Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes








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Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes

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List of Acronyms

AA	Aluminum Association
ACC	American Chemistry Council
ACEEE	American Council for an Energy-Efficient Economy
AE	Anode effects
AEO	*Annual Energy Outlook*
AGF	American Gas Foundation
AF&PA	American Forest & Paper Association
AI	Alternative ironmaking
AISI	American Iron and Steel Institute
APMA	Automotive Parts Manufacturers' Association of Canada
ASM	*Annual Survey of Manufacturers*
BART	Best Available Retrofit Technology
BOF	Basic oxygen furnace
BOH	Basic open hearth
BPA	Bonneville Power Administration
Btu	British thermal units
CAA	Clean Air Act
CAP	Criteria air pollutant
CEF	*Scenarios for a Clean Energy Future*
CEPA	Clean Energy Program Administrators
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHP	Combined heat and power
CKD	Cement kiln dust
CO	Carbon monoxide
CO_2	Carbon dioxide
CTL	Coal-to-liquids
DG	Distributed generation
DR	Demand response
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DOT	U.S. Department of Transportation
DSW	Definition of solid waste
EAF	Electric arc furnace
EERE	Energy Efficiency and Renewable Energy (DOE)
EIA	Energy Information Administration (DOE)
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPI	Environmental Performance Indicator
FERC	Federal Energy Regulatory Commission
FIRE	Food Industry Resource Efficiency
GDP	Gross domestic product
GHG	Greenhouse gas
GTL	Gas-to-liquids
HAP	Hazardous air pollutant
HVAC	Heating, ventilating, and air conditioning
IGCC	Integrated gasification combined cycle
IOF	Industries of the Future (DOE)
IRS	Internal Revenue Service (U.S. Department of the Treasury)
ISO	International Organization for Standardization
ITP	Industrial Technologies Program (DOE)
KBtu	Thousand Btu
lb	Pound
LBNL	Lawrence Berkeley National Laboratory
LPG	Liquified petroleum gas
MACT	Maximum Achievable Control Technology
MBtu	Million Btu
MECS	*Manufacturing Energy Consumption Survey*
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System

NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NESHAP	National Emission Standards for Hazardous Air Pollutants
NGL	Natural gas liquids
NH_3	Ammonia
NOx	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
NSR	New Source Review
O&M	Operations and maintenance
OAQPS	Office of Air Quality Planning and Standards (EPA)
OAR	Office of Air and Radiation (EPA)
OEM	Original equipment manufacturer
OPEI	Office of Policy, Economics, and Innovation (EPA)
OSHA	Occupational Safety and Health Administration (DOL)
OSW	Office of Solid Waste (EPA)
PCA	Portland Cement Association
PEL	Permissible exposure limit
PFC	Perfluorocarbon
PM	Particulate matter
ppm	Parts per million (pollutant)
PSD	Prevention of Significant Deterioration
PURPA	Public Utility Regulatory Policies Act
PV	Photovoltaic
R&D	Research and development
RCRA	Resource Conservation and Recovery Act
RD&D	Research, development, and demonstration
ROI	Return on investment
RSE	Relative Standard Error
RTO	Regenerative thermal oxidizer
SCC	Source Classification Code (NEI)
SGP	Strategic Goals Program
SIC	Standard Industrial Classification
SO_2	Sulfur dioxide
SOBOT	Saving One Barrel of Oil per Ton (AISI initiative)
SOCMA	Synthetic Organic Chemical Manufacturers Association
SOx	Sulfur oxides
SPCC	Spill Prevention Countermeasures and Control
SSD	Sector Strategies Division (EPA)
SSP	Sector Strategies Program (EPA)
STAC	State Technologies Advancement Collaborative
TBtu	Trillion Btu
TPY	Tons per year (emissions)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (U.S. Department of the Interior)
VAIP	Voluntary Aluminum Industrial Partnership
VOC	Volatile organic compound

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Executive Summary

Objective

The objective of this report is to assist the Sector Strategies Division (SSD) of the U.S. Environmental Protection Agency (EPA) in developing strategies to promote environmentally preferable outcomes with respect to energy consumption in 12 industrial manufacturing sectors. For the purposes of this analysis, environmentally preferable energy outcomes are achieved by reductions in energy-related air emissions through increased energy efficiency (which reduces fuel consumption and associated emissions) and/or transitioning to less emissions-intensive energy sources. This analysis focuses primarily on emissions of criteria air pollutants (CAPs), but it also includes some projections of carbon dioxide (CO_2) emissions. Other air emissions, such as air toxics, and water and land impacts are not included.

12 Industrial Manufacturing Sectors Examined in This Report

- Alumina and aluminum
- Cement
- Chemical manufacturing
- Food manufacturing
- Forest products
- Iron and steel
- Metal casting
- Metal finishing
- Motor vehicle manufacturing
- Motor vehicle parts manufacturing
- Petroleum refining
- Shipbuilding and ship repair

Across the 12 sectors, this analysis characterizes energy consumption within the context of recent and expected future energy trends and provides a broad overview of the environmental and economic context surrounding sector energy usage. Building on this overview, the analysis provides sector-specific “base case” and “best case” energy scenarios, identifying opportunities for promoting environmentally preferable energy outcomes as well as potential regulatory and nonregulatory barriers to improved environmental outcomes. To address potential regulatory barriers to investment in energy efficiency and clean energy technologies in these sectors, this analysis proposes a number of policy options that EPA could pursue—both internally at EPA and externally in coordination with other agencies and stakeholders—to remove or reduce the barriers.

Approach

Drawing upon the most recent publicly available data sources that address energy consumption in these 12 industrial manufacturing sectors, as well as perspectives and insights provided through interviews with internal and external stakeholders, this report provides a broad overview of sector energy consumption, economic trends, and the environmental impacts of sector energy consumption in terms of energy-related air emissions. In a summary of each sector, we describe current energy trends and associated environmental impacts in terms of air emissions of CAPs and carbon dioxide. We project how future energy trends and associated emissions could be impacted by implementation of key opportunities for energy efficiency and clean energy improvement. We then discuss the ways in which regulations and other nonregulatory factors may create barriers to energy efficiency and clean energy improvement, providing specific examples from the literature we reviewed and the stakeholder interviews we conducted. Finally, we set forth several policy approaches that EPA could explore to address regulatory barriers and promote environmentally preferable outcomes with respect to energy consumption in these manufacturing sectors.

Key Energy Trend Findings

This analysis produced the following overarching insights:

- Comprising the largest fraction of total U.S. energy demand, the industrial sector presents considerable opportunities for improving environmental performance through increased adoption of energy efficiency and clean energy technologies.
- Industrial energy use has been growing more slowly than energy use in the residential, commercial, and transportation sectors. This is because industry as a whole has become a smaller proportion of the economy, has shifted to less energy-intensive types of manufacturing, and has already implemented a number of energy-saving technologies.
- Under a business-as-usual energy scenario, aggregated energy consumption across many of the sectors[a] addressed in this analysis is projected to increase by 20 percent from 2004 levels by 2020, and CO_2 emissions are projected to increase by 14 percent.[1] Faster growth is projected for onsite consumption of fossil fuels and renewable energy (a projected increase of 60 percent over the period) than for purchased electricity (a projected increase of 12 percent over the period).
- Rising energy costs and the pressures of global competition pose continuing challenges for industrial manufacturing sectors but also create an opportunity for energy efficiency to play an increasing role in helping businesses' competitive positions.
- The types of fuel used by industry have changed over time. During the last 50 years, industry has decreased direct coal use and increased natural gas use. Recent increases in both the price and price volatility of natural gas may interrupt these trends, although over the short term, most sectors are not able to switch fuels easily. Industrial use of renewable fuels is growing, and is already higher than the use of renewable fuels in the residential, commercial, and transportation sectors.
- For each sector, this analysis compares energy-related CAP emissions with total CAP emissions, including those that result from manufacturing processes. The primary CAP emissions resulting from energy use are sulfur dioxide and nitrogen oxides. In general, the largest sources of energy-related CAP emissions are external combustion boilers and manufacturing process equipment. Upstream emissions from electrical generating units that supply industrial energy users with purchased electricity are not included in this analysis. Only onsite emissions resulting from energy use are included.
- Investment in energy efficiency and clean energy is fundamentally a business decision, and the success of strategies to promote environmentally preferable energy outcomes will depend primarily on the business case for such investments.
- Strategies for promoting energy efficiency and clean energy investment should be tailored to address sector-specific economic trends and characteristics such as declining/increasing productivity, sensitivity to energy cost fluctuations, average firm size, the homo- or heterogeneity of manufacturing processes within the sector, and the sector's geographic distribution.

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[a] The projections referenced here are contained in supplemental tables to the U.S. Department of Energy's *Annual Energy Outlook 2006* and apply to aggregated energy consumption and carbon dioxide emissions across the following sectors: aluminum, cement, bulk chemicals, food manufacturing, iron and steel, metals-based durables (containing metal finishing), pulp and paper (part of forest products), and petroleum refining.

Key Opportunities for Environmentally Preferable Energy Outcomes

Our analysis focuses on five key opportunities for improved environmental performance with respect to energy usage in industrial manufacturing sectors. Following is a brief definition of each opportunity:[b]

- ***Cleaner fuels.*** Current fuel sources could be replaced with alternate fuels that have lower carbon and/or CAP emissions per unit of energy. This opportunity also includes self-generation of energy with renewable resources (biomass, solar, wind, and geothermal).
- ***Combined heat and power (CHP).*** A form of distributed generation also referred to as "cogeneration," a CHP system increases energy efficiency through onsite production of thermal energy (typically steam) and electricity from a single fuel source.
- ***Equipment retrofit/replacement.*** Energy efficiency could be improved by retrofitting or replacing existing equipment used for onsite heat or power generation and distribution, manufacturing processes, or meeting facility requirements such as lighting and heating, ventilating, and air conditioning (HVAC).
- ***Process improvement.*** Process improvement or optimization refers to either a wholesale process change that requires less energy for a similar level of manufacturing output or an adjustment to the manufacturing process that increases energy efficiency. The process improvement category also includes implementation of best practices in energy management.
- ***Research and development (R&D).*** R&D could focus on developing new energy-efficient or clean energy technologies and processes that could be commercialized within the next one to two decades.

Nonregulatory Barriers to Environmentally Preferable Energy Outcomes

Several nonregulatory factors, including financial, technical, and institutional barriers, limit broader application of the energy efficiency and clean energy technologies addressed in this analysis, and hinder the achievement of environmentally preferable energy outcomes in manufacturing industries:

- ***Financial barriers.*** Most of the energy consumed in the industrial sector is consumed in a few basic industries that produce commodity products—such as steel, basic chemicals, petroleum products, and paper—that are subject to stiff domestic and international competition. Some of these industries have already seen major declines in the United States and are concerned about their future viability. These industries have little appetite for new capital investment at this time, unless it is likely to bolster their future success. Given scarce capital resources in general, the greatest investment priorities are typically for equipment that maintains or increases production and product quality, or is necessary to meet regulatory requirements. Discretionary investments for energy efficiency or clean energy projects must often compete with these higher-priority investments.
- ***Technical barriers.*** Some energy efficiency or clean energy opportunities are not well suited to a given industry's manufacturing process. In other cases, process-related technical constraints affect the extent to which a given opportunity can be utilized.

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[b] Section 2.2.6 contains a more complete definition of each opportunity with important caveats.

- ***Institutional barriers.*** Energy is a small component of the cost of production in most industries. Only in the most energy-intensive industries—such as aluminum, cement, segments of the chemical manufacturing industry, iron and steel, metal casting, and pulp and paper—do energy costs represent more than 3 percent of the industry's annual value of shipments.[c] This reality minimizes institutional incentives to devote organizational resources to pursuing energy efficiency opportunities.

Regulatory Barriers to Environmentally Preferable Energy Outcomes

Regulations also may limit broader application of energy efficiency and clean energy technologies and impede the achievement of environmentally preferable energy outcomes in manufacturing industries. Given EPA's role in developing and coordinating regulations and policies aimed at improving environmental performance, this analysis focuses on regulatory barriers, describing four ways in which regulations—issued by EPA or other agencies—may create barriers to energy efficiency and clean energy improvement:

- Regulations may fail to fully reward the environmental benefits associated with an energy efficiency opportunity, which restricts the potential for businesses to evaluate energy efficiency on an equivalent basis with other pollution control strategies such as add-on controls.
- Regulations may lack procedural flexibility that allows pursuit of energy efficiency or cleaner fuel opportunities, particularly in areas where permitting changes are required to implement an opportunity.
- The rulemaking process may fail to fully consider the energy implications of proposed regulations.
- Regulations or policies may contribute to unfavorable market conditions for energy efficiency or clean energy opportunities.

Sector Opportunity Assessment

For each sector, the report assesses the viability of the five key energy efficiency and clean energy opportunities discussed above, given the financial, technical, institutional and regulatory barriers facing each sector. The analysis ranks the viability of each opportunity as "low," "medium," or "high" based on a qualitative assessment of the magnitude of relevant barriers, rather than a quantitative assessment of energy-savings potential. Table 1 provides a summary of the opportunity assessment rankings for each sector.

Table 1: Sector opportunity assessment summary table

Sector	Opportunities				
	Cleaner Fuels	Combined Heat and Power	Equipment Retrofit/ Replacement	Process Improvement	Research and Development
Alumina and aluminum	Low	Low	Medium	Medium	Medium
Cement	Medium	Low	High	High	Medium
Chemical manufacturing	Medium	High	Medium	Medium	Medium
Food manufacturing	Medium	High	Medium	High	Medium

[c] See Table 9 for energy intensity metrics for each sector, including energy costs per dollar value of shipments.

Sector	Opportunities				
	Cleaner Fuels	Combined Heat and Power	Equipment Retrofit/ Replacement	Process Improvement	Research and Development
Forest products	Medium	Low	Medium	High	High
Iron and steel					
Integrated steelmaking	Low	Medium	Low	Medium	High
EAF steelmaking	Low	Low	Low	Medium	High
Metal casting	Low	Low	Medium	Medium	Medium
Metal finishing	Low	Medium	Medium	High	Medium
Motor vehicle manufacturing	Low	Low	Medium	High	Medium
Motor vehicle parts manufacturing	Low	Low	Medium	High	Low
Petroleum refining	Low	High	Medium	Medium	Medium
Shipbuilding and ship repair	Low	Low	High	High	Low

A key observation from this table is that the viability of a given energy efficiency or clean energy opportunity varies from sector to sector. In addition, for any given manufacturing facility the viability of an opportunity will depend on facility-specific characteristics and operating conditions.

Additional findings from the sector opportunity assessment include the following:

- ***Cleaner fuels.*** Given the technical, financial, and regulatory constraints on fuel-switching, the extent of cleaner fuels opportunities is somewhat limited. However, renewable biomass fuels in the forest products industry, bio-waste in the food manufacturing industry, byproduct fuels in the chemical manufacturing industry, and waste fuels in the cement industry may represent opportunities for improved environmental performance as well as opportunities for reducing the cost of purchased energy for manufacturing industries.
- ***CHP.*** For sectors with high process thermal loads such as chemical manufacturing, food manufacturing, and petroleum refining, a key opportunity for reducing fuel use and associated CAP and CO_2 emissions lies with onsite generation of thermal and electric energy. In sectors that already meet the majority of their thermal or electric energy requirements with CHP, like the forest products industry, future opportunities may be limited.
- ***Equipment retrofit/replacement.*** Reduced fuel use through increased boiler efficiency represents an opportunity to reduce energy-related emissions across multiple sectors, as boilers are among the largest sources of CAP and CO_2 emissions in the industries covered in this analysis. According to National Emissions Inventory (NEI) data, the sectors with the largest energy-related CAP emissions from boilers are forest products, chemical manufacturing, and food manufacturing.
- ***Process improvement.*** Sectors with relatively low energy use and associated emissions represent smaller areas of opportunity for energy-related environmental improvement. Key energy-savings opportunities in these sectors lie with implementation of best practices in energy management as well as with energy efficiency upgrades to electric motors and compressed air systems, facility lighting, and HVAC systems.

- ***R&D.*** Transformational technologies and processes can potentially yield substantial energy savings in sectors such as forest products and iron and steel. In forest products, technologies to reduce drying needs in papermaking, improve fuel concentration in recovery boilers, and increase fuel efficiencies in lime kilns are among the most promising R&D opportunities. New technologies under development in iron and steel include molten oxide electrolysis, ironmaking by flash smelting using hydrogen, and the paired straight hearth furnace.

Policy Options

Based on the evaluation of clean energy opportunities and the potential barriers to those opportunities, as well as EPA's goal to promote environmentally preferable energy outcomes, the report outlines policy options EPA could pursue to address regulatory barriers to energy efficiency and clean energy investment. We offer the following policy options for discussion—both internal to EPA and involving coordination with other agencies—noting that the Agency will determine the definitive actions it intends to undertake:

- ***Develop and promote broader application of regulations that recognize the emission reductions resulting from increased energy efficiency*.** Create additional mechanisms for energy efficiency to serve as a pollution control strategy through the following regulatory approaches:
  - Promoting broader use of output-based emissions standards that account for CHP technology's thermal and electric energy output.
  - Promoting broader use of output-based emissions standards in regulations governing other combustion processes such as energy-generating and manufacturing process equipment.
- ***Increase procedural flexibility to promote environmentally preferable energy use.*** Address permit-related barriers to reducing energy-related emissions on a system-wide level through the following activities:
  - Expanding flexible permitting opportunities that promote reductions in energy-related emissions as part of a pollution prevention strategy, including developing a flexible permitting rule.
  - Promoting broader recycling of wastes and process byproducts for energy recovery.
  - Providing assistance to the regulated community as well as state and local permitting authorities in support of efforts to increase procedural flexibility in environmental regulations, including technical guidance on evaluating energy-related environmental tradeoffs at a system-wide level.
- ***Promote broader consideration of energy implications of rulemakings.*** Review methodologies currently used to assess energy impacts during the rulemaking process, assess how program offices are interpreting/implementing these provisions, and work across the Agency to develop a cohesive EPA position on how such impacts should be assessed and weighed against other Agency priorities.
- ***Promote the development of more favorable market conditions for energy efficiency and clean energy technologies.*** Strengthen policy support for energy efficiency and clean energy technologies by conducting the following activities:
  - Coordinating across federal agencies to support policies that promote the market viability of energy efficiency and clean energy technologies.

- Offering additional grants to support clean energy applications in manufacturing industries.
- Analyzing the environmental impacts of utility demand response programs and working to promote clean energy technologies as a strategy to reduce electricity demand.

- ***Provide additional incentives and assistance through a sector-based approach*.** Promote environmentally preferable energy outcomes in manufacturing industries through the following mechanisms:
  - Supporting energy efficiency and clean energy R&D opportunities through information-sharing and recognition of industry achievements.
  - Providing information regarding financial incentives that are available to support energy efficiency and clean energy opportunities, particularly for small businesses.

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1. Introduction

1.1 Objectives

EPA's Sector Strategies Division (SSD) within the Office of Policy, Economics, and Innovation (OPEI) commissioned this analysis to meet the following objectives:

Chapter 1. Introduction

- Facilitate a general understanding of current energy usage and expected future energy consumption trends within 12 selected industrial manufacturing sectors.
- Assess where opportunities exist within these sectors to increase energy efficiency and use less emissions-intensive energy sources, resulting in improved environmental performance.
- Identify barriers to achieving improved environmental performance with respect to sector energy use, with a particular emphasis on regulatory barriers.
- Propose policy options EPA could pursue to address such regulatory barriers, promoting energy efficiency and less emissions-intensive energy sources in these 12 sectors.

It is important to note that this report is an analytical document and does not convey Agency decisions. The report's findings and policy options are based on the available data used in this analysis.

1.2 Methodology

1.2.1 Sectors Addressed in This Analysis

Using North American Industry Classification System (NAICS) codes, 12 industrial manufacturing sectors are addressed in this analysis, as shown in Table 2.

Table 2: Manufacturing sectors addressed in this analysis

Sector	NAICS
Alumina and aluminum	3313
Cement	327310
Chemical manufacturing	325
Food manufacturing	311
Forest products[d]	321, 322
Iron and steel	331111
Metal casting	3315
Metal finishing	332813
Motor vehicle manufacturing[e]	33611
Motor vehicle parts manufacturing	3363
Petroleum refining	32411, 324110
Shipbuilding and ship repair	336611

[d] Where data are available, this analysis provides detail on the two major subsectors of the forest products industry: pulp and paper and wood products.

[e] Motor vehicle manufacturing (NAICS 33611) refers to automobile and light duty motor vehicle manufacturing and assembly.

Eight of these sectors—cement, chemical manufacturing (specifically, paint and coatings and specialty-batch chemicals), food manufacturing (specifically, agribusiness), iron and steel, metal casting, metal finishing, forest products, and shipbuilding and ship repair—currently participate in the Division's Sector Strategies Program, which uses collaborative partnerships to promote widespread improvement in environmental performance with reduced administrative burden. Together, these 12 sectors represent a broad cross-section of the industrial manufacturing economy, and energy usage in these sectors constitutes a substantial fraction of total industrial energy demand in the United States. Energy-related environmental impacts include carbon emissions that contribute to climate change and criteria air pollutant (CAP) emissions that degrade local and regional air quality, potentially affecting attainment of National Ambient Air Quality Standards under the Clean Air Act.

Assessing energy usage trends and associated environmental impacts, as well as the viability of specific energy efficiency and clean energy opportunities, enables us to envision environmentally preferable energy outcomes. Understanding the ways in which regulations and statutes potentially create barriers to energy efficiency and clean energy investment suggests policy options EPA could pursue to promote environmentally preferable energy outcomes.

1.2.2 Data Sources and Caveats

This analysis relies on the best available and most recent public data sources in the following areas:

- ***Historical and current energy consumption data:***
  - *Annual Energy Review (2005)*: For an overview of U.S. and industrial energy consumption trends, we relied on the most recent annual report containing historical energy statistics from 1949 to the present produced by the U.S. Department of Energy's (DOE) Energy Information Administration (EIA).
  - *Manufacturing Energy Consumption Survey (MECS) (1998 and 2002)*: For detailed sector energy consumption data, including fuel use and energy intensity, we relied upon the two most recent issues of EIA's survey of manufacturing energy use, which is conducted every four years.
- ***Energy-related emissions data:***
  - *National Emissions Inventory (NEI) (2002)*: Data runs were conducted using the NEI database (*ALLNEI_CAP* dataset), prepared by EPA's Emission Factor and Inventory group within the Office of Air Quality Planning and Standards, to produce sector-level data on energy-related emissions of CAPs, including sulfur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds.
  - As NEI does not contain data on greenhouse gas (GHG) emissions, we also reference CO_2 emissions projections from the *Scenarios for a Clean Energy Future* (CEF) report and DOE's most recent *Annual Energy Outlook* (AEO, described below under "*Energy consumption projections*"). Though EPA has compiled a *Greenhouse Gas Inventory* (April 2006) that includes some of the sectors addressed in this analysis, we used DOE sources for carbon emissions because they entail projections of future carbon emissions under business-as-usual and environmentally preferable energy scenarios.
- ***Economic data:***
  - *Annual Survey of Manufacturers (2001 and 2004)*: U.S. Census Bureau data on economic production (in terms of value added and value of shipments) by sector were

obtained for the years 1997 to 2004. These sources also provided data on annual energy expenditures by sector.

- *CenStats Databases, County Business Patterns (2004)*: Information on the total number of establishments in each sector was obtained from the Census Bureau's online searchable CenStats databases.

- ***Energy consumption projections:***
  - *Scenarios for a Clean Energy Future (2000)*: This CEF report was commissioned by DOE with research conducted by the Interlaboratory Working Group for Energy-Efficient and Clean Energy Technologies. We used the report's reference case and advanced energy case projections to illustrate how sector energy consumption trends might be different under what EPA considers an "environmentally preferable" energy scenario as compared to a business-as-usual energy scenario.[f]
  - *Annual Energy Outlook (2006)*: For an overview of expected future trends for industrial energy consumption and associated CO_2 emissions, as well as energy projections for specific sectors, we referenced EIA's most recent annual forecast of energy demand, supply, and prices through 2030. We also used the sector-specific projections of AEO 2006 to identify areas where recent energy trends may be expected to produce different outcomes than those projected by CEF in 2000.
  - *Natural Gas Outlook to 2020 (2005)*: This analysis was produced by the American Gas Foundation and contains consumption projections for certain industrial sectors that are heavily dependent on natural gas.[g]

- ***Energy efficiency and clean energy opportunities for industrial manufacturing industries:***
  - *Trade associations*: We consulted a number of online and hard copy materials produced by industry trade associations that describe technological and process opportunities for increasing energy efficiency.
  - *Voluntary programs*: Industry commitments to environmental improvement with respect to energy use—particularly through federal public-private partnership programs such as Climate VISION, which is supported by DOE, EPA, and the U.S. Departments of Transportation and Agriculture, and DOE's Industrial Technologies Program—were reviewed for information on emerging industrial energy-efficient and clean energy opportunities for energy-intensive sectors, including developing technologies. Note that individual companies/facilities within each sector may also participate in other voluntary programs (e.g., ENERGY STAR, Performance Track, Climate Leaders, etc.); it was not the goal of this paper to research and reflect those individual commitments.
  - *National laboratories*: A number of national laboratory reports pertaining to industrial energy consumption were also reviewed and referenced in this analysis.

[f] *Clean Energy Future* projections were available for 8 of the 12 sectors addressed in this analysis: alumina and aluminum, cement, chemical manufacturing, food manufacturing, forest products, iron and steel, metal casting, and petroleum refining.

[g] *Natural Gas Outlook* projections were available for the following sectors: chemical manufacturing, food manufacturing, iron and steel, petroleum refining, and pulp and paper (within forest products).

- ***Regulatory barriers to energy efficiency and clean energy improvement:***
  - *Trade associations*: We collected anecdotal information from the regulated community and reviewed industry trade association materials to identify key concerns with respect to federal, state, and local regulations that may pose barriers to energy efficiency or clean energy improvement.
  - *Government publications*: We also reviewed several analyses produced by federal regulatory agencies, including EPA, and national laboratories that discuss potential regulatory barriers to energy efficiency or clean energy improvement.

Though our research involved a thorough review of the most commonly referenced, publicly available information sources regarding energy consumption and associated environmental impacts, as well as energy efficiency and clean energy opportunities for industrial manufacturing sectors, this analysis did not involve an exhaustive literature search. Other important caveats regarding the data sources used in this analysis include the following:

- Sectors included in this analysis are defined according to the NAICS codes shown in Table 2. In some cases, the data sources consulted in this analysis do not align exactly with these sector definitions. In such instances, we use the closest available NAICS category to EPA's sector definition and note such differences between EPA's and the source's sector definition in a footnote.
- Though the 2002 *Manufacturing Energy Consumption Survey* provides the most detailed data on sector energy consumption, energy prices have undergone major changes in the last four years, and the effects of such changes on sector energy consumption are not reflected in the 2002 MECS or other data sources used in this analysis.
- *Scenarios for a Clean Energy Future* provides the best available mechanism for illustrating how sector energy consumption might differ under an environmentally preferable energy scenario versus a business-as-usual scenario. At the same time, the study was produced in 2000 and thus does not reflect recent changes in economic production, energy prices, and technology advancements that affect industrial energy consumption.
- In this analysis, we seek to provide a structure for understanding the ways in which regulations can potentially serve as barriers to energy efficiency and clean energy improvement in industrial manufacturing sectors. Our research into regulatory barriers has focused on collecting anecdotal reports from the regulated community obtained through interviews with industry representatives and through a literature review, rather than a systematic survey approach.
- Our analysis of energy-related environmental impacts focuses primarily on a sector-by-sector assessment of potential changes in energy-related air emissions that could occur under business-as-usual and environmentally preferable energy scenarios. The report uses energy-related CAP emissions from the NEI database (where available). It also includes a more general assessment of opportunities to reduce GHG emissions, focusing on carbon dioxide. The report does not include emissions of hazardous air pollutants, or water or waste impacts resulting from energy use.
- The report first presents general trends in industrial energy consumption, and then current and future energy consumption and fuel use trends within each sector. It is important to note that this report indicates the amount of purchased electricity used by each sector, but does not attempt to quantify indirect energy-related emissions resulting from the

production of electricity by offsite electrical generating units. In other words, the energy-related emissions discussed in this report refer only to onsite emissions at industrial facilities.

- The analysis focuses on fuel inputs for energy use only and does not address feedstock fuel use. While some figures in the report represent total energy consumption data, which includes fuels used as feedstocks (i.e., raw material inputs in the manufacturing process), feedstock energy inputs may or may not contribute to CAP and GHG emissions. As feedstock fuel use does not represent an opportunity for reducing the environmental impacts associated with energy consumption, the reports focuses on energy inputs for fuel use only.

1.2.3 Organization of the Report

The major sections of this report are organized as follows, within "Insights" text boxes where appropriate:

- Chapter 2, *Current Energy Consumption*, characterizes sector energy consumption within the context of U.S. energy demand, assessing sector energy requirements in terms of fuel inputs, energy intensity, and end use applications. In assessing how energy is used and lost in industrial manufacturing processes, the section identifies five key opportunities for improving environmental performance with respect to energy consumption—cleaner fuels, combined heat and power, equipment retrofit/replacement, process improvement, and research and development. In addition, this section provides a broad overview of the environmental and economic context surrounding sector energy usage.
- Chapter 3, *Sector Energy Scenarios*, builds upon the overview of sector energy consumption, environmental impacts, and economic context developed in Chapter 2 and the energy projections described in Chapter 3 to develop "base case" and "best case" energy scenarios for each of the 12 sectors addressed in this analysis. The sections on each sector include the following:
  - A "situation assessment" that provides a general overview of the sector and describes key factors affecting sector energy use.
  - A "base case" energy scenario that describes (1) the expected future trend for sector energy consumption and (2) associated environmental impacts.
  - A "best case" energy scenario that assesses (1) key opportunities for improving environmental performance with respect to sector energy consumption, (2) potential barriers to implementing such opportunities, and (3) the ways in which an environmentally preferable energy scenario would differ from the "base case" scenario in terms of energy consumption and associated environmental impacts.
- Chapter 4, *Barriers to Environmentally Preferable Energy Outcomes*, provides an overview of financial, technical, institutional, and regulatory barriers to energy efficiency and clean energy improvement in industrial manufacturing sectors. In a focus on regulatory barriers, the chapter identifies key ways in which regulations can present barriers to investment in energy efficiency and clean energy opportunities.
- Chapter 5, *Policy Options*, sets forth possible actions EPA could take to address the regulatory barriers to energy efficiency and clean energy improvement discussed in Chapter 4.
- Appendix A, *Energy Projections*, provides an overview of the energy projections employed to develop business-as-usual versus environmentally preferable energy scenarios for the

12 sectors considered in this analysis. The appendix highlights key similarities and differences between the projections and includes a brief discussion of expected future trends in industrial energy consumption.

2. Current Energy Consumption

2.1 U.S. Energy Overview

This section provides an overview of historical industrial energy consumption and fuel use trends within the larger context of U.S. energy demand, comparing industrial trends with commercial and residential energy consumption trends to illustrate key points that distinguish industrial energy consumption and fuel usage from that of other end use categories.

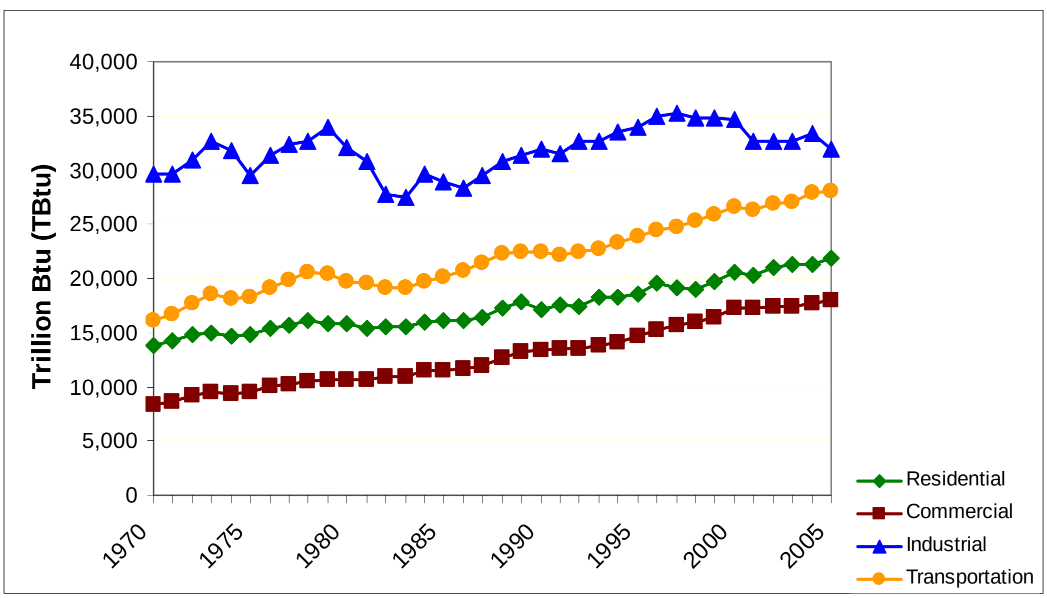
Insights

During the past 35 years, the transition away from heavy industry and towards the commercial and service sectors has contributed to slower energy consumption growth in the industrial sector than in other sectors of the U.S. economy. At the same time, the industrial sector remains the largest end user of energy, and reducing energy consumption in energy-intensive manufacturing industries offers opportunities for improving environmental performance as well as reducing operational costs in an increasingly competitive global marketplace.

2.1.1 Long-Term Energy Consumption Trends

A comprehensive overview of historical energy consumption trends from 1949 through 2005 is provided in the *Annual Energy Review* compiled by the Energy Information Administration (EIA) within the U.S. Department of Energy (DOE). Using data from the 2005 *Annual Energy Review*, Figure 1 shows U.S. energy consumption trends since 1970 across the following end use categories: industrial, transportation, residential, and commercial.

Figure 1: U.S. energy consumption trends 1970-2005: comparison of industrial, transportation, residential, and commercial end uses[2]



> **Energy Consumption Terminology**
>
> - ***Delivered energy*** (also called "site energy") is the amount of energy consumed at the facility level (purchased electricity and fossil fuel inputs as well as onsite renewable energy generation). It does not include losses from offsite energy generation, transmission, and distribution. EIA's *Manufacturing Energy Consumption Survey* (MECS) data presented in this report are in terms of delivered energy consumption.
> - ***Primary energy*** refers to energy consumed onsite plus the total amount of fuels used to generate energy offsite (i.e., by the electric power generating sector). Thus, it includes energy losses from offsite energy generation, transmission, and distribution.
> - ***Total energy*** is primary energy plus the amount of energy consumed by the electricity-generating sector to meet its own energy needs, which is allocated to the end use sectors (industrial, commercial, and residential). Energy consumption data from EIA's *Annual Energy Review* in Section 2.1.1 are in total energy terms.
>
> Source: DOE, Indicators of Energy Intensity in the United States.
> Available at http://intensityindicators.pnl.gov/terms_definitions.stm#economy.

Total energy consumption across all end uses has increased since 1970, but industrial energy consumption has shown the slowest growth over the period, increasing at an annual rate of 0.35 percent from 1970 to 2004.[h] Over the same period, total commercial energy consumption has more than doubled, with an annual growth rate of 2.1 percent, and annual growth rates for energy consumption in the transportation and residential sectors were 1.6 and 1.3 percent, respectively. At the same time, total industrial energy consumption has remained greater than total energy consumption in the other end use categories.[i] Industrial energy consumption has also shown greater responsiveness to energy price increases than the other categories, declining in 1975 and from 1980 to 1983 primarily in response to oil price spikes.[3]

The trend of relatively flat industrial energy consumption compared with other end use sectors is primarily attributable to the U.S. economy's overall shift away from traditional manufacturing industries towards the service and commercial sectors, and from energy-intensive industries towards industries with lower energy intensity, as well as to energy efficiency improvements within industrial manufacturing sectors.

2.1.2 Fuel Consumption Trends

Table 3 presents the fraction of total energy demand that is met by various energy sources and fuel types for each end use sector: industrial, commercial, residential, and transportation.[j] (Note that according to the 2005 *Annual Energy Review*, energy inputs for electricity production are approximately 50 percent coal, 19 percent nuclear, 16 percent natural gas, and 6 percent hydroelectric. The remaining energy inputs for electric power generation include petroleum, wood, waste, and other renewables such as wind, solar, and geothermal.)[4]

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[h] As indicated in the *Energy Consumption Terminology* sidebar, *Annual Energy Review* data are presented in total energy terms. As EIA's 2005 data were preliminary at the time this report was written, 2004 data were used to calculate end use fractions of total U.S. energy consumption. Annual increases are the calculated average growth rate over the period.

[i] Delivered energy consumption by the transportation sector recently surpassed industrial delivered energy consumption.

[j] Percentages were calculated using 2004 total energy consumption data.

Table 3: Fraction of total energy demand met by fuel type in 2004: comparison of residential, commercial, industrial, and transportation end uses[5]

	Electricity	Coal	Coal Coke	Natural Gas	Petroleum	Renewable	TOTAL[k]
Industrial	33.5%	6.1%	0.4%	25.6%	29.3%	5.0%	**99.9%**
Commercial	76.2%	0.6%	0.0%	18.2%	4.3%	0.8%	**100.1%**
Residential	66.8%	0.1%	0.0%	23.6%	7.3%	2.3%	**100.1%**
Transportation	0.3%	0.0%	0.0%	2.2%	96.5%	1.0%	**100.0%**

It is important to note the following characteristics that distinguish industrial energy usage from that of other end use sectors, particularly residential and commercial energy consumption:

- ***Electricity.*** The industrial sector is relatively less dependent on purchased electricity than the commercial and residential sectors, in part because industry produces a greater fraction of its own power through direct fuel inputs and, for some industries, through cogeneration. A form of cogeneration is combined heat and power (CHP), which produces thermal and electric energy from a single fuel source. CHP is a key energy efficiency opportunity for sectors with high process thermal and electricity loads (see Section 2.2.6), particularly the chemical manufacturing, food manufacturing, forest products, and petroleum refining sectors.[l]
- ***Coal.*** Though still an important fuel source for some industries, coal use by the industrial sector has declined steadily since 1950 (when it was the largest fraction of industrial fuel inputs) to a relatively small fraction of industrial fuel inputs today.[6] Over the same period, coal use in electric power generation has grown rapidly (currently supplying more than 50 percent of energy inputs for electric power generation), and thus represents an important, though indirect, source of energy for all three end use categories except transportation, particularly the commercial and residential sectors.
- ***Natural gas.*** For the industrial sector, natural gas represents a larger fraction of total energy consumption than for other sectors, and industry is the largest end user of natural gas (see Figure 2 on page 2-4). Consequently, increasing natural gas prices are of particular concern for U.S. industry. In addition to fuel use, natural gas is also an important raw material in industries such as chemical manufacturing and petroleum refining.
- ***Petroleum.*** Petroleum also represents a larger fraction of industrial energy inputs than it does for the commercial and residential sectors, and petroleum consumption by industry has increased steadily since 1950—only slightly slower than the rate of increase in the transportation sector.[7] However, a large fraction of industrial petroleum consumption is not for fuel use, but rather as raw material in industries like petroleum refining and chemical manufacturing. Off-road transportation in the mining, agriculture, and construction sectors represents another substantial component of industrial petroleum use. It is also important to note that the industrial petroleum consumption data in Table 3 do not capture petroleum inputs for offsite transportation of manufactured goods, as these energy inputs are included under the transportation sector. Though not considered in depth in this analysis,

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k For each row, sum of all columns may not equal 100% due to independent rounding.

l Additional sector-level data for onsite generation of electricity, including cogeneration and renewable power generation, is available through MECS tables 11.3 and 11.4, available at http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/excel/table11.3_02.xls.

fuels used in freight shipping represent an important energy input for manufacturing industries.

- ***Renewables.*** The industrial sector is the largest user of renewable fuels, in part due to the extensive use of biomass fuels in the forest products industry. As is the case for coal, renewable energy is also represented in electricity supplied by utilities, meeting approximately 9 percent of the country's electric power supply, primarily through hydropower.

Focusing on more recent historical trends (1989 to 2005), and comparing industrial fuel consumption with fuel consumption in the other major end use categories, Figure 2 through Figure 5 present consumption trends for natural gas, petroleum, coal, and electricity, respectively. Trends are presented for the three main end use categories—industrial, residential, and commercial—with the following exceptions: (1) the coal consumption graph, Figure 4, compares three primary industrial uses of coal with all non-industrial end uses; and (2) the petroleum consumption graph, Figure 3, also includes the consumption trend for transportation end uses.

Figure 2: Natural gas consumption 1989-2005: comparison of industrial, residential, and commercial end uses[8]

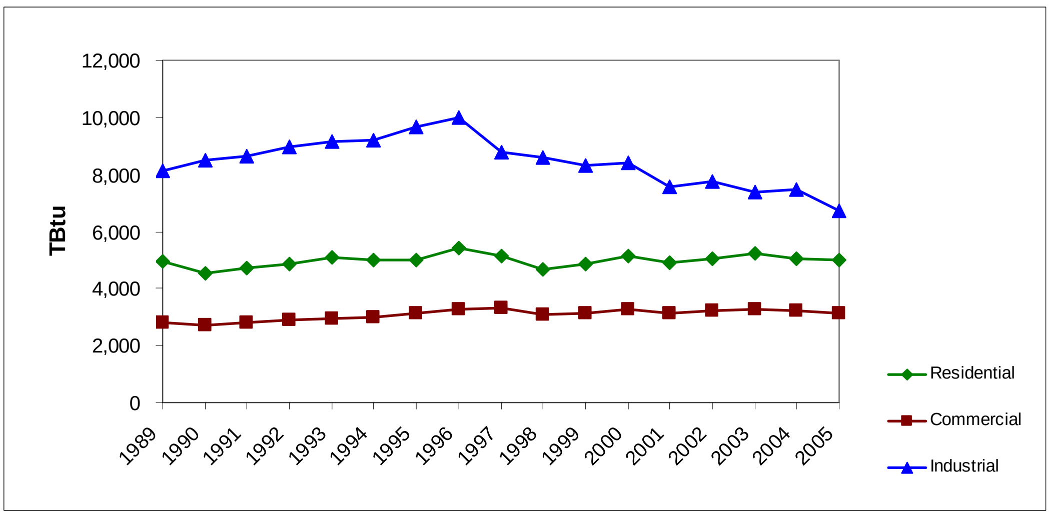


Figure 3: Petroleum consumption 1989-2005: comparison of industrial, transportation, residential, and commercial end uses[9]

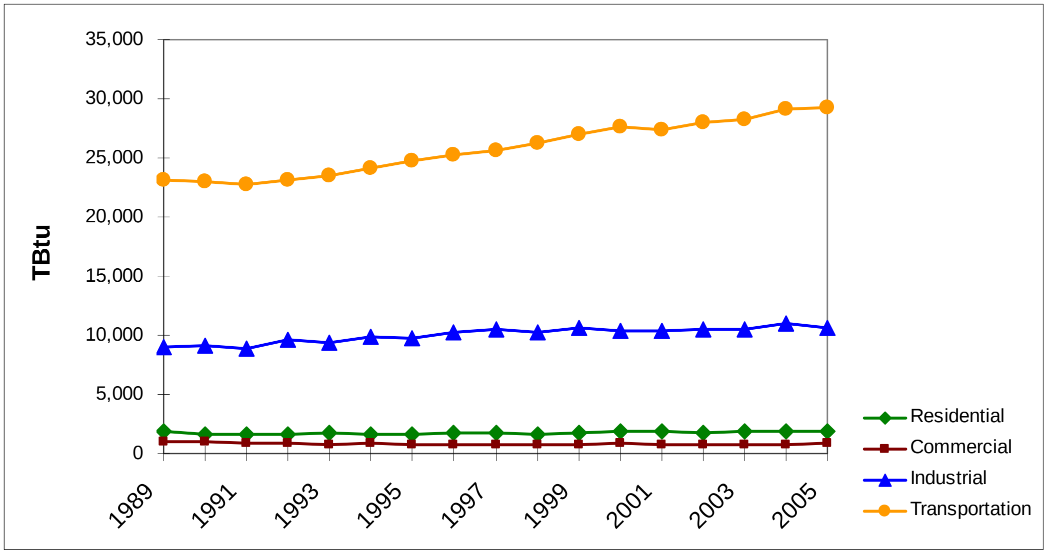
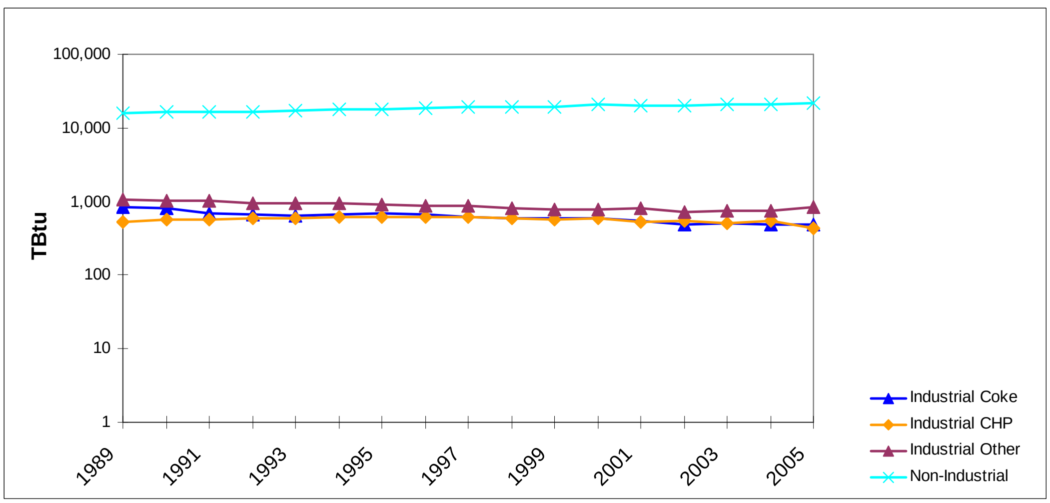
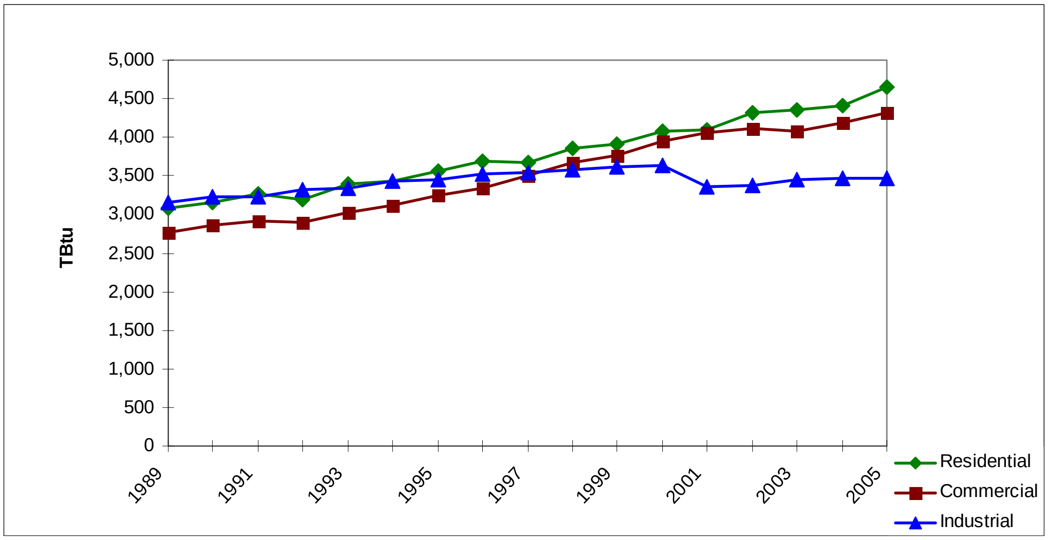


Figure 4: Coal consumption 1989-2005: comparison of industrial and non-industrial end uses[10] [m]



m "Industrial coke" represents coal inputs used by industrial coke plants. "Industrial CHP" contains coal inputs for CHP applications and a small number of electricity-only coal plants. "Industrial Other" contains all other coal inputs in industrial applications.

