-use investments vis-a-vis energy supply.

Lack of Skilled Personnel. Especially for small and medium sized enterprises (SME) the difficulties of selecting and installing new energy-efficient equipment compared to the simplicity of buying energy may be prohibitive (Reddy, 1991). In many firms (especially with the current trend towards *lean* firms) there is often a shortage of trained technical personnel (OTA, 1993), because most personnel are busy maintaining production. A survey in The Netherlands suggested that the availability of personnel is seen as a barrier to invest in energy-efficient equipment by about one third of the surveyed firms (Velthuijsen, 1995). In addition, the possible disruption of the production process is perceived as a barrier, leading to high *transition or opportunity costs.* Transition costs may include the costs of not fully depreciated production equipment, although the capital costs of the new technology in itself may be economically attractive.

Other Market Barriers. In addition to the problems identified above, other important barriers include (1) the "invisibility" of energy efficiency measures and the difficulty of demonstrating and quantifying their impacts; (2) lack of inclusion of external costs of energy production and use in the price of energy, and (3) slow diffusion of innovative technology into markets. A full discussion of these topics is beyond our scope, see (Levine et al., 1994; Fisher and Rothkopf, 1989; Hirst and Brown, 1990; Sanstad and Howarth, 1994). Many companies are risk averse with regard to a possible effect on product quality, process reliability, maintenance needs or uncertainty about the performance of a new technology (OTA, 1993). Firms are therefore less likely to invest in new not yet commercially proven technology. Aversion of perceived risks seems to be a barrier especially in SMEs (Yakowitz and Hanmer, 1993). For commercial and industrial buildings that are rented, there are few incentives for the renter to improve the property that he/she does not own; similarly, the landlord is uncertain of recovering his/her investment, either in higher rents (as it is difficult to prove that improved thermal integrity will save the renter money in utility bills) or in the utility bills, as the bills depend on the behavior of the renter. Builders are often required to minimize first costs in order to win bids, and many building owners do not have sufficient expertise to recognize the benefit of higher first costs to reduce building operating costs (Golove, 1994). ESCOs are able to capture part of this efficiency gap.

Table 5.4 Policies to Address Barriers to Efficiency Improvement in the Industrial Sector

	POLICIES					
	Voluntary Agreements	**Expanded Demonstration Programs**	**Expanded Assessment Programs**	**Expanded Challenge Programs**	**Expanded Labeling Programs**	**Expanded State Programs**
SCENARIO	Both	Both	Both	Both	Both	Both
BARRIERS						
Willingness to Invest	X	X	X	X		
Information / Transaction Costs	X	X	X	X	X	X
Profitability		X		X		
Lack of Skilled Personnel			X	X		X
Pricing				X		
Innovation		X		X		X
Renter/Landlord						

	POLICIES					
	Expanded R&D Programs	**Expanded ESCO/utility Programs**	**Expanded Climate Wise Program**	**Expanded Pollution Prevention**	**Financial Incentives**	**Carbon Trading System**
SCENARIO	Both	Both	Both	Both	Both	Advanced
BARRIERS						
Willingness to Invest		X		X	X	
Information / Transaction Costs		X	X	X		
Profitability	X	X			X	X
Lack of Skilled Personnel		X				
Pricing					X	X
Innovation	X			X		
Renter/Landlord		X				

5.4 METHODOLOGY FOR ANALYZING POLICY IMPACTS

Our analysis begins with an assessment of policies and programs applicable to the industrial sector. We use voluntary industrial sector agreements between industry and government as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions. As discussed above, these voluntary industrial sector agreements are supported by a comprehensive package of policies and programs designed to encourage implementation of energy-efficient technologies and practices.

Each industrial sub-sector is evaluated to determine the potential energy savings and GHG emissions reductions. Since voluntary industrial sector agreements are the umbrella under which a number of policies and programs contribute to decisions to implement energy-efficient technologies and measures, it is often difficult to allocate specific actions to specific policies or programs. Estimates are made to allocate the overall synergetic effects of actions taken due the supporting policies and measures. Table 5.5 outlines how the effects of the different policies and programs are reflected in the CEF-NEMS modeling and model inputs. Appendix A.2 and B.2 provide detailed information on the alterations made to the NEMS-model and on the industrial sector policies and programs. Uncertainties in the assumptions affect the final results of the scenarios. However, as it is not always possible to quantitatively estimate the uncertainties (see sections 5.6 and 5.7) and for reasons of presentation we only present point estimates.

AEO 99 projects energy intensity reductions of 1.0% per year in the baseline scenario, of which 80%, or 0.8% per year, are due to inter-sector structural change and the remaining 0.2% per year is due to efficiency improvements (U.S. DOE, EIA, 1998a). We have retained the AEO99 assumption of a 0.8% contribution inter-sectoral structural change in all CEF, and in the moderate and advanced scenarios modified the change due to efficiency improvements as discussed below.

Five industrial sub-sectors (paper, glass, cement, steel, and aluminum) are modeled in NEMS using physical production values to determine energy intensities. We evaluate three of these subsectors (paper, cement, and steel) in detail, relying on recent process-level assessments of energy use, carbon dioxide emissions, and efficiency potentials (Worrell et al., 1999; Martin et al., 1999; Anglani et al., 1999). We assess the other two sectors based on historic trends and efficiency potentials identified in recent U.S. and international literature. The remaining industrial sub-sectors (agriculture, mining, construction, food, chemicals, metals-based durables, and other manufacturing)[13] are modeled in NEMS using economic production values (value of output) to determine energy intensities. We evaluate these sub-sectors based on historic trends and efficiency potentials identified in recent U.S. and international literature.

5.4.1 Actions Addressed Within CEF-NEMS

All actions due to industrial sector policies were addressed to some degree within CEF-NEMS, including a carbon dioxide emissions trading system with an assumed carbon price of $50/ton in the advanced scenario. We first assessed the level of future energy savings under many policies (see Appendix B.2). Next we determined where and how these energy savings might be achieved in terms of modeling parameters and modeled these changes in CEF-NEMS, on an aggregation level appropriate for the CEF-NEMS model. We adjusted the following parameters of the CEF-NEMS model to reflect the likely impact of the policies on the implementation rate and decision-making process: energy efficiency improvements in existing equipment, energy efficiency improvements in new equipment, material inputs, boiler efficiency, use of CHP, and building efficiency. Some policies may affect one parameter, e.g. research and development is most likely to affect the energy efficiency improvement and availability of new equipment. On the other hand, a carbon trading system will affect the price of energy and will likely influence all parameters of the CEF-NEMS model.

Energy Efficiency Improvements in Existing Equipment. In addition to the over-arching voluntary industrial sector agreements, specific policies that result in more rapid adoption of energy-efficient technologies and measures for existing equipment are expanded assessment programs, expanded Motor and Compressed Air Challenge program, expanded state programs, expanded SIP and Clean Air programs, expanded ESCO/utility programs, expanded ENERGY STAR and Climate Wise programs, tax incentives for energy managers, and expanded demonstration programs.

The rate of adoption of energy-efficient technologies and measures for existing equipment is characterized in NEMS using technology possibility curves (TPCs)[14]. TPC values for existing equipment were modified in the moderate and advanced scenarios in all sectors (see Appendix A-2). For the paper, cement, and steel sectors, the modifications were made based on calculations made outside of CEF-NEMS (see below). For the agriculture, mining, chemicals, glass, and aluminum sectors, we relied on recent analyses (see Appendix A-2) of the energy efficiency improvement potentials in these sectors to determine TPCs for the moderate and advanced scenarios. For the remaining sectors (food, metals-based durables, and other manufacturing), we used the AEO99 HiTech Case TPC values for the advanced scenario and used values between the Base Case and the HiTech Case for the moderate scenario.

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[13] Because petroleum refining is not included in the NEMS industrial model (but rather in the transformation sector) it has been excluded in the analysis of the industrial sector.

[14] TPCs represent average annual rates of change (usually reduction) in the Unit Energy Consumption (UEC) values. TPCs and UECs are provided by process by fuel for each industrial subsector.

