**April 2010**

# Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters

## Draft Report

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# SECTION 1
# INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is proposing national emission standards for hazardous air pollutants (NESHAP) for new and existing industrial, commercial, and institutional boilers and process heaters.[1] The proposed rule would require all major sources to meet hazardous air pollutant (HAP) emissions standards reflecting the application of the maximum achievable control technology (MACT). Under a separate action, EPA is also proposing a NESHAP for two area source categories: industrial boilers and institutional and commercial boilers.[2] The proposed emission standards for controlling mercury and polycyclic organic matter (POM) emissions are based on the MACT. The proposed emission standards for controlling other HAPs are based on EPA's proposed determination as to what constitutes the generally available control technology (GACT) or management practices. As part of the regulatory process, EPA is required to develop a regulatory impact analysis (RIA). The RIA includes an economic impact analysis (EIA) and a small entity impacts analysis and documents the RIA methods and results.

## 1.1 Executive Summary

The key results of the RIA are as follows:

- **Engineering Cost Analysis:** EPA estimates the proposed major source NESHAP's total annualized costs will be $2.9 billion (2008$). For the area source NESHAP, EPA estimates the total annualized costs will be $0.5 billion.
- **Market Analysis:** Under the proposed major source NESHAP, the Agency's economic model suggests the average national prices for industrial sectors could be 0.01% higher with the NESHAP, while average annual domestic production may fall by about 0.01%. Because of higher domestic prices, imports rise by 0.01% per year. Market-level effects for the proposed area source NESHAP are smaller when compared to the proposed major source rule; average price, production, and import changes are less than 0.01%.
- **Social Cost Analysis:** The estimated social cost of the proposed major source rule is just under $2.9 billion (2008$). In the near term, the Agency's economic model suggests that industries are able to pass approximately $0.8 billion of the rule's costs to consumers (e.g., higher market prices). Domestic industries' surplus falls by $2.5 billion, while other countries on net benefit from higher prices (a net increase in rest-of-the world [ROW] surplus of $0.1 billion). Additional costs and fuel savings for

[1] On June 19, 2007, the U.S. Court of Appeals for the District of Columbia Circuit (DC Circuit) vacated the NESHAP for industrial/commercial/institutional boilers and process heaters. This action provides EPA's proposed rule in response to the court's vacatur.

[2] Gas-fired boilers are not part of the area source categories of industrial boilers and institutional/commercial boilers.

new and existing major sources that are not included in the economic model represent a net benefit of $0.4 billion. The estimated social cost of the proposed area source rule is approximately $0.5 billion (2008$). In the near term, the Agency's economic model suggests that industries are able to pass approximately $0.3 billion of the rule's costs to consumers. Domestic industries' surplus falls by $0.3 billion and the net increase in ROW surplus is less than $0.1 billion. Additional costs and fuel savings for unknown, existing, and new area sources not included in the economic model results represent a net benefit of $0.1 billion.

- **Employment Changes:** Near-term employment changes associated with the proposed major source rule are estimated to be less than 8,000 job losses; over a longer time period, net employment effects range between 6,000 job losses to 12,000 job gains. For the area source rule, near-term employment changes associated with the proposed major source rule are estimated to be less than 1,000 job losses; over a longer time period, net employment effects also range between 1,000 job losses to 3,000 job gains.
- **Small Entity Analyses:** EPA performed a screening analysis for impacts on small entities by comparing compliance costs to sales/revenues (e.g., sales and revenue tests). EPA's analysis found the tests were typically higher than 3% for small entities included in the screening analysis. EPA has prepared an Initial Regulatory Flexibility Analysis (IRFA) that discusses alternative regulatory or policy options that minimize the rule's small entity impacts. It includes key information about key results from the Small Business Advocacy Review (SBAR) panel.
- **Benefits Analysis:** In the year of full implementation (2013), EPA estimates the $PM_{2.5}$ co-benefits of the proposed major source rule are $17 billion to $41 billion and $15 billion to $37 billion, at 3% and 7% discount rates respectively. In the year of full implementation (2013), EPA estimates the $PM_{2.5}$ co-benefits of this proposed area source rule are $1.0 billion to $2.4 billion and $910 million to $2.2 billion, at 3% and 7% discount rates respectively. All estimates are in 2008 dollars. Using alternate relationships between $PM_{2.5}$ and premature mortality supplied by experts, higher and lower co-benefits estimates are plausible, but most of the expert-based estimates fall between these estimates. The benefits from reducing other air pollutants have not been monetized in this analysis, including reducing 370,000 tons of carbon monoxide, 37,000 tons of HCl, and 1,000 tons of HF, 8.3 tons of mercury, 3,400 tons of other metals, and 1,200 grams of dioxins/furans each year from major and area sources. In addition, ecosystem benefits and visibility benefits have not been monetized in this analysis.
- **Net Benefits:** The net benefits for the proposed major source rule only are $14 billion to $38 billion and $12 billion to $34 billion, at 3% and 7% discount rates, respectively in 2013. The net benefits for the area source rule only are $500 million to $1.9 billion and $410 million to $1.7 billion in 2013, at 3% and 7% discount rates, respectively. All estimates are in 2008 dollars.

**Table 1-1. Summary of the Monetized Benefits, Social Costs, and Net Benefits for the Boiler MACT (Major Sources) in 2013 (millions of 2008$)[1]**

| | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| **Proposed Option** | | |
| Total Monetized Benefits[2] | $17,000 to $41,000 | $15,000 to $37,000 |
| Total Social Costs[3] | $2,900 | $2,900 |
| Net Benefits | $14,000 to $38,000 | $12,000 to $34,000 |
| **Option 1N and 1E** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[4] | $17,000 to $41,000 | $15,000 to $37,000 |
| Total Social Costs[3] | $12,000 | $12,000 |
| Net Benefits | $5,000 to $30,000 | $3,400 to $26,000 |
| **Proposed Option with Alternate Solid Waste Definition** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[5] | $3,100 to $7,700 | $2,800 to $6,900 |
| Total Social Costs[3] | $2,200 | $2,200 |
| Net Benefits | $930 to $5,500 | $640 to $4,700 |

[1]All estimates are for the implementation year (2013), and are rounded to two significant figures.

[2] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 29,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 1,700 tons of VOC and 340,000 tons of $SO_2$. The benefits from reducing 340,000 tons of carbon monoxide, 37,000 tons of HCl, 1,000 tons of HF, and 7.5 tons of mercury, 3,200 tons of other metals, and 720 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

[3] The methodology used to estimate social costs for one year in the multimarket model using surplus changes results in the same social costs for both discount rates.

[4] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 29,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 6,700 tons of VOC and 350,000 tons of $SO_2$. The benefits from reducing 390,000 tons of carbon monoxide, 42,000 tons of HCl, 8,600 tons of HF, and 8.1 tons of mercury, 3,200 tons of other metals, and 760 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

[5] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 8,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 4,700 tons of VOC and 44,000 tons of $SO_2$. The benefits from reducing 280,000 tons of carbon monoxide, 5,100 tons of HCl, 1,100 tons of HF, and 7.1 tons of mercury, 1,600 tons of other metals, and 290 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

**Table 1-2. Summary of the Monetized Benefits, Social Costs, and Net Benefits for the Boiler Area Source Rule in 2013 (millions of 2008$)[1]**

| | | |
|---|---|---|
| **Proposed Option** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[2] | $1,000 to $2,400 | $910 to $2,200 |
| Total Social Costs[3] | $500 | $500 |
| Net Benefits | $500 to $1,900 | $410 to $1,700 |
| **Option 1N and 1E** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[4] | $8,300 to $20,000 | $7,500 to $18,000 |
| Total Social Costs[3] | $35,000 | $35,000 |
| Net Benefits | $-27,000 to $-15,000 | $-28,000 to $-17,000 |

[1] All estimates are for the implementation year (2013), and are rounded to two significant figures.

[2] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 2,700 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 1,200 tons of VOC and 1,500 tons of $SO_2$. The benefits from reducing 39,000 tons of carbon monoxide, 130 tons of HCl, 5 tons of HF, and 0.75 tons of mercury, 250 tons of other metals, and 470 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

[3] The methodology used to estimate social costs for one year in the multimarket model using surplus changes results in the same social costs for both discount rates.

[4] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 23,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 2,100 tons of VOC and 1,700 tons of $SO_2$. The benefits from reducing 58,000 tons of carbon monoxide, 140 tons of HCl, 6.4 tons of HF, and 1.5 tons of mercury, 6,200 tons of other metals, and 530 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

## 1.2 Organization of this Report

The remainder of this report supports and details the methodology and the results of the EIA:

- Section 2 presents the affected industry profiles.
- Section 3 describes the engineering cost analysis.
- Section 4 describes the economic impact analysis.
- Section 5 describes the small entity analyses.
- Section 6 presents the benefits estimates.
- Section 7 presents supplemental economic analyses for an alternative non-hazardous solid waste definition
- Appendix A describes the multimarket model used in the economic analysis.
- Appendix B provides additional economic model result tables by sector.

# SECTION 2
# INDUSTRY PROFILES

In this section, we provide an introduction selected industries that are affected by the proposed rules. The industries were selected based on high facility population counts within 3-digit NAICs industries reported in the combustion facility survey. The purpose is to give the reader a general understanding of economic aspects and industry trends to provide additional context for the economic impact analysis.

## 2.1 Food Manufacturing

### *2.1.1 Introduction*

Food manufacturing involves the transformation of raw agricultural and livestock products into processed food. Between 1997 and 2002, shipment values stagnated, falling 0.38%, while the number of employees and payroll increased 2.71% and 7.76%, respectively (Table 2-1). This trend reversed between 2002 and 2006, as shipment values rose 4.77 % and number of employees and payroll fell 5.94% and 3.28% respectively (Table 2-1). Shipments, payroll, and employment continued to increase between 2006 and 2007, but there was a notable drop in the number of establishments between 2002 and 2007 (Table 2-1). As Table 2-2 shows, payroll per employee grew 4.91% from 1997 to 2002 and continued to increase, albeit at a slower rate of 2.83%, from 2002 to 2006. Between 2006 and 2007, the payroll per employee declined as the growth in employees outpaced the increase in the annual payroll (Table 2-2).

The food manufacturing industry consists of nine different industry groups, each distinguished by the livestock or agricultural products used as raw materials for the processed food products as follows:

- Animal Food Manufacturing (North American Industry Classification System [NAICS] 3111)
- Grain and Oilseed Milling (NAICS 3112)
- Sugar and Confectionery Product Manufacturing (NAICS 3113)
- Fruit and Vegetable Preserving and Specialty Food Manufacturing (NAICS 3114)
- Dairy Product Manufacturing (NAICS 3115)
- Animal Slaughtering and Processing (NAICS 3116)
- Seafood Product Preparation and Packaging (3117)
- Bakeries and Tortilla Manufacturing (NAICS 3118)

**Table 2-1. Key Statistics: Food Manufacturing (North American Industry Classification System [NAICS] 311)**

| | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Shipments ($2007, millions) | $528,928 | $526,939 | $552,075 | $589,550 |
| Payroll ($2007, millions) | $48,118 | $51,852 | $50,151 | $50,467 |
| Employees | 1,466,956 | 1,506,781 | 1,417,274 | 1,466,683 |
| Establishments | 26,302 | 27,899 | NA | 22,055 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (2007 NAICS Basis): 2002 and 2007." <http://factfinder.census.gov>; (January 4, 2010).

**Table 2-2. Industry Data: Food Manufacturing (NAICS 311)**

| Industry Data | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Total shipments ($2007, millions) | $528,928 | $526,939 | $552,075 | 589,550 |
| Shipments per establishment ($2007, thousands) | $20,110 | $18,887 | NA | $26,731 |
| Average Shipments per employee ($2007) | $360,561 | $349,712 | $389,533 | $401,961 |
| Average Shipments per $ of payroll ($2007) | $10.99 | $10.16 | $11.01 | $11.68 |
| Average Annual payroll per employee ($2007) | $32,800.97 | $34,412.12 | $35,385.46 | $34,409.00 |
| Average Employees per establishment | 56 | 54 | NA | 67 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (2007 NAICS Basis): 2002 and 2007." <http://factfinder.census.gov>; (January 4, 2010).

In 2006, Animal Slaughtering and Processing made up the largest share of both employment (33%) and the value of shipments (27%) in food manufacturing (Figures 2-1 and 2-2).

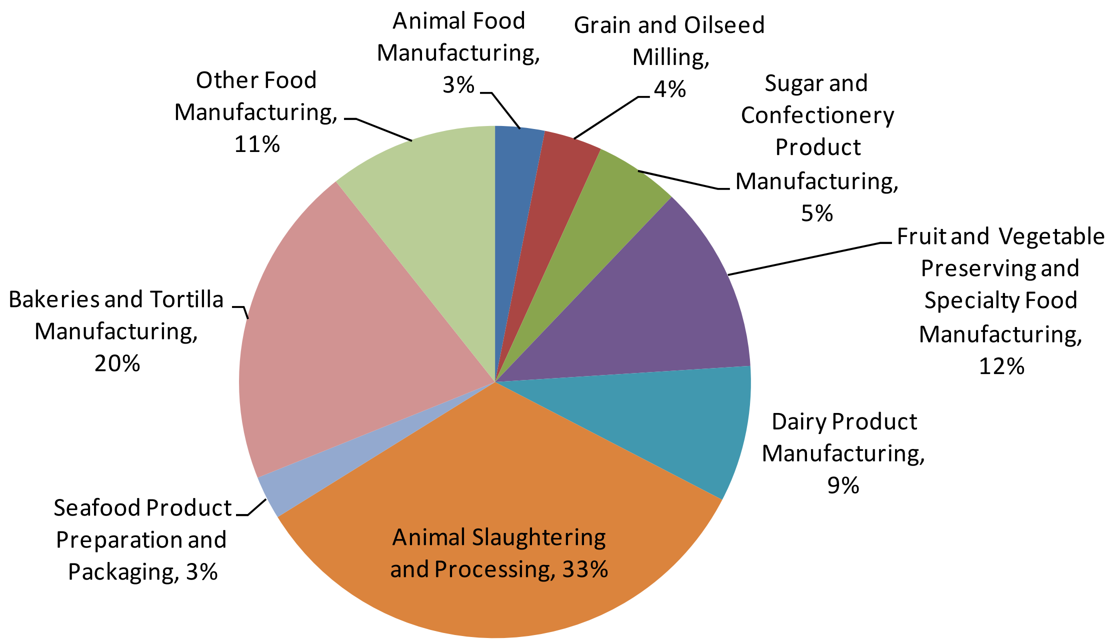


**Figure 2-1. Distribution of Employment within Food Manufacturing (NAICS 311): 2006**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

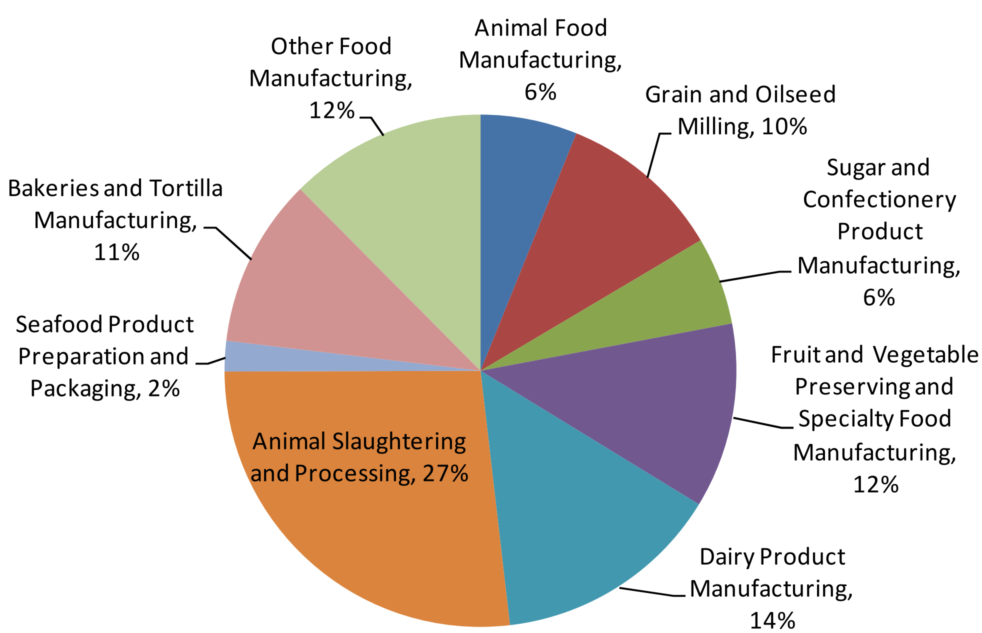


**Figure 2-2. Distribution of Total Value of Shipments within Food Manufacturing (NAICS 311): 2006**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

Many major environmental regulations directly affect the food manufacturing industry and/or other markets that provide key goods and services to the industry (e.g., energy). RTI's multimarket model is specifically designed to analyze these types of regulations. The model emphasizes the links among industrial sectors and provides policy makers with new insights about the direct and indirect effects of a regulatory program and the distribution of costs across the U.S. economy.

### *2.1.2 Supply and Demand Characteristics*

Next, we provide a broad overview of the supply and demand sides of the food manufacturing industry. We emphasize the economic interactions this industry has with other industries and people, including identifying the key goods and services used by the industry and the major uses and consumers of food manufacturing products.

#### *2.1.2.1 Goods and Services Used in Food Manufacturing*

In 2006, the cost of materials made up 57% of the value of shipments in food production. Total employee compensation accounted for 12% of this value, with half of that coming from production workers' wages (Table 2-3).

The top 10 industry groups supplying inputs to food production accounted for 84% of the total intermediate inputs to the industry, with the top three industry groups (food products, animal products, and crop products) accounting for over half of the total intermediate inputs (Table 2-4). Electric power generation, transmission, and distribution accounted for 2% of the total intermediate inputs, whereas boilers, tanks, and shipping containers accounted for 1%.

#### *2.1.2.2 Energy*

The Department of Energy (DOE) classifies the entire food products industry as an energy-intensive industry to model within its Industrial Demand Module (DOE, 2008a). In 2002, food manufacturing accounted for 6.86% of the total fuel consumption by all manufacturing industries (NAICS 311–339) and 19.24% of the conventional boiler use fuel consumption by all manufacturing industries (DOE, Energy Information Administration, 2007).

### Table 2-3. Costs of Goods and Services Used in Food Manufacturing (NAICS 311) ($2007)

| Industry Ratios | 2005 | Share | 2006 | Share |
|---|---|---|---|---|
| Total shipments ($millions) | $563,797 | 100% | $552,075 | 100% |
| Total compensation ($millions) | $64,909 | 12% | $64,027 | 12% |
| Annual payroll | $50,650 | 9% | $50,151 | 9% |
| Fringe benefits | $14,259 | 3% | $13,877 | 3% |
| Total employees | 1,440,283 | | 1,417,274 | |
| Average compensation per employee | $45,067 | | $45,176 | |
| Total production workers' wages ($millions) | $33,983 | 6% | $33,670 | 6% |
| Total production workers | 1,099,530 | | 1,090,081 | |
| Total production hours (thousands) | 2,242,558 | | 2,198,396 | |
| Average production wages per hour | $15 | | $15 | |
| Total cost of materials ($thousands) | $315,993 | 56% | $312,847 | 57% |
| Materials, parts, packaging | $286,895 | 51% | $284,028 | 51% |
| Purchased electricity | $4,513 | 1% | $4,787 | 1% |
| Purchased fuel | $5,136 | 1% | $5,398 | 1% |
| Other | $19,449 | 3% | $18,634 | 3% |

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

### Table 2-4. Key Goods and Services Used in Food Manufacturing (NAICS 311) ($2007, millions)

| Sector | BEA Code | Food Products |
|---|---|---|
| Food products | 3110 | $91,518 |
| Animal products | 1120 | $85,785 |
| Crop products | 1110 | $43,109 |
| Management of companies and enterprises | 5500 | $34,235 |
| Wholesale trade | 4200 | $27,849 |
| Converted paper products | 3222 | $18,782 |
| Truck transportation | 4840 | $12,943 |
| Plastics and rubber products | 3260 | $9,641 |
| Electric power generation, transmission, and distribution | 2211 | $6,004 |
| Boilers, tanks, and shipping containers | 3324 | $4,564 |
| Total intermediate inputs | T005 | $400,067 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

In both 2005 and 2006, purchased electricity and fuel each accounted for 1% of the total value of shipments in food manufacturing (Table 2-3). In 2002, total energy consumption totaled 1,116 TBTU, a 7% increase over 1998 (Table 2-5). Of this total fuel consumption, the largest share (41.72%) was consumed for indirect uses including conventional boiler use and combined heat and power (CHP) and/or cogeneration process (MECS Table 5.2). Between 1997 and 2005, while the manufacturing sector as a whole used less electricity, food manufacturing used more electricity (Figure 2-3). From 2005to 2006, the electricity consumption increased by nearly 9% (Table 2-5).

