Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes

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Prepared by:
ICF International
9300 Lee Highway
Fairfax, VA 22031
(703) 934-3000

3.3 Chemical Manufacturing

3.3.1 Base Case Scenario

Situation Assessment

Chemical manufacturing (NAICS 325) is based on the transformation of organic and inorganic raw materials through chemical processes to formulate products. Chemicals generally are classified into two groups—commodity chemicals and specialty chemicals.

> Recent Sector Trends Informing the Base Case
>
> Number of facilities: ↓
> Value of shipments: ↑
> Energy intensity: ↓
>
> Major fuel sources: Natural gas, LPG & NGL
>
> Current economic and energy consumption data are summarized in Table 26 on page 3-22.

- Commodity chemical manufacturers produce large quantities of basic and relatively inexpensive compounds in large plants, often built specifically to make one chemical. Since they make essentially equivalent products for general use in everyday consumer goods, sales are typically driven by price. Controlling production costs is crucial, which provides an incentive for energy efficiency improvements. At the same time, commodity plants often run continuously, typically shutting down for only a few weeks a year for maintenance. Thus, there is often a limited window of opportunity in which energy efficiency-related improvements can be made.
- Specialty-batch or performance chemical manufacturers produce smaller quantities of more expensive chemicals that are used less frequently. Often there is only one or a limited number of suppliers producing a given product. As sales are based on product performance, controlling production costs may be of less concern than it is for commodity chemical manufacturers.

Both paint and coatings (NAICS 325510) and specialty-batch chemicals (not defined by a NAICS code) currently participate in EPA's Sector Strategies Program.

The chemical industry uses energy both to supply heat and power for plant operations and as a raw material for the production of chemicals, plastics, and synthetic fibers. Many small to medium-sized firms comprise the industry, and are concentrated in areas abundant with other manufacturing businesses, such as the Great Lakes region near the automotive industry, or the West Coast near the electronics industry. Chemical plants are also located near the petroleum and natural gas production centers along the Gulf Coast in Texas and Louisiana. Because chemical production processes often use water, and chemicals are exported all over the world, major industrial ports are another common location of chemical plants. According to the U.S. Department of Labor (DOL), in 2002 approximately half of the establishments in the industry were located in California, Illinois, New Jersey, New York, Ohio, Pennsylvania, South Carolina, Tennessee, and Texas; about 78 percent of sector energy usage was concentrated geographically in the South Census Region.[88]

From 1997 to 2004 the chemicals sector showed economic growth in terms of value added and total value of shipments (see Table 26). However, the number of plants has declined, as has employment. As reported by *Business Week* on May 2, 2005, and quoted by the American Chemistry Council in testimony before the Energy and Mineral Resources Subcommittee on May 19, 2005, 70 plants closed in 2004 (and businesses had targeted 40 more for shutdown in 2005), and employment fell below 880,000, down from over 1 million as recently as 2002. High energy prices, especially natural gas prices, have been a contributing factor to domestic declines, with companies looking to shift production and investment to operations overseas, particularly in the commodity chemicals segment of the industry. Approximately 50 percent of U.S. methanol production capacity and 40 percent of ammonia production capacity were idled in response to increasing natural gas prices after 2000.[89] Niche segments of the industry have the most favorable economic outlook. DOE notes that the fastest growth is expected for industry subsegments like specialty-batch chemicals.[90]

Table 26 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 26: Current economic and energy data for the chemical manufacturing industry

Economic Production Trends				
	Annual Change in Value Added 1997-2004	Annual Change in Value Added 2000-2004	Annual Change in Value of Shipments 1997-2004	Annual Change in Value of Shipments 2000-2004
	1.9%	3.7%	1.5%	1.8%
Energy Intensity in 2002				
	Energy Consumption per Dollar of Value Added (thousand Btu)	Energy Consumption per Dollar Value of Shipments (thousand Btu)	Energy Cost per Dollar of Value Added (share)	Energy Cost per Dollar Value of Shipments (share)
	15.3	8.5	5.4%	3.0%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Natural Gas	Other[nnn]	Net Electricity	Coal	Fuel Oil
45%	31%	14%	8%	1%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	10%
		Fuel Oil	LPG	Electricity
Fraction of natural gas inputs that could be met by alternate fuels		77%	13%	9%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	36%
		Natural Gas	Fuel Oil	Electricity
Fraction of coal inputs that could be met by alternate fuels		82%	25%	1%