Table 5.5 Qualitative Representation of Policy and Program Impacts on CEF-NEMS Inputs by Industrial Subsector

	POLICIES								
	Demon-stration Programs	Assess-ment Programs	Challenge Programs - Motors and Air	Challenge Programs - Steam	Challenge Programs - CHP	Energy Star Buildings and Green Lights	Product Labels	State Programs	Clean Air Act SIPs
Agriculture	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Mining	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Construction	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Food	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Paper	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5	4	1,2,3,5	1,2,3,6,7,9
Chemicals	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,7,9
Glass	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Cement	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5	4	1,2,3,5	1,2,3,6,9
Steel	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,7,9
Aluminum	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Metals-Based Durables	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Other Manufacturing	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Petroleum Refining	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

	POLICIES								
	R&D - IOF	Other OIT R&D	ESCO/ Utility program	Climate Wise Program	Pollution Prevention	Tax Incentives for Energy Managers	Tax Rebates for Specific Industrial Techs	Investment Tax Credit for CHP Systems	Carbon Trading System
Agriculture	2	2,6	1,6,9	1,2,8		1		6,9	1-6,8,9
Mining	2	2,6	1,6,9	1,2,8		1		6,9	1-6,8,9
Construction				1,2,8				6,9	1-6,8,9
Food		2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Paper	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1--9
Chemicals	2	2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Glass	2	2,3,6	1,5,6,9	1,2,8	4	1,5	2	6,9	1-6,8,9
Cement	2	2,3,6	1,5,6,7,9	1,2,7,8		1,5,7	2	6,9	1--9
Steel	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1--9
Aluminum	2	2,3,6		1,2,8	4	1,5	2	6,9	1-6,8,9
Metals-Based Durables	2	2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Other Manufacturing			1,5,6,9	1,2,8		1,5		6,9	1-6,8,9
Petroleum Refining	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9	1-6,8,9

Notes

Modeled within NEMS:

1: increased TPCs in existing equipment
2: increased TPCs in new equipment
3: increased boiler efficiency
4: increased use of recycled materials (throughput changes)
5: improved building energy efficiency
6: increased use of cogeneration (within NEMS)

Modeled outside NEMS:

7: improved TPCs in existing equipment (LBNL-detailed analysis in steel, cement and pulp and paper industries)
8: improved TPCs in existing equipment (ORNL motor system assessment for motors electricity use)
9: increased use of cogeneration (DISPERSE modeling of CHP-policies)

Energy Efficiency Improvements in New Equipment. Voluntary industrial sector agreements provide the overall impetus for making energy efficiency improvements in new equipment. Other programs (such as expanded demonstration programs, Motor and Compressed Air Challenge, expanded state programs, expanded SIP and Clean Air programs, expanded Industries of the Future Programs, expanded other OIT R&D programs, expanded ENERGY STAR and Climate Wise Programs, and tax incentives for specific industrial technologies) provide information and incentives for more rapid adoption of new, energy-efficient technologies and measures.

The rate of adoption of energy-efficient technologies and measures for new equipment is characterized in NEMS using TPCs. The TPCs were modified in the moderate and advanced scenarios in all sectors (see Appendix A.2). For the paper (Anglani et al., 1999), cement (Martin et al., 1999), steel (Worrell et al., 1999), agriculture, mining, chemicals, glass, and aluminum sectors, these modifications were based on recent analyses (see Appendix A.2) of the energy efficiency improvement potential in these sectors to determine TPCs for the moderate and advanced scenarios. For the remaining sectors (food, metals-based durables, and other manufacturing), we used the AEO99 HiTech Case TPC values (US DOE, EIA, 1998a) for the advanced scenario and used values between the Base Case and the HiTech Case for the moderate scenario.

Material inputs. Product labeling programs and pollution prevention programs will reduce primary resources inputs in the paper, glass, cement, steel, and aluminum subsectors as these industries move toward increased use of recycled materials. Material inputs in CEF-NEMS have been adjusted in the moderate and advanced scenarios to reflect such a shift. The AEO99 reference scenario shows only minor increases in recycled material inputs. For paper, the share of waste paper is increased over the 0.3%/year assumed in the AEO99 reference case, by 0.2% per year and 0.4% per year in the moderate and advanced scenarios, respectively. Historically, the share of recycled fiber has increased from 21.5% in 1970 to 33.2% in 1995, equivalent to an average increase of 1.7%/year (McLaren, 1997). As a result the amount of pulping and wood is reduced. Bleaching throughput is reduced by 0.1% per year in the moderate scenario and 0.2% per year in the advanced scenario. For steel, the share of electric arc furnace production is increased to 55% by 2020 in the advanced scenario versus 46% in the AEO99 reference case, in line with expectations of the industry (Barnett, 1998). For cement, we assume that 30.7 million tons of blended cement will be produced by 2010 (PCA, 1997), resulting in reduced clinker production throughout the analysis period. By 2020, clinker production is reduced by 6.9 million tons in the moderate scenario and by 16.4 million tons in the advanced scenario relative to the AEO99 reference case. For aluminum, increased recycling (Plunkert, 1997) is simulated by reducing production growth of primary aluminum production by 0.05% per year in the advanced scenario and by correcting energy use for the aluminum recycled.

Boiler efficiency. Expanded Steam Challenge, expanded state programs, expanded Clean Air programs and SIPs, and expanded OIT R&D programs will all contribute to improved boiler efficiency. Boilers in AEO99 are modeled with a set or fixed efficiency of around 80% for boilers using fossil fuels and 74% for by-product boilers. In reality boiler efficiency can vary widely, e.g. between 65% and 85% for coal boilers (CIBO, 1997). Also, in NEMS boilers are not retired, so the efficiency gains from new boilers are not captured in the model. Boiler efficiency can be improved by reducing excess air, installing combustion controls, or by improved boiler insulation. The CEF-NEMS model also does not retire old boilers, allowing implementation of new efficient boilers. Based on the assumptions in the BAU-scenario, and assessments of boiler efficiency improvements (CIBO, 1997; Einstein et al., 1999) we have determined improvement rates for the policy scenarios, reflecting the retirement of older boilers as well as the potential impact of the policy measures. In the moderate scenario boiler efficiency improvement increases 0.2% per year for fossil fuels, and by 0.1%/year for biomass and waste. In the advanced scenario the improvement rate is determined at 0.2%/year (oil), 0.3%/year (gas and coal) and 0.2%/year for waste and renewable fuels, respectively.

*Building efficiency***.** ENERGY STAR Buildings and Green Lights, expanded state programs, expanded ESCO/utility programs, and tax incentives for energy managers will all lead to improvements in building energy efficiency. The NEMS model does not account for energy use in buildings in the agriculture, mining, or construction industries, but does include building energy use in all of the remaining industries. For these industries, we adopt the energy savings potential for the moderate and advanced scenarios identified in this study for commercial buildings.

5.4.2 Actions Addressed Outside of CEF-NEMS

Various actions due to policies were modeled outside of CEF-NEMS, although some results were fed into the CEF-NEMS model. We assessed the potential impacts of policies on retrofitting existing technologies in the paper, cement, and steel industry, and two related cross-cutting opportunities, i.e. cogeneration (CHP) and motor systems.

In the paper, cement, and steel **industrial sub-sectors** we assessed the technologies available to *retrofit* existing plants. In total, over one hundred technologies were characterized with respect to potential energy savings, costs, and potential degree of implementation. The analyses focus on commercial technologies that have been implemented by plants in the U.S. or other industrialized countries. The technologies have been ranked by cost-effectiveness in energy conservation supply curves. The curves have been used to assess the effect of the policies by adjusting the hurdle rate and energy prices. In the moderate scenario, it was assumed that all measures with zero or net-negative annual costs are implemented using a hurdle rate of 30%. In the advanced scenario, a hurdle rate of 15% was used to reflect the impact of the policy instruments that reduce transaction costs and reduce the financial risks of investments. It is assumed that the measures are fully implemented by the year 2020, allowing a flexible response strategy. This would allow the implementation of technologies to fit scheduled maintenance practices, reducing opportunity and transaction costs. The changes in energy intensity due to the implementation of the retrofit measures were implemented in the CEF-NEMS model as an annualized change relative to the reference year 1994. This allows credit for energy efficiency improvement achieved until today. The detailed assessments and supply curves are reported in separate reports for the cement (Martin et al., 1999), paper (Anglani et al., 1999) and steel industries (Worrell et al., 1999).