**Table 2-5. Energy Used in Food Manufacturing (NAICS 311)**

| Fuel Type | 1998 | 2002 | 2006 |
|---|---|---|---|
| Net electricity[a] (million kWh) | 62,457 | 67,521 | 73,440 |
| Residual fuel oil (million bbl) | 2 | 2 | 4 |
| Distillate fuel oil[b] (million bbl) | 3 | 3 | 3 |
| Natural gas[c] (billion cu ft) | 553 | 560 | 618 |
| LPG and NGL[d] (million bbl) | 1 | 1 | 1 |
| Coal (million short tons) | 6 | 8 | 7 |
| Coke and breeze (million short tons) | * | * | * |
| Other[e] (trillion BTU) | 97 | 90 | 107 |
| Total (trillion BTU) | 1,044 | 1,116 | 1,186 |

[a] Net electricity is obtained by summing purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. It does not include electricity inputs from on-site cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).

[b] Distillate fuel oil includes Nos. 1, 2, and 4 fuel oils and Nos. 1, 2, and 4 diesel fuels.

[c] Natural gas includes natural gas obtained from utilities, local distribution companies, and any other supplier(s), such as independent gas producers, gas brokers, marketers, and any marketing subsidiaries of utilities.

[d] Examples of liquefied petroleum gases (LPGs) are ethane, ethylene, propane, propylene, normal butane, butylene, ethane-propane mixtures, propane-butane mixtures, and isobutene produced at refineries or natural gas processing plants, including plants that fractionate raw natural gas liquids (NGLs).

[e] 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.

* Estimate less than 0.5.

Sources: U.S. Department of Energy, Energy Information Administration. 2007. “2002 Energy Consumption by Manufacturers—Data Tables.” Tables 3.2 and N3.2. Washington, DC: DOE <http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html>.

U.S. Department of Energy, Energy Information Administration. 2009a. “2006 Energy Consumption by Manufacturers—Data Tables.” Table 3.1. Washington, DC: DOE. <http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html>.

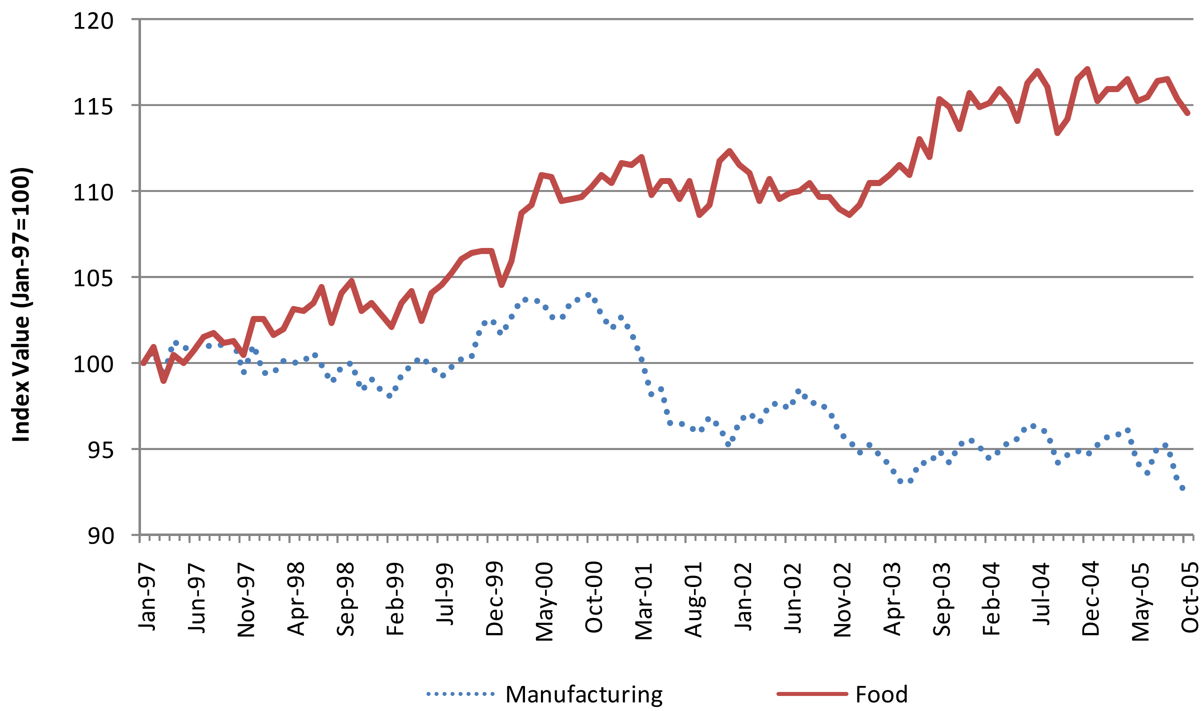


**Figure 2-3. Electric Power Use Trends in Food Manufacturing (NAICS 311): 1997–2005**

Source: Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G311.S. <http://www.federalreserve.gov/datadownload/>.

*2.1.2.3 Uses and Consumers*

The majority of food manufacturing's total commodity output (58%) is sold for personal consumption. Of the sales for intermediate use, 42% are sold back into the food manufacturing industry (Table 2-6).

### ***2.1.3 Firm and Market Characteristics***

This remaining subsection describes geographic, production, and market data. These data provide the basis for further analysis, including regulatory flexibility analyses, and give a complete picture of the recent historical trends of production and pricing.

*2.1.3.1 Location*

In 2002, California had the most food manufacturing establishments in the United States, followed by New York and Texas (see Figure 2-4). In addition, Pennsylvania, Illinois, Wisconsin, New Jersey, and Florida had over 1,000 establishments in their states.

**Table 2-6. Demand by Sector: Food Manufacturing (NAICS 311) ($2007, millions)**

| Sector | BEA Code | Food Products |
|---|---|---|
| Food manufacturing | 3110 | $91,518 |
| Food services and drinking places | 7220 | $37,291 |
| Animal production | 1120 | $15,870 |
| General state and local government services | S007 | $15,170 |
| Retail trade | 4A00 | $13,985 |
| Beverage manufacturing | 3121 | $11,703 |
| Hospitals | 6220 | $9,539 |
| Educational services | 6100 | $4,485 |
| Nursing and residential care facilities | 6230 | $4,187 |
| Social assistance | 6240 | $2,277 |
| Total intermediate use | T001 | $217,570 |
| Personal consumption expenditures | F010 | $301,748 |
| Exports of goods and services | F040 | $28,151 |
| Imports of goods and services | F050 | −$33,119 |
| Total final uses (GDP) | T004 | $299,470 |
| Total commodity output | T007 | $517,040 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

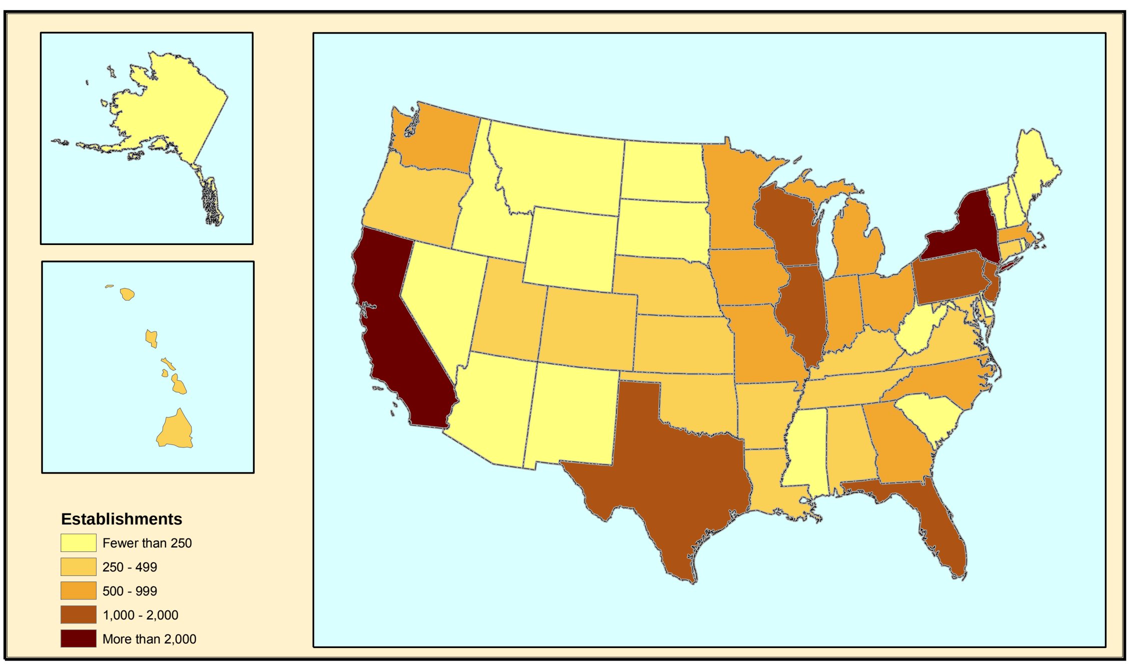


**Figure 2-4. Establishment Concentration in Food Manufacturing (NAICS 311): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

*2.1.3.2 Production Capacity and Utilization*

Capacity utilization of the food manufacturing industry did not fall off during the recession of 2001 as much as the manufacturing sector as a whole (Figure 2-5). Food manufacturing's capacity utilization has remained higher than manufacturing as a whole and went above 85% in the spring of 2008. The effects of the recent economic downturn have not affected capacity utilization as sharply in the food industry relative to the overall manufacturing sector (Figure 2-5).

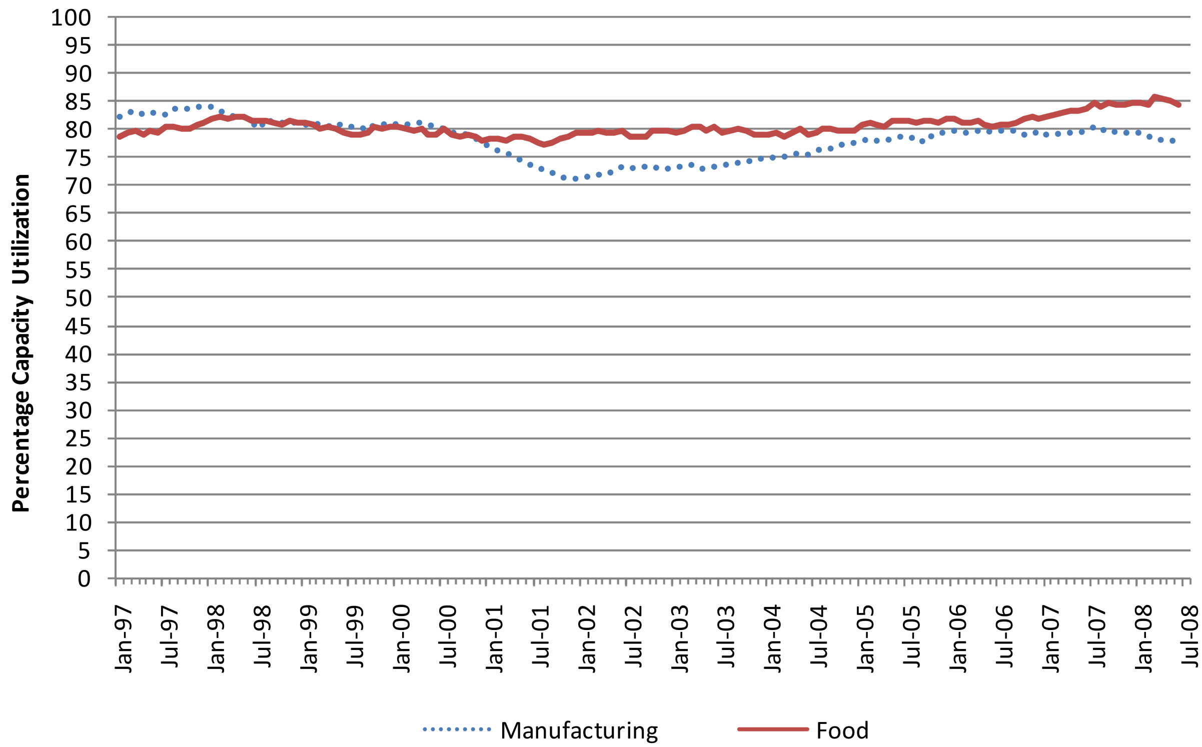


**Figure 2-5. Capacity Utilization Trends in Food Manufacturing (NAICS 311)**

Source: Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G311.S. <http://www.federalreserve.gov/datadownload/>.

*2.1.3.3 Employment*

The geographic distribution of employment in food manufacturing varies substantially from the distribution of establishments. In 2002, Arkansas, ranked thirty-first in number of establishments and had the eighth most employees (53,844) because of its national high of 199 employees per establishment. New York, ranked second in number of establishments, had only the tenth most employees (50,012). North Carolina and Georgia also had greater than 50,000 employees, despite having fewer than 600 establishments (Figure 2-6).

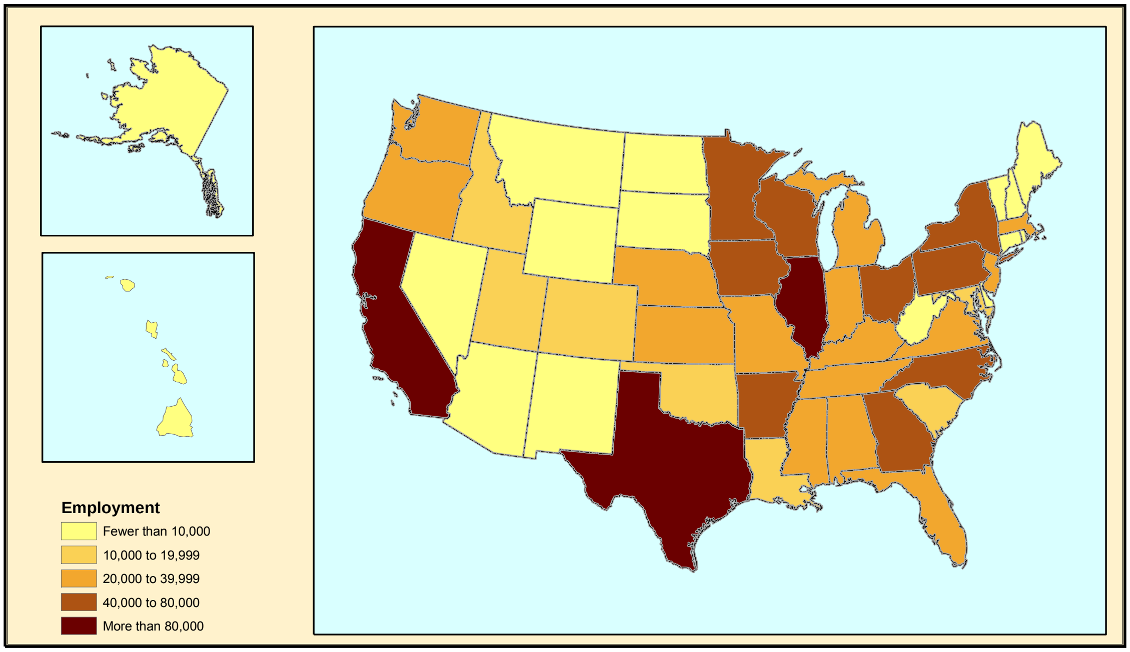


**Figure 2-6. Employment Concentration in Food Manufacturing (NAICS 311): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

#### *2.1.3.4 Plants and Capacity*

Production capacity in food manufacturing only grew 17.94% between 1997 and early 2008, a compound annual growth rate (CAGR) of 1.45%. This is substantially less than the 42.50% growth for the manufacturing industry as a whole (Figure 2-7).

#### *2.1.3.5 Firm Characteristics*

In fiscal year 2007, the top eight food manufacturing companies each had greater than $10 billion in sales. These companies, however, are global, many with a large portion of both sales and production coming from operations outside of the United States (Table 2-7). The largest U.S. food manufacturing company, Kraft Foods Inc., has 50.27% of its long-lived assets located outside of the United States (Kraft Foods Inc., 2008).

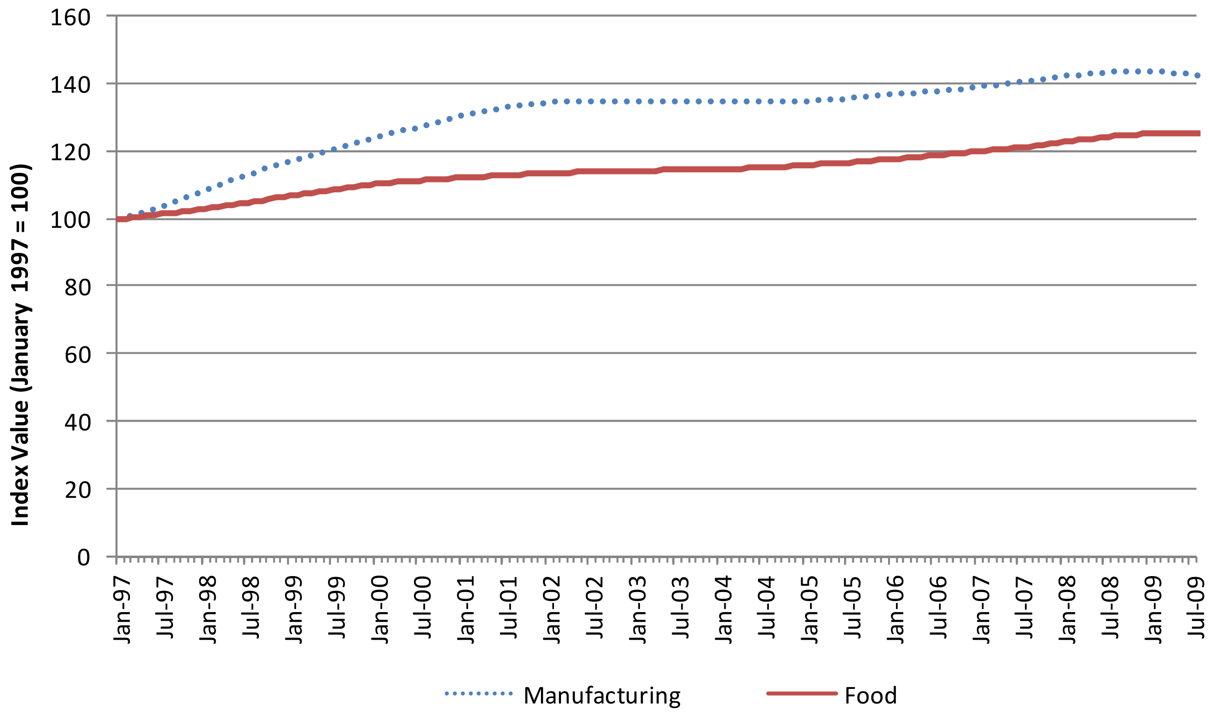


**Figure 2-7. Capacity Trends in Food Manufacturing (NAICS 311)**

Source: Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G311.S. <http://www.federalreserve.gov/datadownload/>.

**Table 2-7. Top Publicly Held U.S. Food Companies: 2007**

| | Sales ($millions) | % of Sales in United States |
|---|---|---|
| Kraft Foods Inc. | 37,241 | 57.8% |
| Tyson Foods Inc. | 26,900 | 90.0% |
| General Mills Inc. | 12,442 | 82.9% |
| Sara Lee Corp. | 12,278 | 53.8% |
| ConAgra Foods Inc. | 12,028 | 89.2% |
| Smithfield Foods Inc.[a] | 11,911 | 86.2% |
| Dean Foods Co. | 11,822 | >99.0% |
| Kellogg Co.[a] | 11,776 | 66.1% |
| H.J. Heinz Co. | 9,002 | 42.3% |
| Campbell Soup Co. | 7,867 | 69.0% |

[a] Percentage of sales in the United States is actually percentage of sales in North America.

Source: Graves, T. 2008. "Food and Nonalcoholic Beverages." *Standard and Poor's Industry Surveys*. 176(25).