Figure 5: Purchased electricity consumption 1989-2005: comparison of industrial, residential, and commercial end uses[11]



As this analysis is concerned with energy usage trends within 12 industrial manufacturing sectors, the preceding graphs highlight several important points regarding macro-level industrial energy consumption trends:

- The industrial sector consumes more natural gas than other sectors, but industrial gas consumption trends are also more volatile than for other sectors. In some cases, price volatility in the natural gas market has contributed to decreasing industrial output as natural gas-dependent industries reduce production in response to escalating energy costs.[12] For example, 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.[13]
- Industrial petroleum consumption is second only to transportation consumption, increasing at 1.3 percent annually from 1989 to 2004. However, as mentioned previously a substantial fraction of industrial petroleum consumption is not for fuel use but rather as a raw material in specific industries.[n] Off-road transportation in the mining, agriculture, and construction sectors represents another substantial component of industrial petroleum use.
- Industrial coal consumption has fallen 2 percent annually from 1989 to 2004. Growth in non-industrial coal use is attributable to expansion of coal use for electric power generation, which has increased steadily since 1950.[14]
- Residential and commercial consumption of purchased electricity exceeded industrial consumption in the mid 1990s. Industrial electricity consumption has remained fairly steady, growing at an annual rate just under 0.4 percent from 1989 to 2004.

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[n] EIA petroleum consumption data include feedstock use. According to 2004 data, 35 percent of industrial petroleum consumption was categorized as "other petroleum," which is defined as: "Pentanes plus petrochemical feedstocks, still gas (refinery gas), waxes, and miscellaneous products. Beginning in 1964, [other petroleum] also includes special naphthas. Beginning in 1983, [other petroleum] also includes crude oil burned as fuel."

It is important to note that as the figures in this section are based on total energy consumption data, they include energy used as feedstocks or raw material inputs in the manufacturing process. Although some manufacturing industries have minimal feedstock energy use, fuels are an important raw material for certain industries. For example, natural gas and petroleum feedstocks are critical to chemical manufacturing and petroleum refining, and both coal and coke are important feedstocks used in iron and steel production. However, feedstock energy inputs may or may not contribute to criteria air pollutant (CAP) and greenhouse gas (GHG) emissions, depending on the specific process in which the feedstock is used, and whether the potential emissions are embedded in the final product. In addition, feedstock inputs do not represent an opportunity for reducing the environmental impacts associated with energy consumption. As the objective of this report is to support the development of strategies for reducing CAP and GHG emissions stemming from energy consumption, the remainder of this analysis focuses on energy inputs for fuel use only and does not address feedstock energy use.

2.2 Sector Energy Overview

Insights

To develop effective sector-level energy management strategies for promoting preferred environmental outcomes, it is important to understand multiple energy usage characteristics: total energy usage, fuel mix, energy intensity, and the relative magnitude of end use applications of energy.

2.2.1 Delivered Energy

Within the constraints of data availability (as noted in table footnotes), Table 4 presents in descending order each sector's energy consumption and energy intensity data compiled in EIA's most recent (2002) MECS, which is produced every four years. While the 2002 MECS is the most recent and comprehensive data set addressing energy consumption across the sectors considered in this analysis, it is important to note that energy trends since 2002—most notably price increases for petroleum-based fuels and natural gas—have affected energy consumption across these sectors. Current energy consumption in some sectors (e.g., iron and steel, forest products, and some components of the chemical manufacturing industry) is likely to be lower than 2002 values as production has declined in light of energy cost trends and other economic factors.

Energy consumption data represent annual fuel-related energy inputs. Energy intensity is the ratio of fuel-related energy consumption to economic production in terms of dollar value of shipments and will be discussed in greater detail in Section 2.2.4.

Table 4: Sector energy consumption and energy intensity in 2002[15]

NAICS	Sector	Energy Consumption (TBtu)	Energy Consumption per Dollar Value of Shipments (thousand Btu (KBtu))
325	Chemical manufacturing	3,769	8.5
324110	Petroleum refining	3,086	16.1
322	Pulp and paper (within forest products)	2,361	15.2
331111	Iron and steel	1,455	27.8
311	Food manufacturing	1,116	2.6
336	Transportation equipment[o]	424	0.7
327310	Cement	409	56.0
332	Fabricated metal products[p]	387	1.7
321	Wood products (within forest products)	375	4.2
3313	Alumina and aluminum	351	12.2
3315	Metal casting[q]	157	5.6

o As MECS does not contain sector-level data for motor vehicle manufacturing (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), or shipbuilding and ship repair (NAICS 336611), in Table 4 through Table 8 these three sectors are represented by the larger NAICS category, transportation equipment (NAICS 336).

p As MECS does not contain sector-level data for metal finishing (NAICS 332813), in Table 4 through Table 8 this sector is represented by the larger NAICS category, fabricated metal products (NAICS 332).

q MECS data refer to NAICS 3315 as "foundries."

In general, the sectors shown in Table 4 with the largest energy requirements are also highly energy-intensive, as is the case for petroleum refining, pulp and paper, and iron and steel. However, some less energy-intensive sectors such as food manufacturing also have substantial energy requirements.

- Energy-intensive industries generally seek to control energy costs by investing in energy efficiency to the degree possible within capital constraints and competition with other uses for capital. It is possible that the easiest energy efficiency opportunities have already been exploited by these industries,[r] but the business case for energy efficiency improvement is also more clear-cut when energy represents a relatively larger fraction of production costs.
- For less energy-intensive industries with high energy usage, multifaceted energy efficiency strategies may be needed due to the wider range in energy end uses within these sectors and typically fewer business incentives to control energy costs through increased energy efficiency.

Energy consumption and energy intensity data do not present the full picture of sector energy use and associated emissions. In assessing the environmental impacts associated with energy consumption, fuel mix is of particular importance, as will be discussed in following sections. In addition, some sectors have unique energy consumption characteristics that distinguish them from other manufacturing industries, which also have implications in terms of energy-related emissions. For example, the forest products industry (pulp and paper and wood products) meets more than half of its energy requirements with renewable biomass fuels that are manufacturing process byproducts. A strategic approach to promoting energy efficiency within the industrial sector would ideally address the largest end users of energy but also consider energy intensity and other energy usage factors such as fuel mix.

2.2.2 Energy Consumption by Fuel Type

In addition to affecting energy-related air emissions, fuel mix is also important in terms of understanding how sectors may respond to changing fuel prices. Table 5 presents MECS 2002 data on annual fuel inputs by sector (energy use as fuel only, not including feedstock energy inputs). Table 6 presents the same data as a fraction of each sector's total fuel energy consumption, with the two largest fuel input fractions highlighted in gray. For comparison purposes in both tables, the line "All Industrial Codes with Figures" provides total fuel usage for all industries included in the MECS survey, including those sectors that are the subject of this analysis.

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[r] A recent paper published by the American Council for an Energy-Efficient Economy, *Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector?* offers a detailed discussion of whether all easy energy efficiency opportunities have already been exploited for the industrial sector. Available at http://aceee.org/.

Table 5: Sector energy consumption by fuel type in 2002[16] [s] [t]

NAICS	Sector	Total (TBtu)[u]	Net Electricity[v] (TBtu)	Residual Fuel Oil (TBtu)	Distillate Fuel Oil (TBtu)	Nat. Gas (TBtu)	LPG & NGL[w] (TBtu)	Coal (TBtu)	Coke & Breeze (TBtu)	Other[x] (TBtu)
All Industrial Codes with Figures		**16,276**	**2,839**	**211**	**142**	**5,794**	**103**	**1,182**	**574**	**5,431**
325	Chemical manufacturing	**3,769**	522	43	14	1,678	37	314	1	1,158
324110	Petroleum refining	**3,086**	121	21	5	821	20	1	0	2,097
322	Pulp and paper (within forest products)	**2,361**	223	100	13	504	6	234	4	1,276
331111	Iron and steel	**1,455**	184	1	10	388	*	36	526	311
311	Food manufacturing	**1,116**	230	13	19	575	5	184	1	90
336	Transportation equipment	**424**	172	6	3	203	4	8	0	28
327310	Cement	**409**	43	1	6	21	*	236	8	95
332	Fabricated metal products	**387**	161	Q	6	209	3	1	Q	2
321	Wood products (within forest products)	**375**	72	1	10	57	5	1	0	229
3313	Alumina and aluminum	**351**	193	*	1	130	1	0	*	26
3315	Metal casting	**157**	54	*	1	77	1	1	23	*

s In Tables 4 through 7 that report MECS data, we have used the "missing data" symbols used in MECS data tables. MECS defines these symbols as follows: *=estimate less than 0.5; W=Withheld to avoid disclosing data for individual establishments; and Q=Withheld because Relative Standard Error (RSE) is greater than 50 percent.

t As noted by EIA, double-counting of fuel inputs may occur when the thermal energy content of an energy input is not completely consumed for the production of heat, power, or electricity generation. These residual energy leftovers may be subsequently consumed for fuel purposes (for example, in steel manufacturing, blast furnace gas may be recovered as a byproduct from coke and other inputs that were not completely consumed and used as fuel). In such cases, fuel consumption estimates will be inflated.

u Total column may not equal the sum of rows for one or more of the following reasons: (1) data on individual fuel inputs may be withheld for reasons noted in previous footnote; or (2) independent rounding of fuel input data.

v "Net electricity" value is obtained by summing electricity purchases, transfers in, and generation from noncombustible renewables, and subtracting quantities of electricity transferred and sold. Thus, it provides a rough approximation of purchased power.

w Liquefied petroleum gases (LPG) and natural gas liquids (NGL).

x "Other" includes net steam (the sum of purchases, generation from renewables, and net transfers) and other energy that respondents indicated was used to produce heat and power.

Table 6: Sector fuel inputs as fraction of total energy requirements in 2002[17]

NAICS	Sector	Total[y]	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Nat. Gas	LPG & NGL	Coal	Coke & Breeze	Other
All Industrial Codes with Figures		**100.0%**	**17.4%**	**1.3%**	**0.9%**	**35.6%**	**0.6%**	**7.3%**	**3.5%**	**33.4%**
325	Chemical manufacturing	**99.9%**	13.8%	1.1%	0.4%	44.5%	1.0%	8.3%	0.0%	30.7%
324110	Petroleum refining	**100.0%**	3.9%	0.7%	0.2%	26.6%	0.6%	0.0%	0.0%	68.0%
322	Pulp and paper (within forest products)	**100.0%**	9.4%	4.2%	0.6%	21.3%	0.3%	9.9%	0.2%	54.0%
331111	Iron and steel	**100.1%**	12.6%	0.1%	0.7%	26.7%	*	2.5%	36.2%	21.4%
311	Food manufacturing	**100.1%**	20.6%	1.2%	1.7%	51.5%	0.4%	16.5%	0.1%	8.1%
336	Transportation equipment	**100.0%**	40.6%	1.4%	0.7%	47.9%	0.9%	1.9%	0.0%	6.6%
327310	Cement	**100.2%**	10.5%	0.2%	1.5%	5.1%	*	57.7%	2.0%	23.2%
332	Fabricated metal products	**98.7%**	41.6%	Q	1.6%	54.0%	0.8%	0.3%	Q	0.5%
321	Wood products (within forest products)	**100.0%**	19.2%	0.3%	2.7%	15.2%	1.3%	0.3%	0.0%	61.1%
3313	Alumina and aluminum	**100.0%**	55.0%	*	0.3%	37.0%	0.3%	0.0%	*	7.4%
3315	Metal casting	**100.0%**	34.4%	*	0.6%	49.0%	0.6%	0.6%	14.6%	*

As indicated by the "All Industrial Codes with Figures" data, the sectors shown in the above tables account for approximately 85 percent of all industrial energy consumption reported to MECS in 2002. The five sectors with the largest energy requirements—chemical manufacturing, petroleum refining, pulp and paper, iron and steel, and food manufacturing—represent more than 70 percent of all industrial energy consumption reported in the 2002 MECS. The following points are important to note about fuel consumption by these industrial manufacturing sectors:

- The composition of the "other" category varies from sector to sector. For chemical manufacturing, "other" fuels include petroleum-derived byproduct gases and solids, woody materials, hydrogen, and waste materials.[18] For petroleum refining, "other" fuels consist primarily of fuel gas generated in the refining process. For forest products (pulp and paper and wood products), "other" fuels are primarily biomass—black liquor, pulping liquor, and wood residues and byproducts—used to generate renewable energy. For iron and steel, the "other" category is largely composed of byproduct fuels such as coke oven gas and blast furnace gas (coal-based in origin).[19] For the cement industry, "other" includes petroleum coke as well as waste materials that are incinerated for fuel, such as old tires and municipal solid waste.[20]
- Petroleum consumption is detailed in three fuel categories: residual fuel oil, distillate fuel oil, and LPG/NGL (which contains both liquefied petroleum gas and natural gas liquids). Petroleum fuel inputs are relatively small for the sectors considered in this analysis (less than 3 percent of total fuel consumption shown in Table 5). Some additional petroleum inputs are contained in the "other" category. For petroleum refining and chemical manufacturing, these petroleum-based fuels are byproduct fuels. For cement and

y Total column may not equal 100 percent for one or more of the following reasons: (1) for sectors that exported energy produced on site, it was not possible to subtract exported energy from fuel inputs, because MECS does not indicate which fuel was used to produce the exported energy (chemical manufacturing and iron and steel report energy shipments); (2) data on individual fuel inputs may be withheld for reasons noted in previous footnotes; or (3) independent rounding of fuel input data.

aluminum, these fuels are petroleum coke. (Table 3 indicated that petroleum accounts for roughly 30 percent of total industrial energy consumption, but the majority of these inputs are used as feedstocks or for off-road transportation in sectors such as mining and construction, as mentioned in Section 2.1.2.)

- Natural gas meets a substantial fraction of energy demand for nine of the sectors listed in the previous tables—an indication of the overall importance of natural gas to industrial manufacturing sectors. Accordingly, manufacturing industries are particularly sensitive to fluctuations in the price of natural gas.
- For sectors with substantial coal consumption, the majority of coal inputs are used to power boilers and process equipment with large thermal energy requirements such as cement kilns.
- Energy-related emissions associated with offsite electric power generation occur at the generating source (usually an electric utility), which means that for sectors where purchased electricity represents a large component of energy consumption (such as aluminum, food manufacturing, metal casting, metal finishing, motor vehicle manufacturing, and motor vehicle parts manufacturing), substantial energy-related emissions occur outside the facility.

It is important to understand which fuel inputs represent the largest fraction of an industry's energy demand in order to anticipate expected responses to rising energy costs, and it is also critical to understand the constraints on an industry's capacity to shift from one energy source to another. Fuel-switching potential is discussed in the following Section 2.2.3. Possible future fuel-switching trends under "base case" and "best case" energy scenarios for each sector will be discussed in Chapter 3.

2.2.3 Fuel-Switching Potential

From an environmental perspective, one concern is that as natural gas prices increase, industries will switch away from natural gas towards more emissions-intensive energy sources such as coal. In the converse, environmentally preferable energy scenarios could involve switching from emissions-intensive energy sources such as coal toward less emissions-intensive energy sources. It is important to note that natural gas prices are sufficiently high at the present time that most facilities that can readily use coal or an alternative fuel are already using it. For existing facilities, switching from coal to natural gas is very difficult to justify on a cost basis, and promoting such fuel-switching is politically sensitive from a policy perspective.

There are considerable constraints on an industrial facility's ability to engage in fuel-switching, including technical constraints, regulatory constraints, and supply constraints.[21] Fuel-switching ability also varies according to fuel type. For example, it is easier to switch from natural gas to petroleum than from natural gas to coal. On the technical side, switching from natural gas to coal requires major changes to fuel handling equipment and boilers. On the regulatory side, if a facility is permitted for natural gas, switching to coal would trigger New Source Review under the Clean Air Act. Supply constraints relate to the cost and availability of fuel substitutes, which vary according to the location of the facility in relation to fuel transportation infrastructure. Supply constraints reduce the magnitude of environmentally preferable switching potential (e.g., from coal to natural gas) as natural gas supply infrastructure may be unable to reliably meet the fuel requirements of large industrial applications, as well as the potential for environmentally detrimental fuel-switching due to transportation infrastructure constraints affecting coal.

The MECS survey instrument asks respondents to indicate the amount of six major fuel inputs that could potentially be switched (within 30 days of the switching decision) to an alternate fuel given constraints imposed by existing equipment configurations and legal obligations such as binding supply contracts and environmental regulations.[z] Based on these survey responses, Table 7 summarizes data from the 2002 MECS on each sector's potential to switch from natural gas to one of seven alternate fuel sources, and Table 8 summarizes similar data for coal. (Data do not include fuels consumed as feedstock.) In each Table, the first three columns show the fraction of each sector's fuel consumption that could be switched to an alternate fuel source, as well as the fraction that is non-switchable, and the fraction that was unreported as either switchable or non-switchable. The remaining columns show the percentage of the switchable fuel fraction that could be met by each of the alternate fuels. (Note that there is double-counting in the alternate fuels columns—for example, a portion of the natural gas fraction could be switched to either distillate or residual fuel oil—so the sum of the alternate fuels columns will not equal 100 percent.)

As we have done with other tables using MECS data, for comparison purposes we also report the totals for all industries included in the MECS survey, including those sectors that are the subject of this analysis. These data appear in the lines entitled "All Industrial Codes with Figures."

Table 7: Sector fuel-switching potential in 2002: natural gas to alternate fuels[22] [aa]

		Natural Gas Switching Potential			Alternate Fuels That Could Be Substituted for Natural Gas (shown as percentage of switchable fraction)						
NAICS	**Sector**	**Switchable Fraction**	**Non-Switchable Fraction**	**Non-Reported Fraction**	**Electric Receipts[bb]**	**Distillate Fuel Oil**	**Residual Fuel Oil**	**LPG**	**Coal**	**Coke & Breeze**	**Other[cc]**
All Industrial Codes with Figures		**19%**	**63%**	**18%**	**10%**	**38%**	**22%**	**34%**	**4%**	**0%**	**7%**
3313	Alumina and aluminum	9%	77%	14%	*	27%	9%	64%	0%	0%	*
327310	Cement	29%	62%	10%	17%	17%	33%	17%	67%	17%	17%
325	Chemical manufacturing	10%	64%	26%	9%	45%	32%	13%	Q	0%	7%
332	Fabricated metal products	Q	57%	43%	*	*	*	Q	Q	*	Q
311	Food manufacturing	28%	53%	19%	13%	45%	26%	41%	1%	*	Q
331111	Iron and steel	12%	78%	10%	*	11%	62%	Q	13%	4%	9%
3315	Metal casting	20%	68%	12%	13%	13%	*	73%	*	*	*
324110	Petroleum refining	18%	64%	18%	8%	19%	5%	58%	*	*	27%
322	Pulp and paper (within forest products)	32%	58%	10%	16%	45%	35%	9%	5%	*	4%
336	Transportation equipment	18%	64%	18%	11%	33%	17%	42%	11%	*	*
321	Wood products (within forest products)	20%	68%	13%	9%	27%	9%	36%	*	*	27%

z For a detailed description of MECS approach and assumptions related to defining fuel-switching capability, see http://www.eia.doe.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html#cfsc.

aa In Tables 4 through 7 that report MECS data, we have used the "missing data" symbols used in MECS data tables. MECS defines these symbols as follows: *=estimate less than 0.5; W=Withheld to avoid disclosing data for individual establishments; and Q=Withheld because Relative Standard Error (RSE) is greater than 50 percent.

bb "Electric receipts" includes quantities of purchased electric power and has not been adjusted to account for any quantities that might have been resold or transferred out. It does not include electricity generated onsite.

cc "Other" includes all other types of fuel that respondents indicated could have been consumed and not otherwise listed.

Table 8: Sector fuel-switching potential in 2002: coal to alternate fuels[23]

		Coal Switching Potential			Alternate Fuels That Could Be Substituted for Coal (shown as percentage of switchable fraction)					
NAICS	Sector	Switchable Fraction	Non-Switchable Fraction	Non-Reported Fraction	Electric Receipts [dd]	Natural Gas	Distillate Fuel Oil	Residual Fuel Oil	LPG	Other
All Industrial Codes with Figures		**30%**	**58%**	**12%**	**3%**	**80%**	**18%**	**17%**	**4%**	**6%**
3313	Alumina and aluminum	0%	0%	100%	0%	0%	0%	0%	0%	0%
327310	Cement	51%	45%	3%	W	91%	W	W	4%	8%
325	Chemical manufacturing	36%	62%	2%	1%	82%	14%	11%	0%	W
332	Fabricated metal products	0%	100%	0%	0%	0%	0%	0%	0%	0%
311	Food manufacturing	20%	80%	0%	0%	83%	Q	13%	19%	0%
331111	Iron and steel	3%	97%	0%	0%	40%	0%	0%	0%	60%
3315	Metal casting	0%	100%	0%	0%	0%	0%	0%	0%	0%
324110	Petroleum refining	W	W	W	0%	W	W	0%	0%	0%
322	Pulp and paper (within forest products)	23%	37%	40%	10%	57%	28%	38%	W	10%
336	Transportation equipment	W	W	W	4%	94%	14%	0%	1%	1%
321	Wood products (within forest products)	W	W	W	0%	W	0%	0%	W	0%

In terms of sectors switching from natural gas to alternate fuel inputs, Table 7 illustrates the following points:

- In all cases, the non-switchable fraction is larger than the switchable fraction, indicating the importance of the aforementioned constraints to fuel-switching (technical, regulatory, and supply constraints).
- In general, there is greater potential for sectors to replace natural gas inputs with petroleum fuel inputs (distillate and residual fuel oil, as well as LPG), and relatively less potential to replace natural gas with purchased electricity or coal.
- For sectors with the largest natural gas consumption (chemical manufacturing, food manufacturing, petroleum refining, and pulp and paper, as shown in Table 5), there is a wide range in ability to switch from natural gas to other fuels. The chemicals sector, which has the highest natural gas consumption, has a particularly low switchable fraction.

In terms of switching from coal to alternate fuel inputs, Table 8 illustrates the following points:

- In all cases except cement, the non-switchable fraction is larger than the switchable fraction.
- Natural gas has the greatest potential as a substitute for coal, which would lead to a decrease in energy-related emissions. However, factors such as the substantially higher cost of natural gas and constraints imposed by natural gas supply infrastructure limit the viability of this opportunity for energy-related environmental improvement.

[dd] "Electric receipts" includes quantities of purchased electric power and has not been adjusted to account for any quantities that might have been resold or transferred out.

- For the four sectors with the largest coal consumption (cement, chemical manufacturing, iron and steel, and pulp and paper, as shown in Table 5), there is again a wide range in the potential for switching to alternate fuel sources. In particular, iron and steel has limited ability to switch away from coal consumption, which is why the industry is interested in the development of technologies that reduce the emissions-intensity of coal consumption.[24]

2.2.4 Energy Intensity

As mentioned previously, energy intensity is the ratio of energy consumed as fuel (i.e., not including energy feedstocks) to economic production. Energy-intensive industries may be more receptive to efforts to increase energy efficiency due to the economic impacts associated with rising fuel input costs. Energy intensity can be measured in terms of energy consumption per volume of production (physical energy intensity) or in terms of energy consumption per dollar value of output (economic energy intensity). In this report, we primarily use metrics of economic energy intensity, supplementing with physical energy intensity metrics where data are available. It is important to note that economic energy intensity is affected both by energy consumption and the value of the product, which contributes to the magnitude of difference in energy intensity between many basic manufacturing industries versus finished product manufacturing industries. For example, a ton of steel or cement has a much lower economic value than a ton of integrated circuits or finished consumer goods. Because steel or cement production have both a lower economic value and a higher energy input, the energy intensity of these basic manufacturing industries is higher than many industries producing finished goods.

MECS presents several ratios of manufacturing energy consumption to economic production; the most useful are energy consumption per dollar of value added and energy consumption per dollar value of shipments.[ee] "Dollar of value added" represents the net economic output, or gross economic output less the value of purchased inputs. This measure of manufacturing activity is derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments (products manufactured plus receipts for services rendered). "Dollar value of shipments" represents the gross economic value of product shipments, including the cost of inputs, and thus does not provide as refined a measurement of an industry's reliance on energy inputs for economic productivity. Value added is considered to be the best metric for comparing the relative economic importance of manufacturing among industries and geographic areas. However, as the key energy projections referenced in this report—EIA's *Annual Energy Outlook*, the *Clean Energy Future* report, and the American Gas Foundation's *Natural Gas Outlook to 2020*—all employ gross value of shipments as an economic metric, we primarily use value of shipments for the purposes of this analysis.

For each sector, Table 9 presents 2002 MECS data on energy consumption per economic output. As a benchmark, the energy consumption per economic output ratios are aggregated for all industrial sectors addressed in the MECS survey (listed as "All Industrial Codes with Figures").[ff] MECS calculates energy intensity based on energy consumed as a fuel, and the ratios do not include fuels consumed as feedstocks.

As MECS does not contain data for four of the sectors considered in this analysis (metal finishing, motor vehicle manufacturing, motor vehicle parts manufacturing, and shipbuilding and

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ee In the 2002 MECS, EIA uses economic data from the U.S. Census Bureau's *2002 Economic Census, Manufacturing - Industry Series*.

ff EIA favors use of a MECS-weighted value of shipments in calculating ratios used in this table in order to minimize any sample peculiarities that may impact both consumption and value of shipments. This may result in deviations from intensities calculated using unweighted MECS energy consumption data.

ship repair), for all sectors we have included 2002 Census Bureau data from the *Annual Survey of Manufacturers* on costs of purchased energy per dollar of value added and per dollar of value of shipments as an approximation of energy intensity. For these metrics, the benchmark is the average for all manufacturing industries (NAICS 31-33).

Table 9: Sector energy intensity in 2002[25] [26]

NAICS	Sector	Energy Consumption per Dollar of Value Added (KBtu)	Energy Consumption per Dollar Value of Shipments (KBtu)	Energy Cost per Dollar of Value Added (share)	Energy Cost per Dollar Value of Shipments (share)
All Industrial Codes with Figures (benchmark)		**8.9**	**4.2**	**3.7%**	**1.8%**
Higher than benchmark					
324110	Petroleum refining	116.3	16.1	21.0%	3.1%
327310	Cement	95.5	56.0	24.5%	15.1%
331111	Iron and steel[gg]	66.5	27.8	20.4%	8.0%
3313	Alumina and aluminum	34.3	12.2	21.0%	6.9%
322	Pulp and paper (within forest products)	31.1	15.2	8.8%	4.3%
325	Chemical manufacturing	15.3	8.5	5.4%	3.0%
321	Wood products (within forest products)	10.6	4.2	4.7%	1.9%
3315	Metal casting	10.3	5.6	8.0%	4.6%
332813	Metal finishing[hh]	NA	NA	6.7%	4.0%
Lower than benchmark					
311	Food manufacturing	6.0	2.6	3.3%	1.5%
332	Fabricated metal products	3.0	1.7	2.7%	1.5%
3363	Motor vehicle parts manufacturing	NA	NA	2.1%	0.9%
336611	Shipbuilding and ship repair	NA	NA	1.2%	0.8%
33611	Motor vehicle manufacturing[ii]	NA	NA	1.1%	0.3%

It is important to note that the MECS energy intensity data are based on delivered energy consumption rather than primary energy consumption. Thus, it does not account for energy losses in the generation, transmission, and distribution of electric power (for additional detail, see the *Energy Losses in Purchased Electricity* sidebar in Section 2.2.5). This means that for a given energy requirement and a given dollar value of output, a sector that derives its process energy from direct combustion of natural gas onsite could have the same delivered energy intensity as one that receives process energy from purchased power. In reality, however, the electric power-dependent sector is more energy intensive from a system-wide perspective because of the losses associated with electric power generation, transmission, and distribution. To some degree the two energy cost columns in Table 9 (energy cost per dollar of value added and energy cost per dollar value of shipments) provide a closer approximation of primary energy intensity, since electric power is more costly on a Btu basis than energy produced from direct fuel inputs onsite.

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gg Census Bureau data are for the larger NAICS category, iron and steel and ferroalloy manufacturing (NAICS 33111).

hh Census Bureau data are for the larger NAICS category, coating, engraving, heat treating, and allied activities (NAICS 33281).

ii Census Bureau data refer to NAICS 33611 as "automobile and light duty motor vehicle manufacturing."

Of the five sectors with the greatest annual energy requirements—chemical manufacturing, petroleum refining, pulp and paper, iron and steel, and food manufacturing—all but food manufacturing are more energy-intensive than the industrial manufacturing benchmark. However, comparing sector energy consumption with energy intensity highlights some important distinctions:

- Though the chemicals sector has the greatest energy consumption, it not the most energy intensive.
- The aluminum industry is highly energy intensive but uses far less energy than the five sectors with the highest energy consumption, in part due to the comparatively smaller size of the aluminum industry.
- The food manufacturing industry ranks fifth in terms of total energy usage (see Table 4), but it has a lower energy intensity than the industry benchmark.

These results indicate the importance of using multiple metrics to characterize sector energy usage. The energy intensity ratios shown in Table 9 are also important because they indicate an industry's expected sensitivity to fluctuations in fuel prices.

- Increasing energy costs are likely to have the greatest impact on industries with higher energy costs per dollar of value added and per dollar value of shipments than the manufacturing industry benchmark—particularly petroleum refining, cement, aluminum, and iron and steel.
- Despite the fact that the aggregated energy requirements of the food manufacturing industry are large, energy costs represent a relatively small fraction of economic output (lower than the manufacturing industry benchmark), which likely accounts for the fact that this sector has not historically engaged in energy efficiency efforts to the same degree as highly energy-intensive manufacturing industries.

When we discuss the economic context for energy usage in Section 2.4, the energy cost and energy intensity ratios are the metrics we use to rank the sectors in terms of sensitivity to energy costs (see Table 17).

2.2.5 The Manufacturing Energy System

For manufacturing industries, including the 12 sectors considered in this analysis, the major stages of energy use include the following:[27]

- ***Energy generation:***
  - Fossil fuels are the largest energy inputs in manufacturing and may be used in central plants to generate electricity, steam, or CHP, or used directly to power manufacturing process systems.[jj]
  - Purchased electric power is another important energy input that is generated offsite by electric utilities and transmitted to the facility.
  - Energy may also be supplied by renewable energy sources onsite. Though the renewable fraction is small for most sectors, in the forest products industry more than half of the sector's energy requirements are provided through onsite power generation using renewable biomass fuels.
  - Though a less commonly utilized energy source than purchased fuels or electricity, some industrial plants also purchase steam and/or chilled water.

> **Energy Losses in Purchased Electricity**
>
> Electric power generation is associated with substantial energy losses, particularly for fossil fuel-fired power plants. The magnitude of such losses varies greatly according to factors such as fuel inputs and age of equipment. Electric power transmission and distribution are associated with smaller energy losses.
>
> Aggregated across the national grid, the energy loss fraction is 67.5 percent of total electric energy, meaning that delivered electricity consumption represents just over 30 percent of total energy inputs for electric power generation.

- ***Energy transmission/distribution:*** Within the facility, energy transmission/distribution systems include piping for steam, hot water, chilled water, cooling water, compressed air, steam condensate return, and chilled water return piping, fuel piping, and wires for electric power transmission.
- ***Energy end uses:***
  - Facility-related energy requirements include lighting, heating, ventilating, and air conditioning (HVAC), and office equipment, and typically comprise a relatively small fraction of manufacturing energy use.
  - Equipment energy use includes direct energy inputs for process heating, cooling, and electrochemical transformation, as well as indirect energy inputs for machine drives that operate pumps, compressors, fans, blowers, conveyors, and mixers. Common processes used in industrial manufacturing applications include separation, melting, drying, mixing, grinding, forming, and waste handling.

Each stage of the manufacturing energy system—energy generation, transmission/distribution, and use—is associated with energy losses. Substantial offsite energy losses are associated with electric generation (see previous sidebar, *Energy Losses in Purchased Electricity*), and these losses are represented by the difference between primary and delivered energy consumption. In the manufacturing energy system, several categories of losses represent general areas of opportunity for increased energy efficiency:[28]

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jj Fossil fuels are also used as manufacturing feedstocks (raw materials) by some sectors, but feedstock fuel use is not included in DOE's manufacturing energy footprint diagrams that are discussed in this section.

- ***Energy generation losses:***
  - *External generation losses* are most significant for electric power generation, transmission, and distribution, but for any given manufacturing facility the external loss fraction will vary according to the efficiency of local sources of electric power generation. (As an average for the entire national grid, DOE assumes the efficiency of utility power generation and transmission is 32.5 percent, meaning that associated energy losses are assumed to be 67.5 percent).[29] A small amount of loss also occurs with fuel transport (approximately 3 percent of total fuel energy). Facilities can reduce offsite energy losses through more efficient use of purchased electricity, and to some degree by replacing purchased electricity with onsite electricity generation, which is also associated with energy losses.
  - *Onsite generation losses* occur in central energy generation applications such as steam plants, power plants, and CHP plants. Losses from boilers vary widely due to equipment age, fuel type, and maintenance, and range from 10 to 45 percent.[30] More efficient generating processes such as CHP are associated with lower internal generation losses.
- ***Onsite energy transmission/distribution losses:*** Within the facility, energy is lost in fuel and electricity distribution lines, as well as steam pipes, traps, and valves. The magnitude of such losses ranges from 3 to 40 percent, but the largest losses are typically in steam pipes (20 percent) with smaller losses associated with fuel transmission lines and electric wires (3 percent).[31]
- ***Equipment energy losses:*** Energy is also lost due to inefficiencies in the wide range of equipment used for preprocess and manufacturing process activities: motors, mechanical drives, process heaters and coolers, etc. Again, there is a wide range in how much energy is typically lost from such equipment. Compressors typically lose as much as 80 percent of energy inputs, pumps and fans typically lose 35 to 45 percent, and motors lose 5 to 10 percent.[32]

DOE's Industrial Technologies Program (ITP) has compiled a set of energy use and loss footprints for many of the sectors considered in this analysis, as well as an aggregated footprint for U.S. manufacturing industries (energy consumption data used in this analysis were from the 1998 MECS).[33] In Table 10, we examine three energy loss categories as a fraction of each industry's primary energy requirements: (1) external losses (losses in energy generation, transmission, and distribution) associated with purchased electricity and fossil fuel inputs; (2) onsite generation, transmission, and distribution losses (generation losses from thermal and electric generating equipment, as well as losses from pipes, valves, steam traps, and electric and fuel transmission lines occurring within the facility); and (3) equipment losses (losses from preprocess energy conversion equipment such as heat exchangers, condensers, heat pumps, machine drives, pumps, and motors). We also examine two energy end use categories as a fraction of each industry's primary energy requirements: (1) process energy consumption (energy used in the manufacturing process) and (2) facilities energy use (energy used for lighting, HVAC, etc.).

Table 10: Sector energy use and loss footprint in 1998[34]

NAICS	Sector	External Generation/ Transmission Losses	Onsite Generation/ Transmission Losses	Energy Conversion Equipment Losses[kk]	Process Energy Consumption	Facilities Energy Use
3313	Alumina and aluminum	54%	3%	13%	28%	1%
327310	Cement	20%	3%	14%	63%	0.5%
325	Chemical manufacturing	27%	14%	13%	44%	2%
332	Fabricated metal products[ll]	46%	3%	11%	28%	12%
311, 312	Food & beverage manufacturing	31%	14%	10%	39%	5%
321, 322	Forest products[mm]	19%	25%	12%	42%	2%
33111	Iron, steel, and ferroalloy[nn]	19%	4%	14%	60%	3%
3315	Metal casting[oo]	37%	3%	9%	41%	10%
324110	Petroleum refining	9%	12%	13%	64%	1%
336	Transportation equipment[pp]	46%	6%	10%	22%	16%

The energy use and loss footprints illustrate important differences in the way these sectors use energy:

- Due to the magnitude of energy losses associated with electricity generation, transmission, and distribution, electricity-dependent sectors such as aluminum, fabricated metal products (the larger NAICS category that includes metal finishing), and transportation equipment have high external generation/transmission losses.
- The magnitude of onsite generation and transmission losses in the chemical manufacturing, food manufacturing, forest products, and petroleum refining industries is attributable to the fact that these sectors meet a larger fraction of their energy needs with onsite generation. Given the magnitude of associate energy losses, boilers and other onsite energy generating equipment represent a key area for energy efficiency improvement.
- The relatively small process energy fraction for less energy-intensive sectors like fabricated metal products and transportation equipment suggests that energy efficiency opportunities are likely to lie in a number of areas, in addition to process-related improvements.

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kk DOE addresses energy use and losses by energy conversion equipment (preprocess) and process equipment separately but does not attempt to quantify process energy losses, primarily because energy conversion equipment and process equipment are frequently integrated, making it difficult to distinguish preprocess from process energy losses.

ll Metal finishing (NAICS 332183) is included in the larger NAICS category, fabricated metal products (NAICS 332).

mm Forest products includes the wood products (NAICS 321) and pulp and paper (NAICS 322) sectors.

nn Iron and steel mills (NAICS 331111) is included in the larger category for iron, steel, and ferroalloy manufacturing (NAICS 33111).

oo DOE refers to NAICS 3315 as "foundries."

pp Motor vehicle assembly (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), and shipbuilding and ship repair (NAICS 336611) are included in the larger NAICS category, transportation equipment (NAICS 336).

2.2.6 Energy Efficiency and Clean Energy Opportunities

In the sector summaries contained in Chapter 3, we focus on five primary opportunities for reducing the environmental impact of energy use—primarily air emissions of GHGs and CAPs. These opportunities promote environmentally preferable energy outcomes by reducing energy-related air emissions through increased energy efficiency (which reduces fuel consumption and associated emissions) and/or transitioning to less emissions-intensive energy sources.

- ***Cleaner fuels.*** These opportunities involve replacing fuel inputs with alternate fuel inputs that produce lower GHG and/or CAP emissions for the same amount of energy in terms of Btus (e.g., natural gas in place of coal). This category also includes onsite renewable electricity generation using biomass, wind, solar, or geothermal power. Two clarifying points need to be made. First, in general there is no perfect hierarchy of what constitutes a "cleaner" fuel across all applications, as emissions will vary according to plant-specific factors such as equipment age and pollution control mechanisms. Second, also note that "alternate fuels," such as waste fuels used in cement kilns, may or may not be cleaner than what they are replacing depending on unit-specific characteristics.
- ***Increased CHP.*** Combined heat and power applications increase energy efficiency by producing heat (typically steam) and power (electricity) from a single fuel source—a form of cogeneration. Some CHP systems are engineered to provide electricity, hot water, and chilled water as well, depending on the needs of the particular industry. Common fuel inputs for CHP include coal, natural gas, biomass, and fuel oil. CHP is a form of distributed generation, as electricity is generated at the facility level rather than by an electric utility, and thus is associated with lower levels of transmission and distribution losses than purchased electricity. Conventional generation of electric power also wastes much of the heat generated in electricity production (which CHP uses), and conventional thermal energy generation often misses an easy opportunity to generate electric power. As a result, CHP systems have efficiencies exceeding 70 percent. CHP systems achieving efficiencies exceeding 80 percent are frequent, and some highly integrated systems have been shown to reach levels in excess of 90 percent. CHP represents a substantial efficiency improvement compared with a state-of-the-art central plant that offers maximum system fuel efficiency for delivered power in the range of 55 to 60 percent.[35]
- ***Equipment retrofit/replacement.*** Energy efficiency can be increased by retrofitting or replacing existing equipment used for onsite heat or power generation and distribution, manufacturing processes, or to meet facility requirements such as lighting or HVAC. Many of the sectors considered in this report have substantial onsite capacity for generating electric and thermal energy, and upgrades to such equipment can reduce energy losses. Given the magnitude of industrial process energy requirements, retrofitting or replacing existing process equipment offers the potential for substantial increases in energy efficiency, and thus a reduction in energy-related emissions per unit of manufacturing output. Equipment is most likely to be replaced at the end of its full service life, because new highly capital-intensive equipment purchases usually cannot be justified on the basis of energy savings alone. Also, equipment replacement often entails substantial time requirements for design, engineering, building, installing, and commissioning. Installing new process equipment typically involves building a new process line rather than shutting down operating equipment, and this constraint requires that the facility have sufficient space available to support the new line. As full equipment replacement often faces these types of hurdles, retrofitting may be a more viable opportunity in many cases. Retrofitting

or replacing facility equipment such as lighting and HVAC system components may also be easier to achieve from an operational and capital standpoint.

- ***Process improvement.*** This term encompasses a broad range of opportunities for increasing energy efficiency and reducing energy-related emissions, some of which are major capital-intensive changes and some of which are relatively minor low-cost improvements. Capital-intensive opportunities entail wholesale process changes such as the transition from wet to dry kilns in cement manufacturing, or from the blast furnace and coke plant to direct iron ore reduction in steelmaking. (Note that in cases where process changes require installation of new equipment, such opportunities could also be classified as “equipment replacement,” but we have made an effort to differentiate these wholesale process-related changes from other types of equipment upgrades). Less capital-intensive opportunities are primarily geared towards implementing energy management best practices or adjusting existing processes to improve energy efficiency and/or achieve other environmental benefits such as waste minimization. Examples include reducing waste treatment energy requirements through increased recycling of process materials and scheduling production activities to reduce equipment idling time.
- ***Research and development (R&D).*** As noted earlier, a number of sectors participate in DOE’s ITP and/or other R&D efforts in order to develop and commercialize higher-efficiency technologies and processes. These projects represent typically longer-term energy efficiency opportunities.

In some cases, exploiting one or more of these opportunities may produce an environmental quality improvement in some respects, and an environmental quality reduction in other areas. For example, reducing inputs of purchased electricity in favor of natural gas may reduce energy-related emissions at the electric generation level and improve the overall efficiency of energy use (because direct natural gas inputs at the facility level are associated with lower energy losses than purchased electricity), but may lead to an increase in energy-related emissions at the facility level. In the *Environmental Implications* section of each sector summary (see Chapter 3), we seek to identify such tradeoffs to the extent possible.

2.2.7 Transportation Energy Consumption

This analysis focuses on energy use and energy efficiency opportunities at manufacturing facilities and does not address in detail transportation energy requirements, which are substantial for many sectors with respect to freight shipping. Though it was not possible to obtain annual data on product shipments for all sectors, Table 11 summarizes commodity shipping data for some of the sectors covered in this analysis. The commodities shown in the table represent more than half of all U.S. commodity shipments in 2002. The food manufacturing sector is particularly intensive in terms of transportation energy requirements.

Table 11: Commodity shipments by sector in 2002[36]

Commodity	Ton miles (millions)[qq]	% of Total
All commodities	**3,137,898**	**100.0%**
Food	678,263	21.6%
Petroleum and coal products	265,684	8.5%
Chemicals	268,560	8.6%
Wood products	127,941	4.1%
Paper	118,557	3.8%
Iron and steel	93,934	3.0%
Fabricated metal products[rr]	42,680	1.4%
Transportation equipment	69,678	2.2%
Remaining commodity shipments	1,472,601	46.9%

qq A ton mile is a unit of freight transportation that is derived by multiplying the distance the freight is hauled in miles by the weight of the shipment in tons. (See DOE's *Energy Efficiency Glossary* at http://www.eia.doe.gov/emeu/efficiency/ee_gloss.htm.)

rr Metal finishing (NAICS 332183) is included in the larger NAICS category, fabricated metal products (NAICS 332).

2.3 Environmental Context

Insights

National Emissions Inventory (NEI) data on energy-related emissions of criteria air pollutants by the sectors considered in this analysis show that sulfur dioxide and nitrogen oxides comprise the largest fraction of energy-related emissions.[ss] Though not represented in NEI emissions data, energy use also contributes to emissions of the GHG carbon dioxide (CO_2), which is an important contributor to global climate change. Key opportunities for reducing energy-related emissions lie with energy efficiency upgrades to external combustion boilers and process equipment.

2.3.1 Sources and Impacts of Energy-Related Air Emissions

Our assessment of the environmental effects of sector energy use focuses on air emissions. Energy-related air emissions sources include the following:

- Stationary source emissions, for the purposes of this analysis, include those that occur at the manufacturing facility from fuels consumed onsite to generate electric or thermal energy, as well as fuels required to power manufacturing process equipment, and offsite emissions from electric power generation that meets the purchased electricity fraction of manufacturing energy requirements.
- Mobile source emissions are primarily associated with freight shipping. We do not seek to quantify sector-related mobile source emissions for the purposes of this analysis.

Table 12 summarizes the health and environmental impacts associated with the primary energy-related air pollutants considered in this analysis.

Table 12: Health and environmental impacts of energy-related air pollutants[37]

Pollutant	Health Impact	Environmental Impact
Carbon dioxide (CO_2)	None	Greenhouse gas that contributes to global warming
Carbon monoxide (CO)	Reduces blood's capacity for carrying oxygen to body cells and tissues; is particularly damaging for people with impaired cardiovascular and lung function	A greenhouse gas precursor that contributes to the formation of methane and carbon dioxide in the atmosphere[38]
Nitrogen oxides (NOx)	Causes lung damage and respiratory illness	Contributes to acid rain that degrades soil and water quality; forms acid aerosols that reduce visibility; contributes to fine particulates and ozone
Particulate matter (PM)	Causes respiratory system irritation and illness; causes lung damage	Forms haze that reduces visibility
Sulfur dioxide (SO_2)	Causes respiratory illness and may lead to lung damage	Contributes to acid rain that degrades soil and water quality; forms acid aerosols that reduce visibility; contributes to fine particulates
Volatile organic compounds (VOCs)	Causes respiratory illnesses including asthma; irritates eyes and respiratory system; some VOCs may cause cancer	Reacts with nitrogen oxides to form ozone; some VOCs damage vegetation
Ozone (ground-level)[tt]	Causes respiratory illnesses including asthma; irritates eyes and respiratory system	Forms smog that reduces visibility; damages vegetation

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ss NEI data also show substantial energy-related carbon monoxide (CO) emissions, but as CO does not typically represent a large component of combustion-related emissions from stationary sources, NEI data may overstate such emissions and thus we devote minimal discussion to emissions of CO.

tt This analysis is not able to quantify ground-level ozone resulting from sector energy consumption, though VOC and NOx emissions that contribute to ozone formation are reported in Section 2.3.2 and at the sector level in Chapter 3.