Combined Heat and Power Production (CHP)[15] is modeled separately to model the interaction with the power sector, effects of policy initiatives, and the replacement of retired industrial boilers. Expanded Steam Challenge, expanded CHP Challenge, expanded Clean Air programs and SIPs, expanded ESCO/utility programs, investment tax credits for CHP systems, and expanded OIT R&D programs will all contribute to increased use of cogeneration. The model allows the use of CHP for new steam generation capacity, due to growth of steam demand in the sectors. The CEF-NEMS model does not retire old boilers. Hence, brownfield applications of CHP can not be modeled inside the model, but are modeled outside the model (see below). As growth in steam demand in most sectors is slow in the policy scenarios, implementation of CHP in the model itself is very limited. Hence, for CHP we relied on the modeling outside the CEF-NEMS framework, to model the impact of CHP policies.

The CHP analysis was performed using Resource Dynamics Corporation's DISPERSE model[16] (see Appendix A-2). The results were compared with results of studies using other utility models, i.e. the IPM model run for US EPA. DISPERSE is a model that compares on-site power generation with the grid on the basis of costs. DISPERSE estimates the achievable economic potential for CHP applications by

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[15] Note that the definition of CHP may vary, e.g. PURPA used a different definition than CCTI. We use varying heat to power ratios for the different sectors, dependent on the characteristics of that sector, and the CHP units implemented, but would fall within the definitions commonly used.

[16] Distributed Power Economic Rationale Selection (DISPERSE) model.

comparing on-site generation economics with competing grid prices. The model not only determines whether on-site generation is more cost effective, but also which technology and size appears to be the most economic. As a result, double counting of market potential for a variety of competing technologies is avoided. This model has been developed over the past five years, and has been applied on a variety of projects for utilities, equipment manufacturers, and research organizations. Fuel and electricity prices are based on those of the CEF scenarios. The overall steam demand for the industrial sub-sectors is taken from the results of the baseline and policy scenarios. For modeling purposes it is assumed that steam use in each site follows the national developments. Various financial parameter assumptions are taken into account, including depreciation periods, tax rates, and insurance.

By permitting retirement of existing boilers where economically feasible, the model estimates cogeneration potential for the year 2020 ranging from 46 to 107 GW, permitting retirement of existing boilers where economically feasible. These estimates include both traditional (where all unit output is used on-site) and non-traditional (where sales of electricity to the grid is permitted) applications of CHP, and is limited to industrial sector applications. District energy applications of CHP are not included in this sector, and are considered in the buildings sector analysis. For each scenario, the DISPERSE model provides results for industrial production of electricity and steam, as well as the fuel consumption associated with the production. These are reported in section 5.5.4.

At this time it was not yet possible to fully integrate the DISPERSE results into CEF-NEMS[17]. Hence we were unable to assess the integrated impact on electricity generation and fuel mix. Section 5.5 reports on the overall results without the contribution of CHP, which is discussed separately in section 5.5.4.

5.5 SCENARIO RESULTS

5.5.1 Overview

In the reference scenario industrial energy use grows from 34.8 Quads in 1997 to 41.0 Quads in 2020, which is almost equal to that of the AEO99 (42.1 Quads), see Table 5.6. The difference between AEO99 and the CEF-reference scenario is due to changes in retirement rates, and changes in the energy consumption of the three sectors modeled in detail, i.e. cement, iron and steel, and pulp and paper. Energy use in the reference scenario shows a slight growth of 0.7%/year, while industrial output grows by almost 1.9%/year. Hence, the aggregate industrial energy intensity decreases by about 1.1%/year, or 23% over the scenario period. The intensity change in the AEO99 scenario is due to inter-sector structural change (almost three-fourths of the change), i.e. a shift to less energy intensive industries, and energy efficiency improvement (about one fourth). Carbon dioxide emissions from the industrial sector in the reference scenario increase by nearly 0.7%/year to 578 MtC (see Table 5.7).

The growth in the reference scenario can be found in other manufacturing industries (e.g. metals based durables, other manufacturing) and the non-manufacturing industries. Growth in energy use is due to the high economic growth of these sectors, and the slow improvement of energy efficiency (see also section 5.7). Food and bulk chemical industries also contribute to the growth. Energy use in the energy intensive industries grows slightly, or is even reduced, due to slower economic growth in these sectors, resulting in the inter-sector structural change of the economy. By 2020, energy intensive industries still consume 51% of total industrial energy use, down from 55% in 1997 (primary energy, including feedstocks).

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[17] Within the timeframe of this study it proved to be impossible to model the cogeneration results into CEF-NEMS model at the industrial sub-sector level. Future work is needed to balance the boiler representation used in DISPERSE-model with steam demand in CEF-NEMS and to integrate the DISPERSE-results in the integrated CEF-NEMS scenarios to estimate impact on power sector energy demand and fuel-mix, as well as second order effects, due to changes in fuel mix and energy demand.

The industrial fuel-mix changes slightly towards less carbon-intensive fuels (more natural gas, less coal). The iron and steel industry is the largest coal consumer. Relative low production growth, associated with reductions in coke use result in a downward trend of coal use, and a reduction in the imports of coke. The importance of biomass in the industrial fuel-mix increases from 5% to 6%, mainly due to improved utilization in the pulp and paper industry. Purchased electricity increases its share of the site fuel-mix, from 13% in 1997 to 14% in 2020.

The policy scenarios show a considerable decrease in energy use and carbon emissions. The policy scenarios assume similar economic growth patterns as in the reference scenarios. Increased energy savings are due to increased energy efficiency efforts and inter-sector structure changes, e.g. a switch to the less energy consuming electric steelmaking process in the steel industry. The advanced scenario results in a doubling of the energy intensity reduction found in the reference scenario, while the moderate scenario, leads to a 50% increase in the intensity improvement rates. In the sections below we will discuss the main features of the results of the policy scenarios. Uncertainties in the inputs influence the results. However, limited resources limited us to assess the uncertainties (see section 5.7).

5.5.2 Moderate Scenario

In the moderate scenario industrial energy use grows from 34.8 Quads in 1997 to 37.9 Quads in 2020, equivalent to a growth of 0.4%/year (excluding CHP). Total industrial energy use in 2020 under the moderate scenario is about 8% lower than the reference scenario. Under the conditions in the moderate scenario overall industry energy intensity falls by 1.5%/year. Intra-sector, inter-sector and energy efficiency improvement, contribute to the observed changes. The policies in the moderate scenario are assumed to be effective by the year 2000, and are increased in the period after the year 2000. This reflects in a relative strong growth in industrial energy use in the first years of the scenario period, followed by a reduction later in the scenario period. Annual carbon emissions are increasing to approximately 521 MtC, or a reduction of 10% relative to the reference scenario. The changes in carbon intensity are a bit larger due to the shift towards lower carbon fuels, as well as intra-sectoral structure changes in the cement, paper and steel industries.

Under the policies in the moderate scenario the light non-energy intensive industries will remain the largest contributors to future growth in energy demand, and carbon dioxide emissions. The high growth in the reference scenario is offset by considerable efficiency improvements (approximately 0.4%/year) in those industries under the moderate scenario (see also section 5.7). A small change in the fuel-mix will result in a larger reduction in carbon dioxide emissions in the light industries. While cement and the steel industries actually show a reduction in overall energy demand, the paper and other energy intensive industries are still slightly growing. Changes to less energy intensive processes and products in the cement and steel industry, combined with the relatively low growth, contribute to the decrease in total energy use and carbon dioxide emissions. The production of blended cements will reduce the carbon emissions in the cement industry at a higher rate than the reduction of energy use. The overall acceleration of energy efficiency improvement rates in these two sectors in the moderate scenario is relatively modest at 0.3%/year (see Fig. 5.4). The other energy intensive industries show a relatively strong improvement rate over the reference scenario, mostly due to increased energy efficiency improvement. This results in a 6% reduction in total energy use by the year 2020. Compared to the reference scenario, increased policy efforts in the pulp and paper industry result in a reduction by 3% and 6% of total energy use and carbon dioxide emissions, respectively. The larger decrease in emissions is due to switch to biomass as the prime energy source in this industry.