For the industry as a whole, the number of corporations as well as the number of corporations with net income in the food manufacturing industry grew between 2004 and 2005. Although the overall number of companies continued to grow in 2006, the number of those with a positive net income declined along with profit margins and total receipts (Table 2-8).

**Table 2-8. Corporate Income and Profitability for Food Manufacturing (NAICS 311)**

| | 2004 | 2005 | 2006 |
|---|---|---|---|
| Number of corporations | 14,408 | 14,956 | 16,146 |
| Number of corporations with net income | 6,541 | 7,503 | 7,333 |
| Total receipts (thousands) | $502,149,944 | $504,944,378 | $484,193,319 |
| Business receipts (thousands) | $477,906,423 | $465,369,666 | $459,884,663 |
| Before-tax profit margin | 5.27% | 10.09% | 7.43% |
| After-tax profit margin | 3.74% | 7.62% | 5.11% |

Source: Internal Revenue Service, U.S. Department of Treasury. 2008. "Corporation Source Book: Data File 2005." <http://www.irs.gov/taxstats/article/0,,id=167415,00.html>; (January, 14 2009).

*2.1.3.6 Size Distribution*

The primary criterion for categorizing a business as small is number of employees, using definitions by the SBA for regulatory flexibility analyses. The data describing size standards are provided in Table 2-9. Over 80% of the NAICS industries within the food manufacturing industry use a cutoff of 500 employees. In 2002, enterprises with fewer than 500 employees accounted for 32% of employment and 23% of receipts within food manufacturing (Table 2-10).

*2.1.3.7 Domestic Production*

Between 1997 and early 2008, overall manufacturing production grew faster (34.88%) than the food manufacturing component (26.18%) (Figure 2-8). The food manufacturing industry has been less volatile, particularly during the recession of 2001 and the current economic downturn.

*2.1.3.8 International Trade*

In 2006, the United States regained a trade surplus in food manufacturing it had briefly lost during 2004 to 2005 (see Figure 2-9). The trade surplus in 2007 was over $4 billion. Both exports and imports have declined since their 2008 peak as a result of the global economic recession.

## Table 2-9. Small Business Size Standards: Food Manufacturing (NAICS 311)

| NAICS | Description | Employees |
|---|---|---|
| 311111 | Dog and Cat Food Manufacturing | 500 |
| 311119 | Other Animal Food Manufacturing | 500 |
| 311211 | Flour Milling | 500 |
| 311212 | Rice Milling | 500 |
| 311213 | Malt Manufacturing | 500 |
| 311221 | Wet Corn Milling | 750 |
| 311222 | Soybean Processing | 500 |
| 311223 | Other Oilseed Processing | 1,000 |
| 311225 | Fats and Oils Refining and Blending | 1,000 |
| 311230 | Breakfast Cereal Manufacturing | 1,000 |
| 311311 | Sugarcane Mills | 500 |
| 311312 | Cane Sugar Refining | 750 |
| 311313 | Beet Sugar Manufacturing | 750 |
| 311320 | Chocolate and Confectionery Manufacturing from Cacao Beans | 500 |
| 311330 | Confectionery Manufacturing from Purchased Chocolate | 500 |
| 311340 | Non-Chocolate Confectionery Manufacturing | 500 |
| 311411 | Frozen Fruit, Juice and Vegetable Manufacturing | 500 |
| 311412 | Frozen Specialty Food Manufacturing | 500 |
| 311421 | Fruit and Vegetable Canning3 | 3,500 |
| 311422 | Specialty Canning | 1,000 |
| 311423 | Dried and Dehydrated Food Manufacturing | 500 |
| 311511 | Fluid Milk Manufacturing | 500 |
| 311512 | Creamery Butter Manufacturing | 500 |
| 311513 | Cheese Manufacturing | 500 |
| 311514 | Dry, Condensed, and Evaporated Dairy Product Manufacturing | 500 |
| 311520 | Ice Cream and Frozen Dessert Manufacturing | 500 |
| 311611 | Animal (except Poultry) Slaughtering | 500 |
| 311612 | Meat Processed from Carcasses | 500 |
| 311613 | Rendering and Meat By-product Processing | 500 |
| 311615 | Poultry Processing | 500 |
| 311711 | Seafood Canning | 500 |
| 311712 | Fresh and Frozen Seafood Processing | 500 |
| 311811 | Retail Bakeries | 500 |
| 311812 | Commercial Bakeries | 500 |
| 311813 | Frozen Cakes, Pies, and Other Pastries Manufacturing | 500 |
| 311821 | Cookie and Cracker Manufacturing | 750 |
| 311822 | Flour Mixes and Dough Manufacturing from Purchased Flour | 500 |

(continued)

## Table 2-9. Small Business Size Standards: Food Manufacturing (NAICS 311) (continued)

| NAICS | Description | Employees |
|---|---|---|
| 311823 | Dry Pasta Manufacturing | 500 |
| 311830 | Tortilla Manufacturing | 500 |
| 311911 | Roasted Nuts and Peanut Butter Manufacturing | 500 |
| 311919 | Other Snack Food Manufacturing | 500 |
| 311920 | Coffee and Tea Manufacturing | 500 |
| 311930 | Flavoring Syrup and Concentrate Manufacturing | 500 |
| 311941 | Mayonnaise, Dressing and Other Prepared Sauce Manufacturing | 500 |
| 311942 | Spice and Extract Manufacturing | 500 |
| 311991 | Perishable Prepared Food Manufacturing | 500 |
| 311999 | All Other Miscellaneous Food Manufacturing | 500 |

Source: U. S. Small Business Administration (SBA). 2008. "Table of Small Business Size Standards Matched to North American Industry Classification System Codes." Effective August 22, 2008. <http://www.sba.gov/services/contractingopportunities/sizestandardstopics/size/index.html>.

## Table 2-10. Distribution of Economic Data by Enterprise Size: Food Manufacturing (NAICS 311)

| | | Enterprises with: | | | | | |
|---|---|---|---|---|---|---|---|
| Variable | Total | 1 to 20 Employees[a] | 20 to 99 Employees | 100 to 499 Employees | 500 to 749 Employees | 750 to 999 Employees | 1,000 to 1,499 Employees |
| Firms | 21,384 | 13,645 | 3,935 | 1,247 | 147 | 63 | 96 |
| Establishments | 25,698 | 13,719 | 4,254 | 1,951 | 370 | 211 | 319 |
| Employment | 1,443,766 | 85,850 | 156,158 | 218,041 | 67,104 | 30,099 | 72,262 |
| Receipts ($millions) | $457,521 | $12,665 | $32,274 | $56,661 | $23,103 | $10,007 | $21,878 |
| Receipts/firm ($thousands) | $21,395 | $928 | $8,202 | $45,438 | $157,163 | $158,835 | $227,898 |
| Receipts/establishment ($thousands) | $17,804 | $923 | $7,587 | $29,042 | $62,440 | $47,425 | $68,584 |
| Receipts/employment ($) | $316,894 | $147,523 | $206,678 | $259,862 | $344,286 | $332,457 | $302,762 |

[a] Excludes *Statistics of U.S. Businesses* (SUSB) employment category for zero employees. These entities only operated for a fraction of the year.

Source: U.S. Census Bureau. 2008. "Firm Size Data from the Statistics of U.S. Businesses: U.S. Detail Employment Sizes: 2002." <http://www.census.gov/csd/susb/download_susb02.htm>.

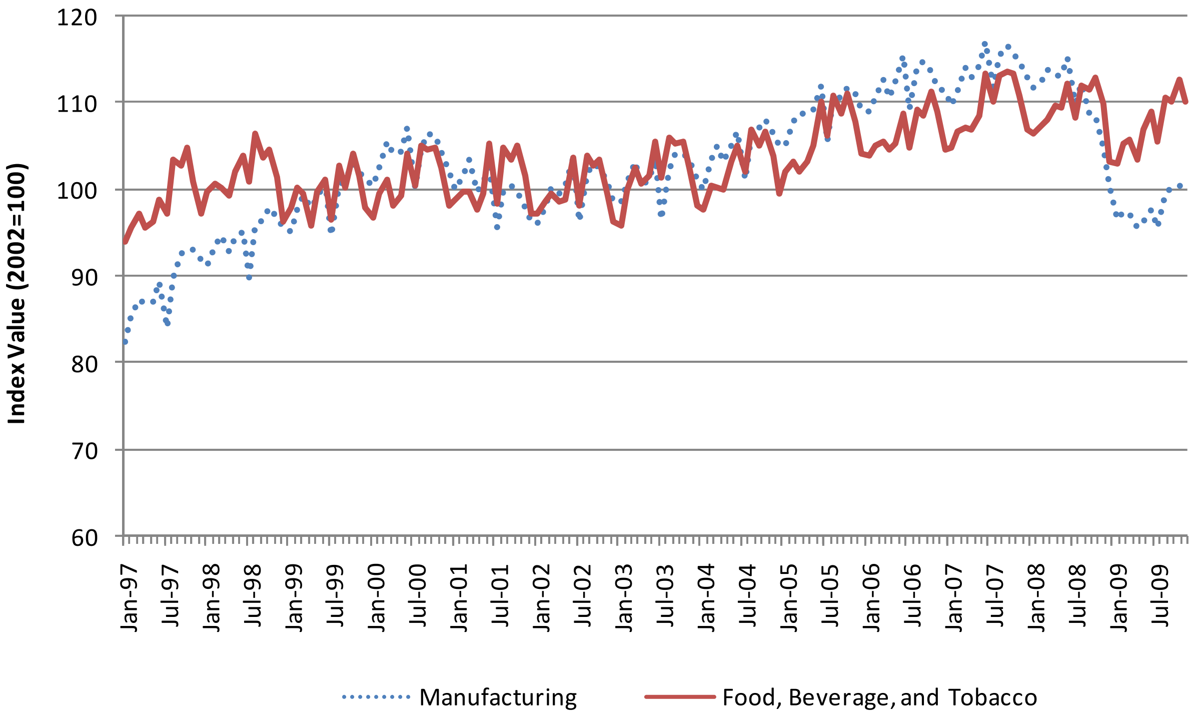


**Figure 2-8. Industrial Production Trends in Food Manufacturing (NAICS 311)**

Source: Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.N & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G311A2.N. <http://www.federalreserve.gov/datadownload/>.

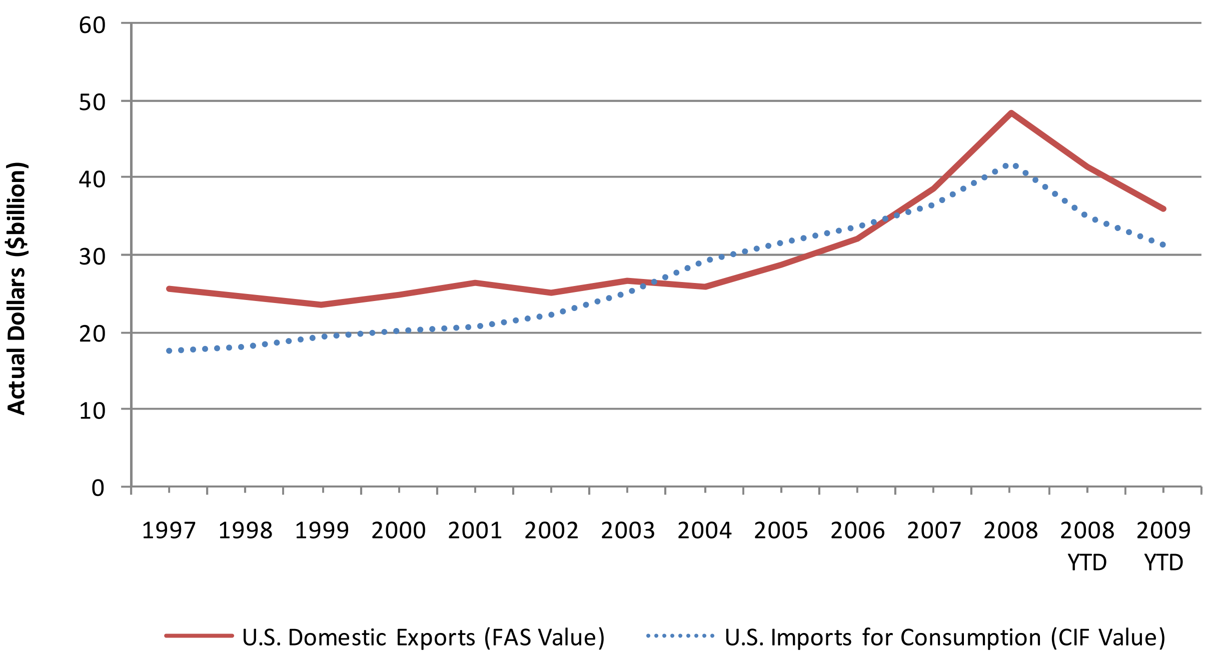


**Figure 2-9. International Trade Trends in Food Manufacturing (NAICS 311)**

Source: U.S. International Trade Commission. 2009a. "U.S. Domestic Exports" & "U.S. Imports for Consumption." <http://www.federalreserve.gov/datadownload/>.

*2.1.3.9 Market Prices*

Prices of goods in food manufacturing have moved generally in line with prices in overall manufacturing (see Figure 2-10). Both indexes increased over 31% since between early 2003 and early 2008, a CAGR of 5.13%. This rise was followed by a marked decline in recent years along with the downward trend in prices throughout the economy.

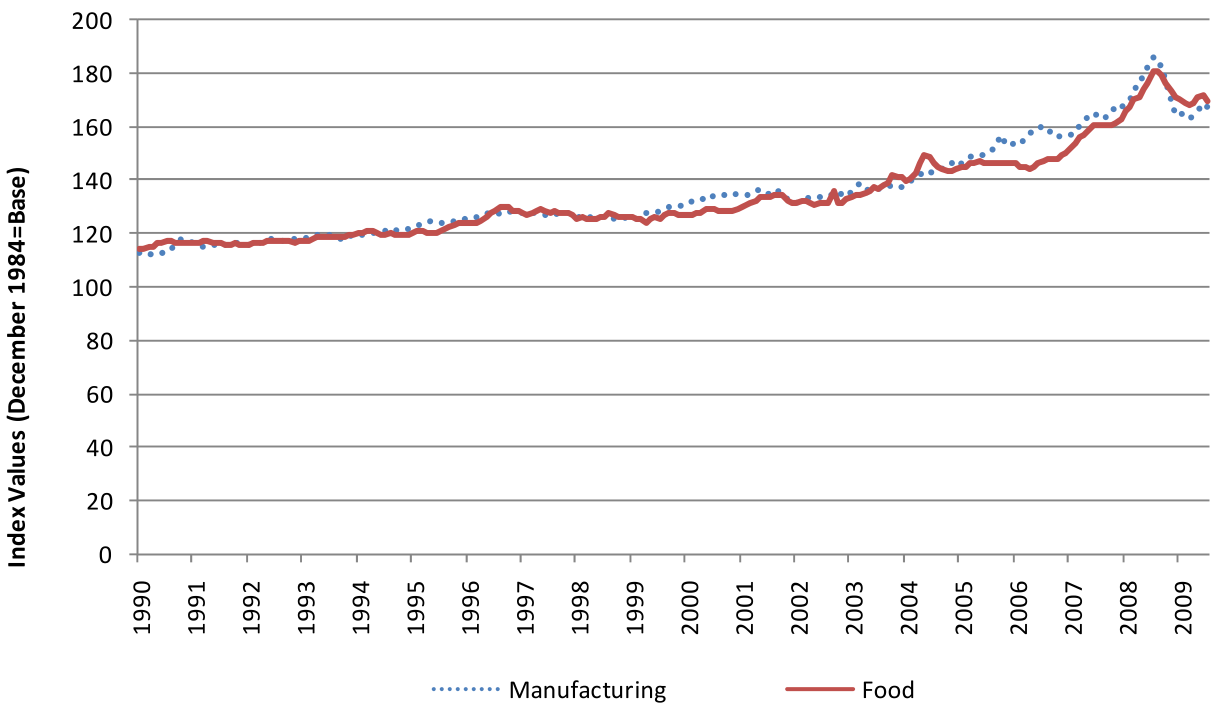


**Figure 2-10. Producer Price Trends in Food Manufacturing (NAICS 311)**

Source: U.S. Department of Labor; Bureau of Labor Statistics. 2010. "Producer Price Indexes." <http://www.bls.gov/pPI/Series Id: PCU311—311—Food Manufacturing & PCUOMFG–OMFG–Total Manufacturing>.

## 2.2 Wood Product Manufacturing

### *2.2.1 Introduction*

According to a report by Standard & Poor's (2008), a number of factors are shaping the current economic environment for wood products, including, but not limited to, the housing slump, high input costs, low prices for lumber and other building materials, and a weak dollar. Table 2-11 shows that revenues in this industry are not entirely predictable, exhibiting a drop in shipment revenue between 1997 and 2002 but a rise back to within $5 billion of the 1997 value in 2006 and a decline to within $14 billion of the 2006 value in 2007.

**Table 2-11. Key Statistics: Wood Product Manufacturing (NAICS 321)**

| | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Shipments ($2007, millions) | $110,956 | $102,721 | $115,390 | $101,879 |
| Payroll ($2007, millions) | $17,959 | $18,528 | $18,623 | $17,439 |
| Employees | 570,034 | 543,459 | 536,094 | 519,651 |
| Establishments | 17,367 | 17,255 | NA | 14,862 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; “Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007.” Accessed on December 27, 2009.

While total payroll dropped 3% over from 1997 to 2007, annual payroll per employee rose 6.5% because of the decline in the number of employees (Table 2-12). Shipments per employee grew 10.6% from 1997 to 2006 and dropped 8.9% from 2006 to 2007 (Table 2-12).

**Table 2-12. Industry Data: Wood Product Manufacturing (NAICS 321)**

| Industry Data | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Total shipments ($2007, millions) | $110,956 | $102,721 | $115,390 | $101,879 |
| Shipments per establishment ($thousands) | $25,613 | $5,953 | NA | $6,855 |
| Average Shipments per employee ($2007) | $194,648 | $189,014 | $215,243 | $196,053 |
| Average Shipments per $ of payroll ($2007) | $6.18 | $5.54 | $6.20 | $5.84 |
| Average Annual payroll per employee ($2007) | $31,504 | $34,093 | $34,738 | $33,558 |
| Average Employees per establishment | 33 | 31 | NA | 35 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; “Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007.” Accessed on December 27, 2009.

The U.S. Census Bureau categorizes this industry's facilities into three categories: "sawmills and wood preservation;" "veneer, plywood, and engineered wood product manufacturing;" and "other wood product manufacturing." These are further divided into the following types of facilities as defined by the Census Bureau:

- Sawmills and Wood Preservation
  - Sawmills and Wood Preservation (NAICS 32111): This industry comprises establishments primarily engaged in one or more of the following manufacturing activities: (a) sawing dimension lumber, boards, beams, timber, poles, ties, shingles, shakes, siding, and wood chips from logs or bolts; (b) sawing round wood poles, pilings, and posts and treating them with preservatives; and (c) treating wood sawed, planed, or shaped in other establishments with creosote or other preservatives to prevent decay and to protect against fire and insects. Sawmills may plane the rough lumber that they make with a planing machine to achieve smoothness and uniformity of size.
- Veneer, Plywood, and Engineered Wood Product Manufacturing
  - Veneer, Plywood, and Engineered Wood Product Manufacturing (NAICS 32121): This industry comprises establishments primarily engaged in one or more of the following manufacturing activities: (a) veneer and/or plywood, (b) engineered wood members, and (c) reconstituted wood products. This industry includes manufacturing plywood from veneer made in the same establishment or from veneer made in other establishments, and manufacturing plywood faced with non-wood materials, such as plastics or metal.
- Other Wood Product Manufacturing
  - Millwork (NAICS 32191): This industry comprises establishments primarily engaged in manufacturing hardwood and softwood cut stock and dimension stock (i.e., shapes); wood windows and wood doors; and other millwork including wood flooring. Dimension stock or cut stock is defined as lumber and worked wood products cut or shaped to specialized sizes. These establishments generally use woodworking machinery, such as jointers, planers, lathes, and routers to shape wood.
  - Wood Container and Pallet Manufacturing (NAICS 32192): This industry comprises establishments primarily engaged in manufacturing wood pallets, wood box shook, wood boxes, other wood containers, and wood parts for pallets and containers.
  - All Other Wood Product Manufacturing (NAICS 32199): This industry comprises establishments primarily engaged in manufacturing wood products (except establishments operating sawmills and wood preservation facilities; and establishments manufacturing veneer, plywood, engineered wood products, millwork, wood containers, or pallets).