In manufacturing industries, the majority of energy-related emissions of CAPs are attributable to combustion processes. Sulfur dioxide emissions mostly result from combustion of sulfur-containing fuels, primarily coal. Nitrogen oxides are also products of combustion, but emissions do not vary as much by fuel type as SO_2 emissions. Particulate matter can be ash and dust resulting from the combustion of coal or heavy oil, or very fine particulates ($PM_{2.5}$), which are largely composed of aerosols formed by nitrogen oxide and sulfur dioxide emissions. Carbon monoxide is a product of incomplete combustion, but the largest source is vehicles, with stationary sources typically contributing a smaller part of the inventory. Volatile organic compounds (VOCs) can also result from incomplete combustion, but the largest energy-related components are fugitive emissions from fuel storage tanks and pipelines, and combustion-related vehicle emissions. The largest components of energy-related CAP emissions from the industrial sector are SO_2, NOx, and larger particulates from combustion of coal. Excepting emissions from off-road vehicles, VOCs and CO emissions from combustion are a much smaller fraction of total energy-related emissions.

More than half of the U.S. population lives in counties that are in non-attainment for ozone and/or particulate matter National Ambient Air Quality Standards (NAAQS).[39] Energy-related emissions of NOx and VOCs contribute to ground-level ozone formation, and SO_2 emissions contribute to PM formation. Thus, reducing energy-related CAP emissions by industrial sources is an important component of ongoing efforts to achieve NAAQS.

Another critical environmental impact of energy use is emissions of the GHG carbon dioxide, which also results from fuel combustion processes and is an important contributor to global climate change. (Other GHGs, such as methane, also contribute to global climate change, but as energy-related sources of these GHGs are not substantial, we focus primarily on CO_2 emissions in this analysis.) Such emissions do not impact regional air quality, but CO_2 is persistent in the upper atmosphere, trapping infrared radiation from the earth's surface and contributing to increases in the earth's temperature.

Though this analysis focuses primarily on CAP and GHG emissions, energy consumption also contributes to emissions of other hazardous air pollutants (HAPs), including mercury. In addition, this analysis does not attempt to quantify energy-related impacts on soil and water quality.

2.3.2 Approach Used to Assess Energy-Related Air Emissions

In our assessment of environmental impacts resulting from sector energy consumption, this analysis focuses on CAP emissions, as well as two pollutants that contribute to the formation of CAPs: VOCs and ammonia (NH_3). (Ammonia is a very minor component of energy-related emissions, but is included in this analysis as it is one of the pollutants represented in the NEI data set.) We collectively refer to emissions of these pollutants as CAPs. In addition to the overview of energy-related CAP emissions across all sectors contained in Section 2.3.3, the sector summaries in Chapter 3 present a more detailed description of energy-related CAP emissions for each sector, using data from NEI.

EPA's NEI is a national database of CAP and HAP emissions based on data from numerous state, tribal, and local air pollution control agencies; industry-submitted data; data from other EPA databases; as well as emissions estimates. State and local emissions inventories are submitted to EPA once every three years for most point sources contained in NEI. This analysis uses the *Draft 2002* NEI data, as the *Final 2002* data are not currently available at the level of detail required for this analysis.

In the NEI database, point source emissions are associated with industry classification codes (NAICS or Standard Industrial Classification (SIC) codes) as are the 12 sectors addressed in this analysis. It is important to note that emissions stemming from the generation of purchased energy (primarily electricity, but also other non-fuel sources of energy such as steam that may be purchased by industrial manufacturing sectors) are attributed to the generating source, not the purchasing entity. Therefore, emissions for any given sector will not include emissions from purchased energy. Recognizing this omission will be particularly important for electricity-dependent sectors, as noted in the sector summaries in Chapter 3.

- CAP emissions in NEI are associated with several levels of source classification codes (SCC) that indicate the detailed source of each CAP emission data point. SCCs are associated with emissions from all source categories (point, area, and mobile). For the purposes of this analysis, more than 1,000 SCCs were identified as being "energy-related" from the list of 9,865 SCCs. Energy-related CAP emissions include emissions from combustion processes, such as those SCCs listed in the following general source categories:
  - External combustion boilers
  - Internal combustion engines
  - Stationary source fuel combustion
- *Energy-related CAP emissions* also include emissions from the use of fuels for energy in industrial processes (such as process heaters) and emissions from the storage of fuels.
- *All other CAP emissions* include process-related CAP emissions not related to fuel combustion, emissions where it was unclear from the SCC whether they are energy-related (such as SCC descriptions "Not Specified," "Not Defined," "Not Classified," "Miscellaneous," "General," or "All Processes"), and sector emissions that are not associated with an SCC.
- In Chapter 3, the figures showing NEI data on energy-related CAP emissions include the following:
  - *Energy-related CAP emissions:* Compares energy-related CAP emissions with all other CAP emissions.
  - *Emissions by criteria air pollutant:* Shows the fraction of total energy-related CAP emissions represented by each CAP.
  - *Emissions by source category:* Shows energy-related CAP emissions by the most general available source category (e.g., external combustion boilers, internal combustion engines, and industrial processes).
  - *Emissions by fuel type:* Shows energy-related CAP emissions that source from the use of a fuel (e.g., distillate oil or natural gas). It also aggregates emissions of combustion byproducts (e.g., exothermic) or handling fuels (e.g., coal handling and storage) as "Unknown."

As NEI data do not capture CO_2 emissions, we include CO_2 emissions estimates and projections from EIA's 2006 *Annual Energy Outlook* and the *Clean Energy Future* report, which address eight of the sectors included in this analysis. We address projected CO_2 emissions under our "base case" and "best case" energy scenarios in Chapter 3.

2.3.3 Stationary Source Emissions

Table 13 presents NEI data on annual energy-related CAP emissions by sector (units are tons per year (TPY)).

Table 13: Energy-related CAP emissions by sector in 2002[40]

NAICS	Sector	CO (TPY)[uu]	NOx (TPY)	PM_{10} (TPY)	SO_2 (TPY)	NH_3 (TPY)	VOC (TPY)	All Energy-Related CAP (TPY)	All CAP Emissions (TPY)
3313	Alumina and aluminum	6,776	13,036	474	51,176	40	1,234	**72,736**	**538,841**
327310	Cement	15,674	11,636	668	12,943	3	553	**41,477**	**544,501**
325	Chemical manufacturing	213,176	220,183	10,510	279,403	4,474	11,377	**739,123**	**1,536,183**
311	Food manufacturing	70,848	73,073	7,218	90,203	860	5,522	**247,724**	**395,289**
331111	Iron and steel	125,574	45,779	6,858	43,589	1,543	4,465	**227,808**	**850,644**
332813	Metal finishing	11	28	1	70	0	1	**111**	**374**
3315	Metal casting	1,790	2,295	150	759	24	207	**5,225**	**72,645**
33611	Motor vehicle manufacturing	2,456	3,720	167	2,235	27	196	**8,801**	**48,761**
3363	Motor vehicle parts manufacturing	201	492	26	9	8	131	**867**	**7,778**
324110	Petroleum refining	46,942	117,470	8,738	108,189	1,366	16,133	**298,838**	**788,985**
322	Pulp and paper (within forest products)	195,218	184,514	17,617	303,285	1,215	19,099	**720,948**	**1,173,568**
321	Wood products (within forest products)	101,106	26,369	17,271	3,658	90	34,791	**183,285**	**289,727**
336611	Shipbuilding and ship repair	186	866	90	1,150	6	121	**2,419**	**5,520**
Total		**779,958**	**699,461**	**69,788**	**896,669**	**9,656**	**93,830**	**2,549,362**	**6,252,816**

As noted in Section 2.3.2, the NEI data presented in Table 13 represent energy-related emissions that occur at the facility level but do not capture emissions associated with the generation and transmission of purchased electricity. For electricity-dependent sectors such as aluminum, the magnitude of such emissions is likely to be substantial but also vary depending upon the energy inputs used to generate electricity at the utility level (for example, hydroelectric generation is considerably less emissions-intensive than coal-powered generation, and many aluminum manufacturing facilities are located in the Pacific Northwest, which has extensive hydropower resources).

Data presented in the table above raise the following points regarding energy-related CAP emissions:

- Sulfur dioxide (35 percent) and nitrogen oxides (27 percent) represent the largest fraction of energy-related CAP emissions. Increasing energy efficiency or promoting a cleaner fuel mix in these sectors is likely to have the greatest impact on emissions of these pollutants. (According to NEI data, carbon monoxide, a product of incomplete combustion, also represents a substantial fraction (31 percent) of energy-related CAP emissions, but NEI data errors may contribute to an overstatement of CO emissions, as they are not typically

uu As CO does not typically represent a large component of combustion-related emissions from stationary sources, NEI data may overstate such emissions and thus we devote minimal discussion to emissions of CO.

a very large component of combustion-related emissions from stationary sources. Therefore, we devote minimal discussion to CO emissions.)

- Energy-related CAP emissions are a function of total energy consumption, fuel mix, process energy requirements, and equipment type. Thus, there are many factors that determine whether a sector's energy-related CAP emissions are higher or lower than any other sector.
- Between sectors there is wide variation in the fraction of total CAP emissions that is classified as energy-related—from 8 percent to 63 percent of total CAP emissions. Total CAP emissions also range widely due to industry-specific factors inherent to the manufacturing process, such as the magnitude of process heating requirements. Thus, it is not necessarily meaningful to compare the energy-related CAP fractions across sectors, especially since NEI data do not include indirect emissions from offsite electricity generation, which is a substantial component of energy use in sectors such as aluminum, metal finishing, motor vehicle manufacturing, etc.
- The fraction of energy-related CAP emissions also depends on unique characteristics of sector energy use. For example, in food manufacturing, pulp and paper, and wood products, energy-related CAP emissions comprise more than 60 percent of total CAP emissions. This result is in large part due to the magnitude of onsite power generation in these sectors, which in itself may represent an environmentally preferable energy strategy. For example, in the forest products industry (pulp and paper and wood products), a large fraction of the sector's energy requirements are met with onsite generation of electric and thermal energy using biomass fuels that are byproducts of the manufacturing process. Increased use of such renewable biomass fuels would reduce energy losses associated with offsite electricity generation, transmission, and distribution (see Section 3.5).
- Energy efficiency and clean energy improvement in the sectors with the greatest energy-related CAP emissions (chemical manufacturing, food manufacturing, forest products, iron and steel, and petroleum refining) offer the greatest potential for reducing the environmental impact of sector energy use.

Table 14 presents NEI data on the sources of energy-related CAP emissions presented in Table 13. External combustion boilers have multiple applications in industrial manufacturing facilities, including central power generation, steam generation, process heating, and space heating. Industrial process emissions include emissions from direct fuel combustion in the manufacturing process, such as from fuel-fired equipment. The internal combustion engine category includes central power generation applications such as turbines and reciprocating engines. The petroleum and solvent evaporation category includes emissions from equipment like heaters used in coating operations. The "other" category includes all miscellaneous sources that are associated with energy-related CAP emissions, such as emissions from other combustion processes (e.g., fires).

Table 14: Energy-related CAP emissions by source category in 2002[41]

NAICS	Sector	External Combustion Boilers	Industrial Processes	Internal Combustion Engines	Petroleum and Solvent Evaporation	Other	TOTAL[vv]
3313	Alumina and aluminum	82%	18%	0%	0%	0%	**100%**
327310	Cement	16%	82%	2%	0%	0%	**100%**
325	Chemical manufacturing	60%	33%	6%	0%	0.3%	**99%**
311	Food manufacturing	94%	3%	3%	0%	0.2%	**100%**
331111	Iron and steel	59%	41%	0%	0%	0%	**100%**
332813	Metal finishing	90%	8%	2%	0%	0%	**100%**
3315	Metal casting	49%	39%	11%	1%	0%	**100%**
33611	Motor vehicle manufacturing	74%	8%	9%	0%	8.9%	**100%**
3363	Motor vehicle parts manufacturing[ww]	17%	6%	77%	0%	1%	**101%**
324110	Petroleum refining	51%	37%	10%	0%	2%	**100%**
322	Pulp and paper (within forest products)	95%	4%	1%	0%	0%	**100%**
321	Wood products (within forest products)	88%	12%	0%	0%	0.5%	**101%**
336611	Shipbuilding and ship repair	71%	1%	27%	0%	1%	**100%**
Total		**75%**	**21%**	**3%**	**0%**	**0.4%**	**100%**

Several points are important to note regarding the data contained in Table 14:

- It may not be possible to make definitive distinctions between some of these source categories, particularly the industrial processes category and the boiler and engine categories. NEI data are based on facility reporting, modeling, and estimates, where there may be inconsistencies in how sources of energy-related emissions are categorized. For example, fuel combustion related to process heating could be categorized as an industrial process energy use or defined under the external combustion boiler category.
- For a given sector, the primary source of energy-related CAP emissions depends primarily on industry-specific factors inherent to the manufacturing process.
- In general, the primary opportunities for reducing energy-related CAP emissions lie with external combustion boilers and process equipment, with boilers comprising the largest source of emissions in most industries. Process equipment dominates energy-related CAP emissions in a few key industries including cement kilns, fluid process heaters in the chemical and petroleum refining industries, and fired systems such as furnaces, metal melters, and heaters in iron and steel.

Additional detail on energy-related emissions of carbon and CAPs is provided in the sector summaries in Chapter 3.

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vv Rows may not sum to 100% due to independent rounding.

ww The high fraction of energy-related CAP emissions from internal combustion engines is the result of an NEI data reporting error, as noted in Section 3.10.

2.3.4 Comparison of Energy Consumption Characteristics

To continue our characterization of sector energy consumption from Section 2.2 and gain insight into how energy consumption and energy intensity relate to CAP emissions, Table 15 ranks the sectors on the basis of three metrics: total energy-related CAP emissions, total energy consumption, and energy intensity.

Table 15: Comparison of 2002 data on energy-related CAP emissions, total energy consumption, and energy intensity by sector[42 43 44]

		Emissions		Energy Consumption		Energy Intensity	
NAICS Code	**Sector**	**Total Energy-Related CAP Emissions (TPY)**	**Rank**	**Total Energy Consumption (TBtu)**	**Rank**	**Energy Consumption per Dollar Value of Shipments (KBtu)**	**Rank**
325	Chemical manufacturing	739,123	1	6,465	1	8.5	6
322	Pulp and paper	720,948	2	2,363	3	15.2	4
324110	Petroleum refining	298,838	3	6,391	2	16.1	3
311	Food manufacturing	247,724	4	1,123	5	2.6	9
331111	Iron and steel	227,808	5	1,308	4	27.8	2
321	Wood products	183,285	6	377	9	4.2	8
3313	Alumina and aluminum	72,736	7	473	6	12.2	5
327310	Cement	41,477	8	409	8	56.0	1
33611	Motor vehicle manufacturing[xx]	8,801	9	429	7	0.7	10
3315	Metal casting	5,225	10	165	10	5.6	7
336611	Shipbuilding and ship repair	2,419	11	429	7	0.7	10
3363	Motor vehicle parts manufacturing	867	12	429	7	0.7	10
332813	Metal finishing	111	13	NA	NA	NA	NA

The following points are evident from the comparison of sector rankings in terms of energy-related CAP emissions, total energy consumption, and energy intensity as shown in Table 14:

- There is a good degree of correlation between energy-related CAP emissions and total energy consumption for most sectors, with the important caveat that for sectors with substantial purchased electricity requirements (e.g., aluminum, metal casting, metal finishing, motor vehicle manufacturing, motor vehicle parts manufacturing, and shipbuilding and ship repair), NEI data underestimate energy-related CAP emissions by attributing emissions associated with electric power generation to the generating sources rather than to the purchasing entity.
- There is less consistent correlation between energy intensity (energy consumption per value of economic output) and energy-related CAP emissions. For most sectors, the emissions ranking is either equivalent (within one point) to the energy intensity ranking or

[xx] As MECS does not contain sector-level data for motor vehicle manufacturing (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), or shipbuilding and ship repair (NAICS 336611), energy consumption and energy intensity data for these three sectors are for the larger NAICS category, transportation equipment (NAICS 336).

at least two points higher. For three sectors—aluminum, cement,[yy] and iron and steel—the energy intensity ranking is two or more points higher than the energy-related emissions ranking. In the case of aluminum, this result may be partly attributable to the fact that NEI data do not include emissions associated with purchased electricity. Still, the lack of correlation between energy intensity and energy-related CAP emissions suggests that in terms of reducing the environmental impacts of sector energy use, focusing on the most energy-intensive sectors may not produce the environmentally preferable outcome.

[yy] For the cement industry, the majority of the sector's energy requirements and associated emissions result from the thermo-reduction of limestone, clay, and sand. Given the high energy requirements of this process, and the fact that NEI data for the cement industry only classify 8% of the sector's total CAP emissions as "energy-related," it appears likely that NEI data misclassify some energy-related CAP emissions as non-energy-related.

2.4 Economic Context

Insights

Sector-based strategies for promoting energy efficiency and clean energy investment may be required due to varying economic trends (i.e., declining or increasing production and profitability), as well as characteristics such as the industry's sensitivity to energy cost fluctuations, average firm size, the homo- or heterogeneity of manufacturing processes within the sector, and the sector's geographic distribution.

2.4.1 Economic Production

A sector's economic production trends have important implications for energy management strategies. For example, industries undergoing growth in production may be less capital-restricted than sectors with declining production and may also be receptive to efforts to improve their competitive edge through increased management of energy costs. Moreover, growing sectors are adding capacity, which provides the most cost-effective opportunity to install more efficient equipment. Targeting energy efficiency efforts on industries with high energy intensity, high total energy use, and high economic growth is one obvious strategy for improving environmental performance. Table 16 presents recent economic trends for sectors considered in this analysis in terms of the annual change in value added and value of shipments from 1997 to 2004. To distinguish more recent from longer-term trends, the table also presents the annual rate of change in these metrics from 2000 to 2004.[zz]

Table 16: Annual growth in value added and value of shipments 1997-2004[45]

NAICS	Sector	Annual Change in Value Added		Annual Change in Value of Shipments	
		1997 - 2004	2000 - 2004	1997 - 2004	2000 - 2004
324110	Petroleum refining	5.4%	6.3%	6.6%	5.0%
3366	Shipbuilding and ship repair	2.7%	5.4%	1.8%	2.4%
311	Food manufacturing	2.5%	2.5%	0.8%	1.8%
327310	Cement	2.2%	1.2%	1.5%	1.6%
325	Chemical manufacturing	1.9%	3.7%	1.5%	1.8%
321	Wood products (within forest products)	1.8%	2.5%	0.3%	0.2%
331111	Iron and steel[aaa]	1.1%	8.3%	1.7%	6.1%
332813	Metal finishing[bbb]	0.1%	-1.2%	-0.3%	-2.0%
3363	Motor vehicle parts manufacturing	0.0%	-2.2%	-0.1%	-2.3%
322	Pulp and paper (within forest products)	-1.2%	-3.6%	-1.6%	-4.0%
33611	Motor vehicle manufacturing	-2.2%	1.9%	0.3%	0.1%
3313	Alumina and aluminum	-2.9%	-2.3%	-2.4%	-2.2%
3315	Metal casting	-3.2%	-5.4%	-2.4%	-3.7%

zz Census Bureau data were converted to inflation-adjusted 2000 dollars before annual growth rates were calculated.

aaa Economic data are for the larger NAICS category of iron, steel, and ferroalloy manufacturing (NAICS 33111).

bbb Economic data are for the larger NAICS category of coating, engraving, and heat treating (NAICS 33281).

Though presenting annual rates of change is the simplest way to capture long-term trends, this approach masks interannual variation, which is particularly worth noting for certain sectors:

- Though iron and steel and ferroalloy manufacturing shows growth in value added and value of shipments over the period, both metrics actually declined from 1997 to 2003 during a period of industry restructuring. From 2003 to 2004 value added jumped by more than 70 percent and value of shipments jumped by more than 45 percent. This turnaround was primarily due to a dramatic increase in the price of steel prices driven by surging demand for raw materials in Asian countries like China, India, South Korea, and Thailand,[46] and by the strengthened financial position of the industry post-restructuring.
- For shipbuilding and ship repair, value added and value of shipments grew relatively slowly from 1997 to 2001, then value added increased by almost 30 percent and value of shipments jumped by 6 percent from 2001 to 2002.
- Motor vehicle manufacturing, motor vehicle parts manufacturing, and metal finishing show relatively larger degrees of interannual variation.

Sectors showing economic growth trends include the following:

- Chemical manufacturing, cement, and petroleum refining are energy-intensive industries with consistent growth in economic output. Petroleum refining shows more interannual variation than the other two sectors but also shows the strongest growth trend over the time period. The sector’s strong economic position is in part due to an industry turnaround after considerable consolidation occurred in the 1990s.
- Food manufacturing is a less energy-intensive sector that shows consistent economic growth. Wood products also shows growth over the timeframes considered but had greater interannual variation than food manufacturing due primarily to changes in demand for construction materials.

Sectors with declining economic trends include the following:

- Aluminum, metal casting, and pulp and paper are energy-intensive industries with declining economic trends, and thus are likely to face substantial capital constraints that affect decision-making about energy efficiency and clean energy investments.

2.4.2 Sector Composition

Other economic factors may be considered in developing sector-based strategies for promoting investment in energy efficiency and clean energy opportunities, including whether a sector consists of many small firms or a few large ones; whether a sector is geographically concentrated or dispersed across the country; and as discussed previously, whether energy costs comprise a relatively larger or smaller fraction of production costs. Designing policies aimed at increasing energy efficiency within a sector may be relatively simpler when a sector consists of a small number of large players with similar manufacturing processes, or is concentrated in a limited number of geographic regions. Communicating to a large number of small firms is more labor-intensive, and such industries may be less influenced by the best practices of industry leaders. In addition, sectors that encompass a broad range of manufacturing processes (the chemicals industry is one example) might not be well served by a homogeneous policy approach to promoting energy efficiency and clean energy investment.

We characterize each sector in terms of the relative number of firms in the industry, the average size of firms comprising the industry, and whether the sector is geographically dispersed across the country or concentrated in specific regions. Table 17 summarizes these attributes for the sectors included in this analysis; sector-specific write-ups in Chapter 3 provide additional information to support these characterizations.

Table 17: Overview of key economic characteristics by sector

NAICS	Sector	Economic Production Trend	Relative Firm Number	Relative Firm Size	Geographic Distribution	Energy Cost Sensitivity[ccc]
3313	Alumina and aluminum	Declining	Few	Large	Concentrated	High
327310	Cement	Increasing	Few	Large	Concentrated	High
325	Chemical manufacturing	Increasing	Many	Small/Large[ddd]	Dispersed	High
311	Food manufacturing	Increasing	Many	Large	Dispersed	Low
331111	Iron and steel[eee]	Increasing	Few	Large	Concentrated	High
3315	Metal casting	Declining	Many	Small	Concentrated	High
332811	Metal finishing[fff]	Mixed	Many	Small	Concentrated	High
33611	Motor vehicle manufacturing	Mixed	Few	Large	Concentrated	Low
3363	Motor vehicle parts manufacturing	Mixed	Many	Small/Medium	Dispersed	Low
324110	Petroleum refining	Increasing	Few	Large	Concentrated	High
322	Pulp and paper (within forest products)	Declining	Few	Large	Concentrated	High[ggg]
3366	Shipbuilding and ship repair	Increasing	Few	Large	Concentrated	High
321	Wood products (within forest products)	Increasing	Few	Large	Concentrated	High

[ccc] The energy cost sensitivity rating is primarily based on whether the industry rated higher or lower than the manufacturing industries' benchmark for energy cost per dollar of value added shown in Table 9.

[ddd] Certain segments of the chemical manufacturing industry, such as specialty-batch chemicals, are dominated by smaller firms, while others, such as commodity chemicals, are dominated by larger firms.

[eee] The economic trend assessment for the iron and steel sector is based on Census Bureau data for a larger NAICS category: Iron and steel and ferroalloy manufacturing (NAICS 33111).

[fff] The economic trend assessment for the metal finishing sector is based on Census Bureau data for a larger NAICS category: Coating, engraving, heat treating, and allied activities (NAICS 33281).

[ggg] Though the forest products industry (pulp and paper and wood products) is energy intensive, it is important to note that more than half of its energy requirements are met by manufacturing byproducts (biomass). The industry has increased utilization of its biomass resources, reducing the impact of rising costs for purchased energy.

3. Sector Energy Scenarios

Insights

Each of the 12 sectors addressed in this analysis has implemented various energy efficiency and clean energy improvements that are reflected in their "base case" assessments. Many have committed to further energy intensity reductions through one or more public-private partnerships, including Climate VISION. There are continued energy efficiency and clean energy opportunities for each sector, both through existing technologies and in the development of new technologies and processes.

Chapter 3. Sector Energy Scenarios

Drawing on current energy consumption data and industry trends, as well as future energy consumption projections made in two reports produced by the U.S. Department of Energy (DOE), *Scenarios for a Clean Energy Future* (CEF) and EIA's 2006 *Annual Energy Outlook* (AEO 2006), Chapter 3 develops "base case" and "best case" energy scenarios for the 12 sectors addressed in this analysis.

Each sector summary is composed of the following elements:

- ***Base Case Scenario:***
  - *Situation Assessment*: Discusses high-level trends affecting sector energy use, including economic production, geographic distribution, investments in energy efficiency and/or clean fuels, and voluntary commitments to energy efficiency and/or greenhouse gas (GHG) reduction.
  - *Expected Future Trends*: Assesses business-as-usual energy consumption trends in terms of fuel use and energy intensity through 2020. For the eight sectors modeled in DOE's National Energy Modeling System (NEMS)—aluminum, cement, chemicals, food, forest products, iron and steel, metal finishing,[hhh] and petroleum refining—the trends assessment includes

CEF Projections

We have included CEF reference case and advanced energy projections for sector energy consumption to facilitate the assessment of possible fuel-switching trends under business-as-usual and environmentally preferable energy scenarios. However, in several cases CEF energy consumption data differ significantly from 2002 Manufacturing Energy Consumption Survey (MECS) data presented in Chapter 2 and from information industry representatives have provided regarding current energy consumption. Such differences may be due to a number of factors, most importantly the age of the CEF study (published in 2000 and using energy consumption data from 1998) and differences in how sectors are defined. (To the extent possible, we have noted how CEF sector definitions differ from EPA/North American Industrial Classification Code (NAICS) definitions in footnotes.) Thus, we place greater emphasis on relative energy consumption and fuel mix changes under the CEF scenarios, rather than absolute energy consumption values. In addition, we include AEO 2006 projections in the base case scenarios to identify areas where recent energy trends may be likely to produce substantially different future outcomes than those projected by CEF in 2000.

hhh Projections are for the larger NAICS category, fabricated metal products (NAICS 332).

reference case (i.e., "business-as-usual") energy consumption projections made in the CEF report and AEO 2006.

- *Environmental Implications*: Discusses National Emissions Inventory (NEI) data on current energy-related criteria air pollutant (CAP) emissions and carbon dioxide emissions projections from AEO 2006. Reviews how expected future energy trends are likely to affect energy-related emissions.

- ***Best Case Scenario:***
  - *Opportunities*: Evaluates the viability of each of the five energy efficiency and clean energy opportunities discussed in Section 2.2.6: cleaner fuels, increased combined heat and power (CHP), equipment retrofit/replacement, process improvement, and research and development (R&D). For each sector, the viability of each opportunity is rated "low," "medium," or "high" based on conclusions drawn from the reference material reviewed in connection with this analysis. It is important to note that such rankings are a qualitative (and necessarily subjective) assessment of the viability of each opportunity based on research conducted, rather than a quantitative assessment of energy-savings potential. Where applicable, regulatory and other barriers to implementing the opportunities are discussed.
  - *Optimal Future Trends*: Assesses likely changes from the base case scenario that would occur under an environmentally preferable energy scenario (i.e., increased energy efficiency and/or cleaner fuels) in terms of fuel mix, energy intensity, and energy consumption changes that effect energy-related criteria air pollutants and carbon emissions. For the eight sectors modeled in NEMS, this section also summarizes CEF advanced case projections.
  - *Environmental Implications*: Discusses how the environmentally preferable energy scenario differs from the business-as-usual scenario in terms of CAP and GHG (carbon dioxide) emissions.

> **Why Compare the CEF Reference Case and Advanced Case Projections?**
>
> The industrial manufacturing chapter of the CEF study provides sector-level energy consumption projections under both a business-as-usual reference case and an advanced energy case, which captures the impact of a wide range of policies to promote environmentally preferable energy outcomes.
>
> For the purposes of this analysis, absolute changes in energy consumption (as projected by CEF) are less important than relative differences between the two scenarios.
>
> Reporting the CEF projections in Chapter 3 allows us to envision how a "best case" energy scenario might look at the sector level, and how it compares with a "base case" energy scenario.

- ***Other Reference Materials Consulted:***
  - Lists additional data sources and reference materials used in this analysis.

Appendix A provides an overview of the energy consumption projections used in this analysis (CEF and AEO 2006), methodologies and assumptions, and a brief overview of similarities and differences between the two projections. On the whole, because it employs more recent energy consumption and economic data, AEO 2006 produces a more realistic projection for the business-as-usual scenario. However, we include the CEF projections for two primary reasons: (1) AEO 2006 does not provide sufficient sector-level detail for its "high technology" case to allow development of an advanced energy scenario that could be compared with the reference case; and (2) CEF projections are a closer approximation of a "best case" scenario because they produce a slower rate of increase in industrial energy consumption and a faster decrease in industrial energy intensity than the AEO 2006 high technology case.

The CEF advanced case projections are based on six policy elements that promote more aggressive energy efficiency and clean energy improvement through: (1) expanded voluntary federal programs such as the CHP Challenge and ENERGY STAR; (2) expanded federal informational programs such as energy assessments and equipment labeling; (3) expanded investment-enabling programs such as state grant programs, utility incentive programs, and tax rebates and credits; (4) mandatory efficiency standards for motors; (5) expanded federal demonstration and R&D programs; and (6) a domestic carbon emissions trading program. Arguably even more aggressive policies could be envisioned under a "best case" energy scenario. However, we have not found other analyses that provide detailed sector-level energy consumption projections under comparable business-as-usual and environmentally preferable energy scenarios for the industries featured in this analysis.

3.1 Alumina and Aluminum

3.1.1 Base Case Scenario

Situation Assessment

> **Recent Sector Trends Informing the Base Case**
>
> Number of facilities: ↓
> Domestic production: ↓
> Value of shipments: ↓
> Avg. energy consumption/kg Al produced: ↓
>
> Major fuel sources: Electricity & natural gas
>
> Current economic and energy consumption data are summarized in Table 18 on page 3-5.

The U.S. Geological Survey (USGS) reports that bauxite is the only raw material used on a commercial scale in the United States in the production of alumina and aluminum (NAICS 3313). As a general rule, four tons of dried bauxite is required to produce two tons of alumina, which in turn provides one ton of primary aluminum metal (NAICS 331312). As reported in *USGS Mineral Commodity Summaries 2006*, in 2005:

- Nearly all of the bauxite consumed in this country was imported; more than 90 percent was converted to alumina at domestic refineries located in Louisiana and Texas.
- Of the total alumina used domestically, about 90 percent went to primary aluminum smelters.
- Six companies operated 15 primary aluminum smelters at about two-thirds of rated or engineered capacity; another four smelters were idle. All modern primary aluminum smelting plants employ the "Hall-Heroult" process to reduce alumina to aluminum through electrolysis.[47]

Data for 2005 mark a decline in production capacity since 2000, a year in which USGS reported that 12 U.S. companies operated 23 primary aluminum smelters across the country. The reduction in U.S. aluminum production and capacity since 2000 is in large part due to energy pricing pressures, particularly in the Pacific Northwest, where the majority of aluminum smelters are located. The aluminum industry showed a decline in value added and value of shipments between 1997 and 2004 (see Table 18).

In 2001, electricity prices soared in response to the combination of high temperatures which increased energy demand, and reduced hydroelectric power generation brought on by historically low snow packs and regulations mandating the spill of water to aid salmon migration. These high prices meant it was more economical for several Pacific Northwest smelters (which accounted for over 40 percent of U.S. primary production capacity) to stop production and sell back their power (which was on low-cost, fixed price contracts) to the power authority. These low-cost electricity contracts were a result of the Northwest Power Act of 1980, which ensured that Pacific Northwest smelters would obtain their power from Bonneville Power Administration (BPA) at preferential prices. Recently BPA, which controls about half of the power marketed in the region, announced it would discontinue all electricity service at preferential prices; consequently, many of the smelters operating in this region have remained closed. Continued high energy market prices have prevented the restart of many of these smelters, which were some of the oldest and, therefore, most energy-intensive operations in the United States.[48] In 2002 energy costs represented approximately 21 percent of the industry's value added and around 7 percent of the industry's value of shipments[49] (see Table 9).

The industry-wide average energy consumption per kilogram of aluminum production has generally declined in recent years through a number of factors: (1) the closure of older, more energy-intensive “Soderberg” smelters in the Pacific Northwest; and (2) the implementation of best management energy efficiency practices, including (a) improvements in the molten cryolite chemical bath composition; (b) improved training of cell operators and monitoring to reduce anode effects (AE); (c) use of improved, computerized cell control systems and other process controls to prevent AE; and (d) installation of alumina point feed systems.[50] As is the case with other capital-intensive industries, replacing older equipment/processes with state-of-the-art equipment/processes holds potential for energy efficiency improvement.[51] In 2000, typical energy consumption achieved by operating smelters was between 13 kWh/kg of Al for state-of-the-art facilities (e.g., point feed pre-bake) to 20 kWh/kg of Al for older Soderberg smelters (many of which were located in the Pacific Northwest and have now been shut down).[52]

Aluminum recycling also has an impact on sector energy use, as production from recycled aluminum requires only five percent of the energy required for primary ore production.[53] Recycling one kilogram of aluminum can save up to 14 kilowatt hours of electricity.

Robert Strieter at the Aluminum Association (AA) noted that for primary aluminum production, there are no air-related policy issues that prevent the implementation of measures to increase energy efficiency. However, Best Available Retrofit Technology (BART) requirements to address regional haze (e.g., installation of sulfur dioxide scrubbers) may exert capital expenditure pressures on primary aluminum producers. Similarly, implementing heat recovery technologies in remelt furnaces to meet Maximum Achievable Control Technology (MACT) requirements may also exert capital expenditure pressures on secondary production (recycling) operations.

Table 18 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 18: Current economic and energy data for the aluminum 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
	-2.9%	-2.3%	-2.4%	-2.2%
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)
	34.3	12.2	21.0%	6.9%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
		Net Electricity	Natural Gas	Other
		55%	37%	7%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	9%
			LPG	Fuel Oil
Fraction of natural gas inputs that could be met by alternate fuels			64%	36%

Expected Future Trends

Though the industry may undertake energy efficiency improvements to control production costs, the recent closures of the most inefficient smelters and plant-level improvements undertaken in response to electricity price increases may mean that additional efficiency gains may be relatively more capital intensive. An additional challenge is posed by the industry's trend of declining economic production. As noted in CEF: "Stagnating markets are poor theaters for innovation and investment, and instead rely on already depreciated equipment to maintain low production costs."[54] Given these factors, the implementation rate of further efficiency improvements is likely to be slow.

The data examined in this analysis do not show a fuel-switching trend in response to increases in energy price—the primary response has been to shut down the most energy-intensive facilities, as discussed above. Under the business-as-usual scenario, CEF projects the aluminum industry energy consumption to be dominated by purchased electricity and natural gas, and economic energy intensity (energy consumption per dollar value of output) to decrease at the rate of 0.9 percent per year.[iii]

Voluntary Commitments

The U.S. Aluminum Association (AA) and its members participating in Climate VISION have committed to a direct carbon intensity reduction in carbon and perfluorocarbon (PFC) emissions from the carbon anode consumption process that occurs in primary aluminum reduction. As large industrial energy consumers, primary aluminum producers also agree to continue their efforts to reduce indirect carbon emissions through continued energy efficiency improvements. See http://www.climatevision.gov/sectors/aluminum/index.html.

This commitment builds on the efforts of the Voluntary Aluminum Industrial Partnership (VAIP), a program that EPA has had with the industry since 1995. VAIP reduced PFC emissions by more than 45 percent in 2000 compared to the industry's 1990 baseline. VAIP's 2010 target is a 53 percent total carbon equivalent reduction from these sources from 1990 levels.[a] This new commitment equates to an additional direct carbon-intensity reduction of 25 percent since 2000. See http://www.epa.gov/highgwp/aluminum-pfc/.

The aluminum 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.

AA targets a 2020 goal to meet or exceed 11 kWh/kg of Al through technological and process improvements, such as inert anode, wetted cathodes, and non-Hall-Heroult processes. See http://www.eere.energy.gov/industry/aluminum/.

Though energy consumption is projected to decrease across all fuel categories, the largest decrease is projected for natural gas (26 percent decline from 1997-2020), with a smaller decrease projected for delivered electricity (16 percent).

CEF reference case projections for the aluminum industry are summarized in Table 19. Economic assumptions underlying these projections are that production will grow slowly at the rate of 0.2 percent per year, with the value of the industry's output increasing at the same rate.

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iii Aluminum is one of the sectors for which CEF made adjustments to the NEMS model used to produce AEO 1999. However, CEF projections are for the primary aluminum industry (NAICS 331312), a sub-set of aluminum and alumina (NAICS 3313).

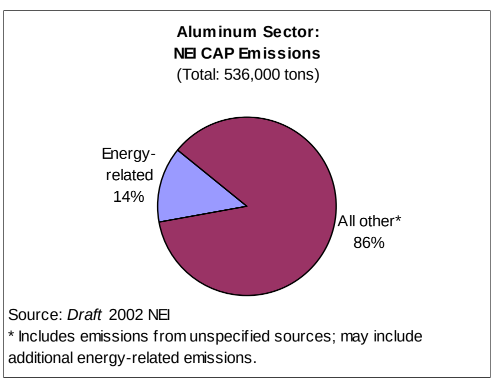
Table 19: CEF reference case projections for the aluminum industry

	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Natural gas	0.081	31%	0.060	28%
Delivered electricity	0.183	69%	0.153	72%
Total	0.264	100%	0.213	100%
Annual % change in economic energy intensity (energy consumption per dollar value of output)				-0.9%
Overall % change in energy use (1997-2020)				-19%

In an effort to assess the impact of recent trends that may have affected aluminum industry energy consumption since the CEF report was produced, we also examined reference case energy consumption projections 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 data provide more detailed fuel consumption data than CEF and give a better indication of how high electricity prices in the Pacific Northwest have affected sector energy consumption—namely, indicating increased reliance on natural gas and other fossil fuel inputs at the expense of purchased electricity. According to AEO 2006, in 2004 the aluminum industry's fuel mix was 47 percent purchased electricity and 34 percent natural gas, with petroleum (11 percent, mainly petroleum coke) and coal (8 percent) comprising the remaining fractions. From 2004 to 2020, AEO 2006 projects the sector's energy consumption to fall by 11 percent. Natural gas and coal consumption remains static over the period, while purchased electricity falls by 18 percent and petroleum coke consumption falls by 24 percent. In 2020, electricity is projected to meet 43 percent of the sector's energy needs, compared with 38 percent for natural gas.

Environmental Implications

Figure 6: Aluminum sector: energy-related CAP emissions



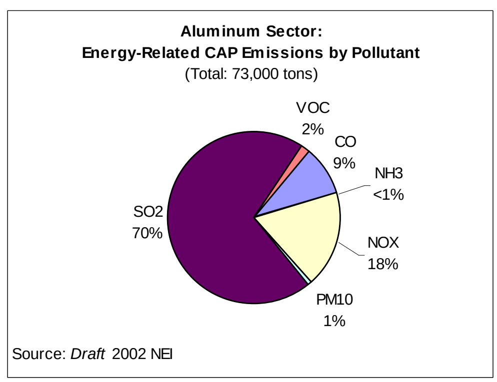


Figure 6 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the aluminum sector. According to the figure, energy-related CAP emissions are a relatively small fraction of total emissions; however, NEI data attribute emissions from the generation of purchased energy to the generating source, not the purchasing entity. Therefore, energy-related emissions from an electricity-dependent sector like aluminum will be underestimated. Hydroelectric power—a cleaner form of electricity generation than fossil fuel—has historically met a substantial fraction of the sector's purchased electricity requirements.

According to NEI data on emissions by fuel usage (shown below in Figure 7), 18 percent of the energy-related CAP emissions shown in Figure 6 are from natural gas consumption, and 78 percent are from coal consumption. Coal meets a relatively small fraction of the sector's energy needs (less than 0.1 percent of total fuel inputs according to MECS, and approximately 8 percent according to AEO 2006), where natural gas comprises around 30 percent. Thus, the figures demonstrate the emissions intensity of coal inputs as compared with natural gas.

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 7: Aluminum sector: CAP emissions by source category and fuel usage

Figure 7 presents NEI data on the source categories for energy-related CAP emissions shown in Figure 6, as well as emissions by fuel usage. The data suggest that coal-fired external combustion boilers are the source of the majority of energy-related CAP emissions recorded in NEI. However, given the relatively small coal fraction as a percentage of total fuel inputs for the sector, such boilers are likely only in use at a small number of facilities. According to NEI data, key opportunities for reducing the environmental impacts of sector energy use lie with efficiency improvements to external combustion boilers. Opportunities for emissions reduction also lie in the area of process improvement, as industrial processes contribute to 18 percent of energy-related CAP emissions. In one DOE/ITP example, during electrolysis more than 45 percent of energy inputs are lost as heat from the cathode and anode. At the same time, onsite energy-related CAP emissions are small compared with other sectors considered in this analysis—73,000 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

At a system-wide level, the sector's declining energy consumption trend will reduce energy-related CAP emissions. AEO 2006 projections indicate that sector energy use is shifting somewhat from the utility (purchased electricity) to the facility level (fossil fuels) in terms of the relative contribution of various fuel inputs to total energy consumption. However, AEO 2006 does not project any substantial increases in fossil fuel consumption that would increase energy-related CAP emissions at the facility level, with natural gas and coal consumption remaining relatively static, and petroleum coke consumption declining. At the utility level, the expected decrease in purchased electricity requirements would decrease energy-related CAP emissions, particularly given the magnitude of energy losses associated with electric power generation, transmission, and distribution.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 46.5 million metric tons in 2004, including emissions associated with offsite electricity generation. (Additional carbon emissions arise from anode consumption, but such emissions are not considered energy related.) In line with the expected decrease in total energy consumption, AEO 2006 projects that the aluminum industry's carbon dioxide emissions will decline at the annual rate of 1 percent per year, reaching 38.6 million metric tons by 2020.

3.1.2 Best Case Scenario

Opportunities

Table 20 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 20: Opportunity assessment for the aluminum industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	Due to the sector's dependence on purchased electricity, the environmental impact of energy inputs will follow regional trends for electric generation. There may be some opportunity for clean fuels improvement through increased use of renewable energy, either at the facility level or in electric generation. However, much of the industry is concentrated in the Northwest where electricity generation is already largely hydroelectric.
Increased CHP	Low	The aluminum industry has not invested in CHP to an extensive degree, perhaps due to cost considerations and regulatory uncertainties as well as technical constraints (for example, if the electricity load is significantly larger than the thermal load, there might not be sufficient waste heat to generate sufficient amounts of power). However, DOE's Industries of the Future Program identified CHP as an area for further research and demonstration projects to determine viability.[55] New CHP installations also face barriers in terms of utility interconnection requirements if electricity production is expected to exceed onsite demand, and also from NSR/PSD permitting.[56]
Equipment retrofit/ replacement	Medium	For capital-intensive industries, CEF predicts that the largest efficiency gains will come from replacement of old equipment with state-of-the-art equipment. [57] Installation of alumina point feed systems is a currently available technological retrofit that improves energy efficiency. However, the industry's economic circumstances (declining production and pressure from foreign competition) are an important constraint on capital investment.
Process improvement	Medium	There are multiple process-related energy-savings opportunities currently available such as increased waste reduction and recycling, improvements in molten cryolite chemical bath composition, and improved process controls and monitoring. The frequency and duration of anode effects (spikes in voltage caused by changes in the chemical composition of the electrolytic bath) may be reduced through operator training as well as process control improvements, improving energy efficiency and reducing PFC emissions.[58]
R&D	Medium	The aluminum 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/aluminum/. The theoretical minimum energy consumption in aluminum primary production via electrolysis is 5.99 kWh/kg of Al produced.[59] A number of technologies and processes that would substantially reduce sector energy consumption have a long R&D history and are still a long way from commercial implementation, including inert anode and wettable cathodes as replacements for carbon anodes and cathodes in existing Hall-Heroult processes (theoretical energy savings would be achieved through the combined use of inert anode and wettable cathodes), as well as technologies that would replace the Hall-Heroult process in its entirety, such as carbothermic and kaolinite reduction processes.[60]

Opportunity	Ranking	Assessment (including potential barriers)
		The sector has identified technical, cost, and institutional barriers to full-scale implementation and is also concerned that implementing wettable cathodes would require replacement of existing carbon pot-lining, a listed hazardous waste under the Resource Conservation and Recovery Act (RCRA).

Optimal Future Trends

CEF does not project a major shift in the aluminum sector's fuel mix under its advanced energy scenario, with energy consumption decreasing by roughly 29 percent across all fuel types. (As indicated previously, more recent projections in AEO 2006 indicate that a relatively greater share of energy requirements will be met by natural gas and a relatively smaller share met by purchased electricity. However, as AEO 2006 does not provide sector-specific data for its advanced energy scenario, we refer only to CEF data in this section.) Energy intensity is projected to decrease at a greater annual rate than under the base case scenario, primarily through faster replacement of aging equipment with energy-efficient equipment, and accelerated implementation of promising new technologies such as inert anodes and wettable cathodes. Under the advanced energy scenario, CEF projects total aluminum sector energy use to fall by 29 percent from 1997 levels by 2020, compared with a 19 percent reduction in the base case scenario.

As with CEF's projections for all sectors, economic assumptions are the same under the advanced case scenario as the reference case (growth in production and value of output at 0.2 percent per year). (See Appendix A-2 of the CEF report for more detailed descriptions of CEF's modeling assumptions under the business-as-usual and advanced energy scenarios.) Table 21 summarizes the CEF advanced case projections for the aluminum industry.