The overall fuel-mix in industry is changing more rapidly to low carbon fuels, when compared to the reference scenario. Coal and petroleum products show the strongest decrease, at a rate double of that of natural gas. While coal use stabilizes in the steel industry, reductions in coal use are mostly found in the non-energy intensive industries. By 2020 natural gas will provide almost a third of the primary energy needs of the total industry. The slight change in fuel-mix will result in lower carbon dioxide emissions.

Energy service costs, which include annual fuel costs, annualized incremental technology cost of energy efficiency improvement, and annual program costs to promote energy efficiency, decrease by approximately 9% by 2010 and 10% by 2020, relative to the reference scenario (see Table 5.9).

5.5.3 Advanced Scenario

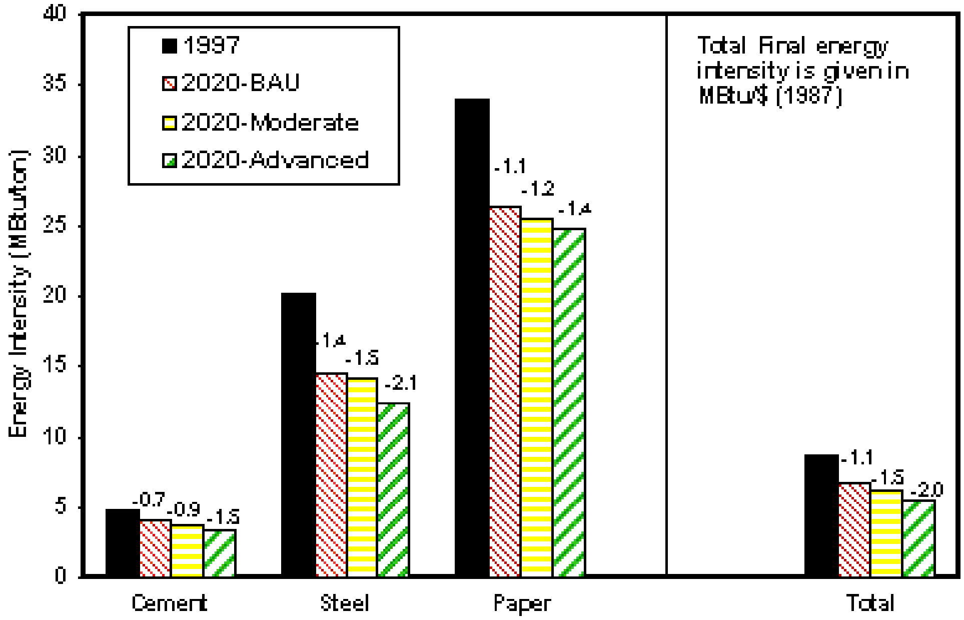
In the advanced scenario a stronger push to reduce GHG emissions will result in an active policy for energy efficiency improvement and GHG emission reduction. This is expected to result in considerable energy savings and carbon dioxide emissions. In the advanced scenario industrial energy use remains stable, decreasing from 34.8 Quads in 1997 to approximately 34.2 Quads in 2020 (excluding CHP). Total industrial energy use in 2020 under the advanced scenario is 16.5% lower than the reference scenario. Under the conditions in the advanced scenario overall industry energy intensity falls by 1.8% per year (see Fig. 5.4), of which 1.0% per year due to energy efficiency improvement. This compares well to the experiences in Germany, Japan and The Netherlands (see page 5.13), that voluntary industrial agreements can potentially contribute an efficiency improvement of 0.4% to 1.3% per year. Intra-sector, inter-sector and energy efficiency improvement, contribute to the total observed changes. Carbon emissions are actually decreasing to approximately 409 MtC, or a reduction of 29% relative to the reference scenario, especially due to de-carbonization in the power sector.

Compared to the reference scenario the largest reduction in energy use can be found in the cement, steel, non-energy intensive and other energy intensive industries. Energy efficiency improvement rate in the non-energy-intensive industries is about 0.9% per year, which reflects the total efficiency improvement (see also section 5.7). This is due to changes in process efficiency, as well as in energy use in industrial buildings. The change in the cement industry is mainly due to the more aggressive introduction of blended cements in the U.S. market, resulting in energy savings, as well as process CO_2 emission reduction in the clinker-making. Similarly, increased use of electric steelmaking will result in energy savings in the steel industry. Gradual introduction of new plants contributes a large part of the total energy savings in other industries.

In the advanced scenario the fuel-mix is expected to favor low carbon fuels, due to the emission trading system. This will lead to a 30% reduction in the share of coal, and 19% reduction in the share of oil, relative to the reference scenario. Large reductions in the carbon dioxide emissions are due to the lower carbon emissions in the power sector, especially in the electricity intensive sectors, e.g. aluminum and the non-energy intensive industries. This leads to a strong reduction in total carbon dioxide emissions. While increased CHP in industry is expected to impact the observed shift to natural gas, the CHP results have not yet been integrated in the current fuel-mix shift.

Annual energy service costs in the advanced scenario are reduced by 8% in 2010 and by 12% by 2020, translating to cost savings of approximately $8 Billion and $14 Billion respectively (see Table 5.9). The savings are significantly higher in 2020 than in 2010, due to the larger investments in energy R&D in the advanced scenario, which results in greater energy savings on the long term.

Fig. 5.4 Energy Intensity Changes in the Three Scenarios for Total Industry and for Cement, Steel and Pulp and Paper Industries for 2020*



*1997 Energy intensities are given for comparison.

Table 5.6 Primary Energy Use by Scenario, Sub-Sector, and Fuel in the Industrial Sector (in quadrillion Btus), Excluding the Effects of Increased CHP (see section 5.5.4)

			2010					*2020*				
Sector & fuel	*1990*	*1997*	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	Q	Q	Q	Q	%	Q	%		Q	%	Q	%
Iron and Steel												
petroleum		0.12	0.11	0.12	2.3%	0.04	-68.6%	0.10	0.10	-0.7%	0.02	-80.3%
natural gas		0.54	0.45	0.40	-9.8%	0.38	-15.6%	0.39	0.34	-14.1%	0.34	-14.2%
coal		0.87	0.80	0.81	1.1%	0.76	-4.4%	0.78	0.79	0.6%	0.76	-3.1%
primary electricity		0.56	0.53	0.50	-5.0%	0.44	-16.8%	0.50	0.45	-10.2%	0.40	-21.4%
Total primary		2.09	1.88	1.83	-3.1%	1.61	-14.4%	1.78	1.68	-5.8%	1.51	-15.1%
Paper												
petroleum		0.12	0.11	0.10	-7.7%	0.08	-31.4%	0.10	0.08	-13.2%	0.07	-29.1%
natural gas		0.67	0.50	0.52	3.8%	0.36	-27.4%	0.43	0.51	18.8%	0.43	0.3%
coal		0.39	0.31	0.28	-10.0%	0.12	-60.8%	0.27	0.23	-14.9%	0.11	-60.3%
renewables		1.48	1.81	1.78	-1.5%	1.94	7.1%	2.00	1.92	-3.7%	2.19	9.5%
primary electricity		0.83	0.80	0.78	-3.5%	0.66	-17.6%	0.79	0.73	-6.9%	0.57	-27.8%
Total primary		3.50	3.54	3.46	-2.2%	3.16	-10.6%	3.58	3.48	-2.8%	3.36	-6.1%
Cement												
petroleum		0.04	0.04	0.03	-3.9%	0.04	7.8%	0.03	0.03	-7.2%	0.03	3.0%
natural gas		0.02	0.02	0.02	16.3%	0.03	105.9%	0.01	0.02	24.3%	0.03	119.1%
coal		0.32	0.32	0.30	-3.9%	0.24	-22.9%	0.31	0.29	-8.0%	0.22	-30.9%
renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
primary electricity		0.10	0.09	0.09	-1.0%	0.09	-2.5%	0.09	0.09	-2.9%	0.08	-11.6%
Total primary		0.47	0.46	0.45	-2.7%	0.40	-12.1%	0.45	0.42	-5.9%	0.36	-20.0%
Other Energy-Intensive												
Petroleum		5.1	5.8	5.5	-5.1%	5.2	-9.9%	5.9	5.3	-11.3%	4.7	-20.5%
Natural gas		4.7	5.1	5.1	0.0%	4.9	-4.8%	5.6	5.6	0.6%	5.3	-5.2%
coal		0.2	0.2	0.2	-19.1%	0.1	-49.5%	0.2	0.1	-36.1%	0.1	-64.7%
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
primary electricity		3.1	3.2	3.0	-5.7%	2.6	-19.4%	3.2	2.8	-12.9%	2.2	-33.2%
Total primary		13.1	14.3	13.8	-3.6%	12.8	-10.7%	15.0	13.8	-7.6%	12.2	-18.2%
Non-Energy-Intensive												
Petroleum		3.0	3.8	3.6	-5.8%	3.5	-7.9%	4.2	3.8	-10.3%	3.6	-14.8%
Natural gas		4.8	5.8	5.4	-6.3%	5.2	-9.6%	6.4	5.7	-11.7%	5.3	-17.3%
coal		0.6	0.7	0.7	-6.8%	0.5	-26.7%	0.8	0.7	-11.5%	0.5	-35.9%
Renewables		0.4	0.5	0.5	0.6%	0.5	0.4%	0.6	0.6	1.3%	0.6	0.5%
primary electricity		6.7	7.6	7.4	-3.1%	6.9	-9.8%	8.2	7.8	-5.1%	6.8	-17.4%
Total primary		15.6	18.4	17.6	-4.7%	16.6	-9.8%	20.2	18.5	-8.4%	16.7	-17.1%
Total Industrial												
Petroleum		8.4	9.8	9.3	-5.3%	8.9	-10.0%	10.4	9.2	-10.8%	8.4	-18.8%
Natural gas		10.7	11.9	11.5	-3.3%	10.9	-8.4%	12.8	12.1	-5.4%	11.4	-11.2%
coal		2.4	2.4	2.2	-5.2%	1.8	-25.1%	2.4	2.1	-9.8%	1.7	-30.0%
renewables		1.9	2.3	2.3	-1.1%	2.4	5.6%	2.6	2.5	-2.6%	2.8	7.5%
primary electricity		11.3	12.2	11.8	-3.8%	10.6	-13.1%	12.9	11.9	-7.4%	10.0	-22.1%
Total primary	32.1	34.7	38.6	37.1	-4.0%	34.5	-10.5%	41.0	37.9	-7.4%	34.2	-16.5%