Figure 2-11 shows that the industry proportion of the value of shipments for other wood product manufacturing (51%) was greater than the value of shipments for sawmills and wood preservation (27%) and veneer, plywood, and engineered wood products (22%). Figure 2-12 indicates that the majority of employees in this industry fell under other wood products (60%). Veneer, plywood, and engineered wood products had the same percentage (20%) of employees as sawmills and wood preservation (20%), even though it contributed to a lesser portion of the value of shipments.

### *2.2.2 Supply and Demand Characteristics*

Next, we provide a broad overview of the supply and demand sides of the wood product manufacturing industry. We emphasize the economic interactions this industry has with other industries and people and identify the key goods and services used by the industry and the major uses and consumers wood products.

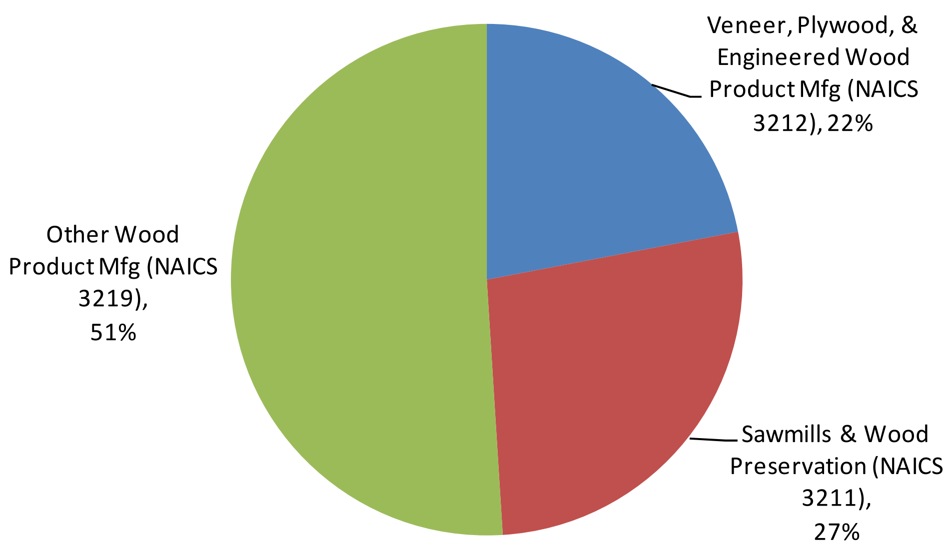


**Figure 2-11. Distribution of Value of Shipments within Wood Product Manufacturing (NAICS 322): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; “Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007.” <http://factfinder.census.gov>. Accessed on December 27, 2009. [Source for 2007 numbers]

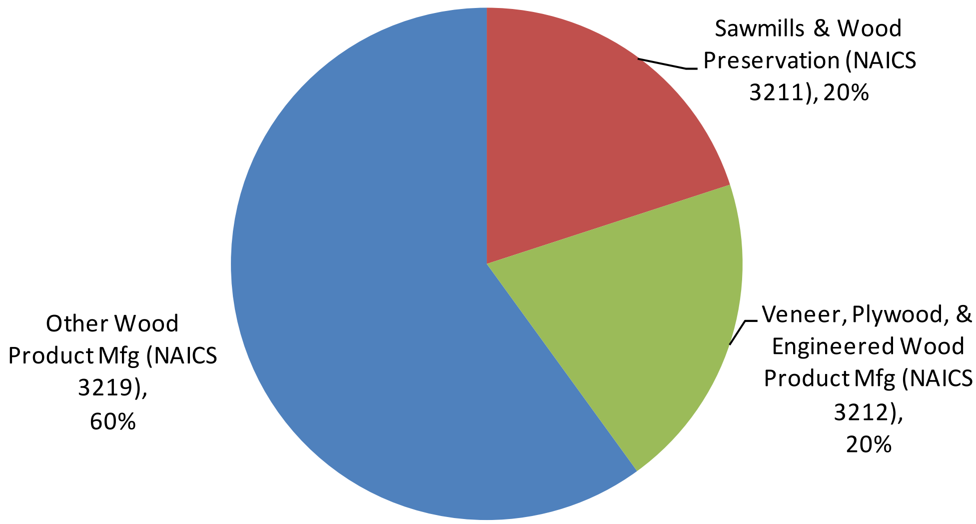


**Figure 2-12. Distribution of Employment within Wood Product Manufacturing (NAICS 322): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; "Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007" Release Date: 12/22/09. <http://factfinder.census.gov>. Accessed on December 27, 2009. [Source for 2007 numbers]

*2.2.2.1 Goods and Services Used in Wood Product Manufacturing*

In 2007, the cost of materials made up 59% of the total shipment value of goods in the wood product manufacturing industry (Table 2-13). Total compensation of employees represented 22% of the total value in 2007. Both the number of total shipments and the number of employees in this industry decreased between 2005 and 2007—the former by 14% and the latter by 3%.

The top 10 industry groups supplying inputs to the wood product industry accounted for 80% of the total intermediate inputs according to 2008 Bureau of Economic Analysis data (Table 2-14). The largest comes from the wood product industry itself. This is quite understandable, since the descriptions of the various industries within wood product manufacturing imply that they supply each other with products in order to add value and distribute their products to the broader market. The top five inputs are rounded out by forestry and logging products, wholesale trade, management of companies and enterprises, and truck transportation, which together make up 70% of the total cost of input.

**Table 2-13. Costs of Goods and Services in Wood Product Manufacturing (NAICS 321) ($2007)**

| Industry Ratios | 2005 | Share | 2006 | Share | 2007 | Share |
|---|---|---|---|---|---|---|
| Total shipments (millions) | $118,705 | 100% | $115,390 | 100% | $102,002 | 100% |
| Total compensation (millions) | $23,327 | 20% | $23,306 | 20% | $22,513 | 22% |
| Annual payroll millions | $18,884 | 16% | $18,623 | 16% | $17,444 | 17% |
| Fringe benefits | $4,442 | 4% | $4,683 | 4% | $5,069 | 5% |
| Total employees | 538,890 | | 536,094 | | 524,212 | |
| Average compensation per employee | $43,286 | | $43,473 | | $42,947 | |
| Total production workers' wages (millions) | $13,363 | 11% | $13,132 | 11% | $12,086 | 12% |
| Total production workers | 431,569 | | 432,315 | | 417,471 | |
| Total production hours (thousands) | 911,332 | | 887,613 | | 837,074 | |
| Average production wages per hour ($2007) | $15 | | $15 | | $14 | |
| Total cost of materials (thousands) | $71,808 | 60% | $69,892 | 61% | $60,682 | 59% |
| Materials, parts, packaging | $65,319 | 55% | $63,499 | 55% | $54,462 | 53% |
| Purchased electricity | $1,530 | 1% | $1,625 | 1% | $1,446 | 1% |
| Purchased fuel | $810 | 1% | $835 | 1% | $843 | 1% |
| Other | $4,149 | 3% | $3,933 | 3% | $3,931 | 4% |

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment: using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." Accessed on December 27, 2009. [Source for 2007 numbers]

***2.2.2.1.1 Energy.*** The Department of Energy (DOE) categorizes wood product manufacturing (NAICS 321) as a non-energy-intensive industry. The 2008 Annual Energy Outlook predicts that the wood product industry will be one of five (out of eight) non-energy-intensive industries experiencing positive average growth of delivered energy consumption between 2006 and 2030 (DOE, 2008).

**Table 2-14. Key Goods and Services Used in Wood Product Manufacturing (NAICS 321) ($2007, millions)**

| Description | BEA Commodity Code | Wood Products |
|---|---|---|
| Wood products | 3210 | $20,989 |
| Forestry and logging products | 1130 | $18,914 |
| Wholesale trade | 4200 | $5,417 |
| Management of companies and enterprises | 5500 | $2,853 |
| Truck transportation | 4840 | $2,542 |
| Electric power generation, transmission, and distribution | 2211 | $1,388 |
| Other fabricated metal products | 332B | $1,310 |
| Nonmetallic mineral products | 3270 | $1,110 |
| Real estate | 5310 | $799 |
| All other administrative and support services | 561A | $748 |
| Architectural and structural metal products | 3323 | $725 |
| Rail transportation | 4820 | $723 |
| Other inputs | | $14,650 |
| Total intermediate inputs | T005 | $72,169 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

Table 2-15 shows that total energy use between 1998 and 2002 Figure 2-13 shows that electrical power use decreased, since 2000.

*2.2.2.2 Uses and Consumers*

Table 2-16 shows that three of the top four consumers of wood products are represented by the construction sector of the economy (NAICS 23). New residential construction, new nonresidential construction, and maintenance and repair construction consume 35% of the total commodity output in this industry. The top 10 consumers of wood products make up 54% of the demand for wood products. Although many of the top consumers deal with construction, repair, or real estate services, other types of consumers, such as food services and drinking places, rail transportation, plastics and rubber products manufacturing, and other, use these products.

## Table 2-15. Energy Used in Wood Product Manufacturing (NAICS 321)

| Fuel Type | 1998 | 2002 | 2006 |
|---|---|---|---|
| Net electricity[a] (million kWh) | 21,170 | 20,985 | 26,723 |
| Residual fuel oil (million bbl) | * | * | 1 |
| Distillate fuel oil[b] (million bbl) | 2 | 2 | 3 |
| Natural gas[c] (billion cu ft) | 71 | 56 | 84 |
| LPG and NGL[d] (million bbl) | 1 | 1 | 1 |
| Coal (million short tons) | * | * | Q |
| Coke and breeze (million short tons) | — | — | * |
| Other[e] (trillion BTU) | 341 | 229 | 228 |
| Total (trillion BTU) | 504 | 375 | 445 |

[a] Net electricity is obtained by summing purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. It does not include electricity inputs from on-site cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).

[b] Distillate fuel oil includes Nos. 1, 2, and 4 fuel oils and Nos. 1, 2, and 4 diesel fuels.

[c] Natural gas includes natural gas obtained from utilities, local distribution companies, and any other supplier(s), such as independent gas producers, gas brokers, marketers, and any marketing subsidiaries of utilities.

[d] Examples of liquefied petroleum gases (LPGs) are ethane, ethylene, propane, propylene, normal butane, butylene, ethane-propane mixtures, propane-butane mixtures, and isobutene produced at refineries or natural gas processing plants, including plants that fractionate raw natural gas liquids (NGLs).

[e] 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.

* Estimate less than 0.5.
Q = Withheld because relative standard error is greater than 50%.

Sources: U.S. Department of Energy, Energy Information Administration. 2007. "2002 Energy Consumption by Manufacturers—Data Tables." Tables 3.2 and N3.2. <http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html>. Washington, DC: DOE.

U.S. Department of Energy, Energy Information Administration. 2007b. "2006 Energy Consumption by Manufacturers—Data Tables." Tables 3.1. <http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html>. [Source for 2006 numbers]

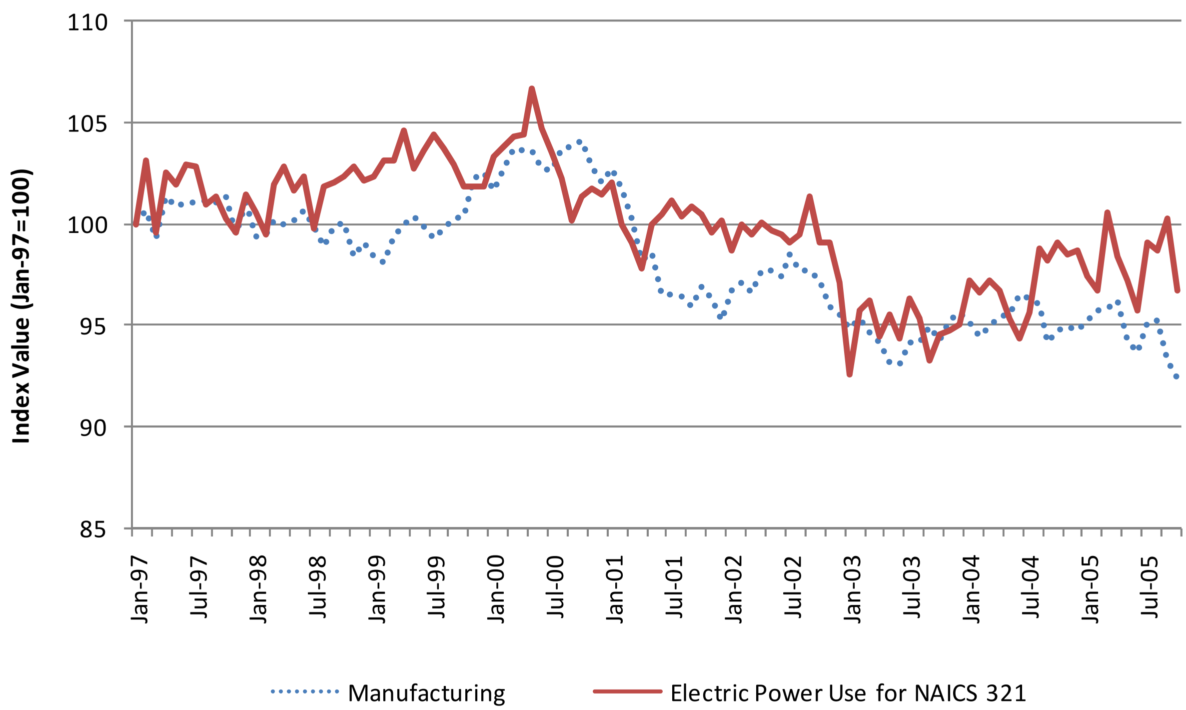


**Figure 2-13. Electrical Power Use Trends in the Wood Product Manufacturing Industry (NAICS 321): 1997–2005**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009.

### *2.2.3 Firm and Market Characteristics*

This section describes geographic, production, and market data. These data provide the basis for further analysis, including regulatory flexibility analyses, as well as a complete picture of the recent historical trends of production and pricing.

#### *2.2.3.1 Location*

As Figure 2-14 illustrates, the states with the largest number of wood product manufacturing establishments are dispersed throughout the country, with a significant concentration of establishments in the northeastern states. Other states with many establishments include California, Texas, and North Carolina.

**Table 2-16. Demand by Sector: Wood Product Manufacturing (NAICS 321) ($2007, millions)**

| Sector | BEA Code | 3210 Wood Products |
|---|---|---|
| New residential construction | 2302 | $19,997 |
| New nonresidential construction | 2301 | $11,854 |
| Furniture and related product manufacturing | 3370 | $8,197 |
| Maintenance and repair construction | 2303 | $4,048 |
| Motor vehicle body, trailer and parts manufacturing | 336A | $2,516 |
| Real estate | 5310 | $2,335 |
| Food services and drinking places | 7220 | $2,307 |
| Other miscellaneous manufacturing | 3399 | $1,311 |
| Wholesale trade | 4200 | $1,284 |
| Rail transportation | 4820 | $1,138 |
| Retail trade | 4A00 | $1,047 |
| Plastics and rubber products manufacturing | 3260 | $877 |
| General state and local government use | S007 | $3,116 |
| Owner occupied dwelling | S008 | $11,209 |
| Private fixed investment | F020 | $7,933 |
| Exports of goods and services | F040 | $3,978 |
| Total final uses (gross domestic product [GDP]) | T004 | $3,719 |
| Total commodity output | T007 | $101,753 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

### *2.2.3.2 Production Capacity and Utilization*

Capacity utilization of the wood product manufacturing industry has been experiencing capacity utilization increases and declines with more extreme fluctuations than those of all manufacturing industries combined. The decline in wood product manufacturing is similar to total manufacturing between 1997 and 2002. However, capacity utilization in total manufacturing, which peaked in 2006, started increasing at a faster rate than wood product manufacturing, but decreased sharply after its peak. Wood product manufacturing experienced its own rapid decrease in capacity utilization between 2007 and 2009, though not at the same rate as total manufacturing (Figure 2-15).

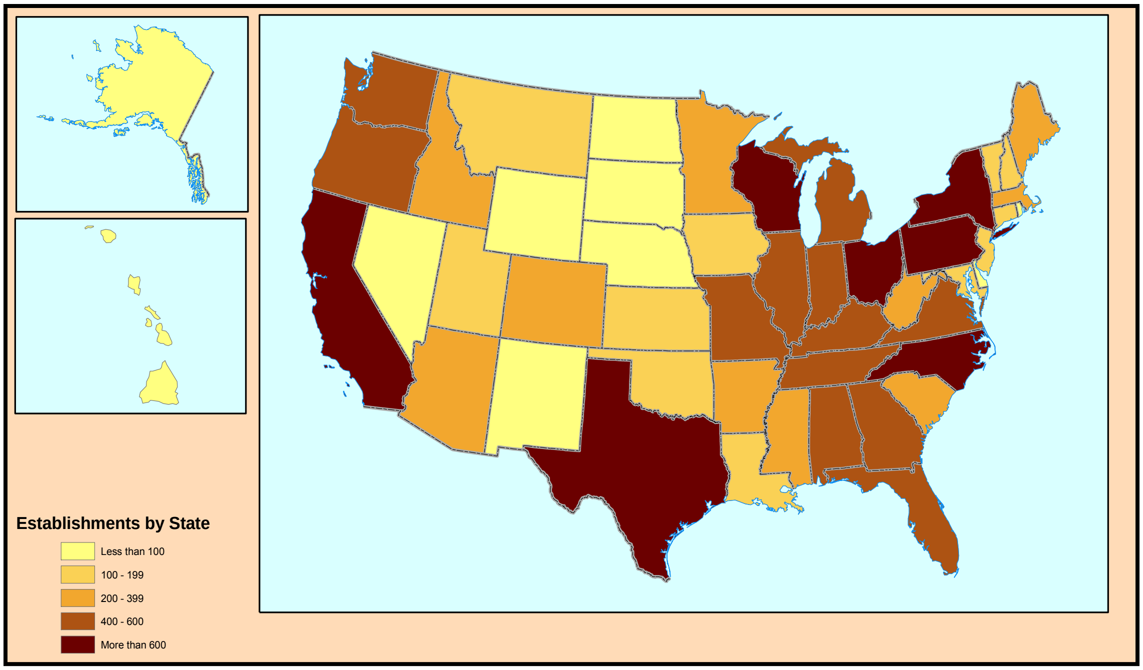


**Figure 2-14. Establishment Concentration in the Wood Product Manufacturing Industry (NAICS 321): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002.” <http://factfinder.census.gov>; (July 23, 2008).

### *2.2.3.3 Employment*

California has the largest number of employees in the wood product manufacturing industry with over 39,000 reported in the 2002 census followed by over 32,000 in Oregon (Figure 2-17). The states with the highest number of employees do not directly correlate with the states with the highest number of establishments. States such as Indiana, Georgia, Arkansas, and Oregon had fewer than 600 establishments, as shown in Figure 2-14, but had more than 20,000 employees, whereas states such as Ohio and New York had fewer than 20,000 employees but more than 600 establishments.

### *2.2.3.4 Plants and Capacity*

While the capacity of the manufacturing sector has been growing consistently since 1997, the wood product manufacturing industry has experienced inconsistent growth. After a small amount of growth in capacity between 1997 and 2001, the wood product manufacturing industry’s capacity dipped between 2002 and 2005 but has been growing at a slow rate since then though it started to dip again in 2008 and 2009 (Figure 2-17).


**Figure 2-15. Capacity Utilization Trends in the Wood Product Manufacturing Industry (NAICS 321)**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009.

*2.2.3.5 Firm Characteristics*

In 2006, the top 10 paper and forest product companies produced over $75 billion in sales, with the top two companies—International Paper and Weyerhaeuser—generating nearly $22 billion each (Table 2-17. The top two companies' revenue consists of 58% of the revenue of the top 10 companies in Standard & Poor's (S&P's) list (Benwart, 2006). Although these numbers do not exclusively reflect wood products, they do convey the market environment in which firms in this sector compete.

*2.2.3.6 Size Distribution*

The primary criterion for categorizing a business as small is the number of employees, using definitions by the SBA for regulatory flexibility analyses. According to SUSB reports for 2002, small companies were the recipients of the majority of receipts in 2002; 53% of receipts were generated by companies with fewer than 500 employees (Table 2-18). The number of employees in the small business cutoff is 500 employees for all subindustries in the wood product manufacturing industry (Table 2-19).