Table 21: CEF advanced case projections for the aluminum industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu)[jjj]	Percentage	Consumption (quadrillion Btu)	Percentage
Natural gas	0.081	31%	0.058	31%
Delivered electricity	0.184	69%	0.129	69%
Total	0.265	100%	0.187	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-1.5%
Overall % change in energy use (1997-2020)				-29%

Environmental Implications

The greatest environmental benefits from increased energy efficiency in the aluminum industry occur outside the facility at the electric power generation level, due to the reductions in purchased electricity and also the reduced carbon intensity of electric generation under CEF's advanced scenario. Under the advanced energy scenario, CEF projects that the aluminum industry will achieve a 51 percent reduction in 1997 carbon emissions levels by 2020. As carbon

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jjj 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.

projections are based on primary energy consumption rather than delivered energy consumption, this decrease is larger than the sector's projected decrease in delivered energy consumption due to the energy losses associated with electric power generation, transmission, and distribution.

At the same time, it is important to note that electric power generation losses are largest for fossil fuel-fired plants, and thus effects on energy-related CAP and carbon emissions would vary depending upon local sources of power. Still, given the geographic concentration of the aluminum industry, CAP emissions reductions are more likely to be concentrated with associated benefits to regional air quality. The benefits of GHG emissions reductions occur on a global level.

At the facility level, reduced GHG and CAP emissions would be achieved through reductions in consumption of natural gas, coal, and petroleum coke. NEI data suggest that reductions in sector energy consumption through efficiency and clean energy improvement will have the greatest effect on emissions of sulfur dioxide and nitrogen oxides.

3.1.3 Other Reference Materials Consulted

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3.2 Cement

3.2.1 Base Case Scenario

Situation Assessment

> **Recent Sector Trends Informing the Base Case**
>
> Number of facilities: Virtually unchanged
> Domestic production: ↑
> Value of shipments: ↑
> Avg. energy consumption/ton of cement produced: ↓
>
> Major fuel sources: Coal & petroleum coke
>
> Current economic and energy consumption data are summarized in Table 22 on page 3-13.

Cement manufacturing (NAICS 327310) requires the thermochemical processing (i.e., pyroprocessing) of substantial amounts of limestone, clay, and sand in huge kilns at very high and sustained temperatures to produce an intermediate product called clinker. Clinker is then ground up with a small quantity of gypsum to create portland cement, which is used as a binding agent in virtually all concrete.

Kilns can employ either wet or dry processes. The wet process was developed to improve the chemical uniformity of the raw materials, which was a deficiency in original dry kiln designs. Technological improvements in the grinding of raw materials have improved the chemical uniformity of the clinker, which has enabled producers to return to the dry process and benefit from its lower energy consumption. On average, wet process operations use 34 percent more energy per ton of production than dry process operations.[61] No new wet kilns have been built in the United States since 1975,[62] and approximately 80 percent of U.S. cement production capacity now relies on the dry process technology.[63]

While 39 companies operate 115 cement plants in 36 states,[64] cement production is somewhat concentrated geographically, with six states—Texas, California, Pennsylvania, Missouri, Michigan, and Alabama, in descending order—accounting for approximately 50 percent of production in 2005.[65] From 1997 to 2004 the cement industry showed economic growth in terms of value added and total value of shipments (see Table 22), mainly in response to a strong construction market. Most of the U.S. demand for cement is met by domestic production. Operating at maximum capacity, in 2004 U.S. facilities produced 95 million metric tons of cement, an increase of 2 percent over 2003.[66] Although a slowdown of the U.S. economy is expected, industry experts predict cement consumption in 2006 to reach 129.6 million tons, an increase of 2.3 percent compared with 2005 levels, extending a three-year period of continual growth. Additional growth in cement consumption of 1.2 percent is forecasted for 2007.[67] To meet increasing demand, U.S. cement manufacturers have announced plans to increase production capacity by 15 percent (nearly 15 million tons) by 2010.[68]

The cement industry currently participates in EPA's Sector Strategies Program.

The cement industry is highly dependent on emissions-intensive energy sources: coal (60 percent of fuel inputs in 2004) and petroleum coke (16 percent).[69] In recent years, the sector has shown increased use of lower-cost waste fuels (primarily tires and used motor oil), and slight decreases in the use of natural gas and coal.[70] In 2002, 15 plants used waste oil, and 40 plants in 23 states used scrap tires; solvents, unrecyclable plastics, and other waste materials were also used as fuels.[71] Cement kiln dust (CKD) is routinely recycled to the kilns, which also can burn a variety of waste fuels (e.g., scrap tires, used motor oil, and paint wastes) and alternative raw materials such as foundry sand, slags, and coal combustion fly ash.[72] Energy intensity (as measured in terms of energy use per ton of cement production) fell by 7 percent from 2001 to 2004.[73]

As is the case with other capital-intensive industries, replacing old equipment with state-of-the-art equipment holds potential for energy efficiency improvement.[74] Options include replacing wet process kilns with new dry process kilns, adding multistage suspension preheaters (i.e., a cyclone) or shaft preheaters, and using high-pressure roller mills and horizontal roller mills in place of ball mills as a grinding technology. In 2006, a cement industry Energy Performance Indicator (EPI) was developed by EPA's ENERGY STAR Industrial Focus program in cooperation with the Portland Cement Association (PCA) and with technical support from the Argonne National Laboratory. EPI scores the energy efficiency of a single cement plant and allows the plant to compare its performance to that of the entire industry. The tool is intended to help cement plant operators identify opportunities to improve energy efficiency, reduce GHG emissions, conserve conventional energy supplies, and reduce production costs.[75]

Table 22 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 22: Current economic and energy data for the cement 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
	2.2%	1.2%	1.5%	1.6%
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)
	95.5	56.0	24.5%	15.1%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Coal	Other[kkk]	Net Electricity	Natural Gas	Coke & Breeze
58%	23%	11%	5%	2%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	29%
		Coal	Fuel Oil	LPG
Fraction of natural gas inputs that could be met by alternate fuels		67%	50%	17%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	51%
		Natural Gas	Other	LPG
Fraction of coal inputs that could be met by alternate fuels		91%	8%	4%

kkk "Other" includes petroleum coke as well as waste materials that are incinerated for fuel.

Expected Future Trends

Cement is one of three sectors (along with paper and steel) for which CEF made detailed parameter modifications to the NEMS model used to produce AEO 99. Modifications included adjustments to baseline energy intensities and rates for annual improvements in energy intensity, which were adjusted to reflect best-available sector-specific research.

> **Voluntary Commitments**
>
> Under its Climate VISION commitment, PCA seeks to achieve a 10 percent reduction in 1990-level carbon dioxide emissions per ton of cementitious product produced or sold by 2020. The industry will achieve this goal and foster further reductions by end users of cement products through the implementation of a three-part strategy to: (1) improve energy efficiency by upgrading plants with state-of-the-art equipment; (2) improve product formulation to reduce energy of production and minimize the use of natural resources; and (3) conduct research and develop new applications for cement and concrete that improve energy efficiency and durability. Efficiency improvement from the first two elements of this plan will contribute to achieving the 10 percent reduction goal. While reductions from the product application element will not count towards the goal, the carbon dioxide reduction benefits of cement and concrete use could be even more significant than those achieved through manufacturing and product formulation. The U.S. cement industry has also adopted a voluntary target of a 60 percent reduction (from a 1990 baseline) in the amount of CKD disposed per ton of clinker produced by 2020. See http://www.climatevision.gov/sectors/cement/index.html.

Under the reference case scenario, CEF projects the cement industry's fuel mix to be dominated by coal, as it is today.[lll] Economic energy intensity (energy consumption per dollar value of output) is projected to decrease very slightly at the rate of 0.1 percent per year, and overall energy consumption is projected to decline by 2 percent from 1997 to 2020. CEF's analysis suggests that as long as fuel prices remain low, facilities will have little incentive to invest in capital-intensive upgrades of existing facilities, and increases in energy efficiency will primarily be achieved through the retirement of old plants with wet kiln capacity and the construction of new plants with dry kiln capacity. Increased energy efficiency in cement kilns will result in reduced coal consumption.

CEF's reference case projections for the cement industry are based on the assumptions that production will grow at 1 percent per year, and value of output will grow at 1.1 percent per year. The sector's declining energy intensity is thus a function both of slow rates of decline in energy consumption and faster rates of increase in economic production. CEF also assumes that wet process clinker production will decline at 2.2 percent per year, comprising 13 percent of total production by 2020.

CEF projections support the expectation of incremental efficiency improvement for the cement industry, rather than large-scale efficiency gains, and are summarized in Table 23.

lll According to USGS data presented in the 2006 *Sector Strategies Performance Report*, 16% of the sector's energy supply was met by petroleum coke, which is a slightly larger fraction than is represented by data used in the CEF analysis.

Table 23: CEF reference case projections for the cement industry

	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.036	9%	0.033	8%
Natural gas	0.018	5%	0.014	4%
Coal	0.315	79%	0.313	80%
Delivered electricity	0.030	8%	0.031	8%
Total	0.399	100%	0.391	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.1%
Overall % change in energy use (1997-2020)				-2.0%

In an effort to assess the impact of recent trends that may have affected cement industry energy consumption since the CEF report was produced, we also examined reference case energy consumption projections 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. Where CEF projects a slight decline in sector energy consumption, AEO 2006 projects that sector energy consumption will increase by 10 percent from 2004 to 2020, driven by annual growth in the industry's value of shipments of 2.1 percent per year. However, energy intensity (energy consumption per dollar value of output) is expected to decrease at the rate of 0.7 percent per year—a faster rate of decline than projected by CEF. Though all fuel inputs are projected to increase, AEO 2006 projects the largest increases for natural gas and purchased electricity. Still, by 2020 AEO 2006 projects no substantial change in the overall fuel mix, with coal meeting 60 percent of the sector's energy demand and petroleum (mainly petroleum coke) meeting 23 percent (these fractions are similar to MECS energy consumption data from 2002).

Environmental Implications

Figure 8: Cement sector: energy-related CAP emissions

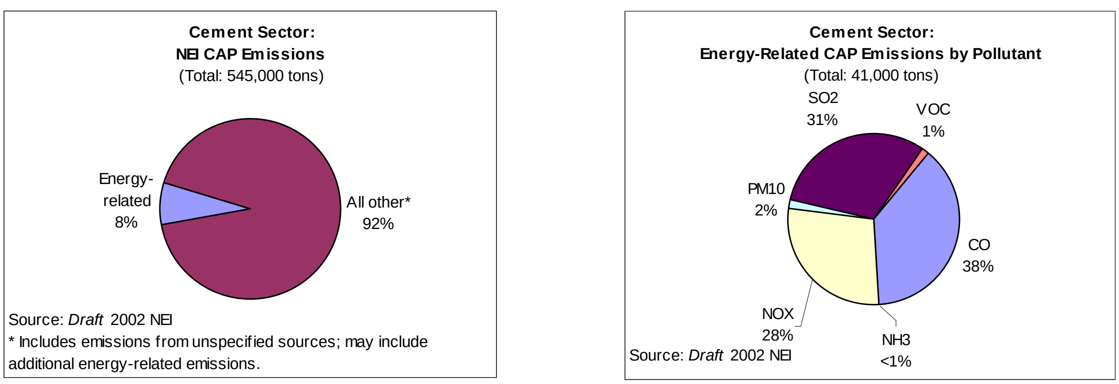


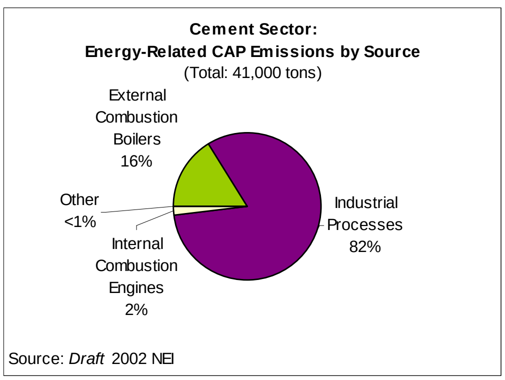
Figure 8 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the cement sector. Although NEI data attribute emissions from electric power generation to the generating source rather than the purchasing entity, because purchased electricity comprises a small fraction of the cement sector's energy requirements, NEI data provide a relatively complete picture of the industry's energy-related CAP emissions. However, the ratio of energy-related CAP emissions to total CAP emissions appears smaller than expected for an energy-intensive sector. As noted in Section 2.3.3, the majority of the sector's energy requirements and associated emissions result from the thermoreduction of limestone, clay, and sand in a process that uses coal both as a fuel and a feedstock. Given that NEI data for the cement industry only classify 8 percent of the sector's total CAP emissions as "energy-related," it appears likely that NEI data misclassify some CAP emissions resulting from this process as non-energy-related.

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.

According to NEI data, 66 percent of the sector's energy-related CAP emissions are due to coal consumption (see Figure 9). As a result, sulfur dioxide and nitrogen oxides (both linked to coal combustion) are fairly equal contributors to energy-related CAP emissions. (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.)

Figure 9: Cement sector: CAP emissions by source category and fuel usage



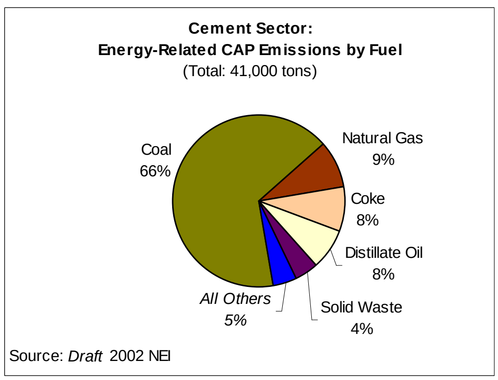


Figure 9 presents NEI data on the source categories for energy-related CAP emissions shown in Figure 8, as well as emissions by fuel usage. According to DOE data, fuel inputs into fired systems such as kilns, preheaters, and precalciners comprise the majority of sector energy consumption,[76] and these systems are classified under the "industrial processes" category in NEI. Given AEO 2006's projected increases in economic production and energy consumption for the cement industry, increases in energy-related CAP emissions are expected, which will primarily occur at the facility level from coal combustion.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 40.1 million metric tons in 2004. (Additional carbon emissions arise from the calcination of limestone, but such emissions are not classified as energy-related.) The projected increase in sector energy consumption is projected to increase carbon emissions to 44 million metric tons by 2020, at a slightly slower rate than the projected energy consumption increase due to expected energy efficiency improvements.

3.2.2 Best Case Scenario

Opportunities

Table 24 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 24: Opportunity assessment for the cement industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Medium	The majority of the industry's energy inputs are met with coal—a relatively inexpensive but emissions-intensive energy source. To the extent possible, the cement industry uses inexpensive waste fuels in its kilns (tires, waste paints, oils, and carpet) to reduce energy costs. The primary environmental benefits of waste fuel use is avoided landfilling and more complete combustion than would be offered by most commercial incinerators due to higher temperatures and longer residence time in kilns.[77] Some waste fuels may be subject to either federal or state RCRA hazardous waste regulations or state solid waste regulations. For example, paint wastes and used oil may be categorized as hazardous waste and, thus, could require plants to obtain hazardous waste permits to burn these materials as fuels. The cement sector also faces technical barriers to greater waste fuel use (e.g., kilns can generally not use more than 25 percent tires, because the zinc slows down setting time) and supply constraints in terms of the long-term stability of sufficient quantities of alternate fuels to meet demand.
Increased CHP	Low	There may be opportunities for increased cogeneration of electricity in the cement industry, particularly if such applications are part of the design for new plants.[78] Such opportunities would primarily involve systems to recover heat from exhaust systems and generate electricity onsite. There are also opportunities for increased waste heat recovery, particularly through waste heat utilization in preheater heat exchange systems.[79] However, the CEF report notes that there may be little incentive to devote capital to waste heat recovery systems as long as the industry is able to obtain low-cost energy (coal, waste fuels, etc.).
Equipment retrofit/ replacement	High	Given the magnitude of kiln-related energy requirements, DOE references the following equipment replacement and retrofit opportunities to improve the efficiency of both wet and dry kilns: installation/upgrades of preheat systems, enhanced heat recovery in the clinker cooler, and more efficient grate coolers.[80] Grinding technology improvements such as replacing ball mills with high pressure roller mills or horizontal roller mills is another example of an energy efficiency improvement opportunity for the cement industry.[81] At the same time, ball mills generally provide better mixing than roller mills, so roller mills may not meet production-related requirements. The expected life of onsite limestone reserves may be a determinant in selecting a retrofit or equipment replacement option. If reserves are limited, small retrofits are more likely to be implemented than full-scale equipment replacement. If reserves are substantial, sites are more likely to undertake larger capital investments, which might include energy efficiency improvements.[82]
Process improvement	High	A recent study notes that the greatest opportunities for reducing energy consumption and lowering emissions lie with improvements in cement pyroprocessing, which currently operates at 34 percent thermal efficiency.[83] In an example of a full-scale process change, the cement industry is transitioning from wet process kilns to dry process kilns, which leads to substantial reductions in energy use per ton of production. The kiln replacement process is slow not due to regulatory considerations but economic considerations—specifically, capital constraints and the long operational lifetime for kilns (30-40 years), which mean that changes in the number and types of kilns occur slowly, and typically only when the kiln has reached the end of its useful life, because operating cost savings are insufficient to justify early retirement of the expensive capital. (At the same time, PCA estimates that nearly 44 percent of U.S. clinker production capacity is older than 30 years.) Opening new dry kilns would trigger NSR review and other requirements (e.g., Maximum Achievable Control Technology (MACT) standards for cement kilns; new NESHAPs for portland cement once finalized); however, the long-term and continuing conversion from wet to dry kilns indicates that this is not an insurmountable barrier to adopting the more energy-efficient dry process.

Opportunity	Ranking	Assessment (including potential barriers)
		CEF cites pollution prevention and waste recycling as having potential to achieve efficiency improvements in the cement industry. [84] Alternative raw materials for cement clinker production and cement blending (e.g., foundry sand) may be used; these alternative raw materials reduce energy consumption by reducing the amount of virgin raw materials that need to be quarried for the cement kilns or reducing the amount of cement clinker that needs to be blended into the cement product. Other process-related opportunities include reducing pyroprocessing energy use through increasing blending and using alternative clinker materials,[85] combustion system optimization, and adaptation to semi-wet conversion processes (wet kilns).[86]
R&D	Medium	Fluidized-bed kilns are an emerging technology that shows capital and operational savings over dry kilns and may be adopted when existing kilns are slated for replacement. R&D efforts focusing on reducing energy requirements in pyroprocessing offer the greatest opportunities for improved environmental performance. A recent study notes the following areas of R&D opportunities: developing less energy-intensive cement manufacturing processes; developing systems for biomass fuel usage in kilns; and developing systems for increased waste fuel utilization.[87]

Optimal Future Trends

Given more recent AEO 2006 projections that indicate an increasing energy consumption trend for the cement industry, CEF's reference case projections appear outdated, calling into question the validity of its advanced case projections. However, AEO 2006 does not provide sector-specific data for its advanced energy scenario, and we must use the CEF study to approximate an environmentally preferable energy consumption trend for the cement industry.

Under its advanced case projections, CEF projects no major change to the cement industry's dependence on coal but shows larger declines in coal inputs than in petroleum and electricity input, and a slight increase in natural gas consumption. Rather than a fuel-switching trend that replaces coal with other energy inputs, the declining coal fraction is the result of reduced energy use in kilns through more aggressive introduction of blended cements in the U.S. market, and faster retirement of wet process clinkers with replacement by modern preheater precalciner dry process kilns. For dry process plants, energy efficiency opportunities reflected in the CEF projections include optimized heat recovery in the clinker grate cooler and conversion to grate clinker coolers. For wet process plants, conversion to semi-wet processes and kiln combustion system improvements produce additional energy efficiency gains. Cross-cutting energy efficiency improvements are achieved through preventative maintenance best practices, improved process control through control system installations, and installation of energy management systems.

As with CEF's projections for all sectors, economic assumptions are the same under the advanced case scenario as the reference case (growth in production of 1 percent per year and growth in value of output at 1.1 percent per year). (See Appendix A-2 of the CEF report for more detailed descriptions of CEF's modeling assumptions under the business-as-usual and advanced energy scenarios.) Given current expectations of production growth for the industry and AEO 2006 reference case projections, it is unlikely that an advanced energy scenario would achieve such aggressive reductions in energy consumption.

CEF's advanced case projections are shown in Table 25.

Table 25: CEF advanced case projections for the cement industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu) [mmm]	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.036	9%	0.034	11%
Natural gas	0.018	5%	0.030	10%
Coal	0.316	79%	0.216	70%
Delivered electricity	0.030	8%	0.028	9%
Total	0.4	100%	0.308	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-1.1%
Overall % change in energy use (1997-2020)				-23%

Environmental Implications

Though an advanced energy scenario may be unlikely to achieve the energy consumption reductions projected by CEF, such a scenario would produce lower CAP emissions at the facility level than are expected under a business-as-usual scenario. Conversion to precalciner kilns also contributes to NOx emissions reductions.

Under the advanced energy scenario, CEF projects the cement industry to achieve a 16 percent reduction in 1997 carbon dioxide emissions levels by 2020 (compared with an increase of 5.7 percent projected under the reference case).

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[mmm] 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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3.3 Chemical Manufacturing

3.3.1 Base Case Scenario

Situation Assessment

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.

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.

- 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

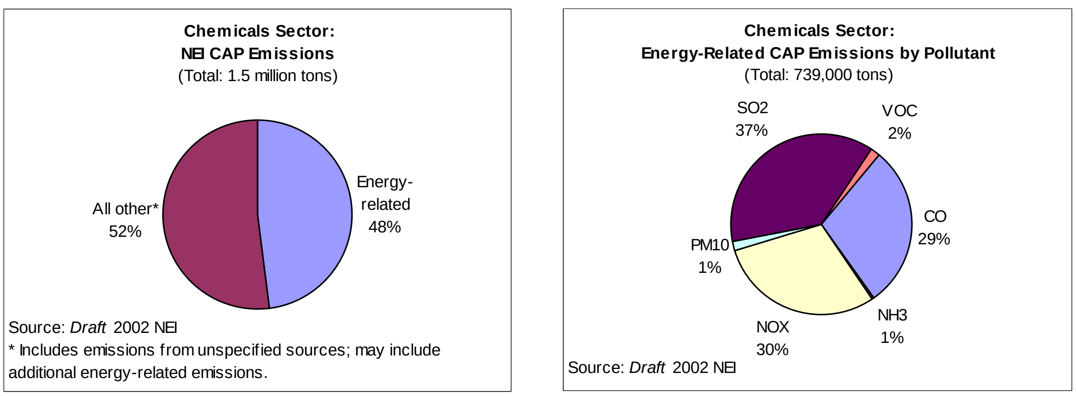
ooo Energy consumption data do not include fuels used as feedstock.

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



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 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.)

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

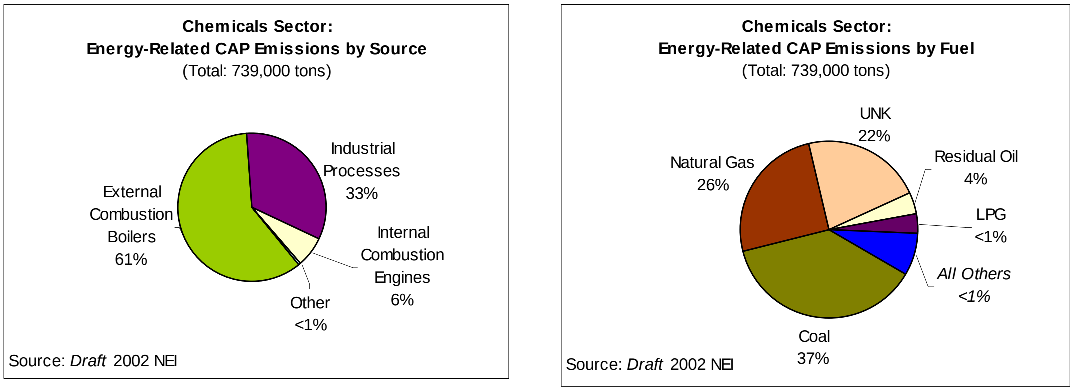


Figure 11 presents NEI data on the sources of energy-related CAP emissions. According to NEI, 37 percent of the energy-related emissions shown in Figure 11 are from coal consumption, 26 percent are from natural gas, and 22 percent are from unknown sources. Most of the sector's sulfur dioxide emissions 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.

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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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3.4 Food Manufacturing

3.4.1 Base Case Scenario

Recent Sector Trends Informing the Base Case

Value of shipments: ↑

Major fuel sources: Natural gas, electricity, coal

Current economic and energy consumption data are summarized in Table 30 on page 3-32.

Situation Assessment

Food manufacturing (NAICS 311) is a multi-billion dollar industry that transforms livestock and agricultural products into a diverse set of products for intermediate or final consumption by humans (or by animals as animal feed). Within the NAICS, industry subsectors are distinguished by the raw materials (generally of animal or vegetable origin) they process into food products. The industry is highly diversified and dominated by large-scale, capital-intensive firms, with more than 26,000 facilities across the United States.[107] Agribusiness participates in EPA's Sector Strategies Program.

From 1997 to 2004 the food manufacturing sector showed economic growth in terms of value added and total value of shipments (see Table 30). Much of the industry's energy consumption takes place in the East North Central and West North Central regions.[108]

While the food-processing sector is typically amongst the largest manufacturing energy consumers in states where the industry is located, and has the fifth-highest energy consumption of the sectors considered in this analysis, its energy intensity is relatively low (see Table 16). Still, energy is an important input cost for the industry, typically ranking third along with capital in terms of business costs; raw materials and labor are the dominant cost factors.

For food manufacturing, the most important fuels are natural gas, purchased electricity, and coal.[109] According to DOE, approximately 9 percent of the industry's electricity demand is met with onsite power systems, with the majority of that electricity (95 percent) produced in cogenerating units that also produce steam.[110]

The following eight subsectors consume approximately half of the total energy used by the food manufacturing industry: wet corn milling; beet sugar; soybean oil mills; malt beverages; meat packing; canned fruits and vegetables; frozen fruits and vegetables; and bread, cake, and related goods. It is estimated that 40 percent of the value of processed food is added through energy-intensive manufacturing. Process heating and cooling systems (steam systems, ovens, furnaces, and refrigeration units) have the greatest energy requirements in food manufacturing (over 75 percent of the sector's energy use) and are necessary to maintain food safety. Motor-driven systems (pumps, fans, conveyors, mixers, grinders, and other process equipment) represent 12 percent of the sector's energy use, and facility functions (heat, ventilation, lighting, etc.) comprise approximately 8 percent.[111] The sector also has the largest transportation demand of the sectors considered in this analysis, comprising more than 20 percent of the manufactured commodity shipping ton-miles recorded by DOT in 2002 (see Table 11).[112]

Recent fuel consumption trends (1998 to 2002) show increased coal usage, which may indicate that some companies are increasing coal consumption in response to increases in the price of natural gas.[113] (For a detailed discussion of fuel-switching and the limitations thereof, please see Section 2.2.3.) Rising energy costs are a motivator for increased energy efficiency in the food manufacturing industry. Energy ranks third among input costs, behind raw materials and labor, but is often viewed as a fixed cost. The industry may have substantial potential for energy efficiency improvement, as historically it has not taken a strategic approach to energy management, and firms often lack awareness of energy efficiency opportunities. Moreover, the margins in the food manufacturing industry are relatively thin compared to other manufacturing and processing industries; thus, the sector may be typically slower to adopt technologies and processes that require significant capital outlays.

To provide more information to the sector, a Food Industry Resource Efficiency team (FIRE) developed an energy portal for food processors through the State Technologies Advancement Collaborative (STAC) program, administered by the National Association of State Energy Officials for DOE. Other organizations, such as Efficiency Vermont and the Northwest Alliance, work toward assisting specific commodity processors in their regions with improving energy efficiency. This regional approach recognizes that food production and processing tends to be geographically distinctive: wine processing in northern California, dairy in Wisconsin, and so forth.

Table 30 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 30: Current economic and energy data for the food 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
	2.5%	2.5%	0.8%	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)
	6.0	2.6	3.3%	1.5%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Natural Gas	Net Electricity	Coal	Other[qqq]	Fuel Oil
52%	21%	17%	8%	3%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	28%
		Fuel Oil	LPG	Electricity
Fraction of natural gas inputs that could be met by alternate fuels		71%	41%	13%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	20%
		Natural Gas	LPG	Fuel Oil
Fraction of coal inputs that could be met by alternate fuels		83%	19%	13%

[qqq] "Other" fuels include waste materials used as fuel.

Expected Future Trends

In the United States, increasing demand for fresh processed foods by individual consumers and by HRI (hotel, restaurant, institutional) customers has increased energy consumption by the food manufacturing industry. Demographically, the increase in two-earner couples, increased disposable income, and an aging population are all pushing the system to deliver more ready-to-eat or fast-prepared foods. Additionally, if the next wave of food consumption entails more fresh foods, particularly more fruits and vegetables, energy utilization may increase, since reducing spoilage will require even more sophisticated and possible lengthy supply chains, cold-chain accuracy, hot house expansions, etc. AGF projects continued economic growth for the food manufacturing industry through 2020 due to increases in population and disposable income, and the fact that foreign competition is less of a limiting factor than it is for other industries.[114]

Under its reference scenario, CEF projects that energy consumption by the food manufacturing sector will increase by 19 percent from 1997 to 2020, primarily driven by continued economic growth in the sector (the value of industry output is assumed to increase at the rate of 1.2 percent per year). Energy intensity (energy consumption per dollar value of output) is expected to decrease at the slow rate of 0.5 percent per year. Consumption of all fuel types is projected to increase. No large-scale changes in the sector's fuel mix are projected, though the projected minor shift from natural gas to petroleum may be unlikely given the increases in the price of oil that have occurred since the CEF study was published. The sector will continue to remain dependent on natural gas. Supporting CEF projections, AGF predicts that overall natural gas consumption by the food manufacturing industry will increase at 0.4 percent annually through 2020.[115]

Table 31 summarizes the CEF base case projection for the food manufacturing sector. The small renewables fraction is primarily attributable to the use of bio-waste as fuel.

Table 31: CEF reference case projections for the food manufacturing industry

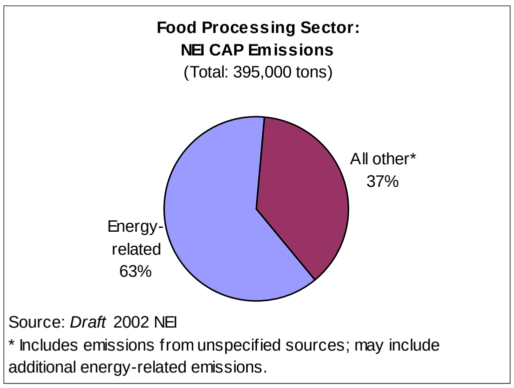
	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.209	17%	0.272	18%
Natural gas	0.625	50%	0.701	48%
Coal	0.183	15%	0.228	15%
Renewables	0.014	1%	0.020	1%
Delivered electricity	0.208	17%	0.251	17%
Total	1.239	100%	1.472	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.5%
Overall % change in energy use (1997-2020)				19%

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 food manufacturing sector 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 faster growth in the industry's value of shipments than CEF (2 percent per year) and a similar rate of decrease in energy intensity (0.6 percent per year). Overall, AEO 2006 projects that sector energy consumption will increase 24 percent from 2004 levels by 2020. The industry's energy needs will continue to be met by natural gas (54 percent of total energy inputs in 2020), purchased electricity (22 percent), and coal (17 percent). Consumption of all fuels is projected to increase, with the exception of petroleum, which is expected to decline by 6 percent over the period. The largest percentage increases in fuel consumption are for renewables (43 percent increase from 2004 to 2020), natural gas (30 percent increase), and purchased electricity (24 percent increase).

Environmental Implications

Figure 12: Food manufacturing sector: energy-related CAP emissions



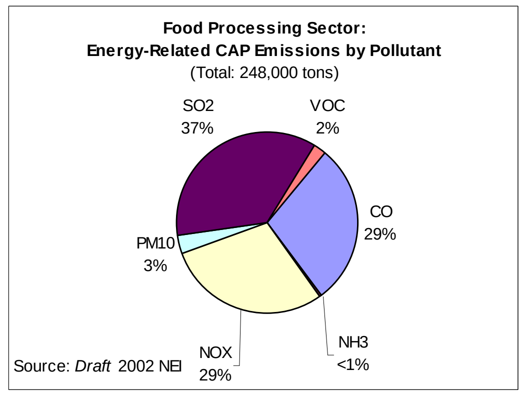


Figure 12 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the food manufacturing sector. According to the figure, energy-related CAP emissions comprise a relatively large fraction of total CAP emissions, in part due to the sector's substantial process heating and cooling requirements. According to MECS data (see Table 30), purchased electricity (net) meets roughly 20 percent of the sector's energy needs. As NEI data attribute emissions associated with electric power generation to the generating source rather than the purchasing entity, there are substantial energy-related CAP emissions that are not represented in NEI data for this 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 13: Food manufacturing sector: CAP emissions by source category and fuel usage

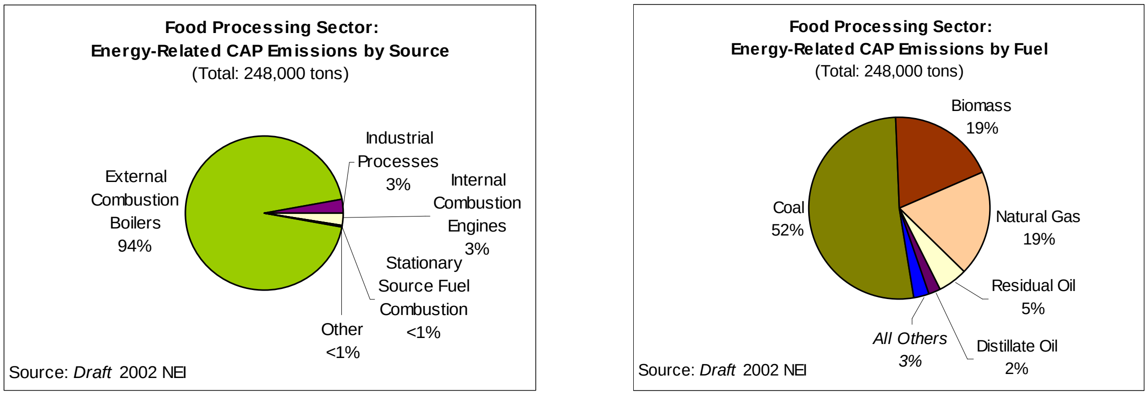


Figure 13 presents NEI data on the sources of energy-related CAP emissions shown in Figure 12. NEI data classify the majority of energy-related CAP emissions as produced by external combustion boilers. As noted previously, NEI data classifications are problematic due to reporting inconsistencies, but equipment classified under "external combustion boilers" likely includes steam systems used for process heating. Segments of the food manufacturing industry with high boiler usage include sugar, malt beverages, corn milling, and meat packing. As noted previously, more than 75 percent of the sector's energy requirements are for process heating and cooling systems, which, according to DOE classifications include steam systems, fired systems, and cooling units. Motor-driven systems are another substantial end use of energy[116] but are primarily electric so associated emissions would not be captured in NEI.

According to NEI data shown in Figure 14, 52 percent of the sector's energy-related CAP emissions are from coal consumption, and 19 percent are from natural gas consumption. The emissions intensity of coal is evident from this figure, as MECS data (see Table 30) report that coal comprises approximately 16 percent of the sector's energy inputs compared with more than 50 percent for natural gas. Sulfur dioxide and nitrogen oxides (both linked to coal combustion), are fairly equal contributors to energy-related CAP emissions for the food manufacturing industry. (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.) Given AEO 2006 and CEF reference case projections of increasing energy consumption through 2020, energy-related CAP emissions are expected to increase as well, with the majority of energy-related CAP emissions continuing to occur at the facility level.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 92 million metric tons for the food manufacturing sector in 2004. AEO 2006 projects that the industry's carbon dioxide emissions will increase 19 percent from 2004 to 2020—a somewhat smaller increase than the projected growth in energy consumption (24 percent). Though we do not address transportation energy use in detail in this analysis, the sector also has extensive freight shipping needs.

3.4.2 Best Case Scenario

Opportunities

Table 32 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 32: Opportunity assessment for the food manufacturing industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Medium	There is potential for increased switching to waste fuels (such as used vegetable oil that can be reused as boiler fuel) and reduced use of coal as boiler fuel. Limitations on this opportunity are imposed by technical constraints (type of boiler and burners in place) and economic constraints (relative price of coal versus less emissions-intensive fuels). Permitting considerations (NSR/PSD) may also affect fuel-switching.
Increased CHP	High	CEF cites increased cogeneration as the greatest energy efficiency opportunity for the sector. One area of opportunity is increased use of waste heat (e.g., using boiler flue gases in CHP processes,[117] or from refrigeration processes, where heat from engines used to drive compressors can be used to preheat water or for space heating at the plant). 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.[118]
Equipment retrofit/ replacement	Medium	Energy efficiency gains are achievable through retrofits or replacement of existing equipment with more efficient new models, particularly in steam systems since these systems have the largest energy requirements and associated energy losses. Equipment-related opportunities noted by DOE include replacing steam systems with direct-fired drying equipment (impulse drying, infrared drying, and press drying).[119] Other areas for steam system retrofits or equipment replacement include boilers, pipes, valves, traps, heat exchangers, and preheaters.
Process improvement	High	Process improvement opportunities include changes in operating techniques to implement best energy management practices, optimizing energy consumption in scheduling processing activities, wastewater reuse, and conversion and/or sale of byproducts. For example, while dehydration systems were originally designed for maximum product throughput, newer systems include recirculating dampers. ACEEE has made several recommendations for the food products industry including industry practices such as pasteurization and sterilization by cold pasteurization and electron beam sterilization; evaporation and concentration by supercritical extraction and protein separation, drying by vapor recompression supercritical extraction; and chilling, cooling, and refrigeration by controlled atmosphere packaging. In some cases, process changes must be reviewed, certified, and approved by USDA, Food and Drug Administration, or other regulatory agencies; the added cost of this regulatory review may serve as a barrier to efficiency improvement.
R&D	Medium	A recent LBNL study notes that membrane technologies can reduce energy requirements associated with traditional filtration, separation, and evaporation processes, and also increase byproduct recovery.[120] Advanced cooling and refrigeration processes also offer potential energy savings, though it is important to note that many larger plants already use ammonia refrigeration systems, which are quite efficient and provide the multiple refrigeration temperatures often required in food manufacturing plants. In addition to membrane technologies and refrigerants, there is also continued research and progress on uses of byproducts, byproduct reduction, analytical methods, sanitizing and cleaning agents and procedures, wastewater treatment technologies, and packaging technologies.

Optimal Future Trends

CEF's advanced energy scenario projects a smaller increase in sector energy consumption (8 percent from 1997 to 2020) than under the business-as-usual scenario (19 percent increase). According to CEF, cogeneration is expected to play an important role in increasing energy efficiency in the food manufacturing sector, contributing to a faster decrease in energy intensity (decline of 0.9 percent per year) than was projected in the reference case (decline of 0.5 percent per year). The effects of increased CHP may also be evident through a slight decline in purchased electricity (1 percent) in the advanced case, despite the overall trend of increasing energy consumption. Over the same period, consumption of natural gas and petroleum is expected to increase by 14 percent and 15 percent, respectively, and coal use is expected to decline by 16 percent. CEF's advanced case employs the AEO 1999 HiTech case assumptions concerning rates of deployment of energy-efficient equipment, and also assumes increased energy efficiency for boilers and commercial buildings.

CEF's advanced case projections are summarized in Table 33.

Table 33: CEF advanced case projections for the food manufacturing industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu) [rrr]	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.210	17%	0.242	18%
Natural gas	0.630	51%	0.718	53%
Coal	0.184	15%	0.155	12%
Renewables	0.014	1%	0.022	2%
Delivered electricity	0.208	17%	0.206	15%
Total	1.246	100%	1.343	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.9%
Overall % change in energy use (1997-2020)				8%

Environmental Implications

Under the advanced energy scenario, CEF projects a smaller increase in sector energy consumption than under its reference case, which is a net gain in terms of energy-related CAP emissions. The advanced case also predicts a shift from coal to natural gas that does not occur under the reference case, which would lead to lower CAP emissions at the facility level than are expected under the business-as-usual conditions—particularly sulfur dioxide and nitrogen oxides.

Despite the overall increase in sector energy consumption, under the advanced energy scenario, CEF projects the food manufacturing industry to achieve an 11 percent reduction in carbon emissions levels by 2020. Projected carbon emissions reductions are attributable to efficiency gains from increased CHP and reductions in purchased electricity (which is

[rrr] 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.

associated with substantial energy losses, as discussed previously), and reductions in the use of carbon-intensive energy sources such as coal. However, replacing purchased electricity with petroleum and natural gas will also have the effect of shifting energy-related CAP and carbon emissions from the utility level to the facility level. The location of carbon emissions is not important from a climate perspective. However, energy trends that are environmentally preferable from a climate perspective may also lead to less-than-optimal trends for facility emissions of criteria air pollutants.

3.4.3 Other Reference Materials Consulted

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3.5 Forest Products

3.5.1 Base Case Scenario

Situation Assessment

Recent Sector Trends Informing the Base Case

Number of facilities: ↓
Pulp and paper value of shipments: ↓
Wood products value of shipments: ↑
Energy intensity: ↓

Major fuel sources: Wood biomass, black liquor, natural gas, & electricity

Current economic and energy consumption data are summarized in Table 34 (pulp & paper) and Table 35 (wood products) beginning on page 3-41.

Forest products manufacturing (NAICS 321 and 322) includes companies that grow, harvest, or process wood and wood fiber for use in products such as paper, lumber, board products, fuels, and many other specialty materials. The forest products sector can be divided into two major categories: (1) pulp, paper, and paperboard products; and (2) engineered and traditional wood products. As reported by DOE's Industrial Technologies Program (ITP), there are more than 4,600 pulp and paper facilities and 11,600 lumber and wood products facilities,[121] typically located near wood sources to minimize transportation costs. While the industry has operations in all 50 states, Wisconsin, California, and Georgia are the nation's top three producers of forest products.[122] The forest products industry participates in EPA's Sector Strategies Program.

From 1997 to 2004 the pulp and paper industry showed a decline in value added and value of shipments, and the wood products industry showed slow growth in both metrics (see Table 34 and Table 35). The primary economic pressure on the U.S. forest products industry is from foreign competition, both from its historical competitors such as Canada, Scandinavia, and Japan, and from countries with emerging industries such as Brazil, Chile, and Indonesia.[123] Over the past 10 years, DOE/ITP reports that many forest product companies have been forced to close or idle a large number of mills to reduce costs and remain competitive.

The forest products sector has several unique energy consumption attributes that distinguish it from other manufacturing sectors. More than half of the sector's energy needs are met with renewable biomass fuels that are byproducts of the manufacturing process, and which facilities burn in boilers to generate steam and electricity.[124] Renewable byproduct fuels are primarily spent pulping liquors (chemicals and other burnable substances dissolved from wood in the pulping process) and "hogged fuel" (logging and wood processing waste such as bark and other wood residuals).[125] The forest products industry is the largest user of wood byproduct fuels, representing 93 percent of total wood fuel usage by U.S. manufacturing industries.[126] According to energy data reported by AF&PA in 2002, spent pulping liquors met more than 40 percent of pulp and paper manufacturing energy requirements, and wood waste met around 15 percent. For wood products manufacturers, wood waste met more than 65 percent of total energy requirements.[127] (These fractions are slightly higher than MECS' estimates of "other" fuel use fractions for the sectors in 2002, which may in part be attributable to differences in the data collection methodologies employed by the two sources.) Trees remove carbon from the atmosphere as they grow, and thus from a lifecycle perspective, consumption of wood byproduct fuels represents an almost carbon neutral energy source. (There is some energy consumption associated with harvesting and transporting biomass, and accounting for such energy use means that it is not entirely carbon neutral). At the same time, the forest products industry has the third-highest fossil fuel consumption among manufacturing industries,[128] so further reducing fossil fuel inputs represents both a cost savings and an environmental improvement opportunity for the sector.

The other characteristic that distinguishes energy consumption by the forest products industry from that of other manufacturing industries is the extent to which combined heat and power

(CHP) applications are used to meet demand for electric and thermal energy. As discussed previously, CHP (also referred to as cogeneration) is considered an environmentally preferable generating technology because the simultaneous production of thermal and electric energy is more efficient than electric-only generating processes, and onsite electricity production eliminates the energy losses associated with long-distance transmission and distribution of electric power over the grid. The forest products sector is the largest cogenerator among U.S. manufacturing industries, with more than 65 of the industry's electricity needs are being met through cogeneration processes.[129] Thermal energy (primarily steam) is used for process heating, evaporation, and drying, as well as to power equipment such as saws and conveyors. Electricity is primarily used to power process equipment.[130]

Energy use by the industry is dispersed geographically but is highest in the East North Central, West North Central, and West South Central regions.[131] Pulp and paper manufacturing accounted for 86 percent of the energy used in 2002, while wood products manufacturing accounted for the remaining 14 percent.[132] The majority (81 percent) of the sector's energy requirements are for process heating and cooling systems, particularly those used for drying and evaporation.[133]

Due to competitive pressures and the energy-intensive nature of its manufacturing processes, the forest products industry is highly motivated to control the costs of purchased energy. According to DOE, long-term reductions in energy intensity have been achieved primarily through process efficiency improvements and addition of CHP capacity.[134] To address the impact of rising energy costs in the 1990s, the sector made comprehensive energy efficiency investments, increased burning of wood waste to produce energy, and reduced petroleum inputs in favor of natural gas. From 1998 to 2002, the energy intensity of the wood products sector declined by 29 percent, and the energy intensity of the pulp and paper sector declined by 19 percent.[135] Available energy consumption data precede energy price increases that have occurred since 2002. AF&PA indicates that further energy intensity reductions have resulted from recent energy price increases, primarily through the closure of inefficient mills. Since 2002, the industry has sought to control energy costs through increased utilization of waste streams for energy content (spent pulping liquors and wood residuals),[136] and achieved energy consumption reductions through installation of variable speed motors and more energy-efficient lighting.[137]

Environmental compliance also represents a substantial cost for the industry. DOE reports that from 1997 to 2002, 14 percent of annual capital equipment expenditures were dedicated to environmental protection measures, at an industry-wide cost of $800 million per year.[138] The intersection between environmental compliance and energy consumption may involve trade-offs. For instance, according to AF&PA, natural gas consumption by the wood products industry has increased due to environmental regulations that require the installation of regenerative thermal oxidizers (RTOs), and the new Plywood MACT is expected to require additional RTO installations by 2008.[139]

Table 34 and Table 35 summarize current economic trend and energy consumption data originally presented in Chapter 2.