(1) BAU = Business-As-Usual scenario: Q = quadrillion Btus of primary energy
(2) % (change) is relative to the BAU scenario in that year.

Table 5.7 Carbon Emissions by Scenario, Sub-Sector, and Fuel in the Industrial Sector (MtC), Excluding the Effects of Increased CHP (see section 5.5.4)

			2010					*2020*				
Sector & fuel	*1990*	*1997*	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	MtC	MtC	MtC	MtC	%	MtC	%		MtC	%	MtC	%
Iron and Steel												
Petroleum		1.93	1.72	1.76	2.2%	0.53	-69.3%	1.52	1.49	-1.8%	0.29	-81.1%
natural gas		7.40	6.08	5.48	-9.8%	5.12	-15.8%	5.33	4.58	-14.0%	4.57	-14.1%
Coal		21.61	20.25	20.46	1.1%	19.37	-4.4%	19.83	19.95	0.6%	19.24	-3.0%
Electricity		8.63	8.72	7.94	-8.9%	5.78	-33.7%	8.53	7.31	-14.3%	4.62	-45.8%
Total		39.56	36.76	35.64	-3.0%	30.79	-16.2%	35.21	33.33	-5.3%	28.72	-18.4%
Paper												
Petroleum		1.99	1.65	1.52	-7.8%	1.11	-32.9%	1.43	1.22	-14.2%	0.97	-32.1%
natural gas		9.19	6.84	7.09	3.7%	4.95	-27.6%	5.83	6.93	18.9%	5.84	0.3%
Coal		9.75	7.95	7.16	-10.0%	3.12	-60.8%	6.82	5.80	-14.9%	2.71	-60.3%
Renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
Electricity		12.87	13.35	12.35	-7.5%	8.76	-34.4%	13.34	11.86	-11.1%	6.63	-50.3%
Total		33.80	29.79	28.12	-5.6%	17.93	-39.8%	27.41	25.81	-5.8%	16.15	-41.1%
Cement												
petroleum		0.59	0.54	0.52	-4.0%	0.57	5.3%	0.49	0.45	-8.3%	0.49	-1.3%
natural gas		0.25	0.21	0.24	16.3%	0.43	105.5%	0.19	0.23	24.4%	0.41	119.1%
coal		7.80	8.02	7.70	-4.0%	6.19	-22.7%	7.92	7.29	-8.0%	5.49	-30.8%
renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
electricity		1.49	1.52	1.44	-5.1%	1.18	-22.7%	1.49	1.38	-7.3%	0.91	-39.1%
total energy emissions		10.13	10.28	9.90	-3.7%	8.37	-18.7%	10.10	9.36	-7.3%	7.29	-27.8%
process emissions		10.98	11.83	11.32	-4.3%	11.32	-4.3%	12.20	11.60	-4.9%	10.56	-13.4%
Total		21.11	22.11	21.22	-4.0%	19.69	-11.0%	22.30	20.96	-6.0%	17.85	-20.0%
Other Energy-Intensive												
petroleum		50.8	53.7	50.7	-5.7%	45.9	-14.6%	51.5	44.2	-14.3%	36.2	-29.8%
natural gas		59.6	65.2	65.3	0.2%	61.9	-5.0%	70.8	71.7	1.3%	67.4	-4.7%
coal		4.4	5.0	4.0	-19.1%	2.5	-49.4%	5.7	3.7	-36.1%	2.0	-64.7%
renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
electricity		47.9	52.7	47.7	-9.5%	33.8	-35.8%	54.5	45.4	-16.8%	25.1	-54.0%
Total		162.6	176.6	167.7	-5.0%	144.2	-18.4%	182.6	164.9	-9.7%	130.7	-28.4%
Non-Energy-Intensive												
petroleum		50.5	58.2	54.7	-5.9%	52.3	-10.1%	63.1	55.9	-11.5%	51.4	-18.6%
natural gas		65.8	79.0	74.0	-6.4%	71.2	-9.9%	87.4	77.2	-11.6%	72.2	-17.3%
coal		14.9	18.4	17.1	-6.8%	13.5	-26.6%	20.0	17.7	-11.5%	12.8	-35.8%
renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
electricity		104.7	126.7	117.8	-7.0%	90.9	-28.2%	139.5	126.4	-9.4%	79.4	-43.1%
Total		236.0	282.3	263.6	-6.6%	228.0	-19.2%	310.0	277.2	-10.6%	215.8	-30.4%
Total Industrial												
petroleum		105.8	115.8	109.2	-5.7%	100.4	-13.3%	118.1	103.2	-12.6%	89.3	-24.4%
natural gas		142.2	157.3	152.1	-3.3%	143.6	-8.7%	169.5	160.7	-5.2%	150.5	-11.2%
coal		58.5	59.6	56.5	-5.2%	44.7	-25.0%	60.3	54.4	-9.8%	42.3	-29.9%
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Electricity		175.6	203.0	187.2	-7.8%	140.5	-30.8%	217.4	192.3	-11.5%	116.6	-46.4%
total energy emissions		482.1	535.7	505.0	-5.7%	429.2	-19.9%	565.3	510.6	-9.7%	398.7	-29.5%
total process emissions		11.0	11.8	11.3	-4.3%	11.3	-4.3%	12.2	11.6	-4.9%	10.6	-13.4%
Total	452	493.1	547.5	516.3	-5.7%	440.5	-19.5%	577.5	522.2	-9.8%	409.3	-29.1%

(1) BAU = Business-As-Usual scenario; MtC = Million metric tons of carbon
(2) % (change) is relative to the BAU scenario in that year.