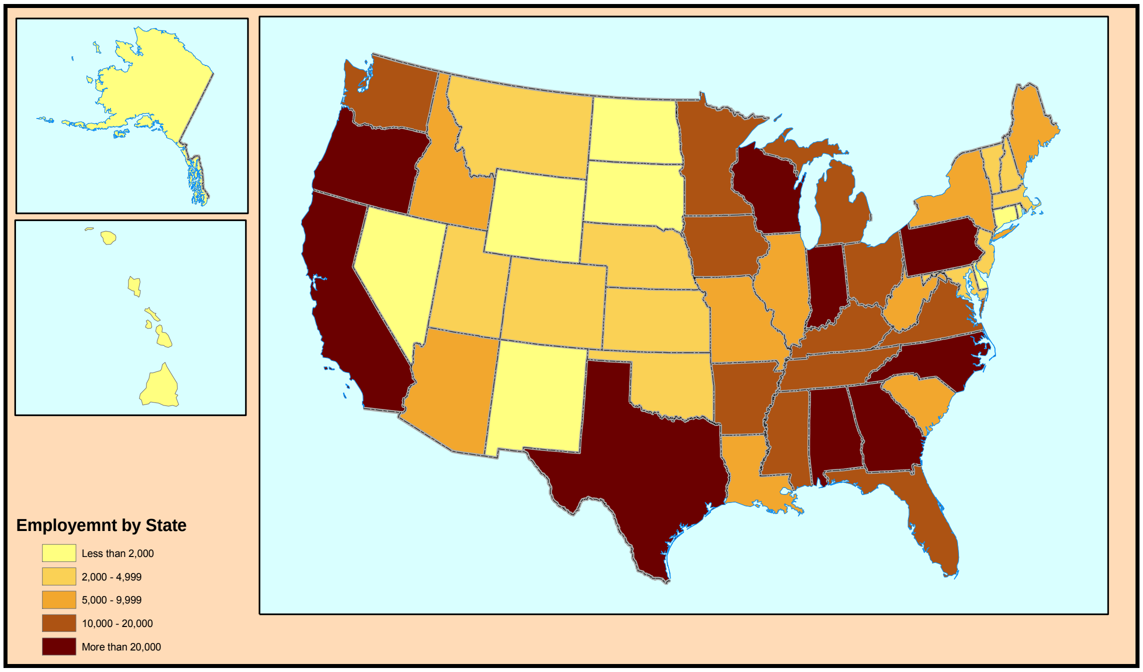


**Figure 2-16. Employment Concentration in the Wood Product Manufacturing Industry (NAICS 321): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

*2.2.3.7 Domestic Production*

Similar to industry capacity rates, industry production rates for wood product manufacturing have decreased since 2006 compared to the steady increase in production for the manufacturing sector since 1997 (Figure 2-18). Similar to capacity utilization trends (Figure 2-16), the index shows a faster rate of decline for wood products than the entire manufacturing sector.

*2.2.3.8 International Trade*

Since 1997, the wood product manufacturing industry has contributed to an increasing trade deficit (Figure 2-16). The value of imports has fluctuated greatly since 1997; however, exports have remained fairly constant, with seasonal changes, since 1997.

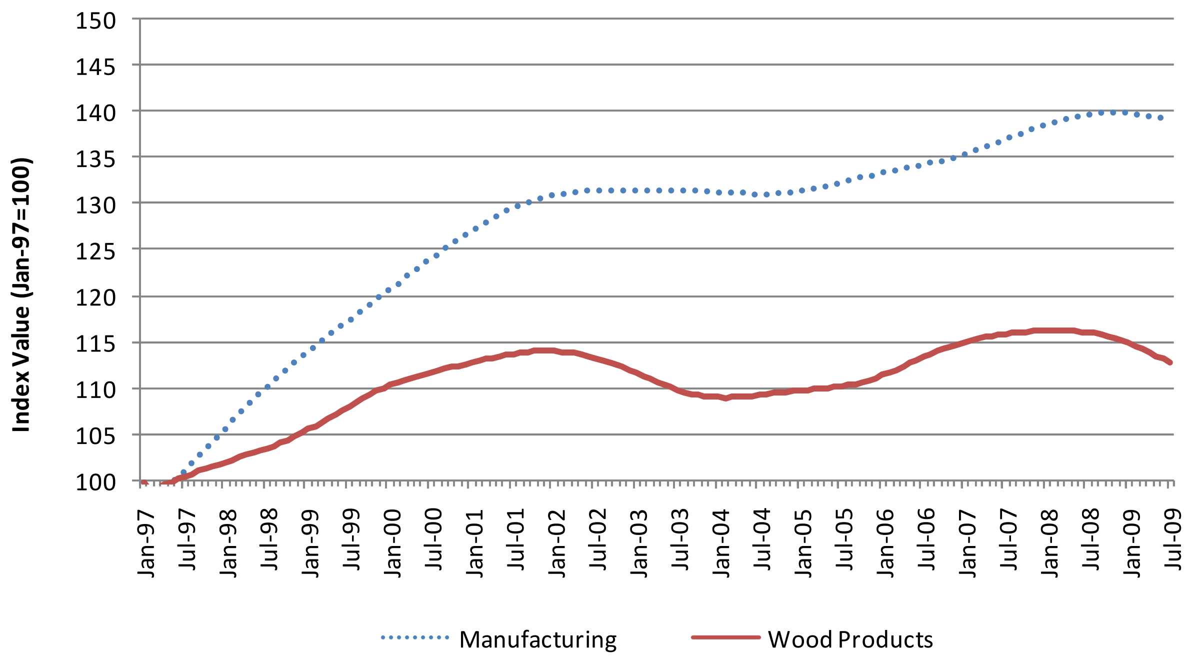


**Figure 2-17. Capacity Trends in the Wood Product Manufacturing Industry (NAICS 321)**

Source: Federal Reserve Board. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009.

**Table 2-17. Largest U.S. Paper and Forest Products Companies: 2006**

| Company | Revenues ($millions)[a] |
|---|---|
| International Paper | 21,995 |
| Weyerhaeuser | 21,896 |
| Smurfit-Stone | 7,157 |
| MeadWestvaco | 6,530 |
| Temple-Inland | 5,558 |
| Bowater | 3,530 |
| Grief Inc. | 2,628 |
| Louisiana-Pacific | 2,235 |
| Packaging Corp. | 2,187 |
| Plum Creek | 1,627 |

[a] Includes revenues from operations other than paper and forest products in certain cases.

Source: Benwart, S.J. 2006. "Paper & Forest Products." *Standard and Poor's Industry Surveys*. 176(28).

## Table 2-18. Distribution of Economic Data by Enterprise Size: Wood Product Manufacturing (NAICS 321)

| Variable | Total | Enterprises with | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 to 20 Employees[a] | 20 to 99 Employees | 100 to 499 Employees | 500 to 749 Employees | 750 to 999 Employees | 1,000 to 1,499 Employees |
| Firms | 15,198 | 9,740 | 3,280 | 791 | 63 | 27 | 30 |
| Establishments | 17,052 | 9,758 | 3,482 | 1,271 | 166 | 91 | 133 |
| Employment | 534,011 | 65,423 | 132,612 | 118,910 | 19,784 | 11,944 | 18,533 |
| Receipts ($thousands ) | $88,649 | $8,204 | $18,276 | $19,717 | $3,192 | $1,902 | $3,118 |
| Receipts/firm ($thousands) | $5,833 | $842 | $5,572 | $24,927 | $50,673 | $70,453 | $103,927 |
| Receipts/establishment ($thousands) | $5,199 | $841 | $5,249 | $15,513 | $19,231 | $20,904 | $23,442 |
| Receipts/employment ($) | $166,006 | $125,393 | $137,818 | $165,814 | $161,363 | $159,262 | $168,231 |

[a] Excludes *Statistics of U.S. Businesses* (SUSB) employment category for zero employees. These entities only operated for a fraction of the year.

Source: U.S. Census Bureau. 2008. "Firm Size Data from the Statistics of U.S. Businesses: U.S. Detail Employment Sizes: 2002." <http://www.census.gov/csd/susb/download_susb02.htm>.

**Table 2-19. Small Business Size Standards: Wood Product Manufacturing (NAICS 321)**

| NAICS | NAICS Description | Employees |
|---|---|---|
| 321113 | Sawmills | 500 |
| 321114 | Wood Preservation | 500 |
| 321211 | Hardwood Veneer and Plywood Manufacturing | 500 |
| 321212 | Softwood Veneer and Plywood Manufacturing | 500 |
| 321213 | Engineered Wood Member (except Truss) Manufacturing | 500 |
| 32121 | Truss Manufacturing | 500 |
| 321219 | Reconstituted Wood Product Manufacturing | 500 |
| 321911 | Wood Window and Door Manufacturing | 500 |
| 321912 | Cut Stock, Resawing Lumber, and Planing | 500 |
| 321918 | Other Millwork (including Flooring) | 500 |
| 321920 | Wood Container and Pallet Manufacturing | 500 |
| 321991 | Manufactured Home (Mobile Home) Manufacturing | 500 |
| 321992 | Prefabricated Wood Building Manufacturing | 500 |
| 321999 | All Other Miscellaneous Wood Product Manufacturing | 500 |

Source: U.S. Small Business Administration (SBA). 2008. "Table of Small Business Size Standards Matched to North American Industry Classification System Codes." Effective August 22, 2008. <http://www.sba.gov/services/contractingopportunities/sizestandardstopics/size/index.html>.

### *2.2.3.9 Market Prices*

Prices of goods in the wood product manufacturing industry have remained roughly the same since 2005. The prices for the entire manufacturing sector increased between 2003 and 2008 but have decreased since August 2008. Producer price indices (PPIs) show that producer prices for wood products increased by 6% from 2004 to 2007 (Figure 2-20).

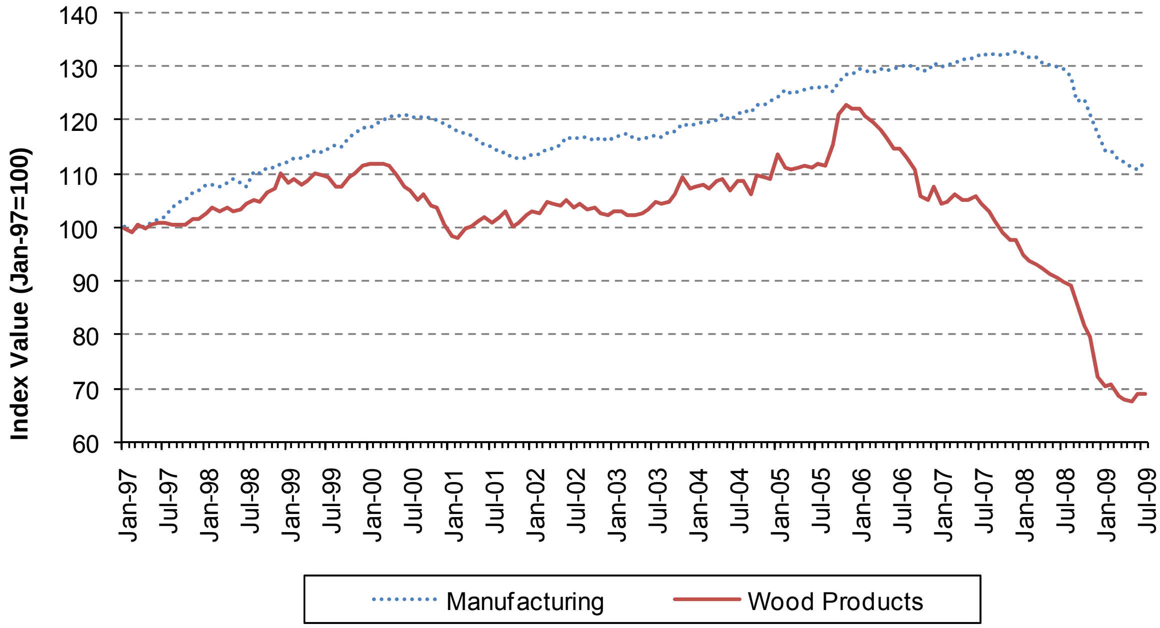


**Figure 2-18. Industrial Production Trends in the Wood Product Manufacturing Industry (NAICS 321): 1997–2009**

Source: Federal Reserve Board. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009.

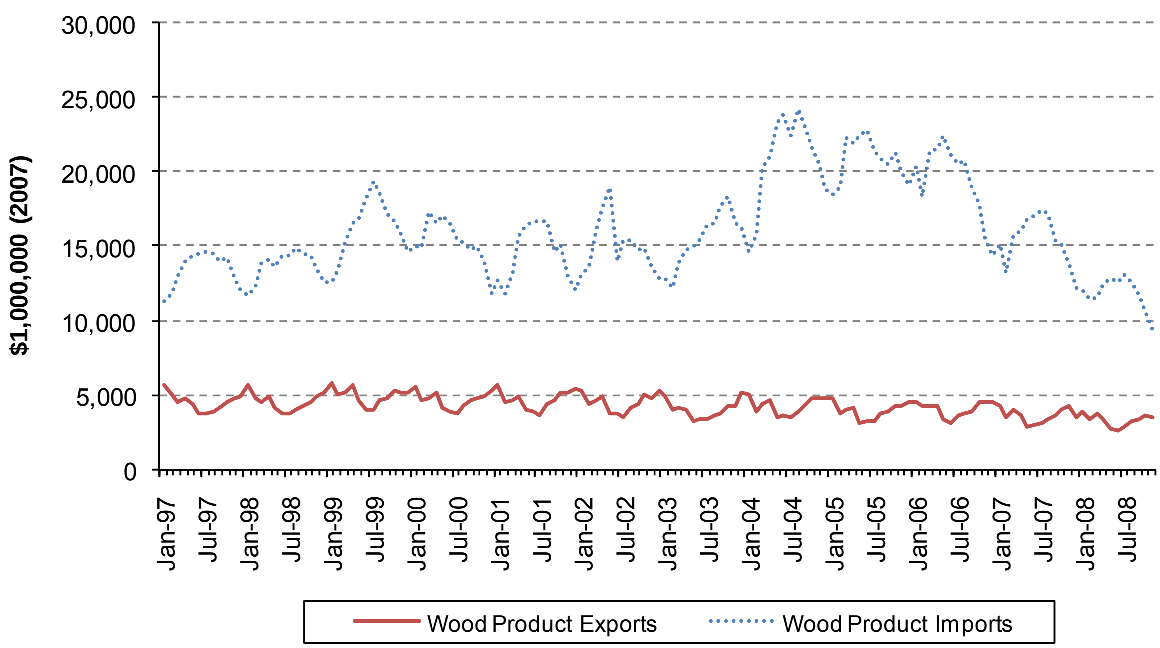


**Figure 2-19. International Trade Trends in the Wood Product Manufacturing Industry (NAICS 321)]**

Source: U.S. International Trade Commission. 2008a. "U.S. Domestic Exports" & "U.S. Imports for Consumption." <http://dataweb.usitc.gov/scripts/user_set.asp>; (July 17, 2008).

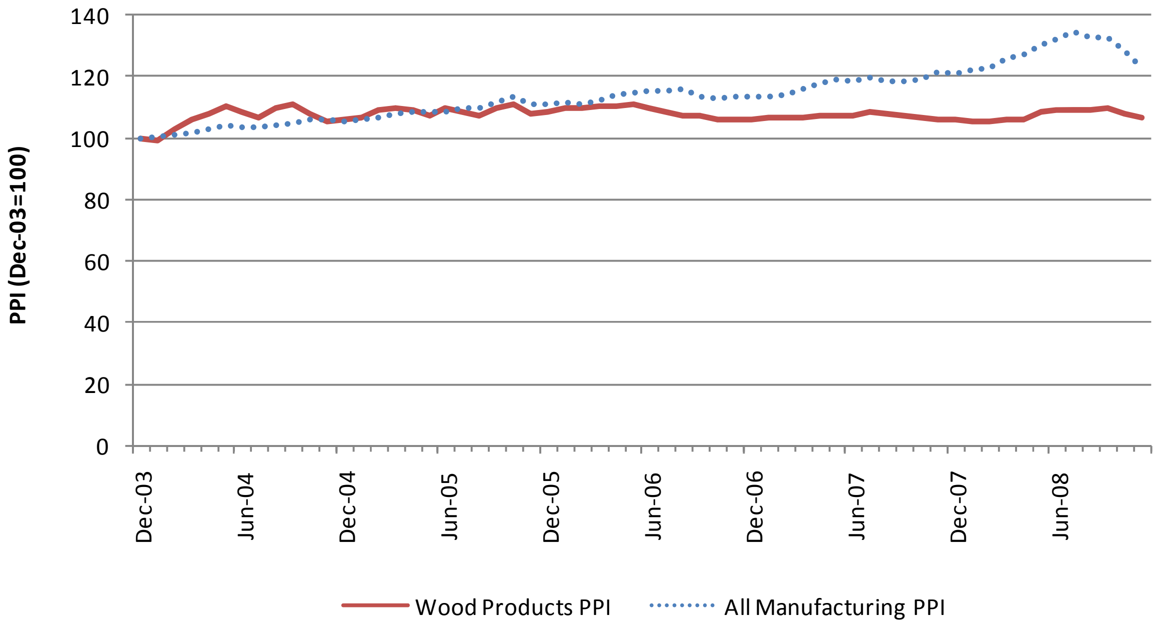


**Figure 2-20. Producer Price Trends in the Wood Product Manufacturing Industry (NAICS 321)**

Source: U.S. Bureau of Labor Statistics (BLS). 2009. "Producer Price Index." Series ID: PCU321—321—& PCUOMFG—OMFG—. <http://www.bls.gov/ppi/home.htm>. Accessed on January 8, 2010.

## 2.3 Paper Manufacturing

### *2.3.1 Introduction*

The paper manufacturing subsector is an essential component of all business operations worldwide. Broadly speaking, paper and paperboard are manufactured by converting timber or other recycled material into products such as printing and writing papers, newsprint, tissue, and containerboard (Benwart, 2006). The subsector has been experiencing a decline in shipments as of late. From 1997 to 2007, shipments in the industry declined 7%, and employment declined by 27% (Table 2-21). While total payroll dropped 26% over this time, annual payroll per employee rose 2% from 1997 to 2007 because of the decline in the number of employees (Table 2-20). Shipments per employee grew 28% from 1997 to 2007, with much of that growth taking place between 2002 and 2006 (Table 2-21).

### Table 2-20. Key Statistics: Paper Manufacturing (NAICS 322)

| | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Shipments ($2007, millions) | $188,496 | $175,983 | $174,887 | $175,806 |
| Payroll ($2007, millions) | $27,983 | $24,561 | $21,188 | $20,804 |
| Employees | 574,274 | 489,367 | 414,049 | 416,886 |
| Establishments | 5,868 | 5,495 | NA | 4,803 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." Accessed on December 28, 2009. [Source for 2007 numbers]

### Table 2-21. Industry Data: Paper Manufacturing (NAICS 322)

| Industry Data | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Total shipments ($2007, millions) | $188,496 | $175,983 | $174,887 | $175,806 |
| Shipments per establishment ($2007, thousands) | $32,123 | $32,026 | NA | $36,603 |
| Average Shipments per employee ($2007) | $328,233 | $359,614 | $422,381 | $421,712 |
| Average Shipments per $ of payroll ($2007) | $6.74 | $7.17 | $8.25 | $8.45 |
| Average Annual payroll per employee ($2007) | $48,727 | $50,189 | $51,174 | $49,904 |
| Average Employees per establishment | 98 | 89 | NA | 87 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." <http://factfinder.census.gov>. Accessed on December 28, 2009. [Source for 2007 numbers]

The U.S. Census Bureau categorizes this industry's facilities into two categories: pulp, paper, and paperboard manufacturing and converted paper product manufacturing. These are further divided into the following types of facilities as defined by the Census Bureau (2001):

- Pulp, Paper, and Paperboard:
  - Pulp Mills (NAICS 32211): This industry comprises establishments primarily engaged in manufacturing pulp without manufacturing paper or paperboard. The pulp is made by separating the cellulose fibers from the other impurities in wood or other materials, such as used or recycled rags, linters, scrap paper, and straw.
  - Paper Mills (NAICS 32212): This industry comprises establishments primarily engaged in manufacturing paper from pulp. These establishments may manufacture or purchase pulp. In addition, the establishments may convert the paper they make. The activity of making paper classifies an establishment into this industry regardless of the output.
  - Paperboard Mills (NAICS 32213): This industry comprises establishments primarily engaged in manufacturing paperboard from pulp. These establishments may manufacture or purchase pulp. In addition, the establishments may also convert the paperboard they make.
- Converted Paper Products:
  - Paperboard Containers Manufacturing (NAICS 32221): This industry comprises establishments primarily engaged in converting paperboard into containers without manufacturing paperboard. These establishments use corrugating, cutting, and shaping machinery to form paperboard into containers. Products made by these establishments include boxes; corrugated sheets, pads, and pallets; paper dishes; and fiber drums and reels.
  - Paper Bag and Coated and Treated Paper Manufacturing (NAICS 32222): This industry comprises establishments primarily engaged in one or more of the following manufacturing activities: cutting and coating paper and paperboard; cutting and laminating paper and paperboard and other flexible materials (except plastics film to plastics film); bags or multiwall bags or sacks of paper, metal foil, coated paper, or laminates or coated combinations of paper and foil with plastics film; laminated aluminum and other converted metal foils from purchased foils; and surface coating paper or paperboard.
  - Stationary Product Manufacturing (NAICS 32223): This industry comprises establishments primarily engaged in converting paper or paperboard into products used for writing, filing, art work, and similar applications.
  - Other Converted Paper Products (NAICS 32229): This industry comprises establishments primarily engaged in one of the following manufacturing activities:
    - converting paper and paperboard into products (except containers, bags, coated and treated paper and paperboard, and stationery products), or

- converting pulp into pulp products, such as disposable diapers, or molded pulp egg cartons, food trays, and dishes.