Chemical production is highly dependent on natural gas: the sector currently consumes 10 percent of the U.S. natural gas supply both as fuel and process feedstocks.[91] In terms of natural gas inputs for fuel use, 55 percent is consumed as boiler fuel (with just over half of that fraction used in CHP/cogeneration boilers and the remaining portion used in conventional boilers) and 40 percent is used for direct process inputs (primarily process heating). The remaining fraction is composed of non-process uses such as facility HVAC and conventional electricity production (1 percent of natural gas end uses were unreported in MECS).[92] Cogeneration and self-generation of electricity are important in the chemical industry, with 31 percent of net electricity consumption produced through cogeneration processes in 2002.[93]

[nnn] "Other" includes petroleum-derived byproduct gases and solids, hydrogen, and waste materials used as fuel.

The chemical industry's prime motivation for energy efficiency is controlling operating and production costs (e.g., fuel and raw material costs) in a competitive, worldwide market.[94] Facility-wide approaches to energy efficiency, such as integrated heat exchanged networks to maximize the use of waste heat, are well established in the industry. While energy consumption in the chemical industry has increased in recent years (increasing 13.2 percent from 1994 to 2008, and 1.75 percent from 1998 to 2002),[95] the sector has reduced energy consumption for heat and power per unit of output by at least 39 percent between 1974 and 1995. Energy intensity (in terms of fuel consumption per dollar value of shipments) decreased by approximately 10.5 percent between 1998 and 2002.[96]

Expected Future Trends

Driven by worldwide growth in demand for chemical products, AGF projects natural gas consumption by the chemical manufacturing sector to increase through 2020. Under AGF's business-as-usual scenario for the chemical manufacturing industry, natural gas consumption for use in boilers and process heating is expected to grow at the rate of 1 percent per year from 2001 to 2020.[97]

Though this analysis does not consider feedstock energy inputs in terms of energy-related emissions, feedstock energy use has important economic implications for certain sectors. Increases in the price of natural gas are detrimental to the chemical manufacturing sector in terms of both fuel and feedstock energy inputs. AGF notes that subsets of the industry with substantial feedstock use of natural gas will continue to be particularly affected by high natural gas prices—for instance, companies engaged in the commodity production of ammonia and methanol. AGF projects gas consumption for these industries to plummet by about 60 percent between 2000 and 2020 due to energy-related pricing pressures. Despite such economic impacts in some subsectors of the industry, AGF projects that overall the chemicals sector will continue to grow due to new product development and expansion into new markets.[98]

> **Voluntary Commitments**
>
> Through the Climate VISION program, the American Chemistry Council (ACC), representing 90 percent of the chemical industry production in the United States, has agreed to an overall GHG intensity reduction target of 18 percent from 1990 levels by 2012. ACC will measure progress based on data collected directly from its members. ACC also pledges to support the search for new products and pursue innovations that help other industries and sectors achieve the President's goal. Activities include increased production efficiencies, promoting coal gasification technology, increasing bio-based processes, and developing efficiency-enabling products for use in other sectors, such as appliances, transportation, and construction. See http://www.climatevision.gov/sectors/chemical/index.html.
>
> The chemicals sector also participates in DOE's Industries of the Future (IOF)/Industrial Technologies Program (ITP) as an "Energy Intensive Industry." ITP's goals for all energy intensive sectors include the following:
>
> - Between 2002 and 2020, contribute to a 30 percent decrease in energy intensity.
> - Between 2002 and 2010, commercialize more than 10 industrial energy efficiency technologies through research, development & demonstration (RD&D) partnerships.
>
> See http://www.eere.energy.gov/industry/chemicals/.