Table 5.8 Energy Intensity Development in CEF-NEMS Scenarios, Expressed as Primary Energy Use per Unit of Output*

Economic Intensities (MBtu/$-output (1987-$) on a primary energy basis							
Scenario		Business-as-Usual		Moderate		Advanced	
Sector	1997	2010	2020	2010	2020	2010	2020
Refining	23.6	26.7	25.3	26.2	23.7	24.1	19.3
Food	4.3	3.9	3.7	3.8	3.6	3.5	3.3
Pulp & Paper	28.0	23.7	22.1	23.1	21.4	21.1	20.7
Bulk Chemicals	32.2	28.9	27.6	27.5	25.3	24.5	22.1
Glass	13.1	11.5	10.6	11.5	10.5	9.9	9.0
Cement	97.7	89.4	84.5	87.1	79.5	78.6	67.6
Iron & Steel	30.1	24.0	21.9	23.3	20.6	20.6	18.6
Aluminum	23.3	19.2	17.3	18.5	16.6	16.2	14.7
Agriculture	5.2	5.0	4.9	4.8	4.5	4.6	4.0
Construction	5.1	4.9	4.7	4.6	4.3	4.5	4.1
Mining	21.4	22.1	22.4	20.8	20.2	20.3	19.2
Metal Durables	2.0	1.8	1.6	1.7	1.5	1.5	1.3
Other Manufacturing	5.5	5.1	4.8	4.9	4.4	4.6	3.9
Total	8.7	7.4	6.7	7.1	6.2	6.6	5.6
Physical Intensities (MBtu/ton) on a primary energy basis							
Pulp & paper	33.9	28.4	26.4	27.8	25.6	25.4	24.7
Glass	17.2	15.2	14.1	15.2	14.0	13.1	12.1
Cement	4.7	4.6	4.0	4.1	3.8	3.7	3.2
Iron & Steel	20.2	18.2	14.5	15.5	14.3	13.7	12.3
Aluminum	125.3	105.7	93.1	99.1	87.4	86.9	79.0

* Bulk chemicals excludes feedstocks. The increased contribution of CHP is excluded in this analysis (see section 5.5.4).

Table 5.9 Annual Total Costs of Energy Services by Scenario in the Industrial Sector (B1997$/year)

		2010					*2020*				
	1997	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	B$/y	B$/y	B$/yr	%	B$/yr	%	B$/yr	B$/yr	%	B$/yr	%
Total - Industry											
Annual fuel cost	105	109	96	-12%	93	-15%	115	95	-17%	87	-24%
Annualized incremental technology cost of energy efficiency	0	0	2.7	N/A	5.8	N/A	0	6.0	N/A	10.4	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	2.2	N/A	0	2.1	N/A	3.9	N/A
Annual total cost of energy services	105	109	100	-9%	101	-8%	115	104	-10%	101	-12%

Notes:

(1) BAU = Business-As-Usual scenario

(2) Buildings in the industrial sector are not included in these results.

(3) % (change) is relative to the BAU scenario in that year.

(4) Energy service costs include cost of purchased fuels and electricity (minus any carbon permit trading fee Transfer payments), and the annualized costs of incremental efficiency improvements.

(5) The results exclude the increased role of industrial CHP (see section 5.5.4).

5.5.4 Cogeneration

The results of the cogeneration (or CHP) calculations could not yet be integrated in the CEF-NEMS framework. In this section we report on the results, and estimate the potential impact. By permitting retirement of existing boilers where economically feasible, DISPERSE estimates the CHP potentials by sub-sector. These estimates include both traditional, non-traditional applications of CHP, and is limited to industrial sector applications (hence, it excludes distributed CHP or district heating). As shown in Table 5.10, the market penetration of industrial CHP in the two CEF policy scenarios is estimated to be between 40 and 76 GW by 2020, and depends on the timing and impact of CHP policies (see Appendix B.2) designed to remove technical and market barriers.

Table 5.10 Estimated Market Penetration and Impacts of Industrial Cogeneration for the Years 2010 and 2020 for the Moderate and Advanced Scenarios

Market Impact	**Year 2010 Impacts**			**Year 2020 Impacts**		
	BAU	Moderate	Advanced	BAU	Moderate	Advanced
New Installed Capacity (GW)	**4.4**	**14.1**	**28.9**	**8.8**	**40.1**	**76.2**
Of which: natural gas	4.4	12.3	24.5	8.8	34.9	63.6
Of which: black liquor gasifier combined cycle	0	1.1	2.6	0	3.1	7.5
Of which: biomass gasifier combined cycle	0	0.7	1.8	0	2.1	5.1
Generated Electricity (TWh)	31	98	201	62	278	539
Fuel Consumed by CHP Systems (TBtu)	**274**	**901**	**1,853**	**551**	**2,542**	**4,985**
Of which: natural gas	274	793	1,595	540	2,232	4,237
Of which: biomass	0	108	258	11	310	747
Fuel Consumed by CHP Systems, above BAU Forecast (TBtu)	NA	627	1,579	NA	1,991	4,434
Fuel Displaced at the Utility by CHP Systems, above BAU Forecast (TBtu)	NA	648	1,909	NA	1,568	4,704
Boiler Fuel Displaced by CHP Systems, above BAU Forecast (TBtu)	NA	277	743	NA	873	2,097
Net Energy Reduction, above BAU Forecast (TBtu)	NA	**298**	**1,073**	**NA**	**450**	**2,367**
Net Carbon Reductions, above BAU Forecast (MtC)	NA	**4.9**	**26.1**	**NA**	**9.7**	**39.7**

In the BAU scenario, 8.8 GW of new CHP is projected, based on a continuation of current market penetration trends. Several technical and market barriers stand in the way of further use of CHP, as evidenced by the fact that over 80 percent of the potential capacity is projected as untapped. Most potential for CHP can be found in the paper, chemical, food and the non-energy-intensive manufacturing sub-sectors.

In the moderate scenario, the projected additional CHP-capacity grows to approximately 14 GW by 2010 and 40 GW by 2020. This includes 3 GW of integrated black liquor gasification cogeneration by 2020. It is expected that expanded research and development will result in black liquor gasifier combined cycle technology, which will result in several demonstration projects by 2010 and an installed base of 3.1 GW by 2020. In addition, this expanded R&D will result in the emergence of high efficiency gas turbines (resulting from the ATS program and efforts targeting the under 1 MW unit size) which is expected to increase CHP capacity in under 5 MW unit size ranges. Furthermore, policies designed to remove financial barriers, expedite siting and permitting, improve grid sell back price, and reduce interconnection costs are expected to contribute significantly to the expanded market potential and penetration.

In the Moderate scenario, newly installed CHP consumes almost 2 quads of energy (principally natural gas) more than in the BAU forecast, by 2020. This is offset by 0.9 quads of boiler fuel that is displaced by the CHP systems and 1.6 quads of energy that is displaced in the power sector. The net impact in 2020 is an energy savings of 0.5 quads and a reduction in carbon dioxide emissions of 9.7 MtC. (In 2010, the net reductions are 0.3 quads of energy and 4.9 MtC of carbon.)

In the Advanced scenario, the projected level of new CHP reaches approximately 29 GW by 2010 and 76 GW by 2020. Accelerated development of black liquor gasifier combined cycle units as well as cost and efficiency improvements in 5 MW and under gas turbines contribute significantly to the 107 GW of market potential. This includes 64 GW of natural gas based cogeneration, 7.5 GW of black liquor gasifier combined cycle capacity, and 5.1 GW of biomass gasifier combined cycle capacity. More aggressive policies designed to remove financial barriers, expedite siting and permitting, improve grid sell back pricing, and reduce interconnection and backup power costs all contribute to improved market penetration levels, as well as reduce the costs of the ATS. This leads to accelerated implementation of CHP, despite the lower steam demand due to energy efficiency improvement.

In the Advanced scenario, newly installed CHP consumes 4.4 quads of energy (3.7 quads of natural gas and 0.7 quads of biomass) more than in the BAU forecast. This is offset by 2.1 quads of boiler fuel that is displaced by the CHP systems and 4.7 quads of energy that is displaced in the power sector. The net impact in 2020 is an energy savings of 2.4 quads and a reduction in carbon dioxide emissions of 39.7 MtC. (In 2010, the net reductions are 1.1 quads of energy and 26.1 MtC of carbon.)