Figure 2-21 shows that the value of shipments for converted paper products was 54% of the value of all paper products in 2007, while the value of shipments for pulp, paper, and paperboard products was 46%. Figure 2-22 indicates that 70% of industry employees worked in the converted paper product category of the industry due to the labor intensive aspects of those facilities.

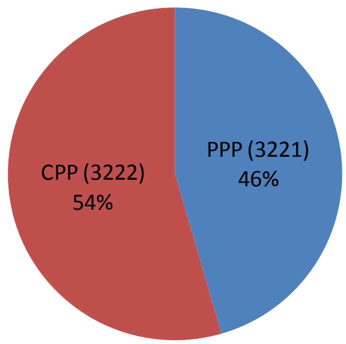


**Figure 2-21. Distribution of Value of Shipments within Paper Manufacturing (NAICS 322): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder: "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." Accessed on December 28, 2009.

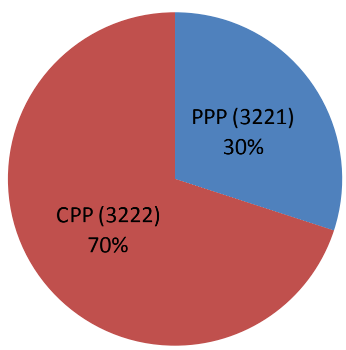


**Figure 2-22. Distribution of Employment within Paper Manufacturing (NAICS 322): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." <http://factfinder.census.gov>. Accessed on December 28, 2009.

### 2.3.2 Supply and Demand Characteristics

Next, we provide a broad overview of the supply and demand sides of the paper manufacturing industry. We emphasize the economic interactions this industry has with other industries and people and identify the key goods and services used by the industry and the major uses and consumers of paper manufacturing products.

#### *2.3.2.1 Goods and Services Used in Paper Manufacturing*

In 2007, the cost of materials made up 53% of the total shipment value of goods in the paper manufacturing industry (Table 2-22). Total compensation of employees represented 15% of the total value in 2007, down from 17% in 2005. The total number of employees dropped by 2%, between 2005 and 2007, while shipments increased by 3% in the same period.

The top 10 industry groups supplying inputs to the paper manufacturing subsector accounted for 70% of the total intermediate inputs according to 2008 Bureau of Economic Analysis (BEA) data (Table 2-23). Inputs for pulp, paper, and paperboard products are notably different from inputs for converted paper products because the NAICS 3221 group represents the initial step in the paper manufacturing process; thus, its inputs include more raw resources such as wood products, forestry and logging products, natural gas, and electricity. This becomes evident when observing inputs for converted paper products: 49% of the cost of inputs comes from pulp, paper, and paperboard products.

***2.3.2.1.1 Energy***. The Department of Energy (DOE) categorizes paper manufacturing (NAICS 322) as an energy-intensive subsector. The 2008 Annual Energy Outlook predicts that the paper-producing subsector will be one of four subsectors experiencing positive average growth of delivered energy consumption between 2006 and 2030 (DOE, 2008).

Energy generation from the recovery boiler is often insufficient for total plant needs, so facilities augment recovery boilers with fossil fuel–fired and wood waste–fired boilers (hogged fuel) to generate steam and often electricity. Industry wide, the use of pulp wastes, bark, and other papermaking residues supplies 58% of the energy requirements of pulp and paper companies (EPA, 2002).

Likewise, Table 2-24 shows that total energy use decreased between 1998 and 2006 by 14%. Figure 2-24 indicates that total electrical power use changed sporadically between 2002 and 2004 but decreased consistently and rapidly after 2004.

**Table 2-22. Costs of Goods and Services Used in the Paper Manufacturing Industry (NAICS 322)**

| Variable | 2005 | Share | 2006 | Share | 2007 | Share |
|---|---|---|---|---|---|---|
| Total shipments ($2007, millions) | $171,477 | 100% | $174,887 | 100% | $176,018 | 100% |
| Total compensation ($2007, millions) | $28,846 | 17% | $27,791 | 16% | $27,150 | 15% |
| Annual payroll | $21,792 | 13% | $21,188 | 12% | $20,804 | 12% |
| Fringe benefits | $7,054 | 4% | $6,603 | 4% | $6,346 | 4% |
| Total employees | 426,748 | | 414,049 | | 417,367 | |
| Average compensation per employee | $67,596 | | $67,121 | | $65,051 | |
| Total production workers wages ($2007, millions) | $14,965 | 9% | $14,689 | 8% | $14,190 | 8% |
| Total production workers | 331,228 | | 321,684 | | 321,937 | |
| Total production hours (thousands) | 716,963 | | 691,134 | | 680,732 | |
| Average production wages per hour | $21 | | $21 | | $21 | |
| Total cost of materials ($2007, thousands) | $91,897 | 54% | $92,452 | 53% | $94,029 | 53% |
| Materials, parts, packaging | $77,494 | 45% | $78,202 | 45% | $79,984 | 45% |
| Purchase electricity | $3,788 | 2% | $3,841 | 2% | $3,780 | 2% |
| Purchased fuel ($2007) | $5,537 | 3% | $5,509 | 3% | $5,511 | 3% |
| Other | $5,078 | 3% | $4,901 | 3% | $4,755 | 3% |

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; “Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007.” <http://factfinder.census.gov>. Accessed on December 28, 2009. [Source for 2007 numbers]

**Table 2-23. Key Goods and Services Used in the Paper Manufacturing Industry (NAICS 322) ($millions, $2007)**

| Description | BEA Code | NAICS 3221 Pulp, Paper, and Paperboard | NAICS 3222 Converted Paper Products | Total |
|---|---|---|---|---|
| Pulp, paper, and paperboard | 3221 | $4,155 | $30,448 | $34,603 |
| Wholesale trade | 4200 | $3,916 | $6,356 | $10,273 |
| Management of companies and enterprises | 5500 | $3,154 | $3,838 | $6,993 |
| Forestry and logging products | 1130 | $5,389 | $0 | $5,389 |
| Basic chemicals | 3251 | $3,734 | $263 | $3,997 |
| Electric power generation, transmission, and distribution | 2211 | $2,690 | $913 | $3,603 |
| Wood products | 3210 | $3,450 | $33 | $3,484 |
| Converted paper products | 3222 | $1,415 | $1,745 | $3,159 |
| Natural gas distribution | 2212 | $2,680 | $345 | $3,026 |
| Truck transportation | 4840 | $1,428 | $1,571 | $2,999 |
| Total intermediate inputs | T005 | $47,835 | $62,690 | $110,525 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

**Table 2-24. Energy Used in Paper Manufacturing (NAICS 322)**

| Fuel Type | 1998 | 2002 | 2006 |
|---|---|---|---|
| Net electricity[a] (million kWh) | 70,364 | 65,503 | 72,518 |
| Residual fuel oil (million bbl) | 24 | 16 | 15 |
| Distillate fuel oil[b] (million bbl) | 2 | 2 | 2 |
| Natural gas[c] (billion cu ft) | 570 | 490 | 461 |
| LPG and NGL[d] (million bbl) | 1 | 2 | 1 |
| Coal (million short tons) | 12 | 11 | 10 |
| Coke and breeze (million short tons) | — | * | — |
| Other[e] (trillion BTU) | 1,476 | 1,276 | 1,303 |
| Total (trillion BTU) | 2,744 | 2,361 | 2,354 |

[a] Net electricity is obtained by summing purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. It does not include electricity inputs from on-site cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).

[b] Distillate fuel oil includes Nos. 1, 2, and 4 fuel oils and Nos. 1, 2, and 4 diesel fuels.

[c] Natural gas includes natural gas obtained from utilities, local distribution companies, and any other supplier(s), such as independent gas producers, gas brokers, marketers, and any marketing subsidiaries of utilities.

[d] Examples of liquefied petroleum gases (LPG) are ethane, ethylene, propane, propylene, normal butane, butylene, ethane-propane mixtures, propane-butane mixtures, and isobutene produced at refineries or natural gas processing plants, including plants that fractionate raw natural gas liquids (NGLs).

[e] 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.

* Estimate less than 0.5.

Sources: U.S. Department of Energy, Energy Information Administration. 2007. "2002 Energy Consumption by Manufacturers—Data Tables." Tables 3.2 and N3.2. <http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html>. Washington, DC: DOE.

U.S. Department of Energy, Energy Information Administration. 2007b. "2006 Energy Consumption by Manufacturers—Data Tables." Table 3.1. <http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html>. Accessed on December 27, 2009. [Source for 2006 numbers]

Over the last 25 years, the pulp and paper subsector has changed its energy generation methods from fossil fuels to a greater use of processes such as increases in the use of wood wastes in place of fuel (Table 2-25). During the 1972–1999 period, the proportion of total industry power generated from the combination of woodroom wastes, spent liquor solids, and other self-generated methods increased from about 41% to about 56%, while coal, fuel oil, and natural gas use decreased from about 54% to about 36% (EPA, 2002).

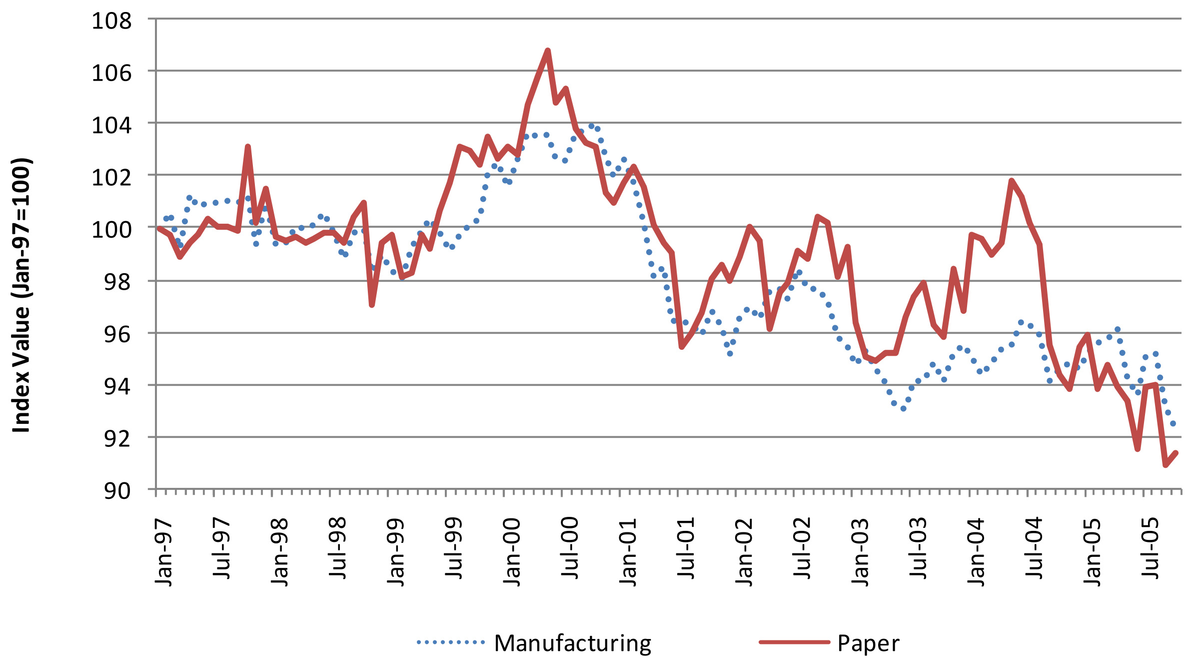


**Figure 2-23. Electrical Power Use Trends in the Paper Manufacturing Industry: 1997–2005**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G322.S. <http://www.federalreserve.gov/datadownload/>.

**Table 2-25. Estimated Energy Sources for the U.S. Pulp and Paper Industry**

| Energy Source | 1972 | 1979 | 1990 | 1999 |
|---|---|---|---|---|
| Purchased steam | 5.4% | 6.7% | 7.3% | 1.5% |
| Coal | 9.8% | 9.1% | 13.7% | 12.5% |
| Fuel oil | 22.3% | 19.1% | 6.4% | 6.3% |
| Natural gas | 21.5% | 17.8% | 16.4% | 17.6% |
| Other purchased energy | — | — | — | 6.7% |
| Waste wood and wood chips (hogged fuel) and bark | 6.6% | 9.2% | 15.4% | 13.5% |
| Spent liquor solids | 33.7% | 37.3% | 39.4% | 40.3% |
| Other self-generated power | 0.6% | 0.8% | 1.2% | 1.6% |

Source: U.S. Environmental Protection Agency. 2002. "Profile of the Pulp and Paper Industry." Sector Notebook Project. <http://www.epa.gov/Compliance/resources/publications/assistance/sectors/notebooks/index.html>.

*2.3.2.2 Uses and Consumers*

Products manufactured in the NAICS groups 3221 and 3222 have different, but complementary, consumer profiles. NAICS 3221 supplies a significant portion of NAICS 3222 demand (37% of total commodity output). Both industries specialize in products with intermediate uses, with an average of 92% of sales between the two going toward this purpose. NAICS 3222 has a very diverse assortment of subsector groups from which it receives demand. Food manufacturing makes up 21% of the demand, making members of this industry the largest consumer of converted paper products (Table 2-26). Pulp, paper, and paperboard products have a large trade deficit, while converted paper products have a very small trade surplus.

**Table 2-26. Demand by Sector: Paper Manufacturing Industry (NAICS 322) ($millions, $2007)**

| Sector | BEA Code | 3221 Pulp, Paper, and Paperboard | 3222 Converted Paper Products | Total |
|---|---|---|---|---|
| Converted paper product manufacturing | 3222 | $30,448 | $1,745 | $32,193 |
| Food manufacturing | 3110 | $638 | $18,782 | $19,421 |
| Printing and related support activities | 3230 | $13,320 | $3,874 | $17,194 |
| General state and local government services | S007 | $6,065 | $7,792 | $13,857 |
| Pulp, paper, and paperboard mills | 3221 | $4,155 | $1,415 | $5,569 |
| Newspaper, periodical, book, and directory publishers | 5111 | $4,851 | $168 | $5,018 |
| Plastics and rubber products manufacturing | 3260 | $1,249 | $3,403 | $4,651 |
| Wholesale trade | 4200 | $990 | $2,619 | $3,609 |
| Food services and drinking places | 7220 | $1,510 | $2,597 | $4,107 |
| Total intermediate use | T001 | $76,729 | $80,862 | $157,591 |
| Personal consumption expenditures | F010 | $11,882 | $9,295 | $21,177 |
| Exports of goods and services | F040 | $7,724 | $5,799 | $13,523 |
| Imports of goods and services | F050 | −$15,284 | −$5,720 | −$21,005 |
| Total final uses (GDP) | T004 | $4,996 | $9,607 | $14,604 |
| Total commodity output | T007 | $81,725 | $90,469 | $172,195 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

### 2.3.3 *Firm and Market Characteristics*

This section describes geographic, production, and market data. These data provide the basis for further analysis, including regulatory flexibility analyses, and give a complete picture of the recent historical trends of production and pricing.

*2.3.3.1 Location*

As Figure 2-24 illustrates, California is home to the most paper manufacturing establishments in the United States, followed by Illinois and some bordering northeastern states. The location of establishments in the paper manufacturing industry varies a great deal by subsector. Wisconsin and New York have the most pulp, paper, and paperboard establishments, while California dominates with over 500 converted paper product establishments. Overall, the United States has 561 pulp, paper, and paperboard establishments and 4,956 converted paper product establishments.

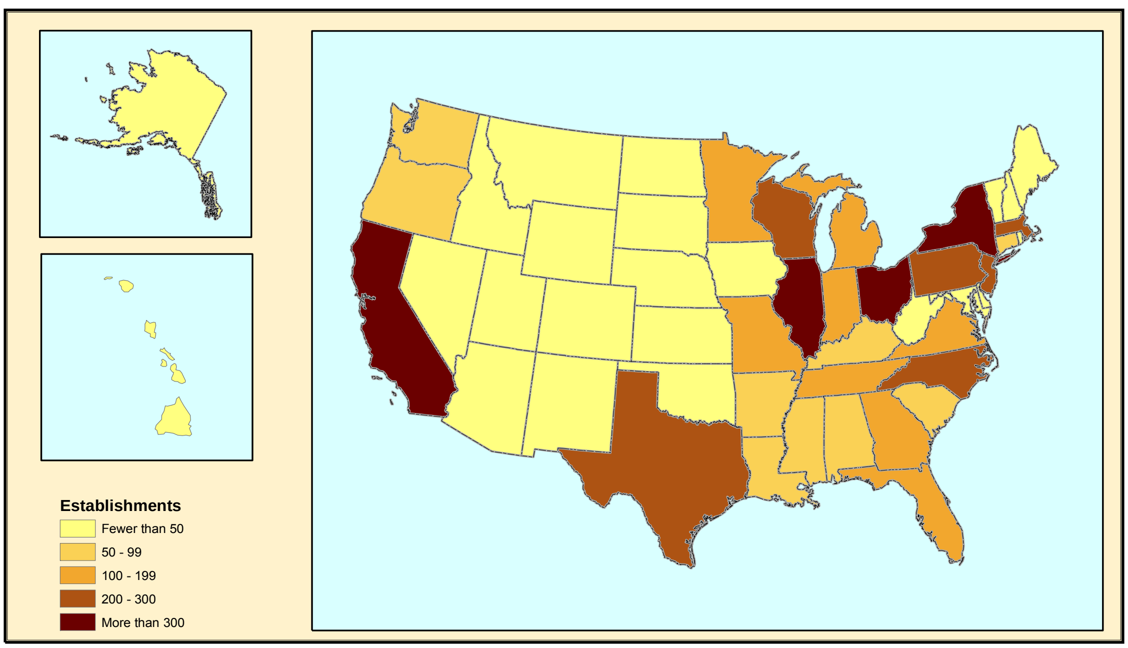


**Figure 2-24. Establishment Concentration in Paper Manufacturing Industry (NAICS 322): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; “Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002.” <http://factfinder.census.gov>; (July 23, 2008).

*2.3.3.2 Production Capacity and Utilization*

Capacity utilization of the paper manufacturing subsector has been experiencing a steady decline, similar to the decline of the total manufacturing sector. However, paper manufacturing has managed to use its capacity at a consistently higher rate than the average for manufacturing industries (Figure 2-25).

