Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes








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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.

[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).

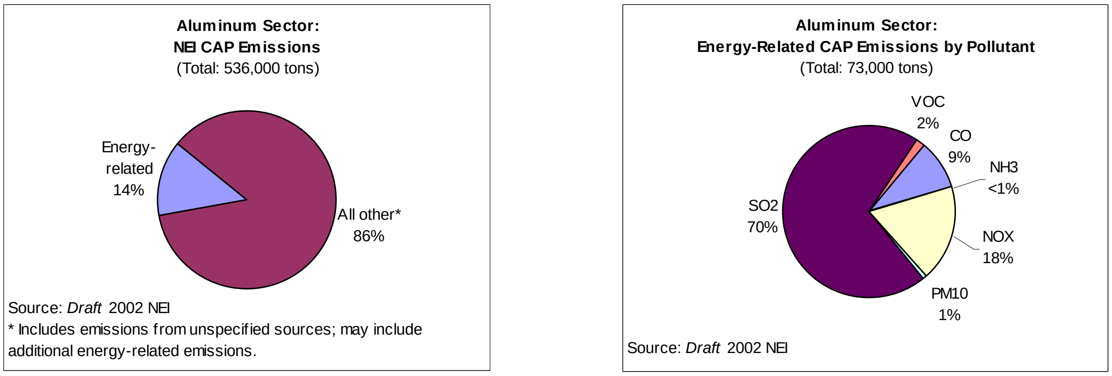
Table 19: CEF reference case projections for the aluminum industry

	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



Aluminum Sector:
NEI CAP Emissions
(Total: 536,000 tons)

Source: *Draft* 2002 NEI
* Includes emissions from unspecified sources; may include additional energy-related emissions.

Aluminum Sector:
Energy-Related CAP Emissions by Pollutant
(Total: 73,000 tons)

Source: *Draft* 2002 NEI

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

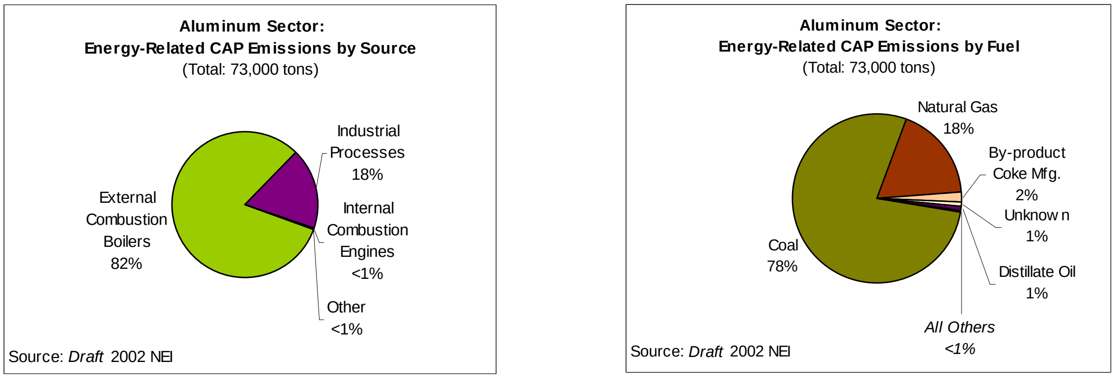


Figure 7 presents NEI data on the source categories for energy-related CAP emissions shown in Figure 6, as well as emissions by fuel usage. The data suggest that coal-fired external combustion boilers are the source of the majority of energy-related CAP emissions recorded in NEI. However, given the relatively 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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