Table 34: Current economic and energy data for the pulp and paper 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
	-1.2%	-3.6%	-1.6%	-4.0%
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)
	31.1	15.2	8.8%	4.3%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Other (Primarily Biomass)[sss]	Natural Gas	Coal	Net Electricity	Fuel Oil
54%	21%	10%	9%	5%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	32%
		Fuel Oil	Electricity	LPG
Fraction of natural gas inputs that could be met by alternate fuels		80%	16%	9%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	23%
		Fuel Oil	Natural Gas	Electricity
Fraction of coal inputs that could be met by alternate fuels		66%	57%	10%

[sss] For pulp and paper manufacturing, biomass fuels categorized as “other” fuels in MECS include spent pulping liquor (approximately 70% of the “other” category) and wood residues and byproducts (approximately 27% of the “other” category).

Table 35: Current economic and energy data for the wood products 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
	1.8%	2.5%	0.3%	0.2%
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)
	10.6	4.2	4.7%	1.9%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Other (Primarily Biomass)[ttt]	Net Electricity	Natural Gas	Fuel Oil	LPG&NGL
61%	19%	15%	3%	1%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
Switchable fraction of natural gas inputs				20%
		Fuel Oil	LPG	Other
Fraction of natural gas inputs that could be met by alternate fuels		36%	36%	27%

Expected Future Trends

The forest products industry will continue to seek to control energy costs in an effort to maintain its competitive position in the global market, and the industry views increased biomass utilization as a key tool for achieving that objective. At the same time, several factors have the potential to increase energy demand:

- Increased facility energy use resulting from stricter pollution control requirements and increased facility automation.
- Reductions in timber acreage lead to increased harvesting of sub-optimal timber that requires more energy-intensive processing.

CEF does not address the wood products sector, but since the pulp and paper industry has substantially greater

Voluntary Commitments

Through Climate VISION, the American Forest & Paper Association has committed to reducing the industry's GHG intensity by 12 percent between 2000 and 2012. Specific initiatives include improving carbon emissions inventories and reporting, enhancing carbon sequestration in managed forests and products, and increasing energy efficiency, cogeneration, use of renewable energy, and recycling. See http://www.climatevision.gov/sectors/forest/index.html.

The forest products 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/forest/.

[ttt] For wood products manufacturing, biomass fuels categorized as "other" fuels in MECS are primarily wood waste.

energy requirements, it is appropriate to focus our future scenario assessments on this subset of the forest products industry. The pulp and paper industry is also one of the three sectors (along with cement and steel) for which CEF made detailed parameter modifications to the NEMS model used to produce AEO 1999. Modifications included adjustments to baseline energy intensities and rates for annual improvements in energy intensity, which were adjusted to reflect best-available sector-specific research. It is important to note that the CEF analysis predates the energy price increases of 2004 and 2005 that have shifted the industry towards even greater use of biomass as an energy source (spent pulping liquor and wood waste), and toward lower energy intensity through the closure of older, less efficient manufacturing facilities.

Under the reference case scenario, CEF projects that the pulp and paper industry's energy consumption will continue to be dominated by renewable fuels (primarily biomass) and natural gas, though renewable energy sources will grow at the expense of natural gas, coal, and petroleum as the industry continues to reduce its demand for purchased fuels. Economic energy intensity (energy consumption per dollar value of output) is expected to decrease at the rate of 0.9 percent per year, and physical energy intensity (energy consumption per ton of production) is projected to decrease at the annual rate of 0.5 percent per year. Economic production is projected to grow at the rate of 1.2 percent per year.

CEF's assumptions about production growth in the pulp and paper sector drive the expected increase in energy consumption despite the trend of decreasing energy intensity. CEF projections are also based on the assumption that Kraft/sulfite pulping will increase from an 83.7 percent market share in 1994 to an 88.7 percent market share by 2020, with mechanical pulping dropping from 9.6 percent to 5.7 percent, and semi-chemical pulping dropping from 6.7 percent to 5.6 percent. Energy efficiency improvements embedded in CEF's reference case projections include an anticipated decline in energy consumption for raw materials preparation, an increase in heat recovery from mechanical pulping processes, slow penetration of energy-efficient grinding technologies, and reduced heat requirements for the papermaking process due to full commercialization of the CondeBelt process by 2020. (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 business-as-usual scenario.)

CEF reference case projections are summarized in Table 36.

Table 36: CEF reference case projections for the pulp and paper industry

	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.122	4%	0.096	3%
Natural gas	0.672	23%	0.427	14%
Coal	0.394	13%	0.269	9%
Renewables	1.483	51%	1.997	65%
Delivered electricity	0.258	9%	0.274	9%
Total	2.929	100%	3.063	100%
Annual % change in economic energy intensity (energy consumption per dollar value of output)				-0.9%
Overall % change in energy consumption (1997-2020)				5%

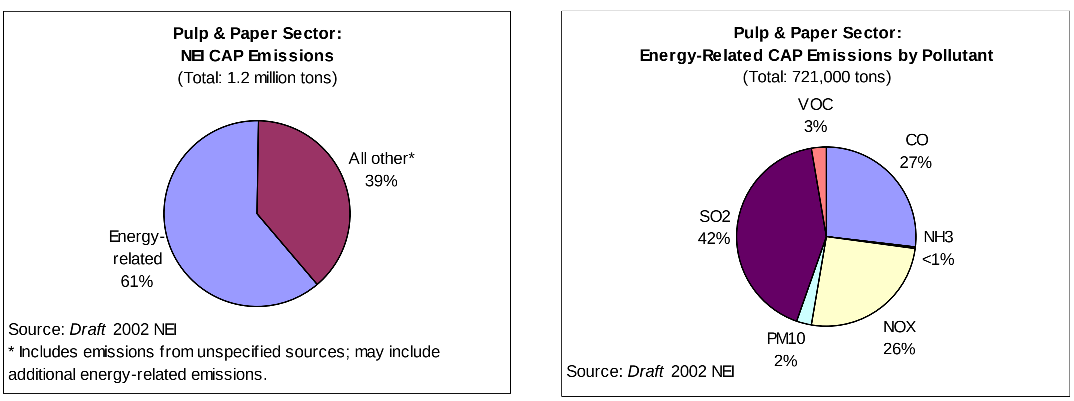
CEF's assumption of increasing economic production may be inconsistent with current industry realities given that key economic indicators for the industry—value added and value of shipments—have declined since 1997 (-1.2 percent per year and -1.6 percent per year, respectively). If economic production remains flat or declines further, sector energy consumption would be expected to decrease given expected energy efficiency improvements.

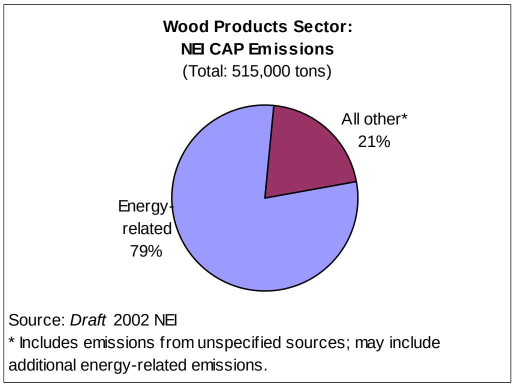
In an effort to assess the impact of recent trends that may have affected industry energy consumption since the CEF report was produced, we also examined reference case energy consumption projections for the pulp and paper industry produced in connection with EIA's *Annual Energy Outlook 2006* (AEO 2006), which also uses the NEMS model but incorporates more recent energy and economic data. However, AEO 2006 also projects production to grow (increasing at 1.1 percent per year), albeit at a slightly slower rate than projected by CEF, which drives an expected increase in energy consumption of 12 percent over the period. AEO 2006 projects a decrease in energy intensity of 0.5 percent per year. Consumption of renewable fuels is expected to grow by 20 percent over the period, meeting the majority of the sector's energy consumption increase. Petroleum consumption is projected to decline, and coal consumption is projected to remain static. CEF and AEO projections of increased reliance on renewable biomass fuels are in line with AF&PA expectations, though according to AF&PA data, the pulp and paper industry already meets 60 percent of its energy needs with biomass.[140]

Continued energy pricing pressures are expected to drive increased utilization of biomass resources as an energy source. At the same time, increased yield and process efficiency reduces the availability of biomass byproducts for energy consumption purposes.[141] The industry is also concerned about increasing demand for biomass that would drive up the cost of the industry's raw material, in part due to government policies that broadly encourage the use of biomass as fuel—for instance, by renewable power generators.[142]

Environmental Implications

Figure 14: Forest products sector: energy-related CAP emissions





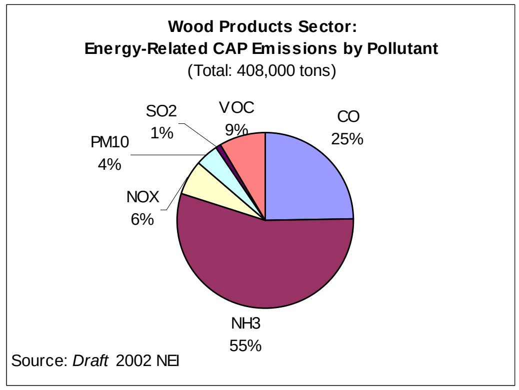


Figure 14 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the two subsectors of the forest products industry: pulp and paper, and wood products. The forest products sector's fraction of energy-related CAP emissions (as a percentage of total CAP emissions) is higher than that of many other sectors included in this analysis. This is in large part due to the extent to which the sector meets its own electric and thermal energy requirements through onsite power generation, with extensive use of relatively more energy-efficient CHP applications. (As discussed previously, onsite power generation also reduces the magnitude of energy losses that occur in power transmission and distribution.) Substantial process heating requirements in both sectors also contribute to the magnitude of the energy-related CAP fraction.

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.

The substantial fraction of ammonia (NH_3) emissions shown for the wood products industry is the result of an NEI data reporting error: 225,000 TPY of ammonia emissions reported in NEI are from a single facility and are believed to be incorrectly reported or misclassified as energy related. After correcting for this error by eliminating that data point, total energy-related CAP emissions for the wood products industry are approximately 180,000 TPY (as reported in Table 13, Section 2.3.3), and the largest fractions of energy-related CAP emissions are carbon monoxide (55 percent), VOCs (19 percent), and nitrogen oxides (14 percent). (As noted in Section 2.3.3, NEI data on carbon monoxide emissions appear higher than would be expected for stationary sources.)

Though the fraction of energy-related CAP emissions for the wood products sector is larger than the energy-related fraction for pulp and paper, due to the greater energy requirements of the pulp and paper industry, on a ton-basis energy-related CAP emissions are much larger for the pulp and paper sector than they are for wood products sector. According to MECS data (see Table 35), in 2002 purchased electricity met nearly 20 percent of the wood products sector's energy requirements, indicating that a substantial fraction of the sector's energy-related emissions are not captured by NEI data for the sector (as such emissions are attributed to the generating source rather than the purchasing entity). For pulp and paper, net electricity met approximately 9 percent of the sector's energy demand in 2002.

Figure 15: Forest products sector: CAP emissions by source category and fuel usage

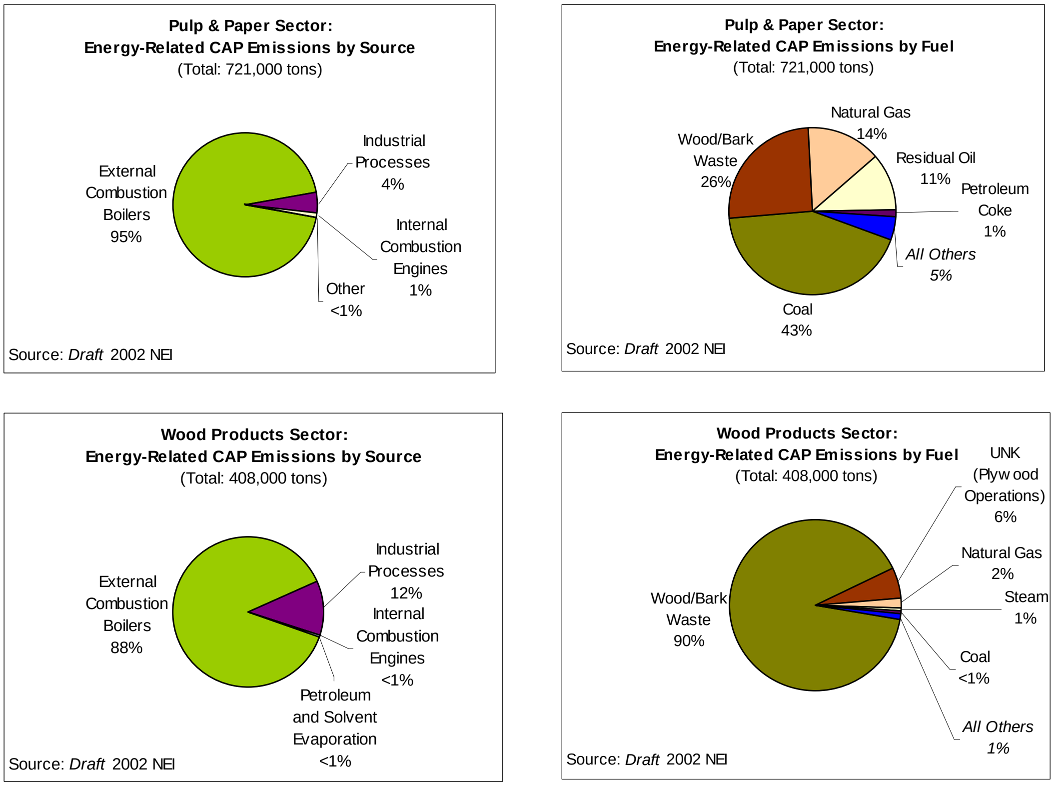


Figure 15 presents NEI data on the sources of energy-related CAP emissions shown in Figure 14. For both sectors, most energy-related emissions are classified as stemming from external combustion boilers. NEI data classifications are problematic due to reporting inconsistencies, as discussed previously. According to DOE data for the pulp and paper industry, process heating and cooling systems represent 81 percent of the sector's energy use, with drying and evaporation processes requiring substantial energy inputs. "External combustion boilers" includes steam systems reboilers. Direct-fired systems such as furnaces are likely included under "industrial processes." Motor-driven systems comprise 13 percent of the sector's end use of energy, which includes pumps, conveyors, compressors, fans, mixers, grinders, and other process equipment,[143] but are primarily electric powered so would not be represented in NEI data.

Although MECS data report that coal supplied only 10 percent of the pulp and paper industry's energy requirements in 2002, NEI data show coal as contributing to 43 percent of the sector's energy-related CAP emissions. As MECS reports more than 50 percent of the sector's energy coming from "other" fuels (which includes biomass), NEI data show that biomass (wood waste) is a less emissions-intensive energy source than coal. For wood products, combustion of wood/bark waste is the dominant energy-related source of CAP emissions.

The trend of increased renewable energy (biomass) consumption and decreased coal consumption projected by CEF and AEO 2006 under a business-as-usual scenario is likely to improve the CAP emissions profile for the pulp and paper industry. The effect of increased fuel usage of biomass on CAP emissions would also be likely to vary from site to site, depending on factors such as boiler characteristics and pollution controls, as well as the type of biomass that is used for fuel (black liquor, waste paper products, wood chips, etc.)

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 113 million metric tons for the pulp and paper industry in 2004. AEO 2006 projects that the industry's carbon dioxide emissions will remain relatively static from 2004 to 2020, despite the expected increase in energy consumption. This projection reflects the industry's utilization of less carbon-intensive biomass energy resources to meet increasing energy demand.

As noted previously, if CEF and AEO 2006 projections overstate future production growth for the industry, energy-related CAP and carbon dioxide emissions could remain static or decrease from current levels.

3.5.2 Best Case Scenario

Opportunities

Table 37 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.

This opportunity assessment relies in large part upon a recent pulp and paper industry energy bandwidth study conducted on behalf of DOE that was published in August 2006.[144] From the energy consumption baseline established by 2002 MECS data, the DOE energy bandwidth study estimates potential reductions in energy consumption that would be possible through industry-wide implementation of best available technologies (technologies and processes in place at the most modern mills) as well as energy-savings potential from industry-wide implementation of advanced technologies (practical minimums). DOE estimates that best available technologies have the potential to reduce the pulp and paper sector's energy consumption by 26 percent and could reduce purchased energy requirements by 46 percent, with a 38 percent reduction in purchased electricity, and a 48 percent reduction in purchased fossil fuels. The largest areas of potential energy savings are in paper manufacturing (32 percent reduction in energy consumption), pulping (28 percent reduction), and onsite energy generating applications (22 percent reduction in energy losses from cogenerating equipment used to produce electricity and steam, referred to as "powerhouse losses.") Implementation of practical minimum technologies would further reduce sector energy consumption 17 below levels achieved by best available technologies.

Though the energy bandwidth study does not address the wood products sector, given the larger energy requirements of the pulp and paper sector it provides an appropriate indication of the largest opportunities for reductions in sector energy consumption.

Table 37: Opportunity assessment for the forest products industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Medium	As the industry meets a substantial fraction of its requirements for thermal energy and electricity with biomass fuels, it uses emissions-intensive energy sources such as coal and petroleum primarily as marginal fuels, except for the direct fossil fuel inputs required by lime kilns in kraft mills.[145] Thus, transitioning to cleaner fuels is not considered to represent a substantial opportunity for environmental improvement. Increased biomass utilization is considered a key opportunity for the industry, but this opportunity is discussed in connection with the Process Improvement and R&D categories below.

Opportunity	Ranking	Assessment (including potential barriers)
Increased CHP	Low	Though approximately 65 percent of the sector's electricity demand is met by CHP, the majority of the sector's demand for steam is met by CHP, limiting the opportunity for additional CHP capacity. There is opportunity to increase the electricity-to-steam ratio of CHP applications through gasification technologies,[146] and such opportunities are discussed in connection with R&D efforts below. Though the forest products sector is currently a net importer of electricity, industry representatives are concerned that recent changes in policy under the Public Utility Regulatory Policies Act (PURPA), Section 210(m), have created less favorable market conditions for onsite power generation. These changes eliminated requirements that electrical utilities purchase power from qualifying facilities in certain markets.[147] The forest products industry believes the new policy presents a barrier to increasing the use of CHP and other technologies that have the potential to increase onsite power generation.[148] New CHP installations may 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.[149]
Equipment retrofit/ replacement	Medium	Energy efficiency gains are achievable through retrofits and through replacement of old equipment with more energy-efficient models. According to DOE, there are substantial energy-savings opportunities associated with implementation of equipment-related best practices, as well as with retrofit and replacement of process equipment—for example, installation of shoe presses to reduce drying energy requirements.[150] There are also energy-savings opportunities associated with power generating equipment, as a majority of recovery furnaces and conventional power boilers in existing pulp and paper plants are 20 to 30 years old; more than half of them will need to be replaced or upgraded in the near future.[151] Limiting the magnitude of equipment-related opportunities, capital turnover in the sector is slow—equipment is capital intensive and has a long service life, and as industry is currently stagnant, there is little need for expanded production capacity that would drive new equipment purchases. Making a business case for equipment modifications can be difficult unless the change is urgently needed to maintain production or environmental compliance. Anecdotal evidence suggests that this climate of scarce capital has discouraged operations managers from advocating even low-risk, cost-effective improvements in energy efficiency.[152] Additionally, mills that want to expand or modify their operations may be subject to PSD or NSR programs.
Process improvement	High	Process optimization is expected to continue to be an important mechanism for achieving energy efficiency gains for the forest products industry. AF&PA prioritizes further efforts to increase energy recovery from biomass waste, both through implementation of existing best practices and from new technology development.[153] Due to the substantial energy requirements of the drying stage of the papermaking process, DOE estimates that the largest potential energy savings are from implementation of best-available technologies in the paper drying process, and substantial additional potential in connection with liquor evaporation, and pulp digesting processes.[154] (In the DOE bandwidth study, potential energy savings from best-available technology implementation include equipment retrofits and replacement as well as process improvement, and it is not possible to disaggregate the relative potential savings from these opportunities.) DOE notes that as much of the sector's boiler fuel comes from renewable biomass fuels that are manufacturing process byproducts, there is a tradeoff between increased process efficiency (which reduces byproducts) and biomass fuel availability.[155]
R&D	High	As the forest products industry has limited resources to devote to R&D efforts, the support of programs like DOE's Industrial Technologies Program is essential to achieving new technology development objectives. In partnership with DOE, the *Forest Products Industry's Agenda 2020* has established a roadmap of R&D priorities, and there is a strong R&D pipeline for the industry (see http://www.eere.energy.gov/industry/forest/). DOE prioritizes three areas as having the greatest opportunity for energy savings: (1) In paper drying, increasing the solids content of material exiting the press sections to reduce drying energy requirements; (2) reducing energy requirements for black liquor evaporation through nonevaporative concentration of weak black liquor, which can be accomplished through processes like ultrafiltration or multiple effect evaporation; and (3) increasing the energy efficiency of the lime kiln.[156] AF&PA has a strong interest in the development of technologies to more fully exploit the industry's biomass resources for energy recovery.[157]

Opportunity	Ranking	Assessment (including potential barriers)
		Other developing technologies that DOE describes as having the potential to enable the industry to achieve practical minimum energy consumption include: (1) CondeBelt drying systems, which have higher drying rates by utilizing the temperature differential between heated and cooled drying belts; (2) black liquor and biomass gasification, involving the production of gas fuel from biomass process waste which, in combination with combined cycle cogeneration turbines, would greatly increase the efficiency of onsite power generation; and (3) forest biorefineries, which extract hydrogen and other chemical feedstocks from wood chips prior to pulping, creating another value stream for the industry. According to DOE, the net energy efficiency of the biorefinery model is still being investigated,[158] but biorefineries are closer to commercialization than gasification technologies.[159] General R&D barriers include the costs and risks associated with developing and commercializing new technologies. As the industry develops improved technologies and processes for utilizing biomass energy resources, one concern noted previously how policies that promote biomass energy might increase demand and bid up the cost of the industry's raw material.

Optimal Future Trends

CEF's advanced energy scenario for the pulp and paper industry is similar to the base case projection, with an even greater share of the sector's energy needs met by biomass fuels, and a slight decrease in coal use as the industry makes even greater reductions in carbon-intensive fuels. AF&PA notes that the industry's objective is to meet an even greater fraction of its energy needs with renewable biomass fuels than the 73 percent share noted in CEF's advanced energy scenario.[160] The annual decrease in economic energy intensity (energy consumption per dollar value of output) is slightly larger than under the reference case scenario, and the projected increase in overall energy use is smaller than under the reference case projection. Compared with the reference scenario, under the advanced scenario, the industry uses even more biomass and relatively less purchased electricity, with electricity inputs falling 22 percent from 1997 levels by 2020.

CEF's advanced case projections are summarized in Table 38.

Table 38: CEF advanced case projections for the pulp and paper industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu)[uuu]	Percentage[vvv]	Consumption (quadrillion Btu)	Percentage
Petroleum	0.123	4%	0.068	2%
Natural gas	0.677	23%	0.429	14%
Coal	0.395	13%	0.107	4%
Renewables	1.483	50%	2.186	73%
Delivered electricity	0.259	9%	0.201	7%
Total	2.937	100%	2.991	100%
Annual % change in economic energy intensity (energy consumption per dollar value of output)				-1.0%
Overall % change in energy consumption (1997-2020)				2%

CEF's advanced case projections are based on the same economic growth assumption as the reference case (1.2 percent per year). As previously noted, CEF's economic assumptions are probably overly optimistic given recent industry trends, and if the trend of decreasing production continues, sector energy consumption would be expected to continue to decline as well. In comparison with the reference case, the faster decline in economic energy intensity is produced by CEF's more aggressive assumptions about energy efficiency increases in new and existing equipment including increased energy efficiency of boilers, steam systems, and motors, falling film black liquor evaporation, increased lime kiln efficiency, and black liquor gasification.[www]

Environmental Implications

Under the CEF advanced case, the decrease in purchased electricity means that energy-related emissions will be concentrated somewhat more at the facility level, as opposed to the utility level. However, due to the energy losses associated with electric generation (particularly from fossil fuel-fired power plants), transmission, and distribution, energy production at the facility level is generally more energy efficient, and thus represents an environmentally preferable energy scenario. Reductions in coal consumption under the advanced energy scenario are expected to decrease CAP emissions, particularly sulfur dioxide and nitrogen oxides.

Under the advanced energy scenario CEF projects the pulp and paper industry to achieve a 52 percent reduction in 1997 carbon emissions levels by 2020, despite the projected increase in overall energy consumption. This difference is attributable to increased energy efficiency and reductions in carbon-intensive energy inputs such as coal. Increased use of carbon-neutral biomass fuels will be a key component of achieving reductions in net carbon emissions.

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uuu 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.

vvv Percentages do not add to 100% due to independent rounding.

www We have noted just a few of the parameter modifications made by CEF under the advanced case NEMS modeling effort. Appendix A-2 of the CEF report contains more detailed descriptions of CEF's advanced case scenario parameters.

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3.6 Iron and Steel

3.6.1 Base Case Scenario

Situation Assessment

The iron and steel industry participates in EPA's Sector Strategies Program. To produce steel, facilities in the iron and steel industry (NAICS 331111) employ one of two production processes, which utilize a variety of raw materials and technologies and have different energy use profiles:

> **Recent Sector Trends Informing the Base Case**
>
> Number of facilities: ↓
> Value of shipments: Mixed (see text for explanation)
> Energy consumption/ton of steel shipped: ↓
>
> Major fuel sources: Coal, natural gas, coke, electricity
>
> Current economic and energy consumption data are summarized in Table 39 on page 3-55.

- Integrated steel mills use a blast furnace to produce molten iron from iron ore, coal, coke, and fluxing agents. A basic oxygen furnace (BOF) is then used to convert the molten iron, along with up to 30 percent steel scrap and alloys, into refined steel. Integrated steelmaking has declined from 52.6 percent of U.S. steelmaking production in 2001 to 44.9 percent of production in 2005 (estimated value updated March 2006).[161]
- Electric arc furnace (EAF) steel mills utilize steel scrap and up to 30 percent of other iron-bearing materials to produce steel. EAF steel plants primarily produce carbon steels as well as alloy and specialty steels. EAF steelmaking has grown from 47.4 percent of U.S. steelmaking production in 2001 to 55.1 percent of production in 2005 (estimated value updated March 2006).[162]

As certain steel qualities require the use of virgin materials, and as there are constraints on the supply of economically available steel scrap, both integrated steelmaking and EAF steelmaking are required and are not direct substitutes for one another. A recent study notes that some integrated steel companies have adopted production technologies traditionally used in minimills (such as advanced EAFs and thin slab casting), and distinctions between the integrated and EAF segments of the industry may be blurring.[163] Though the share of steel produced by the EAF process has steadily increased (growing from 47 percent to 55 percent of total steel production from 2001 to 2005[164]), expansion of EAF steelmaking capacity is predicated on the availability of adequate and cost-effective supplies of scrap. According to AISI, the addition of alternative ironmaking technologies will be essential to facilitating EAF capacity expansion.[165]

Though both processes are energy intensive, integrated steelmaking requires greater amounts of energy per ton of shipped product. Different studies of energy use in the iron and steel industry often employ somewhat different assumptions and boundary conditions which may lead to slightly different energy intensity measurements (energy use per ton of production). Industry data from 2004 establish an average energy intensity of 18.99 million Btu per ton (MBtu/ton) for integrated steelmaking and 5.01 MBtu/ton for EAF steelmaking, with an industry-wide intensity of 11.8 MBtu/ton (based on EAF steelmaking at a 53 percent market share).[166] A 2005 DOE study estimates the average energy intensity of integrated steelmaking at 16.5 MBtu/ton, and EAF steelmaking at 5.7 MBtu/ton.[167]

Iron and steel production is fairly concentrated geographically, with more than 85 percent of the sector's energy use occurring in the Midwest (64 percent) and South (23 percent).[168] Steelmaking in Indiana, Illinois, Ohio, Pennsylvania, Michigan, and New York accounts for approximately 80 percent of U.S. production.[169]

Beginning with employment contraction in the 1980s and accelerating through bankruptcies in the 1990s and early 2000s, the U.S. steelmaking industry has recently undergone major restructuring.[170] Despite the overall growth in value of shipments and value added from 1997 to 2004 (see Table 39), those metrics declined steadily from 1997 to 2003 and then jumped precipitously in 2004 following increases in the price of steel.[171] (The price increase was driven by a surge in global demand for raw materials due to economic growth in China and other Asian countries, as noted Section 2.4.1.) Restructuring strengthened the financial viability of domestic steel production, and the industry's dramatic turnaround was supported by temporary tariffs on imported steel enacted by the Bush Administration in 2002.[172] As a result of the industry's improved economic condition, an industry survey conducted in 2005 indicated that steel producers anticipated increasing their capital spending by 30 percent over the next two years to promote technological changes.[173] The same study notes that for 2005-2006, companies were expecting to increase investments in new equipment by 43 percent over 2003-2004 levels. Despite the recent return to profitability, in the long term U.S. steelmakers remain vulnerable to fluctuations in global supply and demand. China recently became a net exporter of steel, and the United States is joined by other steel-producing countries in its concerns about the potential for Chinese production to contribute to a glut in global steel supply.[174]

Since 1990, the widespread automation of steel production (facilitated by an industry R&D partnership with DOE) and the introduction of thin slab casting and ladle refining furnaces have also decreased the energy intensity of steelmaking. Thin slab casting reduced reheating energy requirements and increased the variety of products that EAF steelmakers were able to produce (such as flat rolled steel).[175] Economic trends and associated industry restructuring have also contributed to declining energy intensity. In the last fifteen years, there has been substantial industry consolidation that involved the closure of older and less efficient steelmaking facilities. According to data compiled by AISI, the composite energy intensity of the U.S. steelmaking industry (integrated and EAF production) has declined from 16.4 MBtu/ton in 1990 to 11.8 MBtu/ton in 2004, a decrease of 28 percent.[176]

Incremental energy efficiency improvements at the plant level may not be able to produce energy intensity reductions of similar magnitude to those that the industry has historically achieved through the transformational processes discussed above. AISI has launched an R&D initiative called "Saving One Barrel of Oil Per Ton (SOBOT)" that seeks to achieve the next revolution in energy intensity reduction through the development of new transformational technologies and processes that are less energy intensive as well as R&D efforts aimed at decreasing the energy intensity of existing processes.[177] Using different boundary assumptions than the AISI estimate, the 2005 *Steel Industry Marginal Opportunity Study* conducted by Energetics on behalf of DOE estimates that an energy intensity reduction of 5.1 MBtu/ton is technically achievable for integrated steelmaking, with implementation of industry best practices and commercially available technologies comprising slightly more than half of that potential, and R&D opportunities comprising the remaining fraction. For EAF steelmaking, the analysis estimates a technically achievable energy intensity reduction of 2.7 MBtu/ton,[xxx] with implementation of industry best practices and commercially available technologies comprising two thirds of that potential, and R&D contributing the remaining third.[178] Discussion of specific opportunities is included in Section 3.6.2.

Energy costs account for about 20 percent of the total cost of manufacturing steel.[179] Coke and coal meet a combined 39 percent of the iron and steel industry's energy needs. (Though not

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xxx DOE produced this estimate of technically achievable potential by taking the difference between the current energy intensity of EAF steelmaking (5.7 MBtu/ton) and a practical minimum energy requirement that is estimated to be 3.0 MBtu/ton. AISI notes that energy-savings opportunities described by DOE as technically available may not be economically viable in all facilities.

considered as part of this study, steelmaking also uses coal and coke as raw materials. They are sources of carbon which, in combination with iron, produces steel.) As natural gas meets 27 percent of the sector's energy requirements, increases in the price of natural gas are a significant concern for the industry. Reducing natural gas requirements is one of the goals motivating the industry's investment in SOBOT.[180] Byproduct fuels produced onsite (listed as "Other" in MECS, such fuels are primarily coal-based coke oven gas and blast furnace gas) and purchased electricity are also important energy inputs. The mix between fuel-based and electricity-based energy inputs differs between integrated and EAF steelmaking. Integrated steelmaking accounts for roughly 75 percent of the industry's fuel consumption and 36 percent of the industry's electricity consumption, while EAF steelmaking accounts for 25 percent of the industry's fuel consumption and 64 percent of its electricity consumption (fractions based on 1998 MECS data).[181]

Table 39 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 39: Current economic and energy data for the iron and steel industry

Economic Production Trends[yyy]				
	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
	1.1%	8.3%	1.7%	6.1%
Energy Intensity in 2002[zzz]				
	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)
	66.5	27.8	20.4%	8.0%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Coke & Breeze	Natural Gas	Other[aaaa]	Net Electricity	Coal
36%	27%	21%	13%	3%

yyy Economic trend data are for the larger NAICS category, iron, steel, and ferroalloy manufacturing (NAICS 33111).

zzz Energy intensity data are for the larger NAICS category, iron, steel, and ferroalloy manufacturing (NAICS 33111).

aaaa For iron and steel, the "other" category is largely composed of byproduct fuels such as coke oven gas and blast furnace gas (coal-based in origin).

Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	12%
		Fuel Oil	Coal	Other
Fraction of natural gas inputs that could be met by alternate fuels		73%	13%	9%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	3%
		Other	Natural Gas	
Fraction of coal inputs that could be met by alternate fuels		60%	40%	

Expected Future Trends

Controlling energy costs is critical to maintaining the competitive viability of the U.S. iron and steel industry in the global marketplace. Recent restructuring has strengthened the industry's position and is expected to spur investment in new technologies.[182] In the long term, global supply and demand fluctuations will continue to play a role in the industry's financial condition and capacity for investment in energy efficiency improvement.

> **Voluntary Commitments**
>
> The American Iron and Steel Institute (AISI) collects data for five indicators of sustainability: energy intensity, GHG emissions, material efficiency, steel recycling, and implementation of environmental management systems. AISI has also shown its commitment to improvements with regard to energy and the environment by joining Climate VISION. With its participation in this program, AISI has committed to improving member energy efficiency by 10 percent by 2012 (from 2002 levels). See http://www.climatevision.gov/sectors/steel/index.html.
>
> The steel sector also participates in DOE's 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/steel/.

The expansion of EAF steel production and contraction of integrated steel production has historically decreased the overall energy intensity of the steelmaking industry. According to 2005 data, more than 75 percent of end-of-life steel products in the United States are recycled, including 100 percent of end-of-life automobiles, 90 percent of end-of-life appliances, and 63 percent of used steel cans.[183] Use of suboptimal scrap produces more waste and requires more energy to process. One industry assessment states that some EAF mills have sought to mitigate the risk of scrap market volatility through investment in onsite alternative ironmaking (AI) production units to supplement scrap inputs. According to that analysis, due to the energy intensity of AI production, increased domestic AI production could slow the rate of energy intensity reduction at EAF mills.[184]

As noted at the beginning of Chapter 3, the age of the CEF study (produced in 2000 and using energy data from 1998) means that its projections are outdated in some cases, and particularly for the iron and steel industry, which has undergone substantial restructuring since the CEF report was produced. However, as the CEF report provides the best-available cross-sector assessment of business-as-usual and environmentally preferable energy trends, we include its projections for the iron and steel sector as we do for other sectors addressed in this report.

The iron and steel industry is one of the three sectors (along with cement and paper) for which CEF made detailed parameter modifications to the NEMS model used to produce AEO 1999. Modifications included adjustments to baseline energy intensities and rates of annual improvement in energy intensity, which were adjusted to reflect best-available sector-specific research at the time (primarily a 1999 study by Worrell et. al. at Lawrence Berkeley National Laboratory, *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector*).

Under the reference case scenario, CEF projects that energy consumption by the iron and steel industry will decrease 15 percent from the 1997 baseline by 2020 and that energy intensity will decline at 1.4 percent per year over the period.

CEF projects no major fuel mix shifts for the iron and steel industry under the reference case. Consumption of all fuels is expected to decline, with the exception of purchased electricity, which CEF expects will increase slightly (2 percent). Natural gas use falls by the greatest amount (28 percent), contributing to the increase in the relative importance of coal, despite the fact that coal consumption is projected to fall by 10 percent.

CEF's projections are based on the economic assumptions that steel production will increase at 0.9 percent per year. The projected reduction in energy consumption for the industry is in part attributable to CEF's assumptions about structural changes within the sector: CEF uses the AEO 1999 assumption that integrated steelmaking will drop from a 61 percent share of total production in 1994 to 54 percent in 2020, with an increase in EAF steelmaking from 39 percent to 46 percent over the same period. (These assumptions are outdated now that EAF steelmaking currently comprises more than 50 percent of steel production.) CEF's assumptions about adoption of energy-efficient technologies also contribute to the projected decline in energy consumption. For example, CEF made adjustments to the AEO 1999 NEMS parameters for the unit energy consumption values and retirement rates for existing equipment, as well as new equipment expected to be installed over the period. At the same time, CEF's technology assessments are based on a Lawrence Berkeley National Laboratory (LBNL) study that relied on industry data from 1994. A more recent industry assessment by DOE assumes that 50 percent of the energy-savings opportunities estimated in that LBNL study have already been achieved as of 2005.[185] (More detailed information about the assumptions underlying CEF's projections and how those assumptions were reflected in CEF-NEMS modeling can be found in Appendix A2 of the CEF report. However, it is not possible to determine from report documentation how much of the projected decline in energy consumption is attributable to structural change within the sector, and how much is attributable to energy efficiency improvement.)

CEF base case projections are summarized in Table 40.

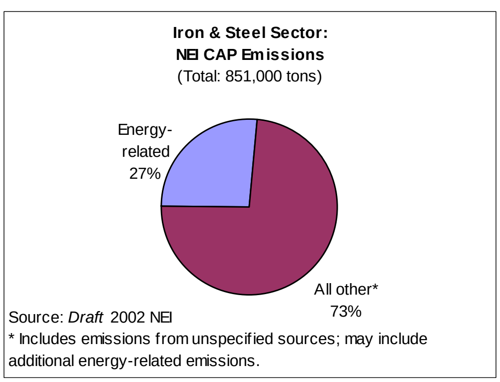
Table 40: CEF reference case projections for the iron and steel industry

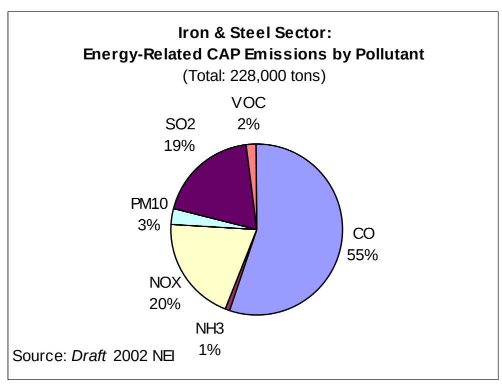
	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.118	7%	0.103	7%
Natural gas	0.541	32%	0.390	27%
Coal	0.873	51%	0.783	54%
Delivered electricity	0.173	10%	0.176	12%
Total	1.705	100%	1.452	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-1.4%
Overall % change in energy use (1997-2020)				-15.0%

As previously noted, EAF steelmaking has surpassed the market share that CEF projected would be achieved by 2020. 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 iron and steel industry 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. In line with CEF projections, AEO 2006 projects annual growth in the industry's value of shipments to be 0.9 percent per year, and industry-wide energy intensity to decline at 1.4 percent per year primarily due to the assumption that most new steelmaking capacity in the United States will be EAF production. (As previously noted, constraints on viable scrap supply impose limits on EAF production capacity, and the addition of alternative ironmaking technologies will be essential to facilitating EAF capacity expansion.) AEO 2006 projects that sector energy consumption will decline by 3.5 percent from 2004 to 2020 (substantially less than the 15 percent projected by CEF), with coal consumption decreasing by 11 percent, and electricity consumption increasing by 14 percent.

Environmental Implications

Figure 16: Iron and steel sector: energy-related CAP emissions





> **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 16 presents NEI data on energy-related CAP emissions by pollutant type for the iron and steel industry. Although NEI data attribute emissions from electric power generation to the generating source rather than the purchasing entity, purchased electricity meets around ten percent of the sector's energy needs, so the above figure provides a fairly complete picture of the sector's energy-related CAP emissions. (Though EAF steelmaking is electricity intensive, the magnitude of the fuel requirements for integrated steelmaking means that electricity remains a fairly small fraction of total energy consumption.) Sulfur dioxide and nitrogen oxide emissions are the largest fractions of energy-related CAP emissions. (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.)

Figure 17: Iron and steel sector: CAP emissions by source category and fuel usage

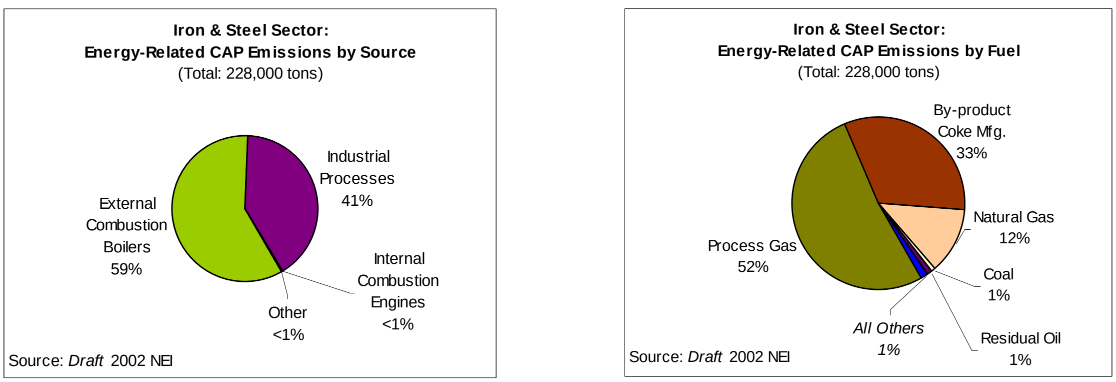


Figure 17 presents NEI data on energy-related CAP emissions by source category and fuel type. Though the largest fraction of energy-related CAP emissions is from external combustion boilers, emissions that are classified as related to industrial processes are also substantial. NEI data classifications are problematic due to reporting inconsistencies, as discussed previously, but equipment classified under "external combustion boilers" includes cogenerating units used to produce heat and electricity, and boilers used for process heating. Equipment classified under "industrial processes" in NEI likely includes fired systems such as blast furnaces, metal melters, and heaters. Highlighting possible issues with NEI data classifications, according to DOE, more than 80 percent of the industry's energy requirements are for fired systems such as furnaces, with boiler systems comprising approximately 7 percent of total energy use.[186]

In integrated steelmaking, the conversion of coal to coke is fueled by a mixture of natural gas and byproducts of the process such as coke oven gas. Energy-related emissions from this process are likely classified as "byproduct of coke manufacturing" in NEI data. The industry also uses other byproduct gases such as blast furnace gas, BOF gas, and EAF gas,[187] which may be classified in NEI as "process gas." Byproduct gases are also used as boiler fuel. As NEI data are dependent on emissions reporting from a number of different sources, it is difficult to precisely align reported energy-related emissions with sector energy consumption data from sources such as MECS.

As previously noted, the CEF energy consumption projections are dated for a number of reasons, and AEO 2006 projects that sector energy consumption will remain relatively static (decreasing at 0.2 percent per year). To the extent that declining coal consumption in the iron and steel industry is attributable to energy efficiency improvement (AISI states that as an industry-wide average, reasonable and obtainable energy efficiency improvements at the plant level can be expected to reduce energy consumption per ton of production by around 0.7 percent per year), such trends would decrease energy-related CAP emissions at the facility level.[188] Reducing natural gas consumption in favor of cheaper coal-based byproduct gases would reflect optimization of waste streams for their energy content. Increases in purchased electricity would affect CAP emissions at the utility level, and emissions impacts would depend upon local energy inputs for electric power generation. According to AISI, DOE's assumptions about increasing EAF production may not be accurate.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 127 million metric tons for the iron and steel industry in 2004. AEO 2006 projects that the industry's carbon dioxide emissions will decline by 3 percent from 2004 to 2020, in line with the expected decrease in sector energy consumption.

3.6.2 Best Case Scenario

Opportunities

Separate opportunity assessments have been conducted for integrated and EAF steelmaking processes using the DOE and AISI analyses. For integrated steelmaking, Table 41 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 42 provides a similar assessment for EAF steelmaking.

Table 41: Opportunity assessment for integrated steelmaking

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	Though the industry is likely to remain heavily dependent on coal, DOE estimates that there are opportunities for greater utilization of coke oven gas and other off-gas byproducts for energy content.[189] According to AISI, most coke oven gas produced by U.S. mills is already used, and other technologies for capture and reuse of steelmaking off-gases have not been adopted in the United States because they are not economically viable to deploy here given current energy prices.[190]
Increased CHP	Medium	Integrated steelmaking has less demand for electricity than EAF production, but the DOE marginal opportunity study notes the opportunity for increased cogeneration, including repowering current systems with off-gas turbine/steam turbine systems (0.48 MBtu/ton). According to DOE, heat recovery opportunities lie with the sintering (0.09 MBtu/ton), BOF (0.4 MBtu/ton), and annealing processes (0.29 MBtu/ton).[191] AISI describes cogeneration opportunities associated with non-recovery cokemaking, which combusts cokemaking off-gases to produce steam to drive a steam turbine generator and produce electricity, either for internal plant use or for sale to the grid. Currently, cokemaking off-gases are processed into materials with economic value (coke oven gas, tar, ammonia, and other chemicals).[192] Whether CHP is economically viable depends in large part upon the comparative value of electricity production versus the capital costs of the CHP equipment. New CHP installations also face barriers in terms of utility interconnection requirements if electricity production is expected to exceed onsite demand, and also from NSR/PSD permitting.[193]
Equipment retrofit/ replacement	Low	Equipment-related opportunities noted in the DOE marginal opportunity study include variable speed drives for pumps and fans (0.03 MBtu/ton), which AISI notes are already in wide use in the industry.[194] Additional equipment-related opportunities are included under "Process improvement."