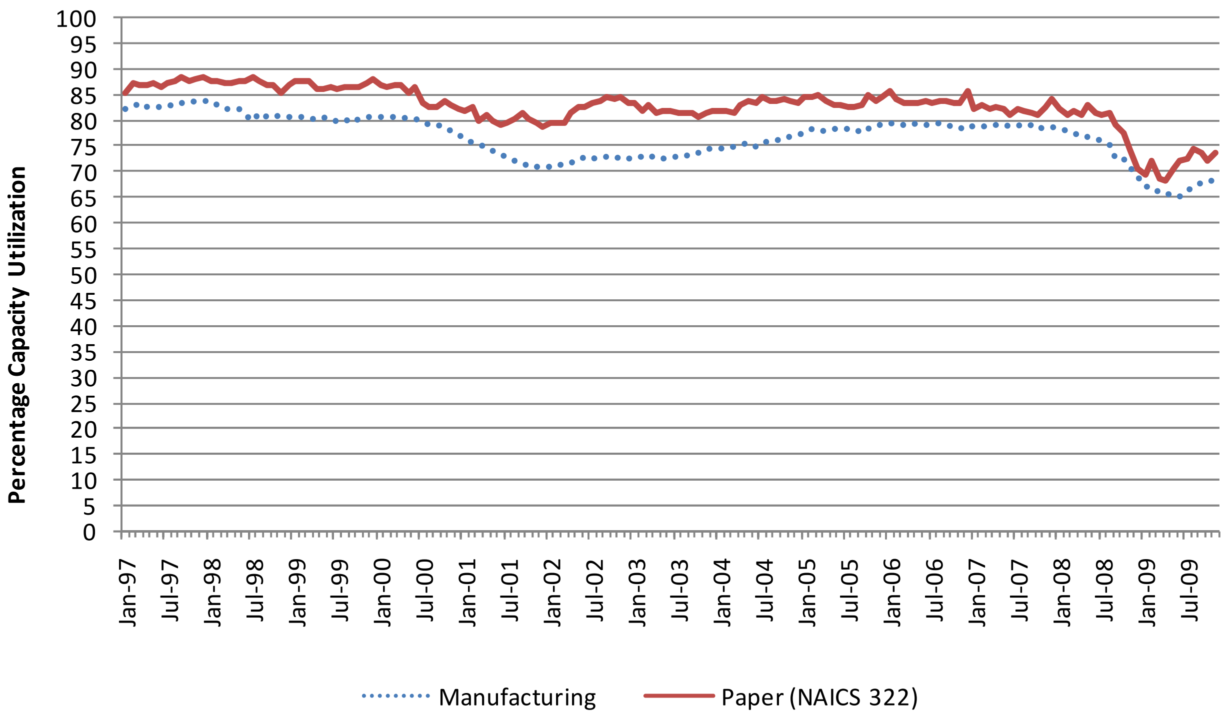


**Figure 2-25. Capacity Utilization Trends in the Paper Manufacturing Industry (NAICS 322)**

Source: Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G322.S. <http://www.federalreserve.gov/datadownload/>.

*2.3.3.3 Employment*

Wisconsin has the largest number of employees in the paper manufacturing subsector with over 38,008 reported in the 2002 census followed by 29,379 in California (Figure 2-26). The converted paper products group has more employees per establishment, 283, than the pulp, paper, and paperboard group, 67.

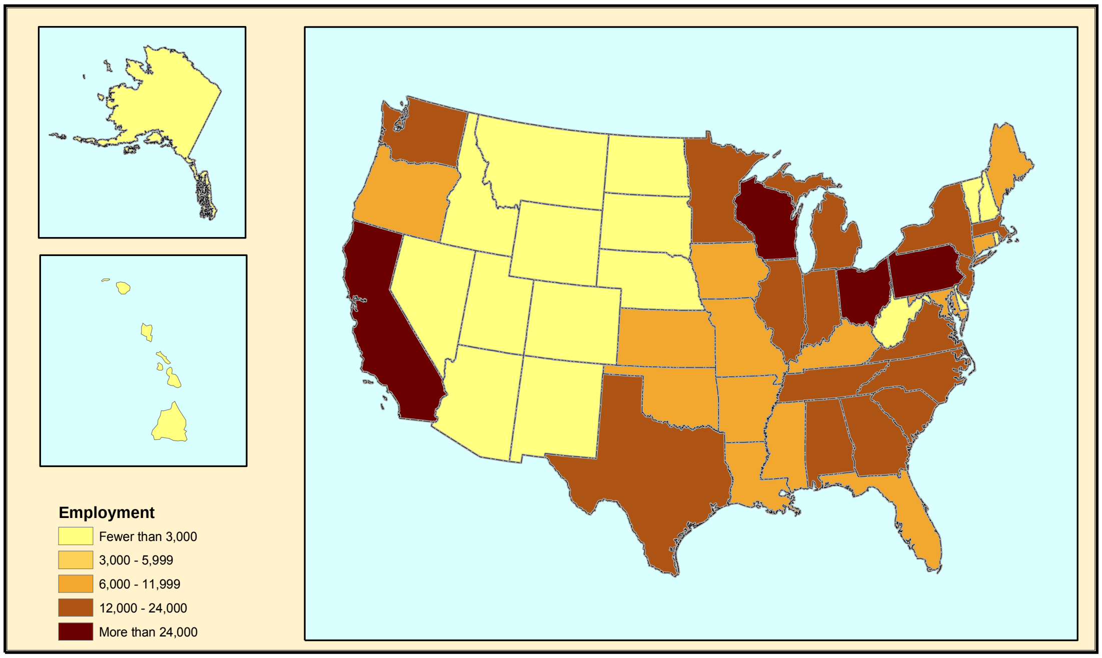


**Figure 2-26. Employment Concentration in the Paper Manufacturing Industry (NAICS 322): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

### *2.3.3.4 Plants and Capacity*

While the manufacturing sector has been growing consistently since 1997, the paper manufacturing sector has not experienced the same amount of success in the same period. Despite a small amount of growth in capacity between 1997 and 2001, the paper manufacturing subsector's capacity has declined to as much as 7% below 1997 capacity levels (Figure 2-27).

### *2.3.3.5 Firm Characteristics*

In 2006, the top 10 paper and forest product companies produced over $75 billion in sales, with the top two companies—International Paper and Weyerhaeuser—generating nearly $22 billion each (Table 2-27). The top two companies' revenue consists of 58% of the revenue of the top 10 companies in Standard & Poor's (S&P's) list (Benwart, 2006). Although these numbers do not exclusively reflect paper products, they do convey the market environment in which firms in this sector compete.

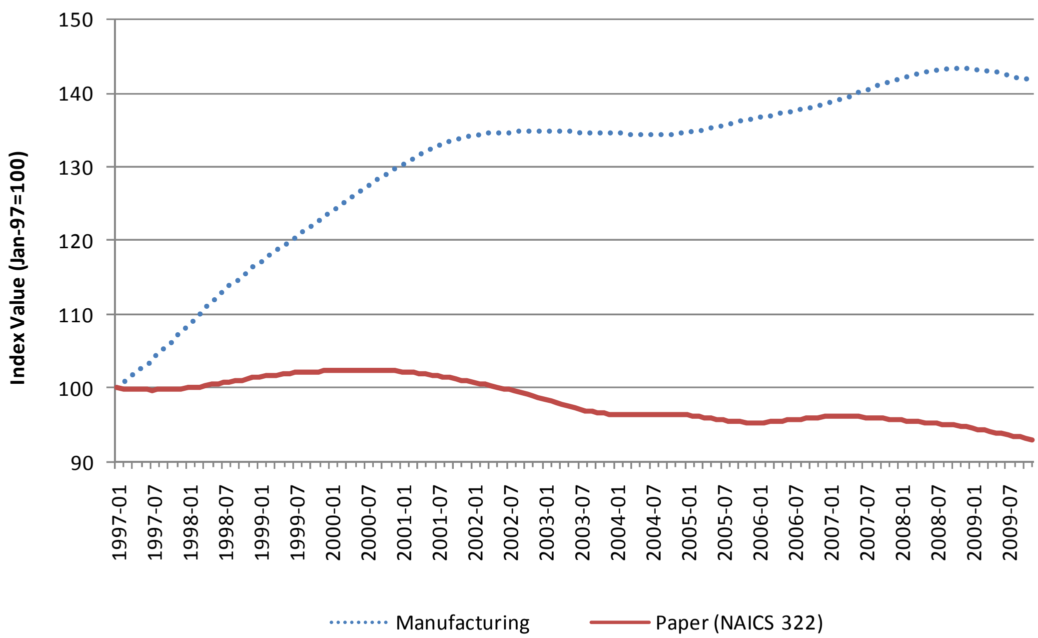


**Figure 2-27. Capacity Trends in the Paper Manufacturing Industry (NAICS 322)**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G322.S. <http://www.federalreserve.gov/datadownload/>.

**Table 2-27. Largest U.S. Paper and Forest Products Companies: 2006**

| Company | Revenues ($millions)[a] |
|---|---|
| International Paper | 21,995 |
| Weyerhaeuser | 21,896 |
| Smurfit-Stone | 7,157 |
| MeadWestvaco | 6,530 |
| Temple-Inland | 5,558 |
| Bowater | 3,530 |
| Grief Inc. | 2,628 |
| Louisiana-Pacific | 2,235 |
| Packaging Corp. | 2,187 |
| Plum Creek | 1,627 |

[a] Includes revenues from operations other than paper and forest products in certain cases.

Sources: Benwart, S.J. 2006. "Paper & Forest Products. Standard and Poor's Industry Surveys." 176(28). U.S. and international sales data from company reports.

*2.3.3.6 Size Distribution*

The primary criterion for categorizing a business as small is the number of employees, using definitions by the SBA for regulatory flexibility analyses. According to SUSB reports for 2002, large companies dominated revenue-generating transactions in the paper manufacturing subsector; 80% of receipts were generated by companies with 500 employees or more (Table 2-28). This was especially true in the pulp, paper, and paperboard group, in which large companies generated 92% of receipts. The number of employees in the small business cutoff varies according to six-digit NAICS codes (Table 2-29). The cutoff for all subsectors in the pulp, paper, and paperboard group is 750 employees, while the cutoff for most converted paper product groups is 500 employees.

**Table 2-28. Distribution of Economic Data by Enterprise Size: Paper Manufacturing (NAICS 322)**

| | | Enterprises with | | | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | **Total** | **1 to 20 Employees[a]** | **20 to 99 Employees** | **100 to 499 Employees** | **500 to 749 Employees** | **750 to 999 Employees** | **1,000 to 1,499 Employees** |
| Firms | 3,538 | 1,482 | 1,200 | 476 | 43 | 22 | 33 |
| Establishments | 5,546 | 1,488 | 1,271 | 755 | 83 | 69 | 138 |
| Employment | 495,990 | 11,325 | 52,334 | 78,402 | 13,293 | 12,496 | 23,283 |
| Receipts ($millions ) | $154,746 | $2,218 | $9,483 | $17,620 | $3,034 | $3,951 | $6,798 |
| Receipts/firm ($thousands) | $43,738 | $1,497 | $7,903 | $37,017 | $70,561 | $179,577 | $206,001 |
| Receipts/establishment ($thousands) | $27,902 | $1,491 | $7,461 | $23,338 | $36,556 | $57,256 | $49,261 |
| Receipts/employment ($) | $311,994 | $195,850 | $181,203 | $224,742 | $228,250 | $316,157 | $291,974 |

[a] Excludes SUSB employment category for zero employees. These entities only operated for a fraction of the year.

Source: U.S. Census Bureau. 2008. "Firm Size Data from the Statistics of U.S. Businesses: U.S. Detail Employment Sizes: 2002." <http://www.census.gov/csd/susb/download_susb02.htm>.

**Table 2-29. Small Business Size Standards: Paper Manufacturing (NAICS 322)**

| NAICS | NAICS Description | Employees |
|---|---|---|
| 322110 | Pulp Mills | 750 |
| 322121 | Paper (except Newsprint) Mills | 750 |
| 322122 | Newsprint Mills | 750 |
| 322130 | Paperboard Mills | 750 |
| 322211 | Corrugated and Solid Fiber Box Manufacturing | 500 |
| 322212 | Folding Paperboard Box Manufacturing | 750 |
| 322213 | Setup Paperboard Box Manufacturing | 500 |
| 322214 | Fiber Can, Tube, Drum, and Similar Products Manufacturing | 500 |
| 322215 | Non-Folding Sanitary Food Container Manufacturing | 750 |
| 322221 | Coated and Laminated Packaging Paper Manufacturing | 500 |
| 322222 | Coated and Laminated Paper Manufacturing | 500 |
| 322223 | Coated Paper Bag and Pouch Manufacturing | 500 |
| 322224 | Uncoated Paper and Multiwall Bag Manufacturing | 500 |
| 322225 | Laminated Aluminum Foil Manufacturing for Flexible, Packaging Uses | 500 |
| 322226 | Surface-Coated Paperboard Manufacturing | 500 |
| 322231 | Die-Cut Paper and Paperboard Office Supplies, Manufacturing | 500 |
| 322232 | Envelope Manufacturing | 500 |
| 322233 | Stationery, Tablet, and Related Product Manufacturing | 500 |
| 322291 | Sanitary Paper Product Manufacturing | 500 |
| 322299 | All Other Converted Paper Product Manufacturing | 500 |

Source: U.S. Small Business Administration (SBA). 2008. "Table of Small Business Size Standards Matched to North American Industry Classification System Codes." Effective August 22, 2008. <http://www.sba.gov/services/contractingopportunities/sizestandardstopics/size/index.html>.

### *2.3.3.7 Domestic Production*

Similar to industry capacity rates, subsector production rates for paper manufacturing have witnessed a decreasing rate of production compared to the steady increase in production for the manufacturing sector since 1997 (Figure 2-28). It seems that the paper manufacturing sector was not able to return to its former levels of growth following the 2001 recession; it has experienced a downward production trend since then.

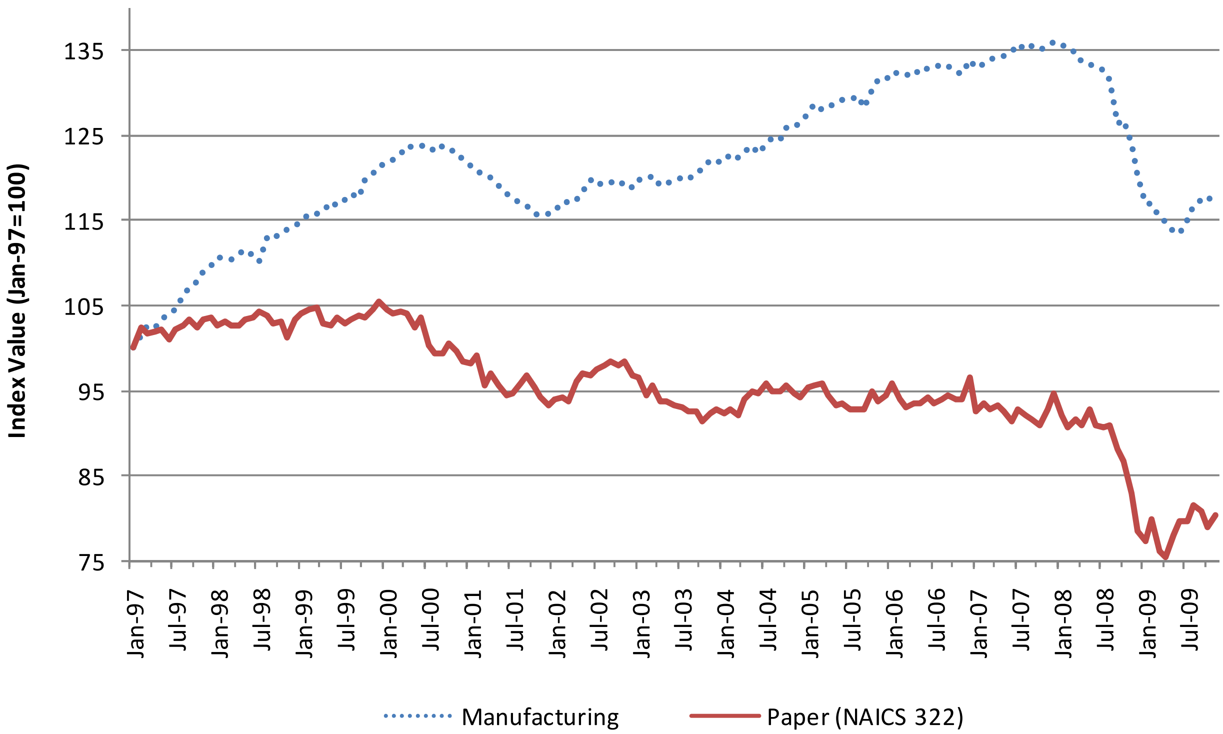


**Figure 2-28. Industrial Production Trends in the Paper Manufacturing Industry (NAICS 322): 1997–2009**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G322.S. <http://www.federalreserve.gov/datadownload/>.

*2.3.3.8 International Trade*

Since 1997, paper manufacturing products, both pulp, paper, and paperboard products and converted paper products, have contributed to an increasing trade surplus in this sector (Figure 2-29). Imports and exports have been changing at similar rates since 1999.

*2.3.3.9 Market Prices*

Prices of goods in paper manufacturing have been increasing at a rate consistent with all manufacturing products (Figure 2-30). Producer price indices (PPIs) show that producer prices for paper in 2007 increased by 20% since 1997, while producer prices for all manufacturing goods increased by roughly 27%.

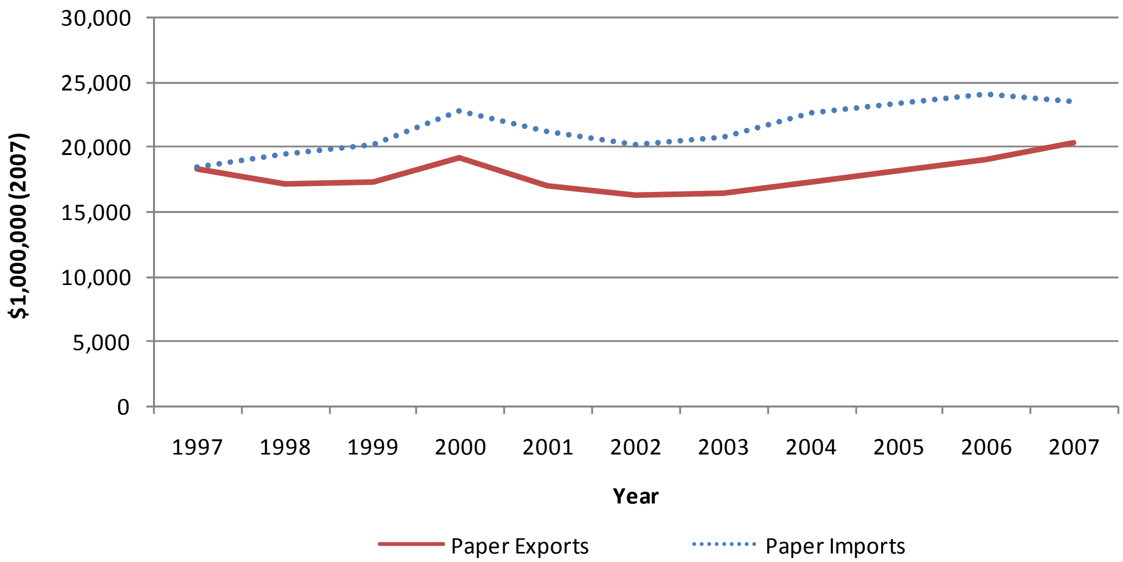


**Figure 2-29. International Trade Trends in the Paper Manufacturing Industry (NAICS 322)**

Source: U.S. International Trade Commission. 2008b. "U.S. Total Exports" & "U.S. Imports for Consumption." <http://dataweb.usitc.gov/scripts/user_set.asp>.