CEF's projections are for the bulk chemicals industry, which includes industrial inorganic chemicals, plastics, industrial organic chemicals, and agricultural chemicals, but does not include pharmaceuticals, soaps, detergents, cleaning preparations, paints, varnishes, and miscellaneous chemical products. Thus, CEF projections address the commodity chemicals subset of the chemical manufacturing industry and do not include the two subsectors that currently participate in the Sector Strategies Program: paint and coatings (NAICS 325510) and specialty-batch chemicals. It is also important to note that where MECS data identify almost a third of the sector's energy needs as being met by "other" fuels—primarily petroleum-derived byproduct gases and solids, hydrogen, and waste materials used as fuel—CEF allocates these fuels to the original fuel type that produced such byproducts or waste.

CEF's reference case projections are based on the economic assumption that the bulk chemical sector's value of output will increase at 1.1 percent per year. Under the reference case scenario, CEF projects that energy consumption for fuel use by the chemicals sector will increase by 13 percent from 1997 to 2020, primarily driven by continued economic growth. Consumption of all fuel types is expected to increase, with the largest percentage increase for coal (30 percent, though overall coal remains a small fraction of total energy use), followed by petroleum (20 percent), purchased electricity (16 percent), and natural gas (9 percent). Energy intensity will decrease at a slower rate than the industrial average of 1.1 percent per year, indicating that slow adoption of energy-efficient technologies is expected. This projection is unsurprising given the thin margins found in the commodity chemicals industry and the fact that due to production requirements, opportunities to implement large-scale energy efficiency projects are limited.

Despite projected consumption increases for other types of fuels, the sector is expected to continue to remain dependent on natural gas. Though CEF predicts the fuel mix will shift slightly away from natural gas toward petroleum, purchased electricity, and coal, these projections were made before recent increases in the price of petroleum and natural gas. Fuel price trends may indicate the potential for larger increases in the coal fraction relative to less carbon-intensive fuels, though such increases would be constrained by technical and permitting constraints as well as fuel availability. According to MECS fuel use tables, chemical manufacturing showed a 15 percent decline in natural gas consumption and an 11 percent increase in coal consumption between 1998 and 2002.[99] However, MECS data also indicate that there is a relatively small switchable fraction of natural gas inputs, and coal is not a viable substitute for these inputs.

Table 27 summarizes the CEF reference case projection for the bulk chemicals sector.

Table 27: CEF reference case projections for the bulk chemicals industry[ooo]

	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.479	14%	0.576	15%
Natural gas	2.188	63%	2.395	61%
Coal	0.175	5%	0.227	6%
Delivered electricity	0.637	18%	0.738	19%
Total	3.479	100%	3.936	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.5%
Overall % change in energy use (1997-2020)				13%

In an effort to assess the impact of recent trends that may have affected industry energy consumption since the CEF report was produced, we also examined reference case energy consumption projections for the bulk chemicals subsector produced in connection with EIA's *Annual Energy Outlook 2006* (AEO 2006), which also uses the NEMS model but incorporates more recent energy and economic data. AEO 2006 projects that the subsector's value of shipments will grow at the rate of 0.6 percent per year (slower than CEF's rate), energy consumption will remain relatively static through 2020 (around 2.7 quadrillion Btu, compared

ooo Energy consumption data do not include fuels used as feedstock.

with 3.5 quadrillion Btu under CEF's base case), and energy intensity (energy consumption per dollar value of shipments) will drop at the rate of 0.4 percent per year. Natural gas consumption is expected to grow by 8 percent over the period, with consumption of all other fuel inputs declining: petroleum by 13 percent, purchased electricity by 8 percent, and coal by 2 percent.

As mentioned previously, the CEF and AEO 2006 projections do not include the two subsectors of the chemicals industry that currently participate in EPA's Sector Strategies Program—paint and coatings, and specialty-batch chemicals. In general, we would anticipate that increasing economic production trends in these subsectors will drive a greater energy consumption increase than is expected for the bulk chemicals subsector. For example, AEO 2006 projects that bulk chemicals' value of shipments will grow 9 percent from 2004 to 2020, where the value of shipments for all other segments of the chemical manufacturing industry will grow by 45 percent.