Opportunity	Ranking	Assessment (including potential barriers)
Process improvement	Medium	AISI notes that with existing technologies and best practices, improvements in blast furnace efficiency are possible through optimized injection technologies and better sensors/process control. Other near-term opportunities noted by AISI include blast furnace coal injection modeling (to reduce energy losses in the cokemaking process) and optimizing processes through minimizing the generation of scrap and oxides.[195] Though some of the process-related energy-savings opportunities noted in the DOE study require equipment installation or retrofits, for the purposes of this analysis they have been classified as process-related so that DOE's estimated potential energy intensity reductions can be included. Options that are noted by DOE that are technically available but that may not be economically viable in all situations include the following: preventative maintenance (0.21 MBtu/ton); installation of energy monitoring and management systems for energy recovery and distribution between processes (0.06 MBtu/ton); coal moisture control and dry quenching in the cokemaking process (0.22 MBtu/ton); and in ironmaking (the most energy-intensive process), pulverized coal and natural gas injection, top pressure recovery turbines, hot blast stove automation, and systems for improved blast furnace control (combined 1.34 MBtu/ton). Casting/hot rolling energy efficiency opportunities include thin slab casting with tunnel furnace (0.93 MBtu/ton).[196]
R&D	High	According to AISI, the greatest potential for reducing the energy intensity of steelmaking lies with development of new transformational technologies and processes. Examples of such transformational R&D efforts (applicable both to integrated and EAF steelmaking) include the following: (1) Molten oxide electrolysis (under development at MIT); (2) ironmaking by flash smelting using hydrogen (under development at the University of Utah); and (3) the paired straight hearth furnace (under development at McMaster University in Ontario, Canada).[197] Other R&D opportunities for integrated steelmaking noted in the SOBOT analysis include reducing/optimizing energy usage in alternative ironmaking processes and increasing the scrap/hot metal ratio in the BOF charge.[198] An example of an alternative ironmaking process, the most significant R&D opportunity noted in the DOE study is replacement of traditional coke-based iron ore reduction (involving the energy-intensive blast furnace) with direct iron ore reduction using coal (2.58 MBtu/ton).[bbbb] [199] The direct reduced iron opportunity has a shorter timeline (2010) than the other R&D opportunities noted by DOE, which assume implementation occurs by 2020. Other R&D opportunities noted by DOE include increased direct carbon injection in the ironmaking process (0.7 MBtu/ton), blast furnace slag heat recovery (0.28 MBtu/ton), and increased scrap input into BOF (3.1 MBtu/ton).[200] Casting and rolling R&D opportunities (applicable both to integrated and EAF steelmaking) include reduction of heat losses from cast products prior to rolling/reheating (0.75 MBtu/ton) and near net shape casting. [201] Near net shape casting is a general term that refers to processes that eliminate a reheating step by casting in the final shape.[202] AISI also describes energy-savings opportunities potentially available from near net shape casting, with thin strip casting representing the largest opportunity in terms of tons of steel production. (DOE estimates potential energy intensity reductions from thin strip casting at 0.5–0.7 MBtu/ton.) Production of strip casting is presently limited to certain markets, and further research is needed to expand the market for this technology. AISI also notes beam blank casting as a growing opportunity for long products.[203] In general, major barriers to new technology and process development include not only the costs and risks associated with the research process itself, but also the implementation of new technology, once developed, is risky and in some cases may be considered a "bet the company" investment.[204] Federal funding (i.e., through DOE's Industrial Technologies Program) to mitigate the costs and risks associated with R&D efforts has also been reduced.

[bbbb] The DOE report notes that if direct iron reduction potential was fully exploited, then some of the other R&D opportunities (such as those affecting blast furnace ironmaking) would not be applicable as they would represent double-counting.

Table 42: Opportunity assessment for EAF steelmaking

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	Due to the substantial electricity requirements for EAF steelmaking, there is little opportunity for cleaner fuels. However, onsite renewable energy generation could have substantial environmental benefits. Barriers to onsite renewables include cost, resource intermittency, and utility interconnection requirements.
Increased CHP	Low	CHP does not represent a major energy efficiency opportunity for EAF steelmaking as the sector has relatively low demand for steam and waste heat is difficult to recover.
Equipment retrofit/ replacement	Low	Some equipment-related opportunities are included under "Process Improvement."
Process improvement	Medium	Process-related opportunities noted by AISI include improvements in process control (such as increased electrical energy transfer efficiency, reduced tap-to-tap times, and increased percentage of power-on time), and improved scrap preheating/charging practices and post-combustion practices.[205] Though some of the process-related energy-savings opportunities noted in the DOE study require equipment installation or retrofits, for the purposes of this analysis they have been classified as process-related so that DOE's estimated potential energy intensity reductions can be included. DOE estimates that for EAF steelmaking, the energy-savings opportunity bandwidth from implementation of best practices and commercially available technology is as twice as large as the R&D opportunity bandwidth. Options that are noted by DOE that are technically available but that may not be economically viable in all situations include: installation of energy monitoring and management systems for energy recovery and distribution between processes; preventative maintenance; and improvements in the EAF process such as improved process control, oxy-fuel burners, DC-arc furnaces, scrap preheating, and post-combustion processes. The combined best practice/commercially available technology opportunity quantified by DOE is 1.8 MBtu/ton. Casting/hot rolling energy efficiency opportunities include thin slab casting with tunnel furnace (0.93 MBtu/ton), which are applicable to both EAF and integrated steelmaking.[206]
R&D	High	According to AISI, the greatest potential for reducing the energy intensity of steelmaking lies with development of new transformational technologies and processes. Examples of such transformational R&D efforts (applicable both to integrated and EAF steelmaking) include: (1) Molten oxide electrolysis (under development at MIT); (2) ironmaking by flash smelting using hydrogen (under development at the University of Utah); and (3) the paired straight hearth furnace (under development at McMaster University in Ontario, Canada).[207] AISI lists the following additional areas as important R&D opportunities for EAF steelmaking: improved processes for low-grade scrap recovery, as well as sensible heat recovery from slags, fumes, and off-gases.[208] R&D opportunities noted in the DOE study include increasing the efficiency of melting processes (0.4 MBtu/ton), integration of refining functions/reductions of heat losses prior to casting (0.35 MBtu/ton), economical heat capture from EAF waste gas (0.26 MBtu/ton), purification/upgrading to scrap, and effective utilization of slag and dust. Casting and rolling opportunities (applicable both to integrated and EAF steelmaking) include reduction of heat losses from cast products prior to rolling/reheating (0.75 MBtu/ton) and thin strip casting (0.5 – 0.7 MBtu/ton). R&D barriers (high costs and risks associated with new technology development, exacerbated by reduced availability of federal funds) are the same as those discussed in association with the integrated steelmaking R&D opportunity assessment.

Optimal Future Trends

The CEF advanced case projection shows a greater reduction in sector energy use and a larger annual decrease in energy intensity than under the business-as-usual projection. The largest fuel decrease is seen in the petroleum category, which falls by 83 percent from 1997 to 2020. Natural gas consumption falls by 36 percent, and purchased electricity falls by 20 percent. Though the coal fraction grows relative to other fuel inputs, total coal consumption falls by 13 percent over the period. Table 43 summarizes the CEF advanced case projections for the iron and steel industry.

Table 43: CEF advanced case projections for the iron and steel industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu) [cccc]	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.118	7%	0.020	2%
Natural gas	0.529	31%	0.336	27%
Coal	0.873	52%	0.758	60%
Delivered electricity	0.173	10%	0.140	11%
Total	1.693	100%	1.254	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-2.0%
Overall % change in energy use (1997-2020)				-26.0%

The economic assumptions underlying the CEF advanced case projections are unchanged from the business-as-usual assumptions (annual steel production increase of 0.9 percent per year and growth in the economic value of the industry's output at 0.9 percent per year). Under its advanced energy scenario, CEF projects that EAF steel production will increase to 55 percent of the market by 2020, compared to 46 percent under the reference scenario. Retrofit measures implemented under the advanced case reduce energy consumption in the following processes: blast furnace (injection of pulverized coal and natural gas, blast furnace gas recovery, improved control systems); EAF steelmaking (scrap preheating, improved process control with neural networks, DC-Arc furnace); cold rolling (automated monitoring and targeting systems, heat recovery on the annealing line); hot rolling (process controls, recuperative burners, energy-efficient drives in the rolling mill); casting (efficient ladle preheating); cokemaking (programmed heating).[dddd] Energy savings are also produced by increased adoption of new process technologies such as alternative ironmaking and near net shape casting. Advanced case assumptions common to all sectors include increased boiler efficiencies and commercial building efficiency.

The CEF advanced case projections likely overstate potential energy savings available under an optimal energy scenario, as EAF steelmaking already comprises 55 percent of production. In addition, many of the technologies noted above are already widely adopted in the industry, and industry restructuring since 2000 has resulted in further decreases in the energy intensity of U.S. steelmaking. At the same time, increased adoption of energy-efficient technologies and new technology development would be expected to accelerate the industry's current trend of decreased energy consumption.

[cccc] 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.

[dddd] Retrofit measures are a partial list of those contained in Appendix A-2, Industry: NEMS Input Data and Scenario Input, of the *Clean Energy Future* report, pp. A-2.70-71.

Environmental Implications

The reductions in fossil fuel consumption that are achieved under the advanced energy scenario would lead to reductions in energy-related CAP emissions at the facility level, particularly sulfur dioxide and nitrogen oxides. CAP emissions reductions at the electric power generation level would also be expected from reductions in purchased electricity.

Under the advanced energy scenario, by 2020 CEF projects carbon emissions by the iron and steel industry to fall 27 percent from 1997 levels, which is roughly equivalent to the projected decline in sector energy usage.

3.6.3 Other Reference Materials Consulted

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3.7 Metal Casting

3.7.1 Base Case Scenario

Situation Assessment

The metal casting industry (NAICS 3315) is a diverse industry that plays a critical role in U.S. manufacturing, as more than 90 percent of all manufactured goods in the United States contain cast metal components.[209]

There are approximately 2,300 metal casting facilities in the United States, including both ferrous and nonferrous (primarily aluminum) foundries and die casting facilities.[210] Most metal casting shops are small, independently owned facilities that perform on a contract basis, though some "captive" foundries are part of larger manufacturing operations.[eeee] DOE data indicate that approximately 70 percent of sector energy use is by independent metal casting facilities and 30 percent is by captive foundries.[211] The industry is dominated by small "job-shop" businesses; 80 percent of metal casting facilities employ 100 people or less.[212] The sector is also varied due to differences in the metals being melted, alloying requirements, product specifications, casting processes used, capacity of operations, etc. Though metal casting facilities are found nationwide, ten states account for more than 80 percent of the industry's shipments: Ohio, Indiana, Wisconsin, Alabama, Michigan, Pennsylvania, Illinois, Tennessee, California, and Texas.[213]

The metal casting sector currently participates in EPA's Sector Strategies Program.

In recent years, the metal casting sector has experienced a downturn in part due to international competition and declines in the automobile industry. Out of all sectors considered in this analysis, the metal casting industry had the largest annual decrease in value added and value of shipments from 1997 to 2004 (see Table 44). At the same time, recent forecasts indicate an improved economic outlook for the sector in the future. By 2008 metal castings sales are projected to increase 15 percent from 2005 levels, and metal casting shipments are expected to be 8 percent higher than 2004 levels.[214] From 2003 to 2004,

Recent Sector Trends Informing the Base Case

Number of facilities: ↓
Value added and value of shipments: ↓
Energy intensity: ↓

Major fuel sources: Natural gas, purchased electricity

Current economic and energy consumption data are summarized in Table 44 on page 3-66.

Voluntary Commitments

The metal casting sector 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.

The program has identified best practices for melting and other efficiency improvement opportunities in the sector that could result in energy savings and CO_2 emission reductions. Specific energy reduction techniques identified include the following:

- Replacing heel melting furnaces used for iron production with modern batch melters.
- Improving casting yield.
- Applying existing air/natural gas mixing methods to reduce ladle heating energy.

Industry participation in the program is managed by the Cast Metals Coalition, which in 1998 set measurable goals for 2020, including using 20 percent less energy to produce castings, compared to the sector's 1998 energy requirements of 320 trillion Btus. See http://www.eere.energy.gov/industry/metalcasting/ and http://cmc.aticorp.org/.

[eeee] According to the DOE analysis, *Theoretical/Best Practice Energy Use in Metalcasting Operations* (2004), energy data that rely on NAICS classifications (as do the sources used in this report) fail to capture energy use by colocated facilities.

the industry's value of shipments grew by more than 7 percent.[215] Growth in the production of light metals is expected to continue, in part due to transportation industry trends.

Profit margins in the industry are generally small and combined with the small average business size, suggest that companies have limited financial resources at their disposal, particularly for R&D initiatives that involve high costs, long investment horizons, and uncertain outcomes. At the same time, R&D is essential to maintaining the industry's position in an increasingly competitive global marketplace. DOE notes that casting processes must continually evolve to meet increasing demand for lighter-weight, higher-strength castings.[216] Thus, public/private R&D partnerships are essential to ensuring the long-term health and productivity of the industry. DOE's Industrial Technologies Program partners with the Cast Metals Coalition (representing 80 percent of the industry) and university researchers to develop transformational technologies that seek to reduce metal casting energy intensity (energy consumption per ton of production) by 20 percent by 2020.[217] Given the industry's limited financial resources, a recent DOE analysis suggests that the most promising technology advancements offer less capital-intensive energy-savings opportunities, such as retrofits aimed at increasing the efficiency of existing furnaces.[218]

The metal casting industry is heavily dependent on natural gas and purchased electricity, and growing interest in energy efficiency has been driven by the impacts of natural gas price volatility.[219] According to DOE, most of the sector's energy use (approximately 55 percent of total energy costs) can be attributed to the melting of metals, but moldmaking and coremaking also utilize significant amounts of energy. Being one of the most energy-intensive industries in the United States, reducing energy usage is a primary goal for the sector.[220]

The table below summarizes economic and energy consumption data presented in Chapter 2.

Table 44: Current economic and energy data for the metal casting 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
	-3.2%	-5.4%	-2.4%	-3.7%
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)
	10.3	5.6	8.0%	4.6%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
		Natural Gas	Net Electricity	Coke & Breeze
		49%	34%	15%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
		Switchable fraction of natural gas inputs		20%
		LPG	Fuel Oil	Electricity
Fraction of natural gas inputs that could be met by alternate fuels		73%	13%	13%

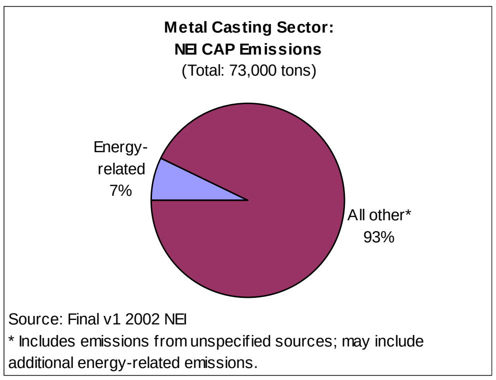
Expected Future Trends

As the CEF report does not address the metal casting sector, we are unable to present detailed energy consumption projections for this industry. DOE analysis conducted in 2003 projected that industry-wide energy consumption would increase through 2009 in response to increasing production.[221] Nonferrous casting shipments are growing due to increased demand for lighter metals (for example, in the transportation industry and for the U.S. military). According to DOE, aluminum casting production comprised 36 percent of sales and 34 percent of industry energy consumption in 2003, and energy use in the typical aluminum casting facility is 381 percent greater per ton of metal produced than is typical for iron casting operations.[222] DOE site visits indicated that inefficient melting and holding operations were common in aluminum casting facilities.

As with other energy-intensive industries (iron and steel, forest products), a gradual decrease in energy consumption per ton of production is expected for the metal casting industry. Though efforts to control energy costs are expected to drive incremental investment in energy efficiency, capital constraints are likely to limit the rate of energy efficiency improvement.

Environmental Implications

Figure 18: Metal casting sector: energy-related CAP emissions



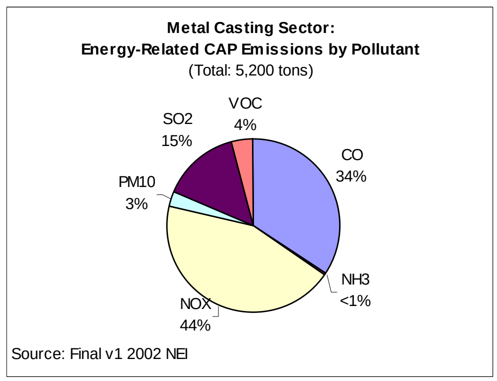
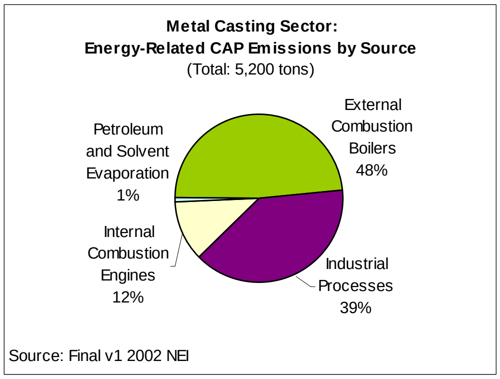


Figure 18 compares NEI data on energy-related CAP with non-energy-related CAP emissions for the metal casting industry. According to the figure, energy-related CAP emissions comprise a relatively small fraction of total CAP emissions. However, purchased electricity meets more than 30 percent of the sector's energy demand. As NEI data attribute emissions associated with electric power generation to the generating source rather than the purchasing entity, NEI data underestimate energy-related CAP emissions for this 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 19: Metal casting sector: CAP emissions by source category and fuel usage



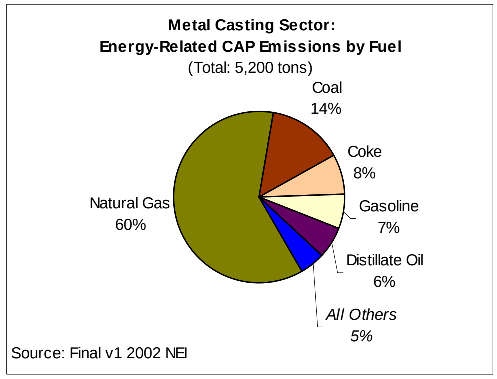


Figure 19 presents NEI data on energy-related CAP emissions by source category and fuel type. Though the largest fraction of energy-related CAP emissions is from external combustion boilers, process-related energy inputs are also substantial. As noted previously, NEI data classifications are problematic due to reporting inconsistencies, but equipment classified under "industrial processes" likely includes melting and holding furnaces that may be fired with coke, natural gas, or electricity.[223] (Cupola melting furnaces are used in ferrous metal casting and are mostly fired with coke. Holding furnaces are used to maintain the temperature of molten metal before input into pouring lines.) Other energy-using equipment that is likely classified as process-related includes equipment used in moldmaking, coremaking, and post-casting activities.

Due to the energy-intensive nature of processes related to melting metals (which represent 55 percent of total energy consumption), DOE notes that substantial energy-savings opportunities lie with energy efficiency improvements in this area—not only to the melting furnace itself, but also in terms of equipment used for metal preparation and pretreatment, refining and treatment of molten metals, molten metal holding, and molten metal tapping and transport.[224] At the same time, onsite emissions of energy-related CAPs are small compared with other sectors considered in this analysis—approximately 5,000 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

3.7.2 Best Case Scenario

Opportunities

Table 45 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 45: Opportunity assessment for the metal casting industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	The sector remains heavily dependent on natural gas and electricity, and shows little fuel-switching potential. Natural gas is likely to remain important in part due to the growth of the nonferrous casting segment of the sector (particularly aluminum casting), which prefers natural gas-driven melting technologies.[225]

Opportunity	Ranking	Assessment (including potential barriers)
Increased CHP	Low	An extensive analysis of CHP opportunities conducted on behalf of DOE indicated little potential for CHP in the metal casting industry, primarily on the basis of cost effectiveness.[226] However, there is potential for increased utilization of waste heat energy through technologies such as heat recuperators, which use heat from exhaust gases to heat incoming combustion air.[227]
Equipment retrofit/ replacement	Medium	The financial barriers in this industry indicate that retrofitting existing technology may be a more viable opportunity for the industry than equipment replacement. In iron metal casting, cupola melting efficiency can be improved with retrofits such as replacing gas-fired hot blasts with recuperative hot blasts, or installing variable speed/frequency drives on large motors.[228] Installation of automated temperature and power controls is another energy-savings opportunity available in multiple melting-related applications. As with retrofits, the greatest energy-savings opportunities from equipment replacement lie with equipment used in melting processes. For iron metal casting, replacing heel melting furnaces with modern batch melters is one such opportunity. A DOE analysis estimates that heel melters account for 60 percent of ductile iron and gray iron induction furnaces used by industry in 2003.[229] For aluminum metal casting, there are substantial energy-savings opportunities from replacing inefficient reverberatory furnaces with best practice stack melters.[230]
Process improvement	Medium	There are also energy-savings opportunities through process improvement in ferrous and nonferrous metal casting operations, e.g., implementation of energy management best practices, optimizing scheduling (continuous melting), scrap cleaning, and improving casting yield.[231]
R&D	Medium	DOE notes that given the energy requirements of melting processes, development of advanced melting technologies is an area of substantial energy-savings potential for the metal casting industry. Developing technologies that involve retrofits to existing furnaces rather than furnace replacement are most likely to be adopted, in part because retrofits may avoid permitting requirements, and also because they are typically less capital intensive. Developing retrofit technologies with substantial energy-savings potential noted by DOE include the following: oxygen-enriched fuel combustion, charge preheating, molten metal delivery, and heat recovery from flue gases. Other promising R&D opportunities noted by DOE include the following: (1) new furnace designs that allow greater scheduling flexibility and reduced energy losses in batch melting processes; (2) technologies for increased waste heat recovery; (3) technologies to promote wider applicability of induction furnaces; (4) continued development of experimental melting furnace technologies, including Isothermal Melting Technologies; and (5) technologies that translate ladle metallurgy furnaces used in wrought steel and aluminum ingot industries to the smaller capacities used in metal casting.[232] DOE notes that the greatest barriers to implementation of advanced melting technologies include the following: (1) composition of the industry (primarily small businesses) increases reluctance to take on the risks and costs associated with developing and implementing new technologies, and also means that smaller facilities may not be able to take advantage of energy-savings opportunities that are cost effective for larger-scale operations; (2) declining profit margins reduce investment capacity; (3) the diversity of the industry limits the applicability of cross-cutting technologies, meaning there is no "one-size-fits-all" approach to promoting energy efficiency improvement; and (4) new furnace technologies that require new/expanded exhaust systems may be subject to state and local permitting requirements.[233]

Optimal Future Trends

As no energy use projections are available for the metal casting industry, it is not possible to compare a business-as-usual energy scenario with an optimal energy scenario. Through research and development on technologies that will transform metal casting energy use, DOE's goal is to achieve a 20 percent reduction in the energy required to produce a ton of product by 2020.[234] An environmentally preferable energy scenario for the industry would primarily involve faster energy efficiency retrofit and replacement rates for existing equipment used in melting processes, increased adoption of best energy management practices, and increased investment in R&D.

Environmental Implications

Improvements in melting furnace efficiency would reduce onsite emissions (both GHG and CAP) stemming from fuel inputs of natural gas and coke. Energy efficiency improvement in cupola melting furnaces—which utilize coke as the primary fuel—would reduce a particularly emissions-intensive (both in terms of GHG and CAP emissions) energy consumption process.

Reductions in electricity consumption (which currently meets over a third of the sector's energy needs) through increased energy efficiency would have a magnified impact on energy-related CAP and GHG emissions at the utility level due to the magnitude of energy losses during electric generation and transmission. As noted previously, CAP emissions reductions would affect regional air quality, while GHG emissions reductions would have a global impact.

3.7.3 Other Reference Materials Consulted

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3.8 Metal Finishing

3.8.1 Base Case Scenario

Recent Sector Trends Informing the Base Case

Number of facilities: ↓
Value of shipments: ↓
Electricity energy intensity: ↑

Major fuel sources: Electricity, natural gas, petroleum

Current economic and energy consumption data are summarized in Table 46 on page 3-72.

Situation Assessment

A subset of the fabricated metal products industry, metal finishing (NAICS 332813) encompasses a variety of surface finishing and electroplating operations that coat an object with one or more layers of metal to improve resistance to wear and corrosion, alter the appearance, control friction, or impart new physical properties or dimensions. This diverse sector is composed of approximately 2,900 facilities, most of which are small, independently owned facilities that employ 50 or fewer people.[235] The industry is geographically concentrated in highly industrialized areas of California, Texas, and the Great Lakes states.[236]

The metal finishing industry participates in EPA's Sector Strategies Program.

The sector faces economic pressures from foreign competition and declines in the U.S. automobile industry, experiencing an 11 percent decline in the number of facilities since 2000, and a 21 percent reduction in the number of employees.[237] Profit margins in the industry are generally small, which, combined with the small average business size, means that metal finishing companies have limited financial resources at their disposal. From 1997 to 2004 the sector experienced no growth in value added and a small annual decline in value of shipments (see Table 46).[ffff] [238] According to the organization Energy Industries of Ohio, electroplating operations have been particularly hard hit by rising production costs and the pressures of foreign competition that keep product prices down. In response, the electroplating industry shows a general trend of moving overseas.[239]

Between 2002 and 2004, electricity represented approximately half of the industry's energy costs, with purchased fuels (a large percentage of which was natural gas) comprising the remaining portion.[240] Different types of metal finishing operations have different energy requirements; though some operations use relatively more direct fossil fuel inputs, electroplating operations are electricity intensive. Since Census Bureau data from the *Annual Survey of Manufacturers* (ASM) do not provide the annual amount of energy produced from purchased fuels, it is not possible to calculate the total energy intensity of the metal finishing industry, though it is possible to calculate electric intensity (kWh/dollar value of shipments). Industry-wide electric intensity increased by approximately 3 percent from 1998 to 2004.[241]

The National Metal Finishing Strategic Goals Program (SGP), a voluntary environmental partnership between EPA and several metal finishing trade associations that focuses on electroplating operations, collected energy intensity data (thousand Btu/dollar of sales) from program participants. According to these data, energy intensity remained relatively steady from 1998 to 2003, increasing by just 0.07 percent over the period, with year-to-year fluctuations that may be attributable to economic production trends and variations in the number of companies reporting data. Additionally, an independent third-party, the National Center for Manufacturing Sciences, tracked the progress of 150 participating metal finishers that consistently reported

ffff U.S. Census Bureau data on the industry's value added and value of shipments from the *Annual Survey of Manufacturers* covers a broader NAICS category (NAICS 3328: coating, engraving, heat treating, & allied activities) than the metal finishing industry.

their environmental progress. Through 2001, cumulative improvements for these facilities included a 7 percent reduction in energy use, normalized by dollar value of sales.[242] The differences in electricity intensity (ASM data) and energy intensity (SGP data) are in part attributable to the fact that the SGP energy intensity metric includes both electric and fuel energy inputs. Also, ASM data represent a larger cross-section of the metal finishing industry, as SGP data are primarily from electroplaters.[243]

In general, most current efforts at improved energy efficiency and technology adoption in the metal finishing sector are being driven by customer demand. These may take the form of improved environmental performance (such as ISO 14001 certification), which requires modification to existing processes, or lower-cost products, which requires efficiency of operations and inputs, including energy. Many of the emerging technologies that offer energy efficiency improvement opportunities for the metal finishing sector focus on waste reduction in existing processes and substitutes to current electrochemical processes. At the same time, metal finishing companies have little in-house technical expertise and tend to rely heavily on their equipment suppliers for information.[244] There are clear energy efficiency opportunities available to the metal finishing industry, but given the economic pressures on the industry, it seems most likely that improvement may come from retrofitting existing technologies with more efficient equipment, as opposed to wholesale process changes.[245]

Table 46 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 46: Current economic and energy data for the metal finishing industry[gggg]

Economic Production Trends[hhhh]				
	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
	0.1%	-1.2%	-0.3%	-2.0%
Energy Intensity in 2002[iiii]				
	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)
	NA	NA	6.7%	4.0%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)[jjjj]				
		Natural Gas	Net Electricity	Fuel Oil
		54%	42%	2%

gggg No fuel-switching data are available for this sector.

hhhh Economic data are for the larger NAICS category of coating, engraving, heat treating, & allied activities (NAICS 33281).

iiii Energy intensity data are for the larger NAICS category of coating, engraving, heat treating, & allied activities (NAICS 33281).

jjjj Fuel use data are for the larger NAICS category of fabricated metal products (NAICS 332).

Expected Future Trends

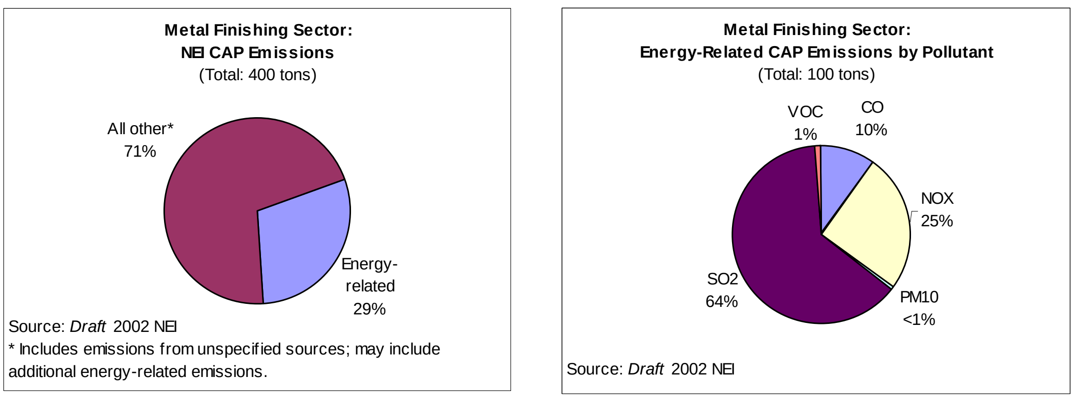
No energy projections are available for the metal finishing industry. The “metals-based durables” sector is one of the industrial sectors modeled in the CEF report and by AEO 2006, and includes the following industries: fabricated metal products, machinery, electric and electronic equipment, transportation equipment, and instruments and related products. Though we do not present a full analysis of CEF and AEO 2006 projections as we do for other sectors, it is helpful to consider the metals-based durables projections in terms of extrapolating what future energy trends are likely to be for the metal finishing industry. Further complicating efforts to predict future energy consumption trends for the metal finishing industry is the heterogeneous nature of the sector itself. For instance, trends for electricity-intensive segments of the industry (like electroplating) may differ from trends in segments that rely more heavily on natural gas.

Under the reference scenario for the metals-based durables industry, CEF and AEO 2006 project no major fuel mix changes through 2020, as the industry remains dependent on natural gas and purchased electricity. In general, there is little opportunity for the metal finishing industry to replace electricity and natural gas inputs with less expensive fuels, and we do not anticipate any future fuel-switching trends for the metal finishing industry.

As is the case with CEF projections, AEO 2006 projects substantial growth in economic production for the metals-based durables industry through 2020, with the value of shipments increasing 60 percent from 2004 levels. Energy consumption grows by 30 percent over the same period, and energy intensity (energy consumption per dollar value of shipments) declines by 1.2 percent per year. Though subsets of the industry like metal finishing may be unlikely to experience the same degree of growth (particularly given recent shifts towards overseas production), some increase in energy consumption may result from increasing production.

Environmental Implications

Figure 20: Metal finishing sector: energy-related CAP emissions

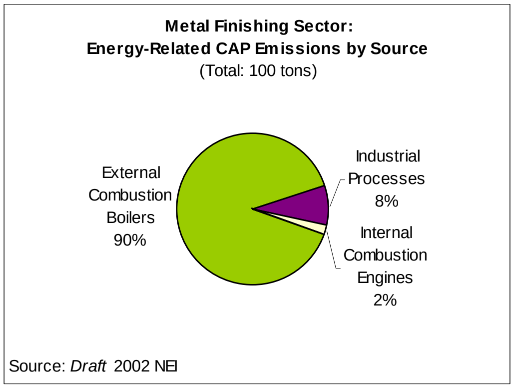


Effects of Energy-Related CAP Emissions

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 20 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the metal finishing sector. According to the figure, energy-related CAP emissions are a relatively moderate fraction of all CAP emissions; however, NEI data attribute emissions from electric power generation to the generating source rather than the purchasing entity. Given that purchased electricity supplies approximately half of the sector's energy needs, NEI data underestimate energy-related CAP emissions for this sector. At the facility level, almost 90 percent of energy-related emissions are sulfur dioxide and nitrogen oxides. On a ton basis, the metal finishing sector's energy-related CAP emissions at the facility level are relatively small compared with energy-related CAP emissions by other sectors (see Table 13).

Figure 21: Metal finishing sector: CAP emissions by source category and fuel usage



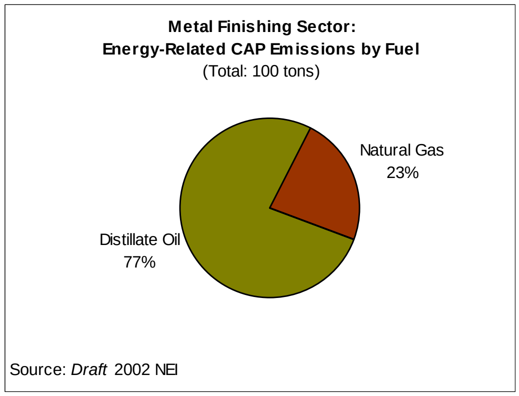


Figure 21 presents NEI data on the sources of energy-related CAP emissions shown in Figure 20. The metal finishing industry is a relatively minor source of onsite energy-related CAP emissions compared with other sectors considered in this analysis—only 100 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

Ninety percent of energy-related emissions are associated with external combustion boilers, with distillate oil contributing to roughly two-thirds of energy-related emissions, and natural gas contributing the remaining third. Given that fuel oil supplies around 2 percent of the sector's energy requirements, the large fraction of energy-related emissions arising from fuel oil use is most likely attributable to NEI data reporting errors.

Increases in sector energy consumption would affect energy-related CAP emissions at the electric power generation level, as well as at the facility level through increased consumption of natural gas and petroleum-based fuels. The geographic dispersion of the metal finishing industry and the relatively small volume of energy-related CAP emissions compared with other sectors included in this analysis indicate that energy trends are unlikely to have a substantial impact on regional air quality.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 157 million metric tons for the metals-based durables industry in 2004. (Carbon dioxide emissions from the metal finishing sector represent a fraction of these emissions.) AEO 2006 projects that by 2020 the metals-based durables industry's carbon dioxide emissions will increase by 25 percent. As discussed previously, a smaller rate of increase in carbon dioxide emissions would be expected for the metal finishing industry, given that energy consumption will likely increase at a slower rate than in the larger metals-based durables sector.

3.8.2 Best Case Scenario

Opportunities

Table 47 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 47: Opportunity assessment for the metal finishing industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	The sector remains heavily dependent on electricity and natural gas and shows little fuel-switching trend.
Increased CHP	Medium	Given that many metal finishers use electric energy in the electroplating stage and thermal energy in heating the plating solution baths, small onsite generators that run on natural gas and have CHP capabilities may be cost effective for some businesses. Low NOx, high-efficiency generators are offered by a number of manufacturers. Local and state permitting requirements to install these devices may pose a potential barrier to implementation.[246] 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.[247]
Equipment retrofit/ replacement	Medium	The financial barriers in this industry indicate that retrofitting (versus replacing) existing technology with state-of-the-art equipment is likely to provide ongoing efficiency improvement. Facilities may also improve their efficiency by upgrading existing lighting and improving their HVAC systems.
Process improvement	High	Multiple process improvement opportunities exist in metal finishing, including using more efficient rinsing techniques and optimizing plating bath temperatures through adding insulation and using timers. Process optimization may have greater potential for adoption due to relatively low associated costs.
R&D	Medium	Several technologies in development could improve the energy efficiency of metal finishing processes, including metal powder coating, thermal spray, and sputtering technologies. Advanced wastewater treatment processes involving ion exchange and permeable membrane technologies may also produce future opportunities for energy savings. The industry is also looking at the substitution of non-cyanide-based plating solutions in place of cyanide solutions, which create costly and energy-intensive waste treatment issues.[248]

Optimal Future Trends

An optimal energy scenario for the metal finishing industry would involve increased energy efficiency through increased penetration of CHP applications, energy-efficient equipment, and process improvements, as well as increased investment in the development of new energy-efficient technologies and processes.

Given that CEF's projections for the metal-based durables industry are not particularly applicable to the metal finishing sector, we have not included a full summary of CEF's advanced case projections in this analysis, but the projections show relatively little change in the sector's fuel mix, a decrease in energy intensity of 2 percent per year (compared with the reference case projection of an annual decline of 0.7 percent), and an increase in energy consumption of 20 percent (compared with the reference case projection of a 60 percent increase).

Environmental Implications

Energy efficiency increases in the metal finishing sector would affect energy-related CAP and carbon emissions at both the electric power generation level and the facility level. Increased CHP would shift energy-related emissions from the electric power generation level to the facility level to some degree. In cases where electric power supply is produced by fossil fuel-fired power plants (which have the highest power generation losses), such a shift would produce the greatest decrease in total energy-related emissions, recognizing that emissions may actually increase at the facility level as power is produced onsite. However, such effects would vary according to local energy inputs for electric power generation. Energy efficiency improvements could also reduce natural gas and petroleum consumption, affecting energy-related CAP and carbon emissions at the facility level. NEI data indicate that sulfur dioxide and nitrogen oxide emissions would be most impacted by such efficiency gains.

Achieving an optimal energy scenario may be relatively more difficult for the metal finishing sector given current financial pressures and the number of small, geographically dispersed firms that comprise the industry.

3.8.3 Other Reference Materials Consulted

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3.9 Motor Vehicle Manufacturing

> **Recent Sector Trends Informing the Base Case**
>
> Number of facilities: ↓
> Value of shipments: ↑
> Electricity intensity: ↓
>
> Major fuel sources: Electricity, natural gas
>
> Current economic and energy consumption data are summarized in Table 48 on page 3-78.

3.9.1 Base Case Scenario

Situation Assessment

This report looks at motor vehicle manufacturing operations—specifically facilities that assemble finished automobiles and light duty vehicles from premanufactured automotive parts including the engine, chassis components, and wheels and tires (NAICS 33611).[249] The assembly process generally includes stamping, body welding, general assembly, and painting.

According to data published by the Alliance of Automobile Manufacturers, in 2006 there were 61 assembly plants for automobiles and light duty trucks operating in 21 states, with Michigan, Ohio, Indiana, Illinois, and Missouri among the states with the most manufacturing facilities.[250] Over the last 20 years, production has gradually shifted south, with new plants opening in central Tennessee in the 1980s, and in Alabama, Mississippi, and South Carolina in the 1990s.[251]

In terms of the dollar value of production, the automobile industry is the largest industry in the United States.[252] The industry's value added declined slightly from 1997 to 2004, but value of shipments increased by a small annual amount (see Table 48). However, the economic data also show substantial interannual variation, and larger annual increases in value added from 2000 to 2004. [253] U.S. automakers face pressure from foreign competitors, which have an increasing manufacturing presence in this country. The Big Three North American Original Equipment Manufacturers (OEMs)—General Motors, Ford, and DaimlerChrysler—are reacting to declining sales figures and economic strain by closing certain plants and downsizing their companies. Ford announced in January 2006 that it would be closing 14 North American manufacturing plants and cutting 18 to 21 percent of employees. GM is following suit with 12 plant closings and a 30,000 job cut through 2008.

The majority of sector energy demand is met by electricity, with natural gas and other purchased fuels meeting the remainder. Energy expenditures comprise approximately 1 percent of total vehicle production costs.[254] Major end uses of electricity include painting systems (27-50 percent), facility lighting and HVAC (26-36 percent), compressed air (9-14 percent), and welding (9-11 percent). Fuels generate hot water and steam used in paint booths and heat in the curing ovens used to dry paint.[255] The amount of energy used in painting systems is affected by VOC control requirements. Low-VOC powder paints (including anti-chip primers, clear coats, and lacquers) have been developed that rely on the electrostatic attraction between the powder and the vehicle to deposit the coating onto the surface.[256] Though powder paints may require more heat in the curing process, by eliminating solvents, less energy is required for ventilation, pollution control, paint application, and paint gun cleaning. In addition, manufacturing powder paints is slightly less energy intensive than solvent paints, resulting in additional indirect energy savings.[257] At the same time, substituting powder-based coating for solvent-based coating cannot be accomplished without major capital-intensive process and equipment changes to the painting lines and operations.

From 1998 to 2004, electricity purchases have ranged between 50 to 60 percent of total energy costs for the industry.[258] Since Census Bureau data from the *Annual Survey of Manufacturers* do not provide the annual amount of energy produced from purchased fuels, it is not possible to calculate the total energy intensity of the motor vehicle manufacturing industry, though it is possible to calculate electric intensity (kWh/dollar value of shipments), which fell by almost 9 percent from 1998 to 2004.

Table 48 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 48: Current economic and energy data for the motor vehicle 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
	-2.2%	1.9%	0.3%	0.1%
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)
	NA	NA	1.1%	0.3%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)[kkkk]				
		Natural Gas	Net Electricity	Other
		48%	41%	7%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	18%
		Fuel Oil	LPG	Coal
Fraction of natural gas inputs that could be met by alternate fuels		50%	42%	11%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	Withheld
		Natural Gas	Fuel Oil	Electricity
Fraction of coal inputs that could be met by alternate fuels		94%	14%	4%

[kkkk] Fuel input and fuel-switching data are for the larger NAICS category, transportation equipment (NAICS 336).

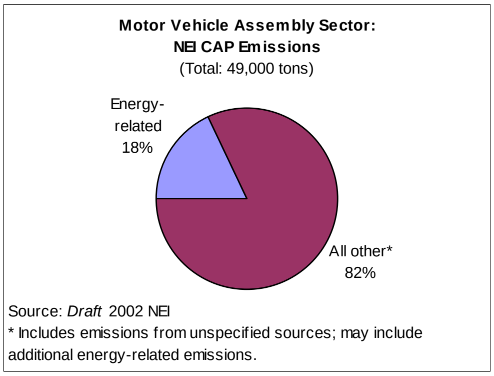
Expected Future Trends

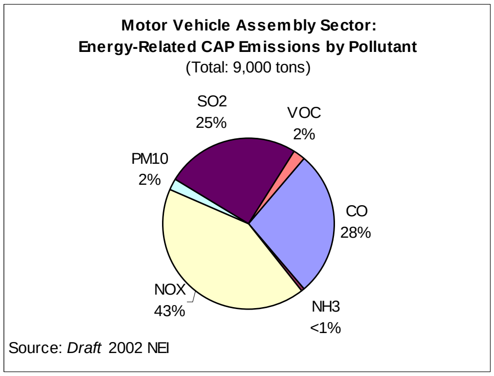
> **Voluntary Commitments**
>
> Through Climate VISION, member companies of the Alliance of Automobile Manufacturers have committed to achieve at least a 10% reduction in GHG emissions from their U.S. automotive manufacturing facilities, based on U.S. vehicle production, by 2012 from a base year of 2002.[a]

Economic pressures on the motor vehicle manufacturing industry are expected to be the primary motivation for efficiency improvement, as the U.S. auto industry seeks to increase its competitive edge on the global market. A recent study predicts that the publicly traded companies that comprise the automotive industry may also be motivated to reduce the impacts of energy cost volatility by investing in efficiency.[259] According to research conducted by the Lawrence Berkeley National Laboratory (LBNL), due to the complexity, process, and technological variation in the automotive assembly industry a wide array of opportunities exist for energy efficiency and pollution prevention for paint, welding, and cross-sector practices (e.g., utilities, lighting, stamping, etc.). However, given the relatively small fraction of total production costs that energy entails, efficiency improvement is likely to be incremental. No major shifts in fuel mix are anticipated.

Environmental Implications

Figure 22: Motor vehicle manufacturing sector: energy-related CAP emissions



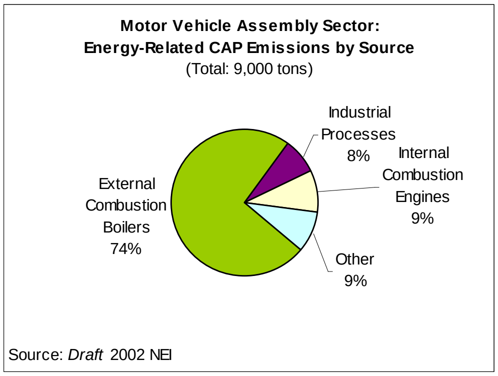


> **Effects of Energy-Related CAP Emissions**
>
> SO_2 and NO_x emissions contribute to respiratory illness and may cause lung damage. Emissions also contribute to acid rain, ground-level ozone, and reduced visibility.

Figure 22 compares NEI data on energy-related CAP emissions by pollutant type with total CAP emissions for the motor vehicle manufacturing industry. The industry is a relatively minor source of onsite energy-related CAP emissions compared with other sectors considered in this analysis—approximately 9,000 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

As purchased electricity meets a substantial fraction of this sector's energy needs, it is important to note that NEI data attribute emissions to the generating source rather than the purchasing entity, and thus underestimate energy-related CAP emissions for this sector. In terms of onsite energy generation, the largest emissions fractions are nitrogen oxides and sulfur dioxide. (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.)

Figure 23: Motor vehicle manufacturing sector: CAP emissions by source category and fuel usage



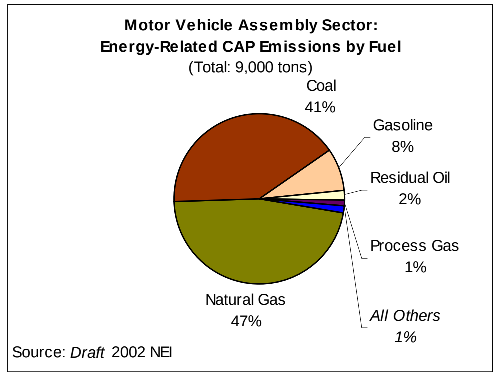


Figure 23 presents NEI data on the sources of energy-related CAP emissions shown in Figure 22, by source category and fuel usage. External combustion boilers contribute to almost two thirds of energy-related emissions for this sector. According to NEI data, 47 percent of energy-related CAP emissions are due to onsite natural gas consumption and 41 percent of energy-related emissions are due to onsite coal consumption. The sector does not use large amounts of coal, but coal's emissions intensity contributes to the relatively high fraction of coal-related CAP emissions (sulfur dioxide and nitrogen oxides are both linked to coal combustion).

NEI data from 2002 show that key opportunities for reducing the environmental impacts of sector energy use lie with reducing coal consumption and increased energy efficiency of external combustion boilers. According to the Alliance of Automobile Manufacturers, the industry has made substantial progress since 2002 in replacing coal-fired equipment with natural gas-fired equipment, including the elimination of coal use at five DaimlerChrysler assembly plants, and similar fuel conversions at other facilities.[260]

Given the motor vehicle manufacturing sector's dependence on purchased electricity, the sector's energy-related environmental footprint in part depends on energy inputs for local electric power generation. Energy efficiency improvements will primarily affect purchased electricity requirements, with associated reductions in energy-related emissions occurring at the utility level.

As there are no energy consumption projections for the motor vehicle manufacturing industry contained in AEO 2006, we do not report carbon dioxide emissions projections for this sector.

