Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes








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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

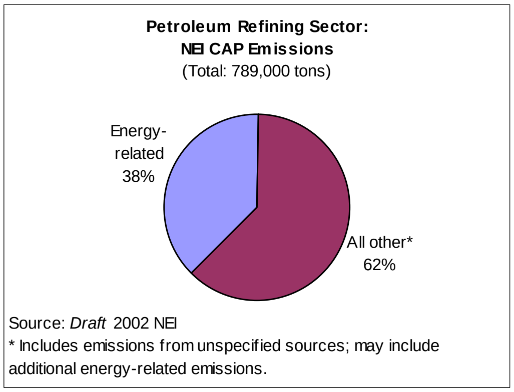
[oooo] According to 2002 MECS data, total energy consumption for the petroleum refining sector in 2002 was approximately twice the value CEF reports for 1997. We are unable to fully account for the magnitude of the difference between the two data sources.

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



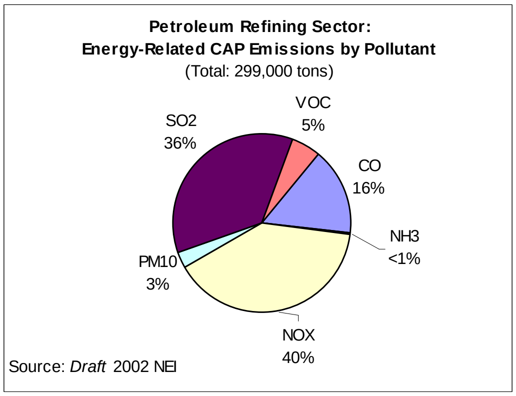
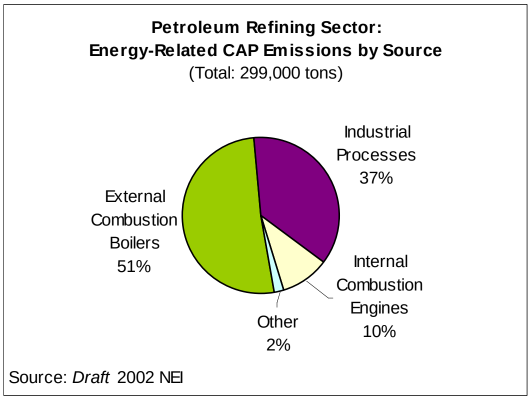


Figure 26 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the petroleum refining sector. According to the figure, energy-related CAP emissions are less than half of all CAP emissions and are dominated by nitrogen oxide and sulfur dioxide. (As noted in Section 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



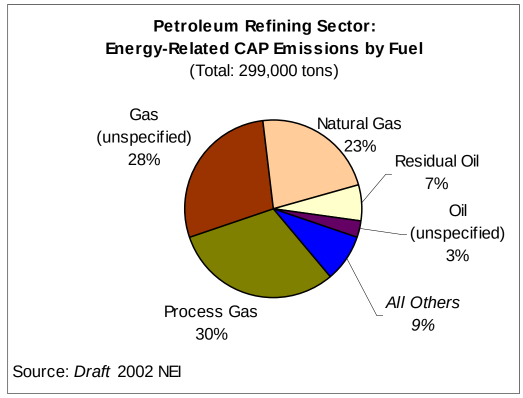


Figure 27 presents NEI data on the sources of energy-related CAP emissions shown in Figure 26. According to MECS data (see Table 52), "other" fuels (primarily refinery gas and still gas) met the majority of the sector's energy needs in 2002. In NEI, such fuels are likely classified either as "gas (unspecified)" 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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