Environmental Implications

Figure 10: Chemical sector: energy-related CAP emissions

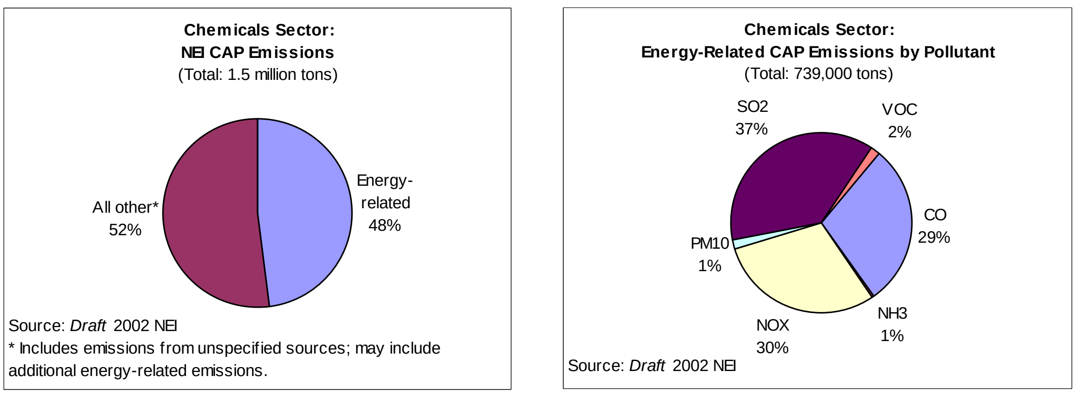
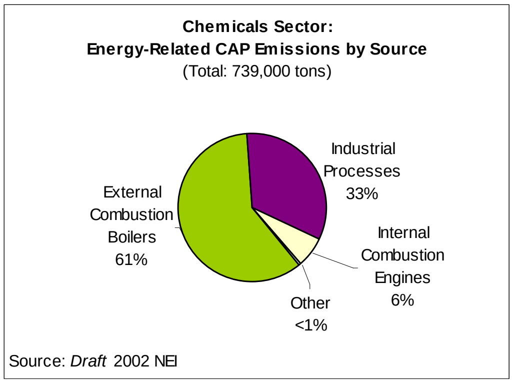


Figure 10 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the chemicals sector. According to the figure, energy-related CAP emissions comprise approximately half of all CAP emissions. Although NEI data attribute emissions from electric power generation to the generating source rather than the purchasing entity, purchased electricity comprises a relatively small fraction of total energy use for the chemicals industry, so NEI data provide a relatively complete picture of the sector's energy-related CAP emissions. Energy-related CAP emissions are split fairly evenly between sulfur dioxide and nitrogen oxides. (As noted in Section 2.3.3, NEI data on carbon monoxide emissions appear higher than would be expected for stationary sources, so we do not address carbon monoxide data in our assessment of CAP emissions for each sector.)

Effects of Energy-Related CAP Emissions

SO_2 and NO_x emissions contribute to respiratory illness and may cause lung damage. Emissions also contribute to acid rain, ground-level ozone, and reduced visibility.

Figure 11: Chemical sector: CAP emissions by source category and fuel usage



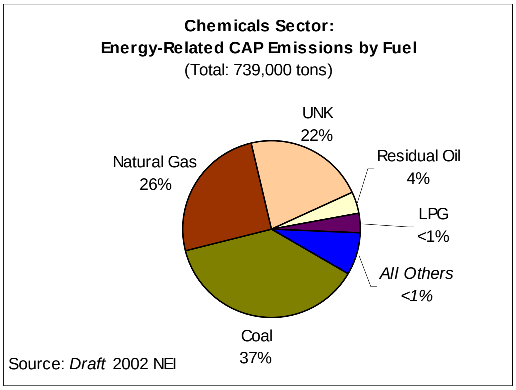


Figure 11 presents NEI data on the sources of energy-related CAP emissions. According to NEI, 37 percent of the energy-related emissions shown in Figure 11 are from coal consumption, 26 percent are from natural gas, and 22 percent are from unknown sources. Most of the sector's sulfur dioxide emissions stem from coal combustion, while nitrogen oxide emissions result from combustion of all fuel types. As coal comprises 37 percent of energy-related CAP emissions but less than 10 percent total fuel inputs for the chemical industry (see Table 26), NEI data demonstrate the emissions intensity of coal as an energy source.