3.9.2 Best Case Scenario

Opportunities

Table 49 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 49: Opportunity assessment for the motor vehicle manufacturing industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	For plants located near landfills, landfill gas may provide an alternative boiler fuel to coal or other fossil fuels. Plants owned by Ford, GM, BMW, and DaimlerChrysler are currently using landfill gas,[261] but the location-specific requirements of this opportunity limit its potential for offering widespread energy savings.
Increased CHP	Low	CHP has limited application in assembly plants because many do not have a large thermal process load that is met by steam or hot water, but CHP may be cost effective for those plants with electricity, process heat, and steam requirements. To increase cost effectiveness, CHP may also be combined with absorption chillers for plants with cooling requirements. Though the LBNL study provided no examples of plants in the United States that implemented CHP, plants in Europe and Germany have successfully implemented CHP projects.[262] New CHP installations also face barriers in terms of utility interconnection requirements if electricity production is expected to exceed onsite demand, and also from NSR/PSD permitting.[263]
Equipment retrofit/ replacement	Medium	Replacing aging equipment with state-of-the-art equipment offers potential for efficiency improvement, within limitations imposed by capital constraints. Due to the high energy requirements of the painting process, painting equipment replacement has substantial energy-savings potential. Specific opportunities include ventilation system, oven, and control system replacement, as well as installation of high-efficiency motors.[264] There are also opportunities for energy efficiency improvements for body welding technologies and process changes.
Process improvement	High	Some process improvements may offer less capital-intensive opportunities for energy efficiency improvement, and also may improve product quality and reduce operating costs. The LBNL study provides many examples of process improvement, including reductions in ventilation energy use through reduced ventilation speed, and turning down air flow during breaks in the production process.[265] A motor vehicle manufacturing company seeking to reduce energy consumption through eliminating a shift was deterred by a potential triggering of NSR permitting requirements. NSR could have been triggered due to the need for additional process equipment during the remaining shift.[266]
R&D	Medium	The LBNL study references multiple ongoing technological developments in the industry that will improve sector energy efficiency. Examples include the development of microwave heating for paint curing, and VOC removal systems that will cost-effectively treat smaller amounts of pollutant than current scrubber systems. Additional R&D is also needed to facilitate further development of low-VOC paints or wet-on-wet painting as viable and cost-effective energy-savings opportunities.[267]

Optimal Future Trends

As no energy use projections are available for the motor vehicle manufacturing industry, it is not possible to compare a business-as-usual energy scenario with an optimal energy scenario. However, a preferred energy management strategy for the industry would primarily involve faster replacement rates of existing equipment with energy-efficient equipment, increased adoption of process improvements, and increased investment in R&D. Pilot applications of CHP in the U.S. automotive industry offer additional opportunities for energy efficiency improvement.

Environmental Implications

Given the automotive industry's dependence on purchased power, and due to the magnitude of energy losses during electric generation and transmission, efficiency gains at the facility level have a magnified impact on energy-related emissions at the utility level. With the automotive industry geographically concentrated in the Midwest, emissions reductions would also be fairly concentrated geographically, with potentially greater effects on regional air quality. Reducing fossil fuel inputs for boiler fuel through increased landfill gas applications offer opportunities for improving the sector's emissions profile at the facility level, particularly for nitrogen oxides, carbon monoxide, and sulfur dioxide.

3.9.3 Other Reference Materials Consulted

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U.S. Environmental Protection Agency. *National Emissions Inventory*. 2002.

3.10 Motor Vehicle Parts Manufacturing

Recent Sector Trends Informing the Base Case

Number of facilities: ↓
Value of shipments: ↓
Electricity intensity: ↑

Major fuel sources: Electricity, natural gas

Current economic and energy consumption data are summarized in Table 50.

3.10.1 Base Case Scenario

Situation Assessment

The motor vehicle parts manufacturing sector (NAICS 3363) encompasses a diverse set of firms that manufacture finished parts used in the assembly of automobiles, ranging from firms that manufacture components such as gasoline engines, transmissions, and steering and brake systems, to those that manufacture electrical and electronic equipment, to those that produce interior seating and trimmings.[268] Original equipment manufacturers (OEMs) produce the equipment parts used in the assembly of new vehicles. The industry is highly fragmented, consisting of thousands of independent companies across the United States. According to the U.S. Census Bureau, there were more than 5,700 establishments in this NAICS in 2002, a decline from 5,800 in 1997. The industry experienced no growth in value added and a small decline in value of shipments from 1997 to 2004 (see Table 50).

According to the Automotive Parts Manufacturers' Association (APMA) of Canada, natural gas meets approximately half of sector energy demand, with electricity meeting approximately 20 percent and petroleum-based fuels meeting approximately 10 percent of demand.[269] For the U.S. industry, the electricity fraction may be higher based on energy cost data compiled by the Census Bureau. From 1998 to 2004, electricity purchases ranged from 69 to 75 percent of total energy costs for the industry, representing smaller fractions in 2003 and 2004 as petroleum and natural gas prices increased.[270]

Since Census Bureau data from the *Annual Survey of Manufacturers* do not provide the annual amount of energy produced from purchased fuels, it is not possible to calculate the total energy intensity of the motor vehicle parts manufacturing industry, though it is possible to calculate electric intensity (kWh/dollar value of shipments). Electric intensity increased by 3 percent from 1998 to 2004. Total electricity consumption increased 14 percent from 1998 to 2004.[271]

Due to the diversity of the automotive parts manufacturing industry, there are a wide array of processes associated with sector energy use, including assembly (18 percent of total energy usage), plastics molding (16 percent), and surface coating and painting (13 percent). [272] Energy costs generally represent less than 10 percent of total production costs for the industry.[273]

Table 50 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 50: Current economic and energy data for the motor vehicle parts 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
	0.0%	-2.2%	-0.1%	-2.3%

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)
	NA	NA	2.1%	0.9%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)[llll]				
		Natural Gas	Net Electricity	Other[mmmm]
		48%	41%	7%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	18%
		Fuel Oil	LPG	Coal
Fraction of natural gas inputs that could be met by alternate fuels		50%	42%	11%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	Withheld
		Natural Gas	Fuel Oil	Electricity
Fraction of coal inputs that could be met by alternate fuels		94%	14%	4%

Expected Future Trends

Though no energy projections are available for the motor vehicle parts manufacturing industry, recent trends suggest that electricity consumption is growing relative to the value of economic output. Increases in electricity intensity suggest that controlling energy costs in a volatile fuel market has not motivated the industry toward increased energy efficiency investment to a notable degree. The available data for this sector suggest a slow rate of energy efficiency improvement in future, primarily through replacement of aging equipment with newer technologies. No fuel-switching trend is expected.

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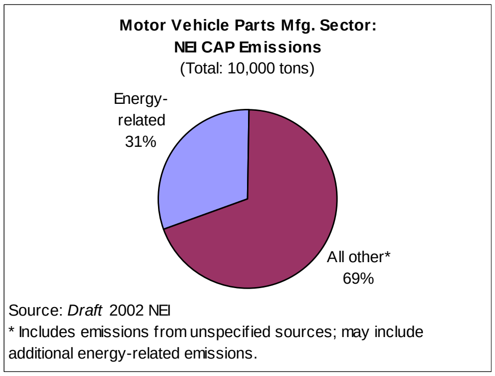
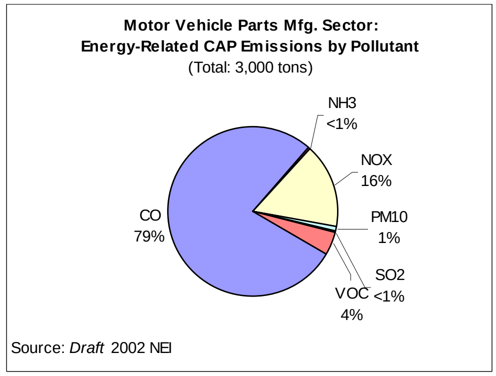
llll Fuel input and fuel-switching data are for the larger NAICS category, transportation equipment (NAICS 336).

mmmm Within MECS, the largest fractions of the "other" category include still gas and waste gas, asphalt and road oil, petroleum coke, and purchased steam.

Environmental Implications

Figure 24: Motor vehicle parts manufacturing sector: energy-related CAP emissions





> **Effects of Energy-Related CAP Emissions**
>
> NO_x emissions contribute to respiratory illness and may cause lung damage. NO_x emissions also contribute to acid rain, ground-level ozone, and reduced visibility.

Figure 24 compares NEI data on energy-related CAP emissions with total CAP emissions for the motor vehicle parts manufacturing industry. As purchased electricity meets a substantial fraction of this sector's energy needs, it is important to note that NEI data attribute emissions to the generating source rather than the purchasing entity. Thus, NEI data underestimate energy-related emissions for this sector. However, the sector is a relatively minor source of onsite energy-related CAP emissions compared with other sectors considered in this analysis—approximately 3,000 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

The large fraction of carbon monoxide (CO) emissions for this sector are believed to be an NEI reporting error, as 92 percent of all carbon monoxide emissions listed in NEI are from a single facility. This error also contributes to the magnitude of energy-related CAP emissions resulting from internal combustion engines and gasoline consumption shown in Figure 25, as that same facility accounts for 98 percent of all CAP emissions resulting from internal combustion engines. After correcting for this error by eliminating the data from that facility, total energy-related CAP emissions for the motor vehicle parts manufacturing industry are approximately 867 TPY (as reported in Table 13, Section 2.3.3), carbon monoxide emissions comprise around 23 percent of energy-related CAP emissions, and nitrogen oxide emissions comprise around 57 percent.

Figure 25: Motor vehicle parts manufacturing sector: CAP emissions by source category and fuel usage

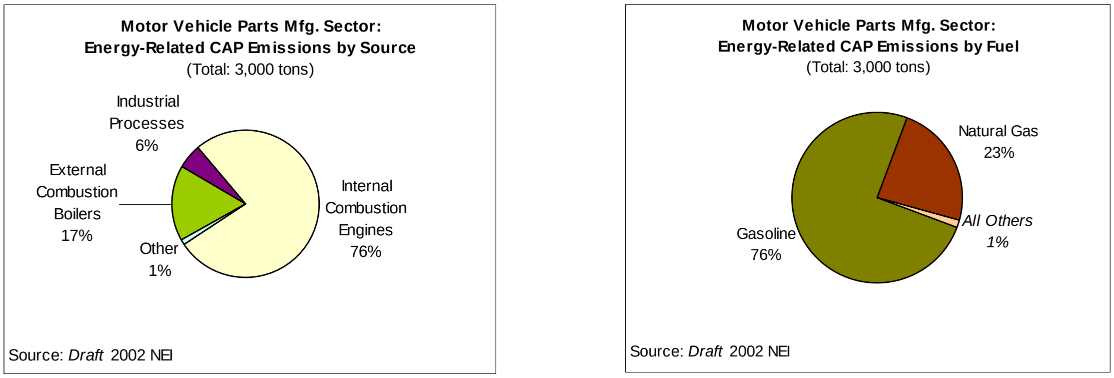


Figure 25 presents NEI data on the sources of energy-related CAP emissions shown in Figure 24, by source category and fuel usage. Though NEI data errors skew the Figures (as previously noted), reductions in onsite energy consumption would have the largest effect on nitrogen oxide emissions resulting from natural gas fuel use.

In terms of CAP emissions, the energy-related environmental footprint for this sector is expected to increase as energy usage increases. Given the sector's dependence on purchased electricity, a fraction of its energy-related environmental footprint is linked to trends in electric generation, with substantial energy-related emissions impacts occurring at the utility level. CAP emissions from natural gas and petroleum fuel use occur at the facility level, and overall increases in energy consumption are likely to increase these energy inputs as well.

As there are no energy consumption projections for the motor vehicle parts manufacturing industry contained in AEO 2006, we do not report carbon dioxide emissions projections for this sector. However, increasing energy consumption would lead to increased carbon dioxide emissions as well.

3.10.2 Best Case Scenario

Opportunities

Table 51 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 51: Opportunity assessment for the motor vehicle parts manufacturing industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	Due to the sector's dependence on purchased electricity, the environmental impact of energy inputs will follow national trends for electric generation. There may be some opportunity for clean fuels improvement through increased use of renewable energy in electric power generation.
Increased CHP	Low	Sector shows little CHP potential.

Opportunity	Ranking	Assessment (including potential barriers)
Equipment retrofit/ replacement	Medium	As in other sectors, replacing aging equipment with state-of-the-art equipment offers potential for efficiency improvement in the motor vehicle parts industry. One example cited by APMA includes fuel-fired equipment controlled by oxygen trim controls to improve combustion efficiency. Facility lighting and HVAC improvements offer additional opportunities for energy savings.[274]
Process improvement	High	Process improvements offer less capital-intensive opportunities for energy efficiency improvement and also may improve product quality and reduce operating costs. System optimization for compressed air, exhaust, and make-up air systems was cited as a best practice by APMA.[275] In plastics molding, reducing the time involved in press changeovers decreases idle running time and saves energy.[276] Other process improvement opportunities may be similar to those found in the metal casting industry, and painting process improvements may be similar to those found in motor vehicle manufacturing.
R&D	Low	Our research did not produce any information regarding an R&D pipeline of energy efficiency technologies unique to this sector.

Optimal Future Trends

As no energy use projections are available for the motor vehicle parts manufacturing industry, it is not possible to compare a business-as-usual energy scenario with an optimal energy scenario. However, a preferred energy management strategy for the industry would primarily involve faster replacement rates of existing equipment with energy-efficient equipment and increased adoption of process improvements.

Environmental Implications

Given the motor vehicle parts manufacturing industry's dependence on purchased power, and due to the magnitude of energy losses during electric generation and transmission, efficiency gains at the facility level have a magnified impact on energy-related emissions at the utility level. Due to the magnitude of energy losses during electric generation and transmission (more than twice the amount of delivered energy for fossil fuel-fired power plants), efficiency gains at the site level have a magnified impact on energy-related emissions at the utility level. At the facility level, energy efficiency improvements will primarily affect nitrogen oxide emissions. However, due to the geographic dispersion of the industry, energy trends are unlikely to have a noticeable impact on regional air quality.

3.10.3 Other Reference Materials Consulted

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3.11 Petroleum Refining

3.11.1 Base Case Scenario

Situation Assessment

> Recent Sector Trends Informing the Base Case
>
> Number of facilities: ↓
> Value of shipments: ↑
>
> Major fuel sources: Refinery gas (fuel gas), natural gas
>
> Current economic and energy consumption data are summarized in Table 52.

The petroleum refining industry (NAICS 32411, 324110) includes establishments engaged in refining crude petroleum into refined petroleum products through multiple distinct processes including distillation, hydrotreating, alkylation, and reforming. In addition to fuels, the industry produces raw materials for the petrochemical industry.

In the 1980s and 1990s, the petroleum refining industry underwent large-scale consolidation, shutting down small, inefficient refineries and expanding refineries with larger capacities. The number of operable refineries dropped from 194 in 1990 to147 in 2004. During the same period, throughput increased from 15.6 to 16.9 million barrels per day, and refinery utilization increased from 87.1 to 93 percent. The industry is now dominated by a relatively small number of large, vertically integrated companies operating multiple facilities.[277]

Sector energy usage is concentrated primarily in the South Census Region (57 percent) and the West Census Region.[278] For petroleum refining, the most important fuels are refinery gas (also referred to as "still" gas, this fuel represents a substantial portion of the "other" fuel category in MECS) and natural gas. Though petroleum refining used to be an industry with slim margins, industry consolidation has largely addressed this problem. Of the sectors included in this analysis, petroleum refining experienced the strongest economic growth in terms of annual increases in value added and value of shipments from 1997 to 2004 (see Table 52).

Table 52 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 52: Current economic and energy data for the petroleum refining 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
	5.4%	6.3%	6.6%	5.0%
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)
	116.3	16.1	21.0%	3.1%

Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
		Other[nnnn]	Natural Gas	Net Electricity
		68%	27%	4%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	18%
		LPG	Other	Fuel Oil
Fraction of natural gas inputs that could be met by alternate fuels		58%	27%	24%

Expected Future Trends

Several trends are expected to impact sector energy use in the future:

- Heavy and/or sour crudes—which require more energy-intensive processing than "premium" crudes—are expected to contribute a growing fraction of fuel oil production. As existing reserves of oil are depleted and there is greater worldwide competition for premium (e.g., light, sweet) crudes, refiners will increasingly utilize heavy and/or sour crudes to meet demand.
- There is expected to be increasing use of unconventional sources of oil like tar sands and shale oil. These materials also require more energy-intensive processing to separate oil from sand or rock strata. The disposal of the rock byproduct after processing is of environmental concern and would lead to further energy consumption to make the processed oil fit for refining into fuel products.
- Production of synthetic fuels (primarily used as blending components for diesel fuel) using coal-to-liquids (CTL), gas-to-liquids (GTL), or other processes will increase, particularly in the face of high oil prices. Synthetic fuel production is generally a more energy-intensive form of fuel production than traditional petroleum refining processes, and is also associated with higher carbon dioxide emissions.

Voluntary Commitments

The American Petroleum Institute is a member of Climate VISION, committing to a 10 percent energy efficiency improvement by 2012. Specific areas of focus include expanding CHP, reducing methane and carbon venting from production operations, gasifying refinery residuals, and developing more robust methods for tracking and reporting GHG emissions industry-wide. See http://www.climatevision.gov/sectors/oil_gas/index.html.

The petroleum refining 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/petroleum_refining/.

[nnnn] "Other" fuels consist primarily of byproduct gas generated in the refining process, often referred to as "still" gas.

- Increasing demand for biofuels will impact transportation fuel supply. The Renewable Energy Standard requires that ethanol—currently at 3 percent of the nation's gasoline supply—grow to 5 percent by 2012, and ethanol is projected to continue growing beyond 2012. This statute will require petroleum refineries to manufacture more gasoline blending stock to support the increase in ethanol production. Ethanol production is also more energy intensive than petroleum refining.
- Lastly, EPA's low sulfur regulations for on-road and off-road diesel are expected to decrease refinery efficiency because the hydrotreatment process of sulfur removal is highly energy intensive.

Under its reference case scenario, CEF projects that overall energy consumption by the petroleum refining sector will increase by 25 percent from 1997 to 2020, primarily driven by increasing production. Energy intensity is projected to increase by 0.2 percent per year (compared with a 1.1 percent annual decrease for industrial manufacturing as a whole). In addition to the production-related factors that drive increased energy consumption described above, according to AGF the industry has exploited many of the easiest opportunities for energy efficiency gains, so the future pace of energy efficiency improvement is likely to be slow.[279]

The sector will continue to depend on refinery gas and natural gas as primary energy sources. Fuel-switching is a readily available option for the petroleum refining industry, and petroleum refineries will continue to switch fuels in response to relative prices.[280]

CEF projections are summarized in Table 53.

Table 53: CEF reference case projections for the petroleum refining industry

	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	2.126	70%	2.291	60%
Natural gas	0.800	26%	1.300	34%
Coal	0.003	0%	0	0%
Delivered electricity	0.110	4%	0.200	5%
Total	3.039[oooo]	100%	3.791	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				0.2%
Overall % change in energy use (1997-2020)				25%

In an effort to assess the impact of recent trends that may have affected energy consumption since the CEF report was produced, we also examined reference case energy consumption projections for the petroleum refining industry 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. From 2004 to 2020, AEO 2006 projects that the industry's value of shipments will grow at the rate of 1 percent per year, and energy consumption will increase by 50 percent over the period—double the increase projected by CEF. AEO 2006 projects that

oooo According to 2002 MECS data, total energy consumption for the petroleum refining sector in 2002 was approximately twice the value CEF reports for 1997. We are unable to fully account for the magnitude of the difference between the two data sources.

energy intensity (energy consumption per dollar value of output) will grow by 1.5 percent per year. Consumption of all fuel types is projected to increase, with the largest increases seen for still gas (43 percent) and coal (500 percent).

The dramatic increase in coal consumption projected by AEO 2006 is primarily driven by the increasing production of synthetic fuels from coal. CTL is the production of coal-based synthetic fuels using either a direct liquefaction process or the Fischer-Tropsch process (which involves a gasification step). This process is fundamentally a feedstock use of coal, but a CHP unit may be added to generate electricity. EIA assumes that expansion of CTL production in the petroleum refining industry will be associated with considerable CHP capacity additions. For the CTL production process modeled by EIA, 49 percent of coal inputs are retained in the product, 20 percent are consumed in conversion processes, and 31 percent are used for electricity generation. Given the minimal electricity requirements of the petroleum refining industry, the majority of such power production would likely be sold to the grid.

Environmental Implications

Figure 26: Petroleum refining sector: energy-related CAP emissions

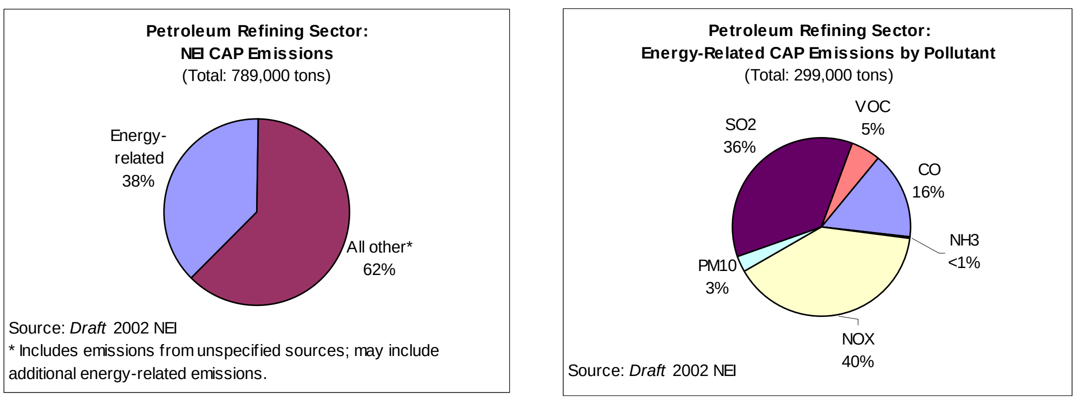
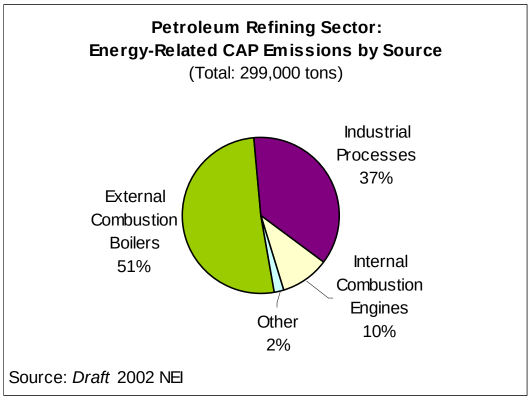


Figure 26 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the petroleum refining sector. According to the figure, energy-related CAP emissions are less than half of all CAP emissions and are dominated by nitrogen oxide and sulfur dioxide. (As noted in Section 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.) Energy efficiency and clean energy improvements are expected to primarily affect emissions of these pollutants. According to MECS data, in 2002 net electricity comprised less than 2 percent of the petroleum refining industry's total energy demand, so NEI data provide a fairly complete picture of the sector's energy-related CAP emissions.

> **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 27: Petroleum refining sector: CAP emissions by source category and fuel usage



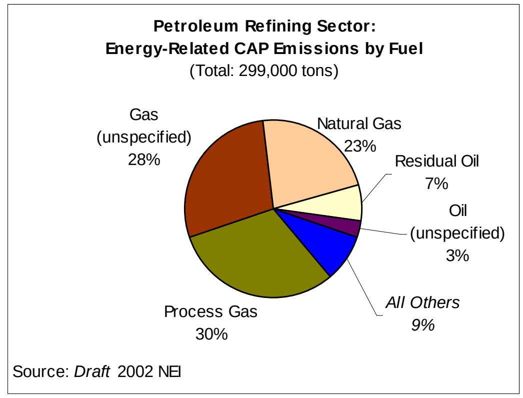


Figure 27 presents NEI data on the sources of energy-related CAP emissions shown in Figure 26. According to MECS data (see Table 52), “other” fuels (primarily refinery gas and still gas) met the majority of the sector’s energy needs in 2002. In NEI, such fuels are likely classified either as “gas (unspecified)” or “process gas.” Though the largest fraction of energy-related CAP emissions is from external combustion boilers, emissions that are classified as related to industrial processes in NEI are also substantial. As previously noted, NEI equipment classifications are problematic due to reporting inconsistencies. DOE reports that the majority of the sector’s energy consumption is from direct fuel inputs into the following systems: boilers, furnaces, reboilers in distillation columns, thermal and catalytic crackers, and steam systems used for steam stripping and other purposes.[281]

CEF and AEO 2006 projections of increasing energy consumption for the petroleum refining industry would primarily increase energy-related CAP emissions at the facility level.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 207 million metric tons in 2004. For the petroleum refining industry, increasing energy consumption leads to a projected increase in carbon dioxide emissions of 56 percent from 2004 to 2020, in line with the expected increase in total energy consumption.

3.11.2 Best Case Scenario

Opportunities

Table 54 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 54: Opportunity assessment for the petroleum refining industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	As the sector’s primary energy source is refinery gas—a byproduct of the production process—there is minimal potential for a large-scale shift toward cleaner fuel inputs.

Opportunity	Ranking	Assessment (including potential barriers)
Increased CHP	High	Though the petroleum refining industry has relatively low demand for electricity, it has the third-largest cogeneration capacity among manufacturing industries. The industry meets 30 percent of its electricity requirements with onsite power generation, most of which is cogenerated.[282] Due to the magnitude of the industry's steam requirements, cogeneration is generally a cost-effective way of meeting this demand. According to DOE analysis there is substantial potential to increase CHP capacity in the refining industry, and also to increase waste heat reduction and recovery (particularly in lower-quality steam and exit gases).[283] As mentioned previously, DOE expects that in the future, increased synthetic fuel production will be a driver of increased cogenerating capacity to the degree that onsite demand for electricity could be exceeded.[284] 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.[285]
Equipment retrofit/ replacement	Medium	For capital-intensive industries, CEF predicts that the largest energy efficiency gains will come from replacement of old equipment with state-of-the-art equipment.[286] Opportunities lie with furnaces, heat exchange equipment (replacement with helical, vertical heat exchangers), sensors and controls, equipment used in separation processes, and containment vessels.[287] Continuous reforming technology improves the efficiency of transportation fuel refining; Digital Equipment Condition Monitoring is a process control technology that allows the system to operate closer to maximum efficiency. Retrofits can also reduce energy losses from steam systems (pipes, traps, and valves). API cites cost and regulatory barriers to energy efficiency improvement, noting "energy efficiency is not usually a business driver and is difficult to justify as an investment when capital recovery is too long."[288] To avoid NSR, refineries may find it easier to retrofit existing equipment as opposed to installing the latest energy-efficient technologies.
Process improvement	Medium	The most energy-intensive processes in petroleum refining include distillation (atmospheric and vacuum), hydrotreating, alkylation, and reforming.[289] Energy losses can be reduced through implementation of energy management best practices, minimization of energy-intensive processes such as distillation, process optimization to reduce downtime and maintenance requirements, and replacement of solid phase catalysts with ionic liquids.[290] API has the objective of increasing usage of less energy-intensive biological processes, including bioprocessing of crude, biotreatment of wastewater, and bioremediation of soil and groundwater contamination. API cites uncertainties about future product requirements as inhibiting some process-related changes. There is uncertainty about future performance-related requirements on the part of consumers, as well as uncertainty about future regulatory requirements.[291]
R&D	Medium	API notes the following R&D focus areas: replacements for existing separation processes, improved process yields through development of more selective catalysts, development of better pathways for hydrocarbon conversion, and bioprocessing.[292] Promising technologies are currently in development, such as membrane separation technologies that increase the efficiency of distillation units by 20 percent. Under Climate VISION, the R&D Challenge focuses on technologies that reduce/sequester carbon emissions.[293] The industry 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/petroleum_refining/. With the elimination of most of the nation's small, inefficient refineries and expansion of remaining, larger, more efficient refineries, refining margins have improved in 2004 and 2005. The industry's strengthened financial position may help attract capital necessary for R&D and other large-scale improvements. API notes the following factors that inhibit the development of new energy-saving technologies and processes in the petroleum refining industry: a number of technical barriers (intrinsic process inefficiency, lack of understanding about mechanisms leading to fouling, inadequate sensing and measuring techniques, inadequate process models), regulatory requirements, costs and risks associated with developing new technology, and a lack of long-term commitment to fundamental research.[294]

Optimal Future Trends

Under its advanced energy scenario, CEF projects the petroleum refining sector's overall energy use to decline slightly below current levels, and energy intensity to decrease by 0.9 percent annually. The decline in sector energy consumption is driven primarily by decreased demand for petroleum-based fuels brought about by the greenhouse gas emissions regulations, rather than from energy efficiency gains within the sector. As GHG regulations included under the advanced scenario drive shifts to less carbon-intensive fuels, CEF projects that the total amount of energy provided by petroleum-based fuels will decrease by 2020, while the amount of energy provided by natural gas will increase over 1997 levels.

CEF's advanced case projections are summarized in Table 55.

Table 55: CEF advanced case projections for the petroleum refining industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	2.126	70%	1.799	61%
Natural gas	0.800	26%	1.014	35%
Coal	0.003	0%	0	0%
Delivered electricity	0.110	4%	0.126	4%
Total	3.039	100%	2.939	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.9%
Overall % change in energy use (1997-2020)				-3.0%

Environmental Implications

Under the advanced energy scenario, CEF projects that the petroleum refining industry to achieve a 15 percent reduction in 1997 carbon emissions levels by 2020, primarily due to the lower carbon intensity of natural gas as compared with petroleum-based fuels. This shift is expected to improve emissions of criteria pollutants as well, particularly nitrogen oxides and sulfur dioxide.

3.11.3 Other Reference Materials Consulted

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3.12 Shipbuilding and Ship Repair

3.12.1 Base Case Scenario

Situation Assessment

> **Recent Sector Trends Informing the Base Case**
>
> Number of facilities: ↓
> Value of shipments: ↑
> Electricity intensity: ↓
>
> Major fuel sources: Electricity, petroleum, natural gas
>
> Current economic and energy intensity data are summarized in Table 56 on page 3-97.

The shipbuilding and ship repair industry (NAICS 336611) consists of 346 facilities that build and repair ships, barges, and other large commercial and military vessels, as well as facilities that manufacture offshore oil and gas well drilling and production platforms.[295] Most shipyards were built prior to World War II, with layout changes made piecemeal through the years. Facilities that are common to most shipyards include drydocks, shipbuilding positions, piers and berthing positions, workshops, work areas, and warehouses. The shipbuilding and ship repair industry participates in EPA's Sector Strategies Program.

Although recent economic indicators have been positive for the shipbuilding and ship repair industry, the sector faces some considerable economic challenges. Value added and value of shipments increased from 1997 to 2004 (see Table 56).[296] However, the long-term economic outlook for the industry may be less favorable. The sector is heavily dependent on military contracts and fairly uncompetitive in the global market of commercial shipbuilding, representing less than one percent of the global new construction market for commercial vessels.[297]

Electricity purchases represent 75 to 80 percent of the sector's energy costs, and purchased fuels represent the sector's remaining energy budget, with no major switching trends (i.e., from electricity toward fuels) evident from 1998 to 2004.[298] As Census Bureau data from the *Annual Survey of Manufacturers* do not provide the annual amount of energy produced from purchased fuels, it is not possible to calculate the total energy intensity of the shipbuilding industry, though it is possible to calculate electric intensity (kWh/dollar value of shipments), which fell by almost 10 percent from 1998 to 2004.[299] There is substantial regional variation in the sector's energy profile. For example, yards in the Northeast have higher fuel usage due to facility heating requirements. Regional differences in electricity and fuel costs may affect the cost-benefit calculations for energy efficiency improvement projects.

Energy-intensive processes for shipbuilding and ship repair include welding (electric arc welding is most common), forging, abrasive blasting, and application of marine coatings. The greatest energy-related environmental improvement opportunities are related to equipment replacement and/or retrofits to increase the energy efficiency of compressed air systems, HVAC systems, lighting, and motors.[300]

Table 56 summarizes current economic trend and energy intensity data originally presented in Chapter 2.

Table 56: Current economic and energy data for the shipbuilding and ship repair industry[pppp]

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
	2.7%	5.4%	1.8%	2.4%
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)
	NA	NA	1.2%	0.8%

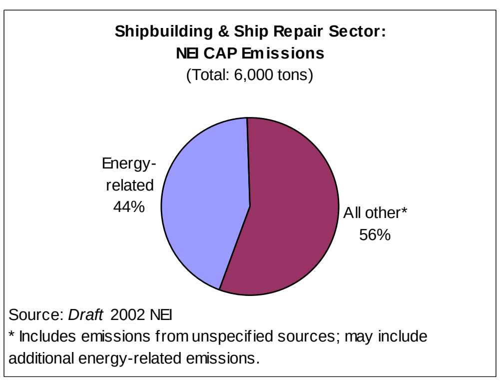
Expected Future Trends

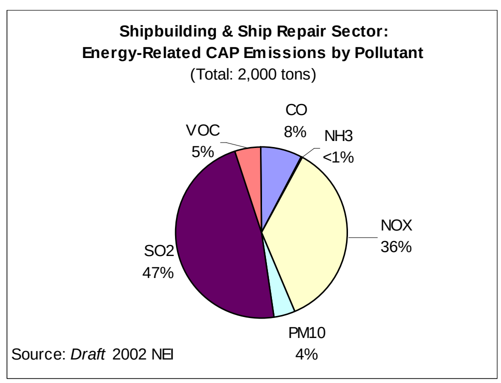
Economic pressures on the shipbuilding industry are expected to play a dominant role in sector energy use. Energy expenses represent a substantial fraction of production costs and, though the industry has not historically taken a strategic approach to energy management, increasing costs for electricity and fuels has driven growing consideration of energy issues, particularly in areas with high electric rates.[301] Efforts to control energy costs are likely to drive incremental efficiency improvement, but capital constraints are likely to limit the extent of major capital improvements. Purchased electricity will continue to meet the majority of the sector's energy requirements.

Increased VOC regulation has the potential to increase energy requirements for pollution control systems. In addition, increased regulation of stormwater discharges could increase energy requirements for water treatment.

Environmental Implications

Figure 28: Shipbuilding and ship repair sector: energy-related CAP emissions





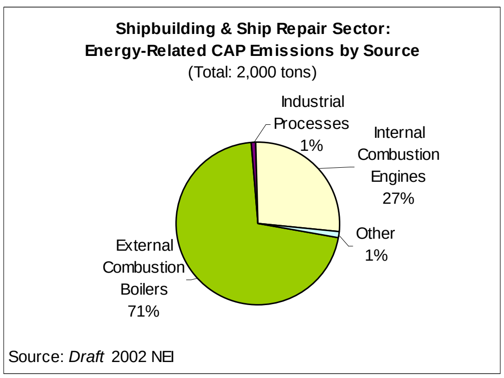
pppp MECS does not provide energy consumption data for this sector.

Figure 28 compares NEI data on energy-related CAP emissions with total CAP emissions for the shipbuilding and ship repair industry. Onsite energy-related CAP emissions are small compared with other sectors considered in this analysis—approximately 2,000 tons per year compared with more than 700,000 tons per year for the chemical manufacturing industry.

> **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.

It is important to note that NEI data attribute emissions to the generating source rather than the purchasing entity. Given the sector's reliance on purchased electricity, NEI data underestimate the industry's energy-related CAP emissions. According to NEI data shown in Figure 29, 63 percent of energy-related emissions are from residual oil consumption and 25 percent are from distillate oil consumption. Figure 28 shows that use of these fuels contributes to high fractions of sulfur dioxide and nitrogen oxide emissions, with those two pollutants comprising 83 percent of total CAP emissions.

Figure 29: Shipbuilding and ship repair sector: CAP emissions by source category and fuel usage



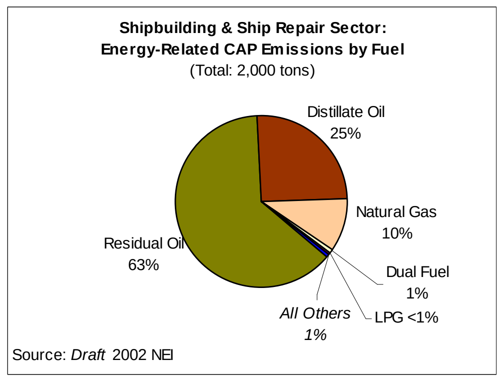


Figure 29 presents NEI data on the sources of energy-related CAP emissions shown in Figure 28, by source category and fuel usage. According to NEI data, the primary opportunities for reducing energy-related CAP emissions lie with reductions in petroleum-based fuel consumption and increased efficiency for external combustion boilers and internal combustion engines. Economic pressures on the industry could lead to reductions in petroleum consumption, which would decrease energy-related CAP emissions at the facility level, particularly sulfur dioxide and nitrogen oxides. Given the sector's dependence on purchased electricity, a portion of the sector's energy-related environmental footprint is linked to trends in electric generation, with most energy-related emissions impacts occurring at the utility level.

As there are no energy consumption projections for the shipbuilding and ship repair industry in AEO 2006, we do not report carbon dioxide emissions projections for this sector.

3.12.2 Best Case Scenario

Opportunities

Table 57 contains a brief assessment of five primary opportunities for improving environmental performance with respect to sector energy consumption, including potential barriers to implementing such opportunities.

Table 57: Opportunity assessment for the shipbuilding and ship repair industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Low	Due to the sector's dependence on purchased electricity, the environmental impact of energy inputs will follow national trends for electric generation. There may be some opportunity for clean fuels improvement through increased use of renewable energy, either at the facility level or in electric generation, but cost considerations limit the magnitude of this opportunity.
Increased CHP	Low	The sector shows little opportunity for CHP.
Equipment retrofit/ replacement	High	Equipment replacement and retrofits offer opportunities for energy efficiency improvement, particularly in the areas of compressed air systems, air handling equipment, lighting, HVAC, and motors. In the forging process, gas-fired heating can be replaced with induction heating (uses a high-frequency electric current), which has lower operational costs and requires lower energy inputs. The industry's limited capital and competing capital demands are the primary barriers to equipment-related opportunities. Industry representatives note that less capital-intensive opportunities such as facility lighting upgrades may be relatively easier to approve.[302]
Process improvement	High	Process improvements may offer opportunities for energy efficiency improvement and also may improve product quality and reduce operating costs. For example, energy-related environmental impacts from welding processes may be reduced through use of alternative energy sources, automation/robotics, and reduced post-weld processing.[303] In forging processes, improved efficiency of press changeovers to reduce idle running time will also save energy.[304] A technical barrier to increased welding automation/robotics is the highly customized nature of most welding operations in U.S. shipyards, where there are relatively few repetitive production processes.
R&D	Low	Given the capital constraints and long-term economic forecast for the shipbuilding industry, low levels of investment in R&D of new technologies are expected. The Welding Industry Vision Workgroup did set forth R&D needs and challenges with respect to welding processes.

Optimal Future Trends

As no energy use projections are available for the shipbuilding industry, it is not possible to compare a business-as-usual energy scenario with an optimal energy scenario. However, a preferred energy management strategy for the shipbuilding industry would primarily involve faster replacement rates of existing equipment with energy-efficient equipment and increased adoption of process improvements.

Environmental Implications

Given the shipbuilding industry's dependence on purchased power, the majority of environmental benefits (in terms of decreased CAP and carbon emissions) from increased energy efficiency in the shipbuilding industry would occur outside the facility at the utility level from reductions in purchased electricity. Due to the magnitude of energy losses from fossil fuel fired electric power generation, efficiency gains at the site level could have a magnified impact on energy-related emissions at the utility level, depending on the energy sources employed by local electric power generators.

Replacing fossil fuel-fired equipment with electric-powered equipment (as in the case of induction heating in forging operations) would shift energy-related emissions from the facility to the utility level. Though electric-powered equipment may be more efficient, fossil fuel-fired electric power generation is associated with substantial energy losses that could offset efficiency gains in terms of energy-related emissions. Such outcomes would depend on local variations in electric power supply.

3.12.3 Other Reference Materials Consulted

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4. Barriers to Environmentally Preferable Energy Outcomes

Insights

Based upon our research—including the data sources we reviewed and the perspectives and insights provided to us during interviews with internal and external stakeholders—this analysis (1) identifies general categories of barriers (financial, technical, institutional, and regulatory) to environmentally preferable energy outcomes in industrial manufacturing sectors; (2) notes that regulations and their underlying legislation do not necessarily take into consideration the potential for an adverse impact on energy efficiency or clean energy improvement; (3) discusses ways in which regulations—issued by EPA or other agencies—may thus create barriers to energy efficiency and clean energy improvement; and (4) identifies specific regulatory requirements that may impact opportunities around cleaner fuels, increased Combined heat and power (CHP), equipment retrofit/replacement, process improvement, and research and development (R&D).

4.1 Overview of Barriers

As discussed in Chapter 3 of this report, including each sector's table of *Best Case Scenario Opportunities*, there are a number of key opportunities for promoting environmentally preferable energy outcomes within each of the 12 sectors. These opportunities—reducing energy-related emissions through use of cleaner fuels, or by increasing energy efficiency through combined heat and power technologies, equipment retrofit or replacement, process improvement, or R&D involving energy-efficient technologies and processes—can be inhibited by a number of barriers. Thus, the next step is to examine what the barriers are to implementing these opportunities.

Based upon our research—including the data sources we reviewed and the perspectives and insights provided to us during interviews with internal and external stakeholders—we identified a number of different types of barriers that can impact energy efficiency and clean energy investments. These include, but are not limited to, nonregulatory barriers (i.e., financial, technical, and institutional constraints) as well as regulatory barriers. Section 4.2 briefly discusses the nonregulatory barriers to provide context for the consideration of regulatory barriers. Section 4.3 then provides a more detailed discussion of regulatory barriers, as the purpose of this analysis is to facilitate the development of policy approaches that EPA can employ to address regulatory barriers and promote energy efficiency and clean energy improvement in select manufacturing industries.

4.2 Nonregulatory Barriers

4.2.1 Financial Barriers

Primary and secondary research identified a number of financial barriers to environmentally preferable energy outcomes associated with financial and human capital investment, fuel cost differentials, and the broader economic circumstances facing one or more sectors. Sector representatives interviewed for this analysis indicated that such cost barriers are among the most important factors constraining energy efficiency and clean energy investments.

Competing Capital Needs

Given scarce capital resources, the greatest investment priorities are typically for equipment that (1) maintains or increases production and product quality or (2) is necessary to meet regulatory requirements (i.e., for equipment required to comply with environmental or worker safety regulations). Discretionary investments for energy efficiency or clean energy projects must often compete with these higher-priority investments.

Stringent Investment Hurdles

Energy efficiency and clean energy investments may also face more stringent investment hurdles than other types of capital investment (i.e., shorter payback periods; evaluating alternatives on the basis of up-front costs rather than lifecycle costs). Companies evaluate capital investments in terms of which ones offer the highest return on investment (ROI). Energy efficiency investments may be viewed less favorably than other investments, since energy is an input that does not necessarily increase production capacity or productivity, improve product quality, increase worker safety, etc. This is particularly true in the case of new technologies that may entail greater risks in implementation. The American Forest & Paper Association (AF&PA) indicated that managers typically want to see an ROI of 25 to 30 percent on an energy efficiency investment.[305] According to a 2004 study by the National Commission on Energy Policy, "business managers routinely forego efficiency opportunities with payback times as short as 6 months to three years—effectively demanding annual rates of return on efficiency investments in excess of 40-100 percent."[306]

Slow Turnover of Capital

If firms have made a substantial investment in equipment that has a long service life, they are likely to continue using such equipment until the end of its useful life before replacing it with a more energy-efficient technology. In industries like cement and forest products, existing energy-intensive equipment such as kilns and boilers have long lifetimes and require substantial amounts of capital to replace, which slows the rate of investment in more energy-efficient technologies. Such barriers are exacerbated when industry production is stagnant or declining and there is no expansion of production capacity, or when the industry is already at risk due to global competition and other economic conditions. This is the case for many of the industries addressed in this report, including aluminum, forest products, and segments of the chemical industry.

Economic Circumstances of the Industry

Firms are unlikely to invest capital in new equipment unless their long-term economic outlook is favorable. Many basic U.S. industries, such as aluminum, forest products, and segments of the chemical industry are not growing due to foreign competition and higher U.S. costs for labor and other variable costs. It may be difficult for these industries to justify large capital investments under current economic circumstances. It may also be more difficult to raise funding in equity markets if a sector is in decline or if investors do not perceive it as capturing value. Capital investment decisions regarding equipment replacement or retrofits may also be affected by resource-related constraints such as the extent of raw material reserves (e.g., the level of investment in equipment upgrades at cement plants may be based on the magnitude of remaining onsite limestone reserves).

Some sectors face increased energy consumption based on consumer demands. Food manufacturers have seen increased demand for ready-to-eat and fast-prepared foods, which consume more energy in processing. Customers of metal finishers and motor vehicle parts manufacturers are also demanding improved environmental performance through certifications such as ISO 14000. Such certification processes are often an important tool in identifying energy-savings opportunities, but they are also typically capital-intensive initiatives that may require expenditures on process modifications that take precedence over energy-related investments.

Resource constraints may also serve as a general barrier to energy efficiency and clean energy investment in certain sectors. As raw material inputs become more constrained for certain sectors (e.g., in petroleum refining, sources of light, sweet crudes, and in forest products, available land for harvesting), they may be forced to process lower-quality materials that have higher energy requirements.

Staff Resource Constraints

Firms may be unable or unwilling to incur the costs (in terms of staff time and effort) associated with evaluating the feasibility of an energy efficiency or clean energy opportunity and making the investment case to management decision-makers. AF&PA indicated that even for cost-effective and low-risk energy-savings opportunities, facility managers must typically develop an internal business assessment of the investment for approval by upper management decision-makers. The staff time and resources required to conduct such assessment may be a barrier to implementing the opportunity. Even greater internal resources may be needed to make the case for higher-risk investments in new technologies.[307]

Fuel Cost Differentials

As it relates to cleaner fuel opportunities, the substantially lower cost of coal (an emissions-intensive energy source) as compared with cleaner fuels such as natural gas is the primary constraint on environmentally preferable fuel-switching opportunities. In addition, the price of natural gas has historically been far more volatile, further diminishing its viability as a clean fuel opportunity. An expert who works with metal casting facilities noted that while oxygen injection increases combustion efficiency, oxygen is typically as expensive or more expensive than natural gas, diminishing the attractiveness of this opportunity.[308]

4.2.2 Technical Barriers

In many cases, a given energy efficiency or clean energy opportunity may not be viable to a sector or specific manufacturing facility given process, resource, quality control, or other constraints.

Some energy efficiency or clean energy opportunities are not well suited to a given industry's manufacturing process (e.g., CHP is not an attractive energy efficiency opportunity for electric arc furnace steelmaking, because the sector has relatively low demand for steam, and waste heat is difficult to recover). Process-related technical constraints may also affect the extent to which a given opportunity can be utilized (e.g., in cement manufacturing, use of waste fuels such as tires in kilns is constrained because the zinc content in tires slows down setting time). The manufacturing process diversity of other sectors (e.g., chemical manufacturing, metal casting) means that processes and technologies that work for some manufacturing facilities may not be applicable to other operations.

Other technical constraints relate to the ability of firms to implement an energy efficiency or clean energy opportunity given equipment configurations (e.g., type of boiler or burner in place), facility constraints (e.g., adequate space for new process equipment), supply constraints (e.g., price and availability of alternative fuels), and location-specific limitations (e.g., proximity to landfills as a source of landfill gas). Industries also face quality-control constraints related to manufactured product output. For example, an R&D opportunity for the metal finishing industry is the substitution of non-cyanide-based plating solutions for cyanide solutions. While some substitute processes reduce energy consumption in the metal finishing process as well as in waste treatment, viable alternatives remain impractical for a number of metals due to product quality issues.