5.6 DISCUSSION OF RESULTS

5.6.1 Key Technologies

This study identified policies to improve industrial energy efficiency. The policies will help to implement efficient practices and technologies. Three sectors were modeled in detail, allowing an assessment of key technologies for these industries. Generally, a number of cross-cutting technologies can achieve large improvements, e.g. preventative maintenance, pollution prevention and waste recycling (e.g. steel, aluminum, cement, paper), process control and management, steam distribution system upgrades, improved energy recovery, cogeneration (CHP), and drive system improvements. However, a large part of the efficiency improvements are achieved by retiring old process equipment, and replacing it with state-of-the-art equipment. This is especially true for many capital-intensive industries (Steinmeyer, 1997). This emphasizes the need for flexibility in achieving energy efficiency improvement targets, as provided by the voluntary industrial agreements.

In the three sectors studied in detail, we can draw more specific conclusions on technologies. The detailed assessments showed that technologies exist to both improve existing as well as new plants (when retiring old capacity). In the steel industry, new electric arc furnaces are far more efficient than existing plants due to various technologies, while new casting technologies reduce material and energy losses further. New advanced smelt reduction technologies (assumed to be become available after 2010 in the advanced scenario) can lead to large energy savings (Worrell et al., 1999). In the pulp and paper industries, improved paper machines as well as reduced bleaching and increased recycling impact energy use, while black liquor gasification substantially changes the energy profile of pulping in the long term (Anglani et al.1999). In cement making, the key technologies and measures are the introduction of blended cements and the gradual retirement of old wet process clinker plants which are replaced by modern pre-heater pre-calciner kilns. New grinding technologies will reduce electricity demand for cement making (Martin et al., 1999).

5.6.2 Key End-Use Sectors

Energy savings are found in all industrial sub-sectors. Production growth is lower in most energy-intensive industries than the less energy-intensive manufacturing industries. This leads to a reduction in energy use and CO_2 emissions by the energy intensive industries. Hence, most of the growth in energy use and emissions can be found in the light industries, growing to approximately 49% of primary energy consumption in the reference scenario by 2020. Energy efficiency improvements in the policy scenarios appear high, as the improvements in the baseline scenario are almost zero in the light industries (see section 5.7). While light industries would consume almost half of the energy by 2020 in the reference scenario, almost 50% of the total energy savings in the advanced scenario are also found in these industries. Energy saving potentials in the steel, cement and aluminum industry are also relatively large, due to the increased use of energy-efficient recycling technologies (or the production of blended cement using wastes in the chemical industry) and the introduction of efficient technology as old plants are retired. The potential savings in the food, paper, and chemical industries are mainly influenced by the savings achieved in the large generation, distribution and use of steam in those sectors. Cogeneration (see section 5.6.1) is expected to play an important role in these sectors. Energy efficiency improvement in petroleum refining is small, as this sector has not been investigated in this study (see section 5.7).

5.6.3 Key Policies

The characteristics of decision makers vary widely, as is evidenced by the literature on policies. Hence, there is no “deus ex machina” or “silver bullet” policy; instead, an integrated policy accounting for the characteristics of technologies and target groups addressed is needed. Acknowledging the differences between individual industries (even within one economic sector) is essential to develop an integrated policy accounting for the characteristics of technologies, conditions and target groups addressed. Policies and measures supporting these voluntary industrial agreements should account for the diversity of the industrial sector while at the same time being comprehensive and flexible, offering a mix of policy instruments, giving the right incentives to the decision maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures.

In this study we have evaluated a large number of policy measures, based on current and potential future initiatives. The voluntary industrial agreements are assumed to integrate the various individual policy measures and provide access to the resources and policies. The framework will strengthen the effects and effectiveness of the individual policy instruments. Hence, it is difficult to highlight individual key policies.

Costs and cost-effectiveness of individual policies vary between the type of instrument applied, as well as the way in which it is implemented, as evidenced by the variety of industrial and commercial DSM programs (Nadel, 1990; Goldman and Kito, 1994). However, recognizing the different roles the policies play, and different barriers and stakeholders addressed by the policies, there is a need for the variety in programs. Key is a good and efficient organization of the policies, flexibility of the policies, as well as easy access to the provided resources. “One stop shops” as provided for some programs by DOE-OIT is a step in this direction, as is the collaboration of DOE and EPA in the development of various policy initiatives and technology development support measures.

5.7 REMAINING ANALYSIS NEEDS

The study highlighted various issues for future research related to modeling and policies based on the results of the study. The available resources limited a quantitative analysis of the uncertainties in scenarios. Hence, future analysis aims not only at areas that need further analysis, but also at assessing the uncertainties in the scenarios.

Currently most available energy models are not capable of explicitly modeling policies. Generally, models represent the actions following policy implementation. However, the link between policies and actions is not straightforward. Decisionmakers react differently to the implemented policies and measures, depending on their (perceived) situation. This will affect the effects and effectiveness of policies. Research in many countries (e.g. U.S., Canada, Germany, The Netherlands) is ongoing to assess and ‘model’ decisionmaking behavior. This has not yet resulted in commonly acceptable methodologies. To model the relationship between actions and policies requires substantial multi-disciplinary research.

Modeling. Modeling within the industrial sector was done primarily in the CEF-NEMS model, based on the EIA-NEMS model. The CEF-NEMS model allows technology modeling at a relatively disaggregated level in a number of the sectors, e.g. steel, cement, paper industries, while in other sectors, e.g. chemical, food, other manufacturing industries, the level of detail is limited to technology categories. In the latter industries energy intensities are often modeled on a monetary basis (energy use/$ value of output), limiting the opportunity to model technologies or policies. In modeling the scenarios we found various issues that warrant further research and adaptation of the model, which we discuss below.

Like most energy models, the NEMS-framework distinguishes industrial sub-sectors (typically a number of energy-intensive sectors and a few non-energy intensive sectors) to model technical changes in energy efficiency. However, the different sub-sectors may not accurately reflect the characteristics for decisionmaking processes in different companies. This limits the modeling within NEMS to modeling the expected actions (in the form of technical changes) that follow implementation of policies. Development of models able to assess the impact of policies is strongly encouraged to fill in this gap (see above), acknowledging the difficulty, and the lack of knowledge of the effectiveness of industrial energy policies (see below).

The integration of CHP-policies could not yet be fully integrated with the CEF-NEMS model. Hence, the feedback of increased industrial cogeneration (and district heating) on the power sector electricity production and fuel use could not be assessed in an integrated way. Preliminary CEF-NEMS assessments show a decrease in new central natural gas capacity, while coal use is only reduced slightly and renewables seem to remain stable. Based on these preliminary assessments, cogeneration could likely reduce total U.S. primary energy consumption by 2.4 Quads in 2020, and reduce GHG emissions by 40

MtC. However, an integrated CEF-NEMS model is needed to quantify the potential impact completely and correctly. The potential large contribution of cogeneration to energy efficiency improvement would warrant the need for further research to integrate the cogeneration in CEF-NEMS.

Industrial processes generate outputs that are used by other processes in the same industry, e.g. coke used in the blast furnace in the steel industry. However, the CEF-NEMS model does not correct endogenously for changes in resource productivity (e.g. decreased coke use in the blast furnace through increased direct fuel injection). We have modeled the impact of reduced resource needs manually in the model, but future research would need to investigate the option to model process connections.

Due to the lack of feedback between processes, it was difficult to model innovative technologies in the NEMS framework. Black liquor gasification in the pulping industry and smelt reduction in the steel industry are examples of technologies integrating various processes, while changing the inputs and outputs. Smelt reduction would even affect energy use in other sectors, e.g. pelletizing at the ore mining. We modeled the penetration of these innovative technologies and interactive effects within the sector by adjusting the UECs in the CEF-NEMS model. The role and modeling of innovative technologies in energy modeling is an important topic that needs more attention in general and in the NEMS-model.

Retirement rates for industrial technologies in the NEMS model seem to be low, when compared to other sources (BEA, 1993), or assessments of technical and economic lifetimes of technologies. Retirement rates are important in assessing future industrial energy use because new technologies often have significantly different energy use characteristics. The importance would warrant future analysis of actual age distribution of the main energy consuming processes in the sub-sectors.

Both retirement of old plants and retrofit of existing plants contribute to the energy savings and CO_2 emission reduction. However, we have not yet assessed the contribution of each of these elements to the total achieved energy savings in the different scenarios. This may generate valuable insights into the contribution of different policies and strategies in the industrial sector.