Though the largest fraction of energy-related CAP emissions are classified as stemming from external combustion boilers according to NEI, emissions that are classified as "process-related" are also substantial. NEI data classifications are problematic due to reporting inconsistencies, as discussed previously. According to DOE, process heating and cooling systems represent over 75 percent of the chemical manufacturing sector's energy consumption, including fired systems such as furnaces and reboilers, steam systems, and cryogenic or other cooling units.[100]

Though AEO 2006 projects a decline in energy consumption for the bulk chemicals subsector that would reduce energy-related CAP emissions at the facility and to a smaller extent at the utility level (from reductions in purchased electric power), we have previously noted that such projections are unlikely to be applicable to all subsectors of the chemical manufacturing industry, particularly sectors with faster-growing production like specialty-batch chemicals. In these subsectors, increasing production is expected to dominate the energy consumption trend, leading to increasing energy-related CAP emissions, primarily at the facility level. However, as no fuel mix changes are expected for the industry, less emissions-intensive fuels will continue to dominate consumption.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 343 million metric tons in 2004. For the bulk chemicals subsector, carbon dioxide emissions are projected to fall by 2 percent by 2020. As is the case for energy-related CAP emissions, these projections may not correlate with trends in faster-growing subsectors of the chemical manufacturing industry.

3.3.2 Best Case Scenario

Opportunities

Table 28 ranks the viability of five primary opportunities for improving environmental performance with respect to energy use (Low, Medium, or High). A brief assessment of the ranking is also provided, including potential barriers.

Table 28: Opportunity assessment for the chemical manufacturing industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Medium	Coal represents a relatively small fraction of the sector's energy consumption, but it is an emissions-intensive energy source (as seen in NEI data). Though MECS data indicate that natural gas is the most viable substitute for coal use, natural gas price trends are unlikely to make this an attractive opportunity for the industry. A substantial fraction of the sector's energy needs are currently met by waste and byproduct fuels, and there are likely opportunities to increase use of alternate and waste fuels without compromising environmental quality (for example, in cases where using waste fuels for energy content reduces total energy consumption by combining energy generation and waste disposal processes). However, hazardous waste permitting requirements (for example, under RCRA Subtitle C) may inhibit energy recovery from waste fuels.
Increased CHP	High	The chemicals industry meets a substantial portion of its electricity demand through onsite power generation, primarily via cogenerating units that also produce steam. DOE notes that particularly for organic chemical manufacturing, waste heat reduction and increased waste heat recovery (including the use of waste energy streams in cogeneration) represents a major opportunity for reducing energy losses.[101] New CHP installations also face barriers in terms of utility rates and interconnection requirements if electricity production is expected to exceed onsite demand, and also from NSR/PSD permitting.[102]
Equipment retrofit/ replacement	Medium	DOE notes that due to the substantial energy requirements for process heating, major energy efficiency gains are achievable through retrofitting or replacing steam system equipment (i.e., boilers, pipes, valves, traps, heat exchangers, and preheaters).[103] The American Council for an Energy Efficient Economy (ACEEE) noted that opportunities exist to reduce water usage and increase energy efficiency by installing more efficient water treatment technologies.[104] The primary barriers to equipment changes are capital constraints, particularly in segments of the industry that are hardest-hit by rising energy costs.
Process improvement	Medium	Process optimization (e.g., waste reduction and improving process yields) is already widely practiced in the industry and likely has additional potential. Process improvement (i.e., using an alternative process or path to produce the same product) may require technological advances or a breakthrough in a new production process, and some areas of R&D offer potential for process improvement, such as catalysis as discussed below. For example, it is estimated that membrane separation in place of separation by distillation may save up to 40 percent of current energy requirements for separation of olefin/paraffin mixtures by 2020.[105] There are likely differences in the viability of process-related opportunities between bulk and batch chemical manufacturing, as batch production processes are typically prescribed by customer requirements. It may also be more difficult to make improvements on continually changing process lines.