4.2.3 Institutional Barriers

In some cases, institutional barriers associated with incentives and information flow constrain investment in energy efficiency and clean energy opportunities.

Incentive Constraints

Incentive constraints refer to industry characteristics that reduce incentives to invest in energy efficiency or clean energy opportunities. Even for the energy-intensive industries addressed in this report, energy costs are less significant than costs for labor and raw materials. Thus, energy efficiency opportunities may not be considered a fruitful area to pursue potential cost savings.

Historically, sectors such as food manufacturing have viewed energy as a fixed cost, which means that there is little incentive to pursue energy-savings opportunities. In some cases, energy costs may be paid by headquarters, while equipment purchasing decision-making happens at the facility level. If energy costs are outside the plant manager’s incentive structure, he or she may have little reason to pursue investments in energy-efficient equipment. Conversely, facility managers may be reluctant to invest the time and effort in making the case for energy efficiency-related capital upgrades to corporate management, as such investments may not be perceived as integral to the business’s profitability.

Informational Constraints

In addition to lacking a systematic approach to energy management, firms may also lack leading-edge information on energy-efficient technologies, or have inadequate internal resources to seek out and evaluate such information. An expert on the metal finishing industry indicated that, within the industry, there is generally a low level of technical capability in this area, with firms relying heavily on equipment suppliers for expertise.[309] In other cases, energy efficiency expertise may be compartmentalized among technical experts, without adequate distribution at the decision-making level of the firm. Sometimes decisions about equipment replacement must be made quickly to limit production interruptions. In such cases, if more efficient technologies have not been identified, replacement decisions may be less than optimal. This problem is compounded by the fact that much industrial capital stock is long lived.

In other cases, informational constraints may be related to an excess of information, especially where there are insufficient staff resources to devote to sorting through a mass of technical assessments to identify which technologies offer the best opportunities for a given manufacturing operation. At least one sector (aluminum) indicated that while there is an enormous amount of technical information available regarding R&D for energy-efficient technologies, it does not seem that this information is optimally coordinated and disseminated across government, the private sector, and academia. Such lack of coordination may limit implementation of newly developed technologies and processes.

4.3 Regulatory Barriers

It is clear that for manufacturing industries, nonregulatory barriers are often the dominant factor inhibiting investment in energy efficiency and clean energy opportunities. Though it is critical to acknowledge the importance of such barriers, the purpose of this analysis is to facilitate the development of policy approaches that EPA can employ to address regulatory barriers and promote energy efficiency and clean energy improvement in select manufacturing industries. This emphasis is appropriate given the role of EPA's Office of Policy, Economics, and Innovation in developing and coordinating cross-agency policy approaches to improving the environmental performance of entire sectors. The focus on regulatory barriers is also appropriate given the purview of other federal agencies working to promote energy efficiency and clean energy opportunities—for instance, DOE's Industrial Technologies Program, which establishes collaborative public-private partnerships to facilitate new technology R&D.

Our assessment of sector energy consumption and National Emissions Inventory data in Chapter 3 indicated that across multiple sectors, major areas of opportunity for improved environmental performance with respect to energy use lie with increased efficiency in electric and thermal energy generating systems, particularly through increased CHP and increased boiler efficiency. Alternatives to fossil fuels also represent key opportunities for some sectors, such as biomass fuels in the forest products industry and waste fuels in cement manufacturing. Thus, our discussion of regulatory barriers focuses on key ways in which regulations may contribute to less environmentally preferable energy outcomes in these areas:

- Regulations may fail to fully reward the environmental benefits associated with an energy efficiency opportunity, allowing energy efficiency to be evaluated on an equivalent basis with other pollution control strategies such as add-on controls.
- Regulations may lack procedural flexibility that facilitates pursuit of energy efficiency or cleaner fuel opportunities, particularly in areas where permitting changes are required to implement an opportunity.
- Notwithstanding their environmental, health, and safety benefits, regulations affecting industrial manufacturing sectors frequently have implications in terms of energy consumption. The rulemaking process may not consider and address such implications in a consistent way.
- Regulations or policies may contribute to unfavorable market conditions for energy efficiency or cleaner fuels opportunities.

As discussed in Chapter 1, this analysis relies primarily on readily available public information, limited interviews with representatives from the regulated community, and inputs from various stakeholders, including industry and regulators. The examples of regulatory barriers discussed in the following sections are not intended to be a comprehensive list of all of the regulatory barriers potentially affecting the sectors included in this analysis, but rather are intended to illustrate key regulatory barriers that affect the most promising energy-related environmental improvement opportunities discussed in this report. Also, it is important to note that these barriers are not new, and many entities at the federal, state, and local level currently have initiatives underway to address them. Our discussion of Policy Options in Chapter 5 will provide some examples of regulatory initiatives at the federal level aimed at addressing these issues.

Regulations May Not Account for Environmental Benefits of Energy Efficiency

Energy efficiency is a form of pollution prevention that leads to decreases in energy-related criteria air pollutant and greenhouse gas emissions through reduced fuel usage. However, some environmental regulations do not fully account for the environmental benefits of energy efficiency and do not provide adequate mechanisms for recognizing or rewarding the emissions reductions that accrue from more efficient fuel use. In particular, input-based standards that establish emissions limits based on heat input (e.g., pounds of pollutant emitted per Btu of delivered fuel) or pollutant concentrations at the outflow (parts per million (ppm)) do not differentiate between more and less efficient fuel usage.[310] Input-based standards—which may be used in permitting regimes as well as in establishing emissions allowances under cap-and-trade systems—do not provide a true indication of environmental performance, as there is no accounting for the amount of energy produced from fuel inputs. By failing to account for the environmental benefits associated with increased energy efficiency, such standards fail to create appropriate incentives for investment in energy-efficient technologies.

Most equipment used to generate thermal or electric energy (boilers, turbines, many industrial process, and CHP applications) have historically been governed by input-based emissions standards.[311] An input-based standard does not differentiate between a more efficient boiler that produces more thermal energy from the same amount of fuel as a less efficient boiler. Though the more efficient boiler generates less pollution on an annual basis due to its lower fuel usage, input-based emissions limits have no mechanism for accounting for the difference in fuel usage between these two boilers, or rewarding more efficient fuel use.

In addition to contributing to general disincentives for energy efficiency investment, input-based standards are particularly problematic for CHP applications because they provide no mechanism for accounting for the two forms of energy output—electric and thermal—that are produced from a single fuel source, and thus offer little incentive for investment in CHP as a pollution control strategy.

As noted in the opportunity assessments in Chapter 3, industry representatives frequently cite the costs imposed by environmental regulations and associated permitting requirements as barriers to investment in energy-efficient equipment, such as the increased capital and operational costs associated with add-on pollution controls that do not increase productive output, or the administrative costs associated with permitting processes. To a large degree, input-based regulations penalize energy efficiency investments by failing to recognize and offer credit for their environmental benefits and requiring additional investments (i.e., through installation of pollution control technology) to create emissions reductions. Input-based regulations reduce compliance flexibility by not providing adequate mechanisms for sources to include energy efficiency as part of their pollution control strategy.

Regulations May Lack Procedural Flexibility

Many of the industry representatives consulted in connection with this analysis cited permitting barriers as inhibiting investments in energy efficiency or cleaner fuels opportunities. A facility may be reluctant to make a change that would require modification or review of an existing operational permit (for instance, under Title V of the Clean Air Act) or trigger a preconstruction permitting requirement under New Source Review (NSR). When energy efficiency or clean energy investments trigger the need for new permits or changes to existing permits, the result may be increased time required to implement a project, increased administrative burdens, or other adverse impacts on the project schedule. Particularly for facilities with limited staff resources, the potential for encountering permitting requirements may discourage pursuit of the opportunity.

Potential permit-related barriers include the following examples:

- Installation of new melting furnace technologies that entail new or expanded exhaust systems typically triggers state and local permitting requirements. Many smaller metal casting facilities would prefer to retrofit existing equipment than to install new technologies due to constraints on capital and personnel resources to address permitting requirements.[312]

- Due to concerns about the time and expense associated with an NSR permitting process, a motor vehicle assembly plant was dissuaded from undertaking a project that would have reduced energy use by eliminating a shift, as this change would have required the installation of additional permitted equipment to increase production during the remaining shift.[313]
- Increased use of alternate or waste fuels (e.g., process byproducts or waste oils, paints, or tires) may represent opportunities for sectors to reduce purchased fuel requirements. In addition, waste fuel use can potentially also represent opportunities for environmental improvement in cases where using waste fuels for energy content reduces total energy consumption by combining energy generation and waste disposal processes, or through more complete combustion than would be offered under alternate disposal mechanisms (for example, the higher combustion efficiency that is achieved in cement kilns as compared with most commercial incinerators[314]).

Permitting requirements are in place to ensure an appropriate level of environmental protection, and an environmentally preferable energy scenario would certainly not dispense with these protections. In the case of increased use of waste fuels, for example, such activity would have to represent a net environmental improvement over alternate mechanisms of disposal. However, there are opportunities for increased flexibility under existing regulations that could be enacted to promote the implementation of energy-related opportunities with demonstrable environmental benefits. In addition, the NSR process could be revised to better recognize energy efficiency and pollution both in the permitting process and structure and in the expression of the results through output-based permit limits.

Regulatory Process May Not Consider Energy Implications

Regulations frequently have implications in terms of energy consumption and associated emissions, notwithstanding their environmental, health, and safety benefits. Examples follow:

- Hydrotreatment used to desulfurize diesel to meet EPA mandates for lower sulfur limits for on-road and off-road diesel is an energy-intensive process that will increase energy consumption at petroleum refineries. Further regulations to lower sulfur limits on home heating oil and residual marine fuel oil may also have similar impacts.
- Regulations requiring the installation of regenerative thermal oxidizers (RTOs) in the wood products industry have increased non-process-related consumption of natural gas. The new Plywood Maximum Achievable Control Technology will require additional RTO installations by October 2008.[315]
- The Occupational Safety and Health Administration's hexavalent chromium permissible exposure limit may increase energy use in the metal finishing industry due to increased use of protective equipment, including greater air monitoring equipment and special sanitizing showers for workers.
- Under the National Pollutant Discharge Elimination System, increased regulation of stormwater discharges could increase energy requirements for water treatment at shipbuilding and ship repair facilities, potentially increasing air emissions.
- Increased volatile organic compound regulations under the National Ambient Air Quality Standards have the potential to increase energy requirements for pollution control systems in multiple sectors.

In some cases, EPA has conducted an effective assessment of the energy-related impacts of proposed regulations as part of the rulemaking process. For example, EPA is undertaking an "energy impact" analysis of the Spill Prevention Countermeasures and Control regulations to determine their effect on energy use in various industries. This analysis is being done in coordination with DOE, the Small Business Administration, the Department of Transportation, and the Department of Commerce. This model might be used to inform other regulatory and nonregulatory efforts. Overall, there may be opportunities for closer consideration of energy-related impacts and a more systematic approach for evaluating such impacts during the rulemaking process.

Regulations May Contribute to Unfavorable Market Conditions

Regulations may also create disincentives for investment in energy-efficient technologies by failing to establish appropriate policy frameworks for promoting broader application of these technologies—either through policy actions that create disincentives for such investments or by failure to enact regulations that establish supportive conditions for investment. Examples of such barriers include the following:

- Recent changes made by the Federal Energy Regulatory Commission regarding implementation of Section 210(m) of the Public Utility Regulatory Policies Act eliminate the requirement that utilities purchase power from qualifying facilities in certain markets, potentially creating less favorable market conditions for onsite power generation.[316]
- New Internal Revenue Service guidance on the biomass tax credit (Section 45) decreased the value of the credit, potentially affecting the financial viability of increased biomass fuel usage.[317]
- Representatives from the iron and steel industry cited the need for greater mitigation of the economic, technical, and environmental risks associated with the use of new technologies. Specifically pertaining to regulatory liability, use of unproven technologies may entail risks associated with long-term liability under the Comprehensive Environmental Response, Compensation, and Liability Act.[318]

Other frequently cited barriers that fall into this category pertain specifically to the adoption of CHP and other distributed generation (DG) technologies. Many utilities create impediments to CHP through their rate structures and through time-consuming interconnection requirements. Such barriers are among the top concerns of organizations working to promote broader adoption of CHP technology like the United States Combined Heat and Power Association.[319]

Common utility rate practices that reduce the financial viability of grid-connected CHP opportunities include excessive rates for backup power, high standby connection charges, and exit fees. In deregulated markets, sources must still pay demand charges to access competitively supplied backup power, and transmission and distribution tariffs governing such charges may also set unfavorable rates.[320] Inequitable rate structures also affect adoption of other DG technologies such as fuel cells and renewable energy generation with biomass fuels or other renewable energy sources. The fact that regulatory agencies have in many cases not prohibited such practices represents an opportunity for policy change.

Interconnection requirements—the technical and procedural requirements associated with connecting a distributed generation technology to the grid—may also inhibit investment in CHP and other DG opportunities. Interconnection requirements vary locally as determined by the utility or entity governing the regional transmission infrastructure, and they are often time and labor intensive, particularly for smaller applications that may be required to meet the same standards as large generating units. To inhibit installation of CHP applications, some utilities have established extensive interconnection requirements such as pre-certification, high safety standards, and costly testing, making the interconnection process time intensive and costly for grid-connected CHP applications.[321] As interconnection requirements vary between jurisdictions, the lack of standardization also serves as a barrier to broader technology adoption (particularly for small units), as it inhibits mass production of DG technologies.[322] The lack of standardized and streamlined interconnection requirements that establish appropriate protocols for smaller versus larger DG applications also represents a regulatory barrier.

4.4 Conclusion

While barriers to broader investment in energy efficiency and clean energy opportunities often stem primarily from nonregulatory factors such as financial, technical, and institutional constraints, regulations can reinforce such barriers by not accounting for the environmental benefits of energy efficiency, by not offering appropriate incentives for investment, by making investment less feasible through a lack of procedural flexibility, and in general by contributing to unfavorable market conditions or failing to create more favorable market conditions for energy efficiency and clean energy technologies. Chapter 5 provides suggested policy options EPA could employ to remove or reduce the regulatory component of impediments to energy efficiency and clean energy investment.

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5. Policy Options

Insights

EPA program offices have already undertaken a number of steps to remove regulatory barriers at the federal level. The research conducted for this analysis—including the data sources we reviewed and the perspectives and insights provided to us during interviews with internal and external stakeholders—has indicated that environmentally preferable energy outcomes may also be promoted through the following policy options: (1) developing and promoting broader application of regulations that recognize the emissions reductions resulting from increased energy efficiency; (2) increasing procedural flexibility to promote environmentally preferable energy use; (3) promoting broader consideration of the energy implications of rulemakings; (4) promoting the development of more favorable market conditions for energy efficiency and clean energy technologies; and (5) providing additional incentives and assistance through a sector-based approach.

The analysis of key opportunities for promoting environmentally preferable energy outcomes in each of the 12 sectors discussed in Chapter 3, and the potential regulatory barriers to implementing those opportunities discussed in Chapter 4, indicate that changes in policy may help to promote the use of cleaner fuels as well as energy efficiency improvement through combined heat and power (CHP), equipment retrofit or replacement, process improvement, and research and development (R&D). EPA could remove potential regulatory barriers through changes in policy or reduce potential regulatory barriers through incentives that make the barriers surmountable from an investment standpoint. Certain activities are within EPA's internal jurisdiction and are discussed in Section 5.1; others extend into broader coordination with external agencies and entities and are discussed in Section 5.2.

As with the discussion of regulatory barriers in Chapter 4, the following policy options are not intended to be comprehensive or definitive in terms of actions to be undertaken by EPA. They are simply intended to illustrate possible approaches for removing and/or reducing potential regulatory barriers identified through our research, which consisted of a review of relevant data sources and interviews with internal and external stakeholders.

5.1 Internal Actions and Coordination

It is important to note that several EPA program offices are in the process of making significant adjustments to existing regulations that would have a direct impact on promoting environmentally preferable energy use:

- EPA continues to reform the New Source Review program. For example, based on final recommendations from EPA's 2002 *New Source Review: Report to the President*, in September 2006 EPA's Office of Air and Radiation proposed making three improvements to specific areas of the NSR program: (1) "debottlenecking," allowing exemptions for projects that increase the overall efficiency of an operation by modifications to one part of a facility that increase throughput in unmodified parts of the facility; (2) clarifying NSR requirements regarding aggregation, treating multiple related projects as a single project for NSR purposes; and (3) "project netting," eliminating the need for complex source-wide emissions analysis if the net effect of a project does not result in a significant emissions increase.[323]

- The Office of Solid Waste (OSW) has proposed a revised definition of solid waste to promote greater recycling primarily through the reuse of hazardous secondary materials.
- The Office of Air Quality Planning and Standards (OAQPS) has a number of initiatives underway to promote energy efficiency, including recently released output-based New Source Performance Standards (NSPS) governing several sizes of boilers and combustion turbines that promote more efficient fuel use and recognize the environmental benefits of CHP. OAQPS also has initiatives underway to assess the climate impacts of proposed rulemakings, as well as a rule that offers increased permitting flexibility for modified wood-fired boilers to encourage the use of non-fossil fuels.

The following policy options suggest additional actions EPA could take to remove the regulatory barriers discussed in Chapter 4 through changes in regulatory policy.

Develop Regulations That Account for Environmental Benefits of Energy Efficiency

EPA could continue to develop and promote broader application of regulations that recognize the emission reductions that result from increased energy efficiency. Output-based regulations provide a mechanism for incorporating the benefits of increased energy efficiency and produce emissions reductions across multiple pollutants through reduced fuel use—achieving emissions targets for regulated pollutants as well as producing incidental reductions in unregulated emissions such as greenhouse gases (GHGs). Output-based regulations promote energy efficiency as a pollution control strategy by allowing equitable comparison between energy-efficient generating equipment and other emissions reduction technologies such as add-on controls. Such regulations are also applicable to market-based approaches to environmental protection by providing sources with greater compliance flexibility and promoting technology innovation.

> **Policy Option:**
>
> Develop and promote broader application of regulations that recognize the emissions reductions resulting from increased energy efficiency, particularly through:
>
> - Output-based emissions standards that account for the thermal and electric energy output of CHP.
> - Output-based emissions standards governing other combustion processes such as energy-generating and manufacturing process equipment.

Suggested areas where the use of input-based standards may indicate opportunities for regulatory improvement include the following:

- Clean Air Act permitting of new CHP applications under NSR typically employs an input-based approach that establishes emissions limits based on fuel inputs. By failing to account for the technology's dual outputs of thermal and electric energy, the input-based approach does not recognize and reward the increased fuel use efficiency of CHP.
- Recent combustion-related rulemakings that also employed input-based standards (lb/MBtu) include the National Emission Standards for Hazardous Air Pollutants (NESHAP) for some sizes of industrial boilers and process heaters. NESHAPs for stationary combustion turbines employed a concentration-based (ppm) standard.

In other recent rulemakings, such as the stationary combustion turbine NSPS, EPA has used output-based standards to promote greater fuel use efficiency. EPA could continue to pursue additional opportunities for the use of output-based standards, particularly with respect to NSR permitting processes and new rulemakings governing combustion equipment (e.g., CHP, boilers, and process heaters).

Increase Procedural Flexibility to Promote Environmentally Preferable Energy Use

To address permit-related barriers to investment in energy efficiency or cleaner fuels opportunities, EPA could increase procedural flexibility in the areas of flexible permitting and increased recycling for energy recovery. In some cases, these strategies will require examining emissions tradeoffs at a broader level than the facility level and quantifying energy consumption and emissions tradeoffs. Options for providing technical assistance to industry and permitting authorities to quantify and evaluate such tradeoffs are also discussed below.

Flexible Permitting

Flexible permitting aims to promote certain environmentally preferable activities by providing exceptions to permitting requirements for certain types of changes (for example, modifications to methods of operation or equipment), provided that plant-wide emissions remain below enforceable caps. Flexible permitting may also entail an advance approval process for specific changes. Like output-based emissions standards, flexible permitting can also be used to support market-based approaches to environmental protection to provide sources with greater compliance flexibility and promote technology innovation.

> Policy Option:
>
> Increase procedural flexibility surrounding opportunities to reduce energy-related emissions on a system-wide level through:
>
> - Expanding flexible permitting opportunities that promote reductions in energy-related emissions as part of a pollution prevention strategy, including developing a flexible permitting rule.
> - Promoting broader recycling of wastes and process byproducts for energy recovery.
> - Providing assistance to the regulated community as well as state and local permitting authorities in support of efforts to increase procedural flexibility in environmental regulations, including technical guidance on evaluating energy-related environmental tradeoffs at a system-wide level.

This policy option might include adding flexibility to the permitting process whereby specific changes to fuel inputs, processes, or equipment that are directly tied to improving environmental performance through energy-related modifications would not automatically trigger the full blown permit review. For example, many industry comments encountered in our research remark that a more flexible definition of “routine maintenance” would help diminish NSR barriers to energy efficiency improvement projects. EPA’s September 2006 proposal is a major step in this direction.

EPA has historically offered flexible permitting on a pilot basis for pollution prevention and is considering developing a formal flexible permitting rule. In connection with its existing efforts, EPA could evaluate additional energy efficiency and clean energy opportunities that are good candidates for flexible permitting incentives, either through existing pilot programs such as those offered by Performance Track or ideally through development of a flexible permitting rule.

Suggested areas where flexible permitting may offer opportunities for regulatory improvement include the following examples:

- Replacement of inefficient boilers with high-efficiency boilers or CHP.
- Other changes to fuel inputs, processes, or equipment that are directly tied to improving environmental performance through energy-related modifications.

- Streamlined permitting processes or permitting exemptions to promote adoption of new energy-efficient technologies, such as those developed through DOE's Industrial Technologies Program (e.g., advanced furnace and process heating technologies).
- Expansion of flexible permitting beyond major sources.

RECYCLING FOR ENERGY RECOVERY

EPA's focus on recycling has traditionally been on promoting recycling for materials recovery with relatively less emphasis on promoting recycling for energy recovery. As such, opportunities to encourage increased energy efficiency or alternatives to fossil fuel consumption through recycling for energy recovery may be overlooked. Beyond efforts currently underway at OSW, EPA could work to (1) find additional areas to promote greater emphasis on recycling for energy recovery under existing regulations and (2) ensure that the development of new regulations does not exclude environmentally beneficial uses of waste or byproduct-derived fuels.

Suggested areas where increased recycling for energy recovery may offer opportunities for regulatory improvement include the following examples:

- Employing a sector-based approach to identify areas where increased use of waste fuels (i.e., solvents, waste oil, or paint) could produce environmentally preferable outcomes over alternate methods of disposal (i.e., through avoided landfilling or through recovery of useful energy from waste that would otherwise be incinerated).
- Evaluating environmental tradeoffs to facilitate the development of regulatory mechanisms that promote greater recycling for energy recovery by recognizing the environmental benefits of energy-related reuse and recycling in the permitting process.
- Assessing energy implications and possible environmental benefits of increased energy-related recycling in the development of new regulations, and developing appropriate mechanisms to incent such activities, provided they ensure an appropriate level of environmental protection.

ASSISTANCE TO INDUSTRY AND PERMITTING AUTHORITIES

In cases were EPA has revised or is in the process of revising regulatory requirements, perception barriers may persist that inhibit investment in energy efficiency or clean energy opportunities. For example, despite recent NSR reforms, industry may still be reluctant to undertake energy-related projects that might potentially trigger NSR due to lingering concerns that NSR requirements will be burdensome. Regulations are technically complex, and while they are established at the federal level by EPA, they are implemented at the state level, which may lead to variability and uncertainty on the part of industry regarding regulatory requirements. A sector-based communications and outreach strategy could be designed to identify key areas where NSR reforms have made energy-related improvement opportunities less burdensome than they would have been previously.

Technical assistance may also be needed to support flexible permitting and increased recycling for energy recovery, particularly where there are environmental tradeoffs between facility-level and system-wide emissions. Implementing such policy options would require EPA to recognize, understand, and articulate energy and environmental tradeoffs—for example, an energy savings of "x" Btus would be "worth" an increase in "y" air pollutant. Moving beyond the facility level to a system-wide perspective will likely require complex analysis. For example, the assessment might involve weighing energy savings and increased pollution at a fuel-using facility versus decreased energy use for waste treatment and handling at a different facility where the waste originated. However, a better understanding of these implications and tradeoffs is critical, because without this information permit writers at the state and local level may not welcome (or implement) any increase in regulatory flexibility. Traditional approaches to environmental protection have been based on pollution control technology rather than efficiency or pollution prevention. Without clear guidelines and a consistent regulatory approach, industry may remain uncertain about varying approaches and requirements across multiple facilities and states, which could create further disincentives for energy-related improvements.

The following examples are suggested areas where increased assistance may offer opportunities for regulatory improvement:

- Developing an information clearinghouse for the regulated community that provides a single point of contact and up-to-date information on regulatory requirements that have been revised to promote greater investment in energy efficiency and clean energy improvement projects.
- Developing guidance for state and local regulators on the environmental benefits of energy efficiency and clean energy technology, and their appropriate treatment in the permitting and regulatory process.

Promote Broader Consideration of Energy Implications of Rulemakings

Environmental regulations can have significant energy impacts. To date, consideration of these impacts has been unevenly incorporated in the regulatory process. Moving forward, EPA could develop a systematic approach for incorporating an assessment of energy impacts in all regulatory venues.

The rulemaking process provides at least three opportunities to consider energy impacts:

- Through Executive Order (EO) 13211, which requires agencies to prepare a Statement of Energy Effects on “significant” energy actions.
- Through EO 12866, which requires agencies to prepare economic impact analyses on rulemakings that have $100 million annual impact, raise novel issues, and/or have “significant” impacts.
- Through the Regulatory Flexibility Act, which requires a regulatory flexibility analysis if a proposed rule would have a “significant” economic impact on a “substantial” number of small entities.

> **Policy Option:**
>
> Review methodologies currently used to assess energy impacts during the rulemaking process, assess how program offices are interpreting/implementing these provisions, and work across the Agency to develop a cohesive EPA position on how such impacts should be assessed and weighed against other Agency priorities.

EPA could explore opportunities under its own authority to require that energy impacts are considered across all rulemaking and regulatory processes. EPA could review methodologies currently used to assess energy impacts during the rulemaking process, assess how program offices are interpreting/implementing these provisions, and work across the Agency to develop a cohesive EPA position on how such impacts should be assessed and weighed against other Agency priorities. Having a standardized policy would allow EPA to make more informed decisions about energy resources and environmental benefits, including potential variations for large versus small entities.

5.2 External Actions and Coordination

The following policy options suggest actions EPA could take to reduce regulatory barriers (as well as certain nonregulatory barriers discussed in Chapter 4) through direct incentives or policy support that make such barriers surmountable from an investment standpoint. Such policy support would extend into broader jurisdictions beyond those that are in EPA's direct purview.

Promote Favorable Market Conditions

To promote the development of more favorable market conditions for energy efficiency or clean energy opportunities, EPA could pursue additional avenues of cross-agency coordination, grantmaking, and analysis.

Cross-Agency Coordination

Across other federal agencies, EPA could implement a consistent approach to promoting policies that increase the market viability of energy efficiency and clean energy opportunities. As noted in Chapter 4, research to date has identified a number of existing or potential environmental regulations and policies that might impact one or more sectors, including the following:

- Changes to the Public Utility Regulatory Policies Act that potentially affect the viability of onsite power generation.
- Changes to the Internal Revenue Service code that reduce incentives for biomass fuel use.

> Policy Option:
>
> Promote more favorable market conditions for energy efficiency and clean energy technologies through:
>
> - Coordinating across federal agencies to support policies that promote the market viability of energy efficiency and clean energy technologies.
> - Offering additional grants to support clean energy applications in manufacturing industries.
> - Analyzing the environmental impacts of utility demand response programs and working to promote clean energy technologies as an electricity demand reduction strategy.

EPA could monitor proposed regulations and perform a cross-agency coordination function to assess energy implications of proposed regulations or policy changes. A successful model EPA already employs in this area is the Combined Heat and Power Partnership, which works to promote more favorable market conditions for CHP and other distributed generation technologies. EPA could explore additional opportunities for similar efforts, including coordination with state regulators as well as with other federal agencies such as DOE and FERC. Cross-agency coordination of these efforts could be designed to assure appropriate coverage of relevant issues, facilitate communication, and avoid duplication of efforts.

Grantmaking

EPA could consider additional opportunities for offering direct grants to support clean energy applications in industrial manufacturing sectors. Utilities and Clean Energy Program Administrators, such as The Renewable Trust Fund-Massachusetts Technology Collaborative, have set up distributed energy resources in areas where the energy load is overwhelming. EPA could identify and work with such entities in grantmaking to sectors. Such grants would allow facilities to install solar or photovoltaic panels on their roofs—thereby integrating renewables into how industrial load is met as a way to offset purchased energy requirements.

Demand Response Analysis

Energy supply disruption and market volatility are concerns to all energy users but are of particular concern to industrial customers for whom such disruption would negatively impact the process line. In areas of the country such as the Northeast, there is strong interest in the ability of demand response (DR) mechanisms to address system infrastructure constraints. For example, some utilities and transmission system operators offer incentives for customers to curtail their electricity usage at certain times to reduce peak demand. However, environmental regulators are concerned with the potential environmental impacts of some DR technologies, such as generators that produce an emissions-intensive form of backup power. EPA is currently helping the Northeast states assess the environmental impacts of different DR technologies. This effort provides an example of another area where EPA could seek to promote better convergence between energy and environmental goals. Expanding on its existing efforts, EPA could analyze DR programs and work with utilities in particularly volatile or transmission-constrained electricity markets to promote clean DR technologies across one or more sectors.

Provide Incentives and Assistance Through a Sector-Based Approach

EPA could explore additional sector-based approaches to promoting environmentally preferable energy outcomes in manufacturing industries, including the following:

- Support and promote energy efficiency and clean energy R&D activities that are underway across a variety of other voluntary programs. Possible activities include the following:
  - Providing sector-based information on R&D opportunities on an EPA Web page.
  - Vetting and/or promoting various online emissions reduction/benefits calculators.
  - Promoting energy-saving assessments and other initiatives launched by DOE under its Industrial Technologies Program.
  - Showcasing sector-specific awardees under other programs (e.g., ENERGY STAR).
- Similar to its work on diesel retrofits for the construction and ports sectors, EPA could assess whether any federal, state, or local grant funding could be made available (or whether tax incentives exist) for plant upgrades—particularly for small businesses in high energy intensity markets. EPA could serve as an information clearinghouse regarding such opportunities that may be available to manufacturing sectors.

> Policy Option:
>
> Employ a sector-based approach to promoting environmentally referable energy outcomes through the following mechanisms:
>
> - Supporting energy efficiency and clean energy R&D opportunities.
> - Providing information regarding financial incentives that are available to support energy efficiency and clean energy opportunities, particularly for small businesses.

5.3 Conclusion

This analysis has suggested a number of potential strategies EPA could employ to remove or reduce regulatory barriers to improved environmental performance with respect to energy use in the 12 industrial manufacturing sectors. These policy options include actions the Agency could take internally—such as developing regulations that account for the environmental benefits of energy efficiency, increasing procedural flexibility to promote environmentally preferable energy use, and generally increasing consideration of energy impacts in rulemakings—as well as actions involving increased coordination with other agencies and entities to promote favorable policy and market conditions for energy efficiency and clean energy technologies.

Appendix A: Energy Projections

To develop the "base case" and "best case" future energy consumption scenarios for each sector as described in Chapter 3, we relied primarily upon projections produced by three analyses:

- ***Scenarios for a Clean Energy Future* (CEF).** Commissioned by the U.S. Department of Energy (DOE) in 2000, this report was produced by the Interlaboratory Working Group for Energy-Efficient and Clean Energy Technologies. For 8 of the 12 industrial manufacturing sectors considered in this analysis, the CEF report projects future industrial energy consumption trends based on three alternative technology and policy-based scenarios.[324] In Chapter 3, the CEF analysis forms the basis for our "base case" and "best case" future energy scenarios for many of the sectors addressed in this report.[325]
- ***Annual Energy Outlook 2006* (AEO 2006).** AEO 2006 is the most recent annual forecast of energy demand, supply, and prices for the United States produced by DOE's Energy Information Administration (EIA). AEO 2006 includes energy consumption and carbon emissions projections for U.S. industrial manufacturing as well as for eight of the twelve sectors considered in this analysis.[326] As the CEF report was produced in 2000, we used AEO 2006 to assess the impact of recent energy trends, and how those trends might be expected to produce different outcomes than projected by CEF in 2000. AEO 2006 also provided estimated annual carbon dioxide emissions for many of the sectors addressed in this analysis.
- ***Natural Gas Outlook to 2020.*** This analysis was produced by the American Gas Foundation (AGF) and develops natural gas consumption projections under three alternative public policy scenarios regarding natural gas exploration and production. Projections include consumption trends for certain industrial sectors that are heavily dependent on natural gas.[327]

In the following sections we provide a brief overview of the approaches taken by these studies, and discuss how they were used in our analysis. For CEF and AEO 2006, we highlight key similarities and differences between the projections and discuss general implications for future industrial energy consumption trends.

A.1. Clean Energy Future Scenarios

Overview

To develop CEF projections, the Interlaboratory Working Group used a modified version of the National Energy Modeling System (NEMS) developed and maintained by EIA to produce its *Annual Energy Outlook* projections. (The NEMS version used in connection with the CEF analysis was the version used to produce the 1999 *Annual Energy Outlook* (AEO 1999)).

For the reference case scenario, modifications to the NEMS industrial demand module were made in the following areas: (1) for all industrial sectors, equipment retirement rates were changed to reflect actual lifetimes of installed equipment and (2) for the paper, cement, steel, and aluminum industries, more detailed modifications were made to baseline energy intensities and rates of energy intensity improvement to reflect best available research from those sectors. As a result, the CEF reference scenario projects industrial energy consumption to be 3 percent lower by 2020 than the projection made by AEO 1999.

CEF developed moderate and advanced energy scenarios that are primarily based on voluntary commitments by industry to energy efficiency improvement. Our analysis focused on the advanced scenario, which promotes more aggressive energy efficiency improvement through a combination of (1) expanded voluntary federal programs such as the Combined Heat and Power (CHP) Challenge and ENERGY STAR; (2) expanded federal informational programs such as energy assessments and equipment labeling; (3) expanded investment enabling programs such as state grant programs, utility incentive programs, and tax rebates and credits; (4) mandatory efficiency standards for motors; (5) expanded federal demonstration and research and development (R&D) programs; and (6) a domestic carbon emissions trading program.

Table 58 compares the CEF reference case and advanced case projections for industrial energy consumption.

Table 58: Comparison of CEF industrial energy consumption projections through 2020: reference case and advanced case[328]

	Reference Case	Advanced Case
Base year energy consumption[qqqq] (1997)	27.0 quadrillion Btu	27.0 quadrillion Btu
Energy consumption in 2020[rrrr]	32.7 quadrillion Btu	27.8 quadrillion Btu
Annual energy consumption growth[ssss]	0.8% per year	0.1% per year
Annual energy intensity growth	-1.1% per year	-1.9% per year
Annual CHP capacity growth	No data available	No data available

qqqq Given the age of the CEF study and that current industrial energy consumption as reported in AEO 2006 is lower than the CEF base year, we put relatively little emphasis on CEF consumption data and greater emphasis on projected rates of consumption growth/decline, as well as relative changes in the fraction of various fuel inputs.

rrrr Energy consumption projections are in terms of site or delivered energy, though CEF also provides primary energy projections.

ssss All rate calculations are the calculated average growth rate.

	Reference Case	Advanced Case
Annual fuel consumption growth		
Petroleum	0.9%	0.0%
Natural gas	0.8%	0.3%
Coal	0.0%	-1.5%
Purchased electricity	1.1%	0.0%
Renewable	1.4%	1.7%
Total value of shipments in 2020 (billion 2000 dollars)	8,378	8,378

Advanced Energy Scenario

As discussed at the beginning of this section, the parameters that drive CEF's advanced energy projections include a broad range of policy pathways for improving environmental outcomes with respect to energy use, including a cap-and-trade system for greenhouse gas (GHG) emissions. Table 59 presents an abbreviated version of a table that appears in the CEF study showing how various advanced energy policies affected different NEMS model parameters for the industrial manufacturing sectors included in the CEF analysis. The policies appear in the header rows, and the affected parameters are listed by number, with a key below.

Table 59: Qualitative representation of advanced energy policy impacts on CEF-NEMS model[329]

	Technology Demonstration Programs	Energy Assessment Programs	Challenge Programs - Motor and Air	Challenge Programs - Steam	Challenge Programs - CHP	ENERGY STAR Buildings and Green Lights	Product Labels	State Programs	Clean Air Act Incentive Programs
Alumina and Aluminum	1,2,8	1	1,2,8	3,6,9	6,9	5	n/a	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
Chemical Manufacturing	1,2,8	1	1,2,8	3,6,9	6,9	5	n/a	1,2,3,5	1,2,3,6,7,9
Food Manufacturing	1,2,8	1	1,2,8	3,6,9	6,9	5	n/a	1,2,3,5	1,2,3,6,9
Iron and Steel	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5	n/a	1,2,3,5	1,2,3,6,7,9
Metals-Based Durables[tttt]	1,2,8	1	1,2,8	3,6,9	6,9	5	n/a	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
Pulp and 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

tttt Section 3.8 includes a more detailed description of how CEF's definition of the "metals-based durables" sector matches with the metal finishing sector as defined in this analysis.

	R&D - Industries of the Future	Other R&D	ESCO / Utility Programs	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
Alumina and Aluminum	2	2,3,6	n/a	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	n/a	1,5,7	2	6,9	1-9
Chemical Manufacturing	2	2,3,6	1,5,6,9	1,2,8	n/a	1,5	2	6,9	1-6,8,9
Food Manufacturing	n/a	2,3,6	1,5,6,9	1,2,8	n/a	1,5	2	6,9	1-6,8,9
Iron and Steel	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1-9
Metals-Based Durables	2	2,3,6	1,5,6,9	1,2,8	n/a	1,5	2	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
Pulp and Paper	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1-9

Modeled within NEMS	Modeled outside NEMS, then used to adjust NEMS parameters
1: Increased annual rate of efficiency improvement in existing equipment	7: Increased annual rate of efficiency improvement in existing equipment (iron & steel, cement, and pulp & paper)
2: Increased annual rate of efficiency improvement in new equipment	8: Increased annual rate of efficiency improvement in existing equipment (motor electricity use)
3: Increased boiler efficiency	9: Increased use of cogeneration (DISPERSE modeling of CHP-policies)
4: Increased use of recycled materials (throughput changes)	
5: Improved building energy efficiency	
6: Increased use of cogeneration (within NEMS)	

Given that the CEF study (produced in 2000) predates recent price increases for natural gas, we vetted CEF base case projections against projections developed by AGF in its report, *Natural Gas Outlook to 2020*.[330] This study develops natural gas consumption projections under three alternative public policy scenarios regarding natural gas exploration and production, including consumption projections for certain industrial sectors that are heavily dependent on natural gas such as chemicals, petroleum refining, pulp and paper, and food manufacturing. These projections were developed by Energy & Environmental Analytics using a proprietary gas market data and forecasting model. We focused on the "expected" policy scenario for industrial demand as the closest approximation of a business-as-usual scenario (the "existing" and "expanded" scenarios, which respectively involve lesser and greater degrees of natural gas exploration and infrastructure development than is currently planned, were less useful for our analysis). Where appropriate, references to differences and similarities between the CEF and AGF projections for natural gas consumption are made in the sector summaries contained in Chapter 3.

A.2. Annual Energy Outlook Scenarios

Overview

Each year EIA uses NEMS to develop its long-term forecasts of energy supply, demand, and prices called the *Annual Energy Outlook*. Energy consumption projections for specific industrial manufacturing sectors are included as a supplement to the main report. The sector-specific projections that are applicable to this analysis include the following: aluminum, bulk chemicals (the commodity chemicals subset of chemical manufacturing), cement, fabricated metal products (which includes metal finishing), food manufacturing, iron and steel, petroleum refining, and pulp and paper (part of forest products). AEO 2006 also includes projected carbon dioxide (CO_2) emissions for these sectors, which EIA calculated based on fuel consumption projections using CO_2 coefficients from the EIA report, *Emissions of Greenhouse Gases in the United States 2004*.[331]

Our review of AEO 2006 began with comparing reference case projections for industrial manufacturing as a whole with projections under the high industrial technology case, which were examined as the EIA's closest approximation of a "best case" scenario for industrial energy consumption. Reference case projections are based on growth in gross domestic product (GDP) of 3 percent per year (based on 2000 chain-weighted dollars), population growth of about 0.8 percent per year, and oil prices of $55.93 in 2005 rising to $56.97/barrel by 2030 (all oil prices are in 2004 dollars). The industrial high technology case "assumes earlier introduction, lower costs, and higher efficiencies for energy technologies."[332]

Table 60 compares AEO 2006 reference case and high industrial technology case projections. Though AEO 2006 projections are made through 2030, we only include projection data through 2020 to facilitate comparison with the CEF analysis.

Table 60: Comparison of AEO 2006 industrial energy consumption projections through 2020: reference case and high technology case[333]

	Reference Case	High Technology Case
Base year energy consumption (2004)	25.68 quadrillion Btu	25.68 quadrillion Btu
Energy consumption in 2020[uuuu]	28.91 quadrillion Btu	27.48 quadrillion Btu
Annual energy consumption growth[vvvv]	0.7% per year	0.4%
Annual energy intensity growth[wwww]	-1.3%	-1.7%
Annual CHP capacity growth[xxxx]	2.6%	3.0%
Annual fuel consumption growth		
Petroleum	0.7%	0.2%
Natural gas	0.7%	0.4%
Coal	1.0%	0.6%
Purchased electricity	0.7%	0.2%
Renewable	1.1%	1.6%
Total value of shipments in 2020 (billion 2000 dollars)	7,778	7,778

uuuu Energy consumption projections are site or delivered energy, though AEO 2006 also provides primary energy projections.

vvvv All rate calculations are the calculated average growth rate.

wwww Energy intensity is measured as total energy consumption (TBtu) per dollar value of shipments (in 2000 dollars).

xxxx Industrial CHP capacity is measured in gigawatts.

Compared with the reference case, the AEO 2006 high technology case projects that faster adoption of new technologies will produce greater energy efficiency gains, particularly in manufacturing industries. To some degree, the high technology case envisions expanded energy production capacity through additional CHP and biomass recovery capacity, but overall efficiency improvements in energy production and process energy use means that the high technology case projects lower energy consumption by 2020 compared with the reference case.

Under the reference case, EIA predicts that energy intensity will decrease at a higher rate in the manufacturing sector (1.2 percent a year) than in the non-manufacturing sector (1.0 percent a year). EIA attributes this difference to a continuing shift within U.S. manufacturing where the value of shipments by non-energy-intensive sectors increases from 54 percent in 2004 to 61 percent in 2030, and the value of shipments by energy-intensive sectors declines from 21 percent in 2004 to 17 percent in 2030. The rate of energy intensity decrease is even greater under the high technology case due to efficiency gains, but the high technology case does not involve a faster macroeconomic shift from energy-intensive to non-energy-intensive manufacturing.

Under the reference case, industrial fuel consumption increases across all fuel types. The relatively higher rate of increase in coal consumption (compared with other fuels) is not strictly driven by energy-related end uses, as industrial coal consumption for traditional energy-related applications is fairly static. However, EIA assumes that expansion of coal-to-liquids (CTL) production in the petroleum refining industry will be associated with considerable cogeneration capacity additions through integrated gasification combined cycle (IGCC) technologies (see Section 3.11). IGCC technologies combust gasified coal in a modified gas turbine and recover exhaust heat to generate steam.

Aside from industrial energy consumption and intensity trends, another important factor affecting future environmental impacts of industrial energy use is the trend in fuel inputs for electric power generation. The AEO 2006 reference case projects that purchased electricity will meet 13.5 percent of industrial demand by 2020 (roughly the same fraction as in 2004). Through 2030, AEO 2006 projects that the majority of new electric generation capacity will be supplied by coal-fired plants, which are more expensive to build but much cheaper to operate than natural gas-fired plants that tend to be used primarily to meet peak demand. The Southeast and the West are expected to see the greatest additions of coal-fired electric generating capacity. The majority of power plants retired over the period are expected to be oil- and natural gas-fired steam capacity. By 2030, AEO 2006 projects that coal-fired plants will meet 57 percent of the nation's electricity demand, compared with 50 percent today. In part, increased coal consumption in the electric power sector is driven by increases in electricity generation from coal gasification in combination with IGCC technologies. Compared with traditional forms of coal-powered generation, IGCC technologies have lower CAP emissions but equivalent carbon dioxide emissions. Research is ongoing into carbon sequestration applications in combination with IGCC to improve environmental performance.

Comparison of CEF and AEO 2006 Projections

In comparing the CEF and AEO 2006 projections, it is important to note that the CEF base year (1997) value for industrial delivered energy consumption is higher than the AEO 2006 base year (2004) value. This difference is attributable to the roughly 5 percent decrease in industrial delivered energy consumption that occurred from 1997 to 2005.[334] Since base year industrial energy consumption in CEF is higher, it is misleading to compare 2020 consumption projections between the two studies. The calculated annual growth rates are therefore a more appropriate gauge for comparing the two analyses.

For the reference cases, CEF and AEO 2006 projections for annual increases in industrial energy consumption are fairly close—0.8 percent and 0.7 percent per year, respectively. The CEF reference case projects a slightly slower rate of energy intensity improvement than the AEO 2006 reference case projection of 1.3 percent per year. CEF projects that industrial energy intensity will decrease by 1.1 percent per year, with 75 percent of this improvement attributed to inter-sector structural change (i.e., shifts towards less energy-intensive manufacturing industries) and 25 percent to sector-specific efficiency improvement. Despite projections that aggregated industrial energy intensity will continue to decrease, in this analysis we are primarily interested in projected decreases or increases in energy intensity at the sector level, as discussed in Chapter 3.

In terms of projected annual changes in fuel consumption, the CEF reference case differs from the AEO 2006 reference case, projecting faster increases in consumption of all energy inputs (including renewables) except coal. It is unsurprising that CEF envisions no coal increase under the reference scenario, as the analysis was produced before recent price increases for natural gas that may create incentives for switching to coal, and as the analysis does not consider the energy-related impacts of CTL technology that are part of AEO 2006.

Where the CEF reference case projection is less optimistic than AEO 2006, the CEF advanced case projection is considerably more aggressive in terms of its energy consumption and intensity reduction outcomes. This too is unsurprising, given that AEO projections are policy neutral and limited to those policies that have already been enacted and funded, with implementation rules established.[335] Thus, the CEF reference case (which is based on AEO 1999) includes the effect of already adopted policies and regulations in place as of 1999.

Where appropriate, references to differences and similarities between the CEF and AEO 2006 projections for specific industrial manufacturing sectors are made in the sector summaries contained in Chapter 3.

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