Carbon dioxide emissions are due to the combustion of fossil fuels. Fossil fuels are also used as feedstock, e.g. for plastics. The carbon from these feedstocks will not be released in the industrial process, but later when the product containing the feedstock is combusted (e.g. waste incineration). However, in some production processes the carbon in the feedstock is partially emitted, e.g. in ammonia and methanol manufacturing. The EIA-NEMS model correctly assumes partial emission factors for the feedstocks. Only detailed assessments of material flows can improve the assessment of how feedstock use in NEMS is accounted in the emissions calculations.

Energy use in industries is broken down (where appropriate) into process, buildings and boilers and power generation. In the current NEMS model boiler efficiency has been set at a standard efficiency rate, and hence does not improve over time, nor are boilers retired. We have simulated retirement of boilers by a slow improvement rate of the boiler efficiency.

Cogeneration is part of the boiler module of the NEMS model. The current NEMS model does not allow retirement of boilers, nor replacement by cogeneration units. It only allows cogeneration for new (increased) boiler capacity, and hence underestimates the role of cogeneration. We have modeled the potential role of the cogeneration in each of the industries based on the DISPERSE model, but have not yet integrated the results into CEF-NEMS.

Steam, fuels and electricity are used in the buildings. While building energy use is comparatively small in energy-intensive industries, it is large part of energy use in the light manufacturing industries. In NEMS, energy use in buildings is a set as energy use per employee, and only reacts to changes in number of employees in an industry, ignoring changes in building energy use, retirement of buildings, and also the potential impact of programs like EnergySTAR Buildings and Green Lights. We have modeled energy use in buildings in the moderate and advanced scenarios based on the saving potentials identified for commercial buildings. This may need more attention in future work.

Energy intensity declines over time in most industries, due to autonomous trends as well as policy effects. For some industrial sub-sectors (i.e. agriculture, mining, construction, metal based durables and non-intensive manufacturing) NEMS assumes no autonomous improvement trend in the baseline scenario. Only when energy prices increase over a specified threshold, would energy intensity decline. This is contrary to long term trends observed in most industries (see Appendix A.2).

Historical energy intensity trends observed in various sub-sectors do not reflect the trends found in the AEO 99 baseline (see Appendix A.2). Historical energy use in the construction industry (and hence cement industry) follows cycles in the industry and economy. However, in NEMS a continuous growth is assumed over the next decades. Improved calibration of NEMS scenarios with historical trends in production, energy intensity and energy use is needed to improve modeling results.

Policies. Detailed evaluations of industrial energy efficiency policies are rare (Convery, 1998; Martin et al., 1998; US DOE, 1996). Estimating the effects of energy efficiency policies on energy use and economic performance is a difficult task. The figures in this report are based on assessments, using different methodologies and assumptions, and evaluations by program managers. The results should be seen as a first estimate. Future analysis of the effects and effectiveness of industrial energy policies (ex-ante, and ex-post) is needed to improve the current results.

Literature on industrial energy efficiency improvement has focused on energy policies. As shown by the variety of policies evaluated in this study, a large number of other policies will affect industrial energy use. Study of the effects of other industrial or environmental policies on industrial energy use is needed to better quantify the effects of these policies.

Policies are never implemented in isolation. Individual policies may have feedback effects, which could either improve or reduce the effectiveness of other policies. A comprehensive set of well-designed policies is needed to address the wide variety of stakeholders in the industrial sector. Little is known regarding these effects. Case studies may be needed to assess the feedback effects.

Energy efficiency improvement may entail investment costs or other costs. Supply curves are often used to estimate the potential energy savings and associated costs, replacing linear cost functions used in earlier modeling. The previous Interlaboratory study used the LIEF model to estimate the investment costs for the industry as a whole (Interlaboratory Working Group, 1997). The LIEF model uses historical data to generate a cost function. Historical data may not reflect the future correctly. Detailed supply curves using costs and savings for technologies and practices would be better suited to achieve this. However, supply curves are not available for all sub-sectors. LBNL has developed supply curves for three sub-sectors that are studied in detail in this study; steel (Worrell et al, 1999), cement (Martin et al., 1999) and paper (Anglani et al., 1999). For the other sub-sectors we have used the results of the previous Interlaboratory study. Future research is needed to assess the potentials and associated investments of energy efficiency improvement in these sectors.

Industrial technology development is often aimed at improving productivity rather than improving energy efficiency. New technologies often improve energy and resource efficiency while reducing manufacturing costs considerably (Pye, 1998). Thin slab casting is an excellent example of a technology reducing production costs of steel products, as well as reducing energy use considerably (Worrell et al., 1999). The productivity gains are often difficult to quantify. In our detailed technology analysis of the three sub-sectors, we incorporated these costs in the assessments of the energy efficiency improvement potentials. However, future research is needed to better quantify the other benefits of energy efficiency measures.

Economic development follows cycles. However, most energy modeling tools (including NEMS) use continuous growth trends. The effects and effectiveness of policies will depend on the phase of the business cycle, especially when modeling short-term effects. The twenty-year time period in this analysis may be less sensitive to these effects, but the sensitivity can not be assessed. This would need additional analysis of business cycles, retirement rates, and investment policies.

The results of the scenario analysis have shown that strong economic growth in the light manufacturing industries may considerably affect future emissions in the industrial sectors. However, knowledge on energy efficiency and GHG emission reduction options in these sectors is very scattered. Assessment of energy efficiency opportunities in these sectors is needed. The large variety in processes used and the large number of industries involved also emphasizes the important role of states in designing energy efficiency policies capable of meeting the demands set by this variety. Future analysis may also need to focus on strengthening the role of states in designing and implementing energy efficiency policies.

The scenario results show also the important role of replacing retired capital and energy intensive equipment (typically with long lifetimes) in achieving large improvements in energy efficiency. Although policies may affect retirement rates, detailed evaluations are needed to assess the extent and impact of such policies on competitiveness and energy use. This underlines the need to assess the models and rates of diffusion of innovative technologies in different (energy) markets, and the impact that innovative industrial technology may have on retirement (and hence diffusion) rates and energy use.

Climate change abatement policies will not only be limited to policies and measures with respect to CO_2 emissions. Industry also emits varying quantities of the five other GHGs, distinguished in the Kyoto Protocol. An industrial GHG abatement strategy and policy will also include the other five GHGs. It is argued that this may lead to a more cost-effective strategy (Reilly et al.,1999). This study has only addressed the CO_2 emissions related to energy use and process emissions from clinker manufacture in the cement industry. Future work should address the contribution of abatement of other gases and the cost-effectiveness of such actions and policies.

5.8 SUMMARY

Industrial primary energy consumption is estimated at 34.85 Quads, or 37% of total primary energy use in the U.S. in 1997. Associated carbon dioxide emissions are estimated 494 MtC (including process emissions from the cement industry), or 33% of total U.S. carbon dioxide emissions. The industrial sector is extremely diverse, and includes energy-intensive manufacturing, non-energy-intensive manufacturing, and non-manufacturing (e.g. agriculture).

We have investigated three policy scenarios, entailing different degrees of commitment to environmental issues in the definition of U.S. energy policy. Under the business-as-usual scenario industrial energy consumption would grow to approximately 41 Quads in 2020. Under the moderate scenario, total energy use would be approximately 38 Quads in 2020 (-7%), while in the advanced scenario total energy use would be approximately 34 Quads (-17%). Carbon dioxide emissions would grow to 578 MtC by 2020 under the BAU-scenario, approximately 521 MtC (-10%) under the moderate, and 409 MtC (-29%) under the advanced scenario. This compares to estimated 1990 emissions of 452 MtC in the industrial sector. These figures exclude the contribution of CHP. CHP may lead to a net increase in industrial fuel use, but a net decrease in primary energy demand due to fuel use offsets for (onsite) steam and (grid) power generation. Energy efficiency opportunities are found throughout the industry.

The characteristics of decision makers vary widely. Therefore, an integrated policy framework accounting for the different characteristics of decision makers, technologies and sectors is necessary. The framework may consist of a variety of programs.

Future research needs are highlighted, both with respect to modeling as policy analysis and evaluation. The main issues are technology representation and efficiency trends in the model, and the need for detailed evaluation of the effects and (cost-) effectiveness of industrial energy efficiency policies.

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