Opportunity	Ranking	Assessment (including potential barriers)
R&D	Medium	The chemical sector has developed mission statements and roadmaps for crucial R&D priority efforts as part of its efforts with DOE/IOF; see http://www.eere.energy.gov/industry/chemicals/. Energy-savings opportunities that continue to be areas for industry research include membrane separation technologies; improved process control systems, including adjustments to control flooding in distillation columns; and process improvement through catalysis, which lowers the heat input necessary to convert reactant species into products. The sector also promotes research and funding into coal gasification due to its interest in developing less expensive feedstock and fuel alternatives to natural gas. Gasification is the first step in some coal-to-liquids (CTL) processes used to produce synthetic fuels (syngas) from coal. Some of this fuel can be used as feedstock for chemical products, and some can be used to power gas turbines, generating electricity and thermal energy with substantially lower SOx, NOx, and particulate emissions than coal.

Optimal Future Trends

CEF's advanced energy scenario projects a 3.5 percent decrease in sector energy consumption by 2020, compared with the 13 percent increase projected under the business-as-usual scenario. As CEF does not assume any difference in the economic growth rate between the base case and advanced case scenarios, the projected decrease in overall energy consumption under the advanced scenario is driven by substantial increases in energy efficiency. According to CEF, cogeneration is expected to play an important role in increasing energy efficiency in the chemicals sector. Currently, 51 percent of natural gas inputs for boiler fuel are consumed in CHP/cogeneration processes and 49 percent are consumed in conventional boilers.[106] An optimal energy scenario increases the magnitude of the CHP fraction at the expense of the conventional boiler fraction, boosting energy efficiency. Increased CHP would also reduce purchased electricity consumption, as is evident from the decline in the purchased electricity category projected under CEF's advanced energy scenario.

Other energy efficiency improvements affecting CEF's advanced case projections include the following: increased boiler efficiency; steam system retrofits such as steam trap monitoring and maintenance, insulation and condensate recovery; reduced electricity consumption through installation of energy-efficient motors, drives, fans, and compressors; and increased commercial building efficiency. (Appendix A-2 of the CEF report contains detailed descriptions of CEF's adjustment to the NEMS model in terms of expected rates of efficiency improvement for existing equipment and implementation of new energy-efficient technologies under the advanced scenario.)

The CEF advanced scenario summarized in Table 29 projects a cleaner fuel mix by 2020, with natural gas meeting a greater share of the sector's energy demand, and petroleum, coal, and purchased electricity meeting a relatively smaller share. Consumption of all fuel types except natural gas is expected to decline; natural gas usage is projected to increase by 18 percent from 1997 to 2020, compared with a 9 percent increase under the base case scenario. As discussed previously, increases in natural gas prices that have occurred since the CEF projections were made call into question whether such outcomes could realistically be achieved.

Table 29: CEF advanced case projections for the chemicals industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu) [ppp]	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.479	14%	0.206	6%
Natural gas	2.204	63%	2.611	77%
Coal	0.176	5%	0.080	2%
Delivered electricity	0.639	18%	0.478	14%
Total	3.498	100%	3.375	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-1.2%
Overall % change in energy use (1997-2020)				-3.5%

Environmental Implications

At the facility level, CEF's advanced case projections indicate a moderate improvement in energy-related CAP emissions under the advanced scenario through reduction in coal use. However, petroleum use remains relatively unchanged and natural gas use increases. The reduction in purchased electricity would affect energy-related emissions at the utility level. Emissions reductions associated with electric power generation would vary according to the energy inputs employed by local power producers.

Under the advanced energy scenario, environmental benefits come from reduced emissions due to the overall reduction in sector energy usage from 1997 levels. Under the advanced energy scenario, CEF projects the chemicals industry to achieve a 24 percent reduction in 1997 carbon emissions levels by 2020. As seen with other CEF projections, reductions in the carbon intensity of energy use are achieved both at the sector level through energy efficiency improvement—for the chemicals sector, CHP will be a key driver of this trend—reductions in emissions-intensive energy sources such as coal, and also through a cleaner fuel mix in offsite electric power generation.

3.3.3 Other Reference Materials Consulted

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[ppp] As is the case with several sectors addressed in the CEF analysis, there are slight differences between 1997 fuel consumption data in the reference and advanced cases. We could find no explanation for such differences in the CEF analysis, but it could be that CEF made modifications to the base year (1997) parameters under the advanced case as compared with the reference case.

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