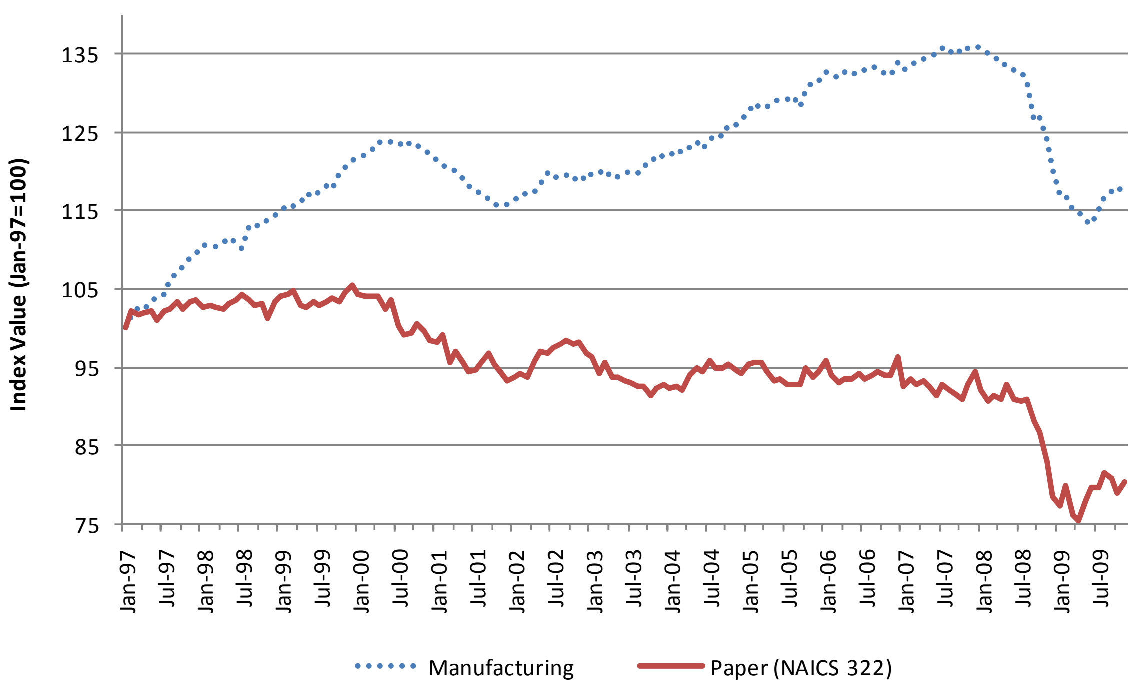


**Figure 2-30. Producer Price Trends in the Paper Manufacturing Industry (NAICS 222)**

Source: U.S. Bureau of Labor Statistics (BLS). 2009. "Producer Price Index." Series ID: PCU322–322– & PCUOMFG–OMFG–. <http://www.bls.gov/ppi/home.htm>.

## 2.4 Chemical Manufacturing

### *2.4.1 Introduction*

The chemical manufacturing industry produces over 70,000 chemical substances, many of which are ubiquitous in American life. Broadly speaking, chemical manufacturing operates by converting feedstocks into chemical products that can serve as intermediate goods or final products such as medicine, soap, and printer ink. From 1997 to2007, shipments in the industry grew 42%, while employment declined by 8% (Table 2-30). While total payroll dropped 0.6% over this time, annual payroll per employee rose 7.8% from 1997 to 2007 because of the decline in the number of employees (Table 2-31). Shipments per employee grew 54% from 1997 to 2007, with much of that growth taking place between 2002 and 2006 (Table 2-31).

Chemical manufacturing (NAICS 325) covers a diverse set of industry groups, which we have aggregated into the following three groups:

- Bulk Chemicals—Includes the most energy-intensive industry groups as aggregated by the Department of Energy (DOE) (DOE/EIA-0554, 2008): Basic Chemical Manufacturing (NAICS 3251); Resin, Rubber, and Artificial Fibers Manufacturing (NAICS 3252); and Agricultural Chemical Manufacturing (NAICS 3253).
- Pharmaceutical and Medicine Manufacturing (NAICS 3254)—Consists primarily of pharmaceutical preparation manufacturing. This industry group is the largest importer of goods within chemical manufacturing.
- Other Chemical Manufacturing: Consists of Paint, Coating, and Adhesive Manufacturing (NAICS 3255); Soap, Cleaning Compound, and Toiletry Manufacturing (NAICS 3256); and Other Chemical Product and Preparation Manufacturing (NAICS 3259).

In 2007, each of these groups generated approximately one-third of the total employment in chemical manufacturing (Figure 2-31). The bulk chemicals group accounted for the biggest share of chemical manufacturing's total value of shipments (Figure 2-32).

## Table 2-30. Key Statistics: Chemical Manufacturing (NAICS 325)

| | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Shipments ($2007, millions) | $521,251 | $531,173 | $675,223 | $738,303 |
| Payroll ($2007, millions) | $49,961 | $51,317 | $46,981 | $49,648 |
| Employees | 882,645 | 853,224 | 747,134 | 814,024 |
| Establishments | 13474 | 13,475 | NA | 12,937 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." <http://factfinder.census.gov>. Accessed on December 27, 2009. [Source for 2007 numbers]

## Table 2-31. Industry Data: Chemical Manufacturing (NAICS 325)

| Industry Data | 1997 | 2002 | 2006 | 2007 |
|---|---|---|---|---|
| Total shipments ($2007, millions) | $521,251 | $531,173 | $675,223 | $738,303 |
| Shipments per establishment ($thousands) | $38,686 | $39,419 | NA | $57,069 |
| Shipments per employee ($2007) | $590,556 | $622,548 | $903,750 | $906,979 |
| Shipments per $ of payroll ($2007) | $10.43 | $10.35 | $14.37 | $14.87 |
| Annual payroll per employee ($2007) | $56,603 | $60,145 | $62,882 | $60,991 |
| Employees per establishment | 66 | 63 | NA | 63 |

NA = Not available.

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 00: EC0700A1: All Sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." <http://factfinder.census.gov>. Accessed on December, 27, 2009. [Source for 2007 numbers]

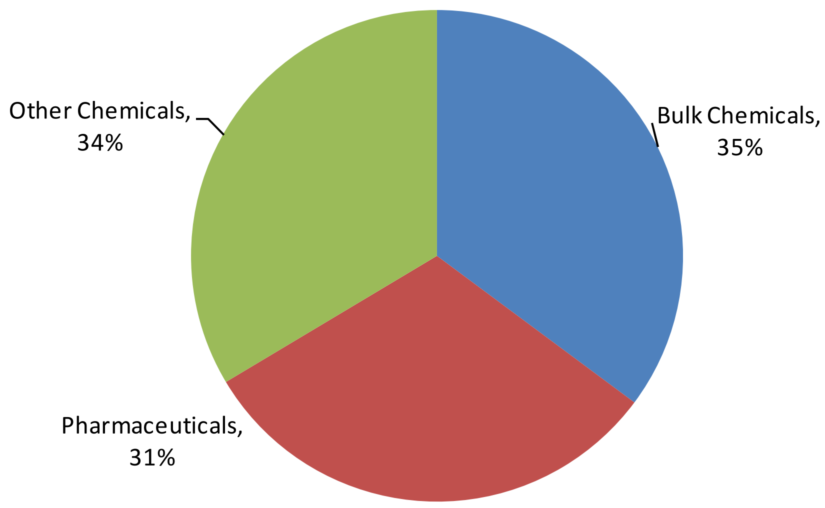


**Figure 2-31. Distribution of Employment within Chemical Manufacturing (NAICS 325): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the U.S.: 2007." Release date: October 30, 2009. Accessed on December 27, 2009.

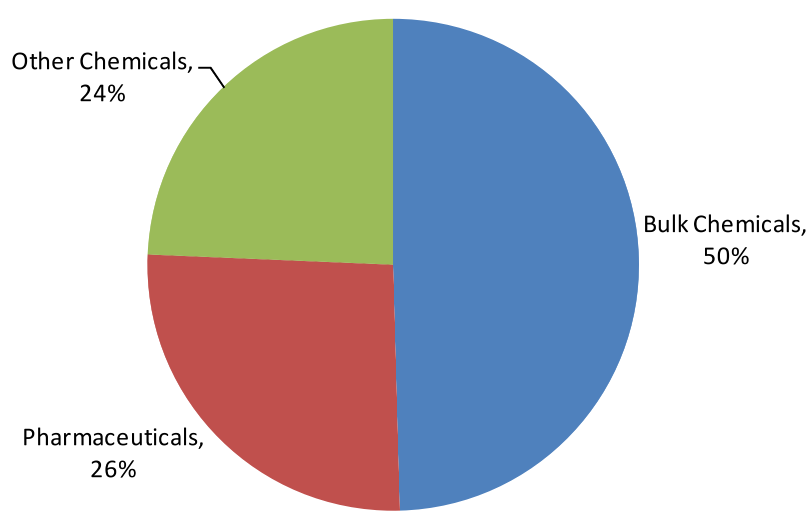


**Figure 2-32. Distribution of Total Value of Shipments within Chemical Manufacturing (NAICS 325): 2007**

Source: U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 31:EC0731I1: Manufacturing Industry Series: Detailed Statistics by Industry for U.S.: 2007." <http://factfinder.census.gov>. Accessed on December 27, 2009.

### 2.4.2 *Supply and Demand Characteristics*

Next, we provide a broad overview of the supply and demand side of the chemical manufacturing industry. We emphasize the economic interactions this industry has with other industries and people, including identifying the key goods and services used by the industry and the major uses and consumers of chemical manufacturing products.

The top 10 industry groups supplying inputs to the chemical manufacturing industry in 2002 accounted for 71% of the total intermediate inputs (Table 2-32). Bulk chemicals' production was the most energy intensive, using 79% of the chemical manufacturing inputs from petroleum and coal products, electric power generation, transmission and distribution, and natural gas distribution.

**Table 2-32. Key Goods and Services Used in Chemical Manufacturing (NAICS 325) ($2007, millions)**

| Good or Service | BEA Code | Bulk Chemicals | Pharmaceuticals | Other Chemicals | Total |
|---|---|---|---|---|---|
| Basic chemicals | 3251 | $59,495 | $4,772 | $14,021 | $78,288 |
| Management of companies and enterprises | 5500 | $15,071 | $19,380 | $16,396 | $50,846 |
| Pharmaceuticals and medicines | 3254 | $0 | $25,125 | $0 | $25,125 |
| Wholesale trade | 4200 | $9,428 | $8,367 | $6,077 | $23,872 |
| Scientific research and development services | 5417 | $6,172 | $6,139 | $5,554 | $17,865 |
| Petroleum and coal products | 3240 | $10,066 | $398 | $3,432 | $13,896 |
| Plastics and rubber products | 3260 | $2,675 | $1,132 | $5,556 | $9,363 |
| Resins, rubber, and artificial fibers | 3252 | $4,048 | $0 | $4,949 | $8,996 |
| Electric power generation, transmission, and distribution | 2211 | $6,025 | $716 | $807 | $7,548 |
| Natural gas distribution | 2212 | $6,390 | $154 | $390 | $6,934 |
| Total intermediate use | T005 | $167,699 | $82,403 | $91,833 | $341,935 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

### *2.4.2.1 Goods and Services Used in Chemical Manufacturing*

In2007, the cost of materials made up 49% of chemical manufacturing's total shipment value (Table 2-32). Total compensation to employees represented 9% of total shipment value, down from 10% in 2005.

***2.4.2.1.1 Energy.*** The Department of Energy (DOE) classifies bulk chemical manufacturing as an energy-intensive industry. Pharmaceuticals and other chemical manufacturing are categorized as non-energy-intensive industries, grouped together with other industry groups under the "Balance of Manufacturing" category (DOE, 2008).

Fuel used in chemical production can either facilitate chemical processes or provide the feedstock to derive value-added chemicals. In 2007, 70% of chemical manufacturing's energy bill was spent on fuel used as feedstocks (O'Reilly, 2008). These fuel costs represented 2% of chemical manufacturing's total value of shipments (Table 2-33).

As a whole, chemical manufacturing use less energy over the last 10 years. According to DOE, natural gas use by the chemical manufacturing industry dropped 30% from 1998 to 2006, and electricity use fell 10% (Table 2-34). From 1997 to 2005, when data ceased to be available, chemical manufacturing used less electricity relative to the manufacturing sector as a whole (Figure 2-33).

### *2.4.2.2 Uses and Consumers*

Products manufactured in the groups bulk chemicals, pharmaceuticals, and other chemicals have very different consumer profiles. Bulk chemicals is dominated by intermediate use, representing 93% of its total commodity output and 56% of the total intermediate use of chemical manufacturing products. Pharmaceuticals has both a high level of demand from personal consumption, accounting for 67% of the total personal consumption of chemical manufacturing products, and a large trade deficit (Table 2-35).

## Table 2-33. Costs of Goods and Services Used in Chemical Manufacturing (NAICS 325) ($2007)

| Variable | 2005 | Share | 2006 | Share | 2007 | Share |
|---|---|---|---|---|---|---|
| Total shipments | $646,895 | 100% | $675,223 | 100% | $722,494 | 100% |
| Total compensation (millions) | $62,669 | 10% | $61,683 | 9% | $63,591 | 9% |
| Annual payroll | $48,159 | 7% | $46,981 | 7% | $48,780 | 7% |
| Fringe benefits | $14,510 | 2% | $14,702 | 2% | $14,811 | 2% |
| Total employees | 756,078 | | 747,134 | | 801,567 | |
| Average compensation per employee | $82,887 | | $82,559 | | $79,333 | |
| Total production workers' wages (millions) | $22,643 | 4% | $22,231 | 3% | $23,157 | 3% |
| Total production workers | 431,502 | | 430,880 | | 463,802 | |
| Total production hours (thousands) | 899,499 | | 885,993 | | 948,244 | |
| Average production wages per hour | $25 | | $25 | | $24 | |
| Total cost of materials ($thousands) | $299,859 | 46% | $318,945 | 47% | $357,055 | 49% |
| Materials, parts, packaging | $247,851 | 38% | $260,934 | 39% | $291,656 | 40% |
| Purchase electricity | $8,291 | 1% | $8,490 | 1% | $8,936 | 1% |
| Purchased fuel | $14,568 | 2% | $13,667 | 2% | $14,227 | 2% |
| Other | $29,148 | 5% | $35,855 | 5% | $42,236 | 6% |

Sources: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." Accessed on December, 27, 2009.

## Table 2-34. Energy Used in Chemical Manufacturing (NAICS 325)

| Fuel Type | 1998 | 2002 | 2006 |
|---|---|---|---|
| Total (trillion BTU) | 3,704 | 3,769 | 3,159 |
| Net electricity[a] (million kWh) | 169,233 | 153,104 | 151,646 |
| Residual fuel oil (million bbl) | 8 | 7 | 4 |
| Distillate fuel oil[b] (million bbl) | 2 | 2 | 2 |
| Natural gas[c] (billion cu ft) | 1,931 | 1,634 | 1,349 |
| LPG and NGL[d] (million bbl) | 15 | 9 | 2 |
| Coal (million short tons) | 13 | 14 | 8 |
| Coke and breeze (million short tons) | * | * | * |
| Other[e] (trillion BTU) | 748 | 1,158 | 1,045 |
| Total (trillion BTU) | 3,704 | 3,769 | 3,159 |

[a] Net electricity is obtained by summing purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. It does not include electricity inputs from on-site cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).

[b] Distillate fuel oil includes Nos. 1, 2, and 4 fuel oils and Nos. 1, 2, and 4 diesel fuels.

[c] Natural gas includes natural gas obtained from utilities, local distribution companies, and any other supplier(s), such as independent gas producers, gas brokers, marketers, and any marketing subsidiaries of utilities.

[d] Examples of liquefied petroleum gases (LPGs) are ethane, ethylene, propane, propylene, normal butane, butylene, ethane-propane mixtures, propane-butane mixtures, and isobutene produced at refineries or natural gas processing plants, including plants that fractionate raw natural gas liquids (NGLs).

[e] 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.

* Estimate less than 0.5.

Sources: U.S. Department of Energy, Energy Information Administration. 2007b. "2006 Energy Consumption by Manufacturers—Data Tables." Table 3.1. Washington, DC: DOE. <http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html>. [Source for 2006 numbers]

U.S. Department of Energy, Energy Information Administration. 2007. "2002 Energy Consumption by Manufacturers—Data Tables." Tables 3.2 and N3.2. Washington, DC: DOE. <http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html>.

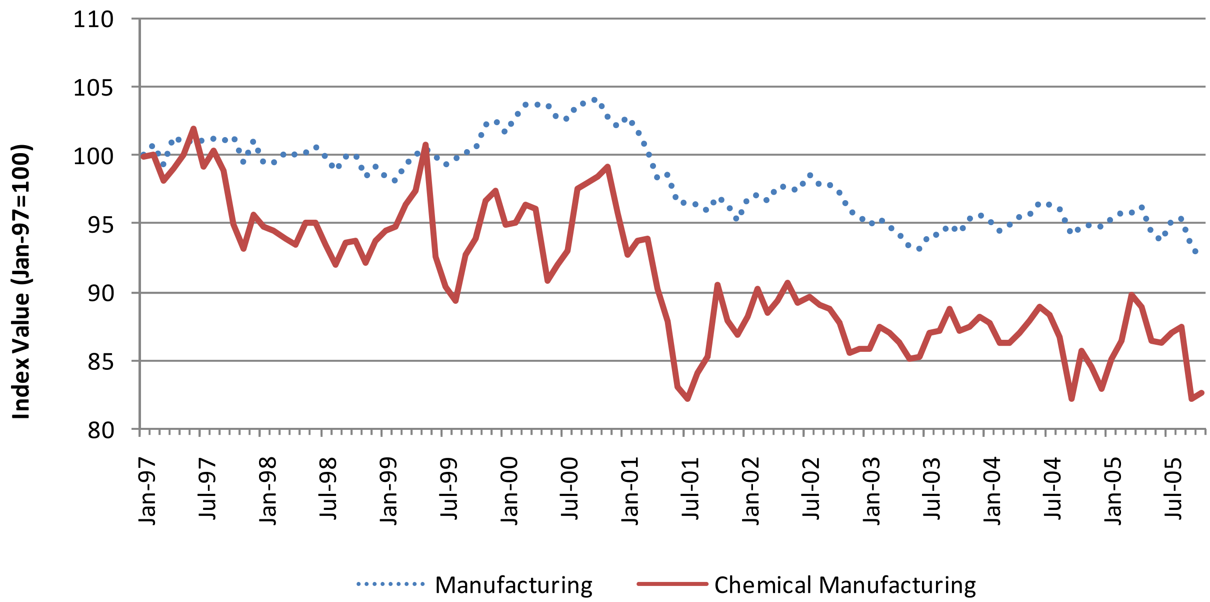


**Figure 2-33. Electric Power Use Trends in Chemical Manufacturing (NAICS 325): 1997–2005**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G325.S. <http://www.federalreserve.gov/datadownload/>; (November 17, 2009).

### *2.4.3 Firm and Market Characteristics*

This remaining subsection describes geographic, production, and market data. These data provide the basis for further analysis, including regulatory flexibility analyses, and give a complete picture of the recent historical trends of production and pricing.

#### *2.4.3.1 Location*

In 2002, California had the most chemical manufacturing establishments in the United States, followed by Texas and New Jersey (Figure 2-34). The composition of establishments in these states differs among the different industry groups. Despite the fact that each group employed an approximately equal share of people in 2002, 54% of the total establishments were other chemicals establishments, and only 13% were pharmaceutical establishments.

**Table 2-35. Demand by Sector: Chemical Manufacturing (NAICS 325) ($2007 millions)**

| Sector | BEA Code | Bulk Chemicals | Pharmaceuticals | Other Chemicals | Total |
|---|---|---|---|---|---|
| Plastics and rubber products manufacturing | 3260 | $39,353 | $0 | $3,057 | $42,410 |
| Basic chemical manufacturing | 3251 | $33,972 | $0 | $1,675 | $35,647 |
| Pharmaceutical and medicine manufacturing | 3254 | $4,778 | $25,125 | $462 | $30,365 |
| Resin, rubber, and artificial fibers manufacturing | 3252 | $28,249 | $0 | $1,076 | $29,325 |
| Ambulatory health care services | 6210 | $2,716 | $22,900 | $934 | $26,550 |
| General state and local government services | S007 | $7,150 | $10,586 | $8,807 | $26,543 |
| Hospitals | 6220 | $2,936 | $15,390 | $394 | $18,720 |
| Other chemical product and preparation manufacturing | 3259 | $8,021 | $0 | $2,680 | $10,701 |
| Textile mills | 3130 | $9,568 | $0 | $930 | $10,498 |
| Soap, cleaning compound, and toiletry manufacturing | 3256 | $3,886 | $0 | $6,289 | $10,176 |
| Total intermediate use | T001 | $212,996 | $83,279 | $82,107 | $378,382 |
| Personal consumption expenditures | F010 | $4,449 | $123,746 | $55,882 | $184,077 |
| Exports of goods and services | F040 | $47,121 | $15,683 | $13,136 | $75,940 |
| Imports of goods and services | F050 | −$38,732 | −$67,950 | −$10,906 | −$117,588 |
| Total final uses (GDP) | T004 | $15,733 | $73,485 | $58,023 | $147,241 |
| Total commodity output | T007 | $228,729 | $156,765 | $140,129 | $525,623 |

Source: U.S. Bureau of Economic Analysis (BEA). 2008. “2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level.” Table 2. Washington, DC: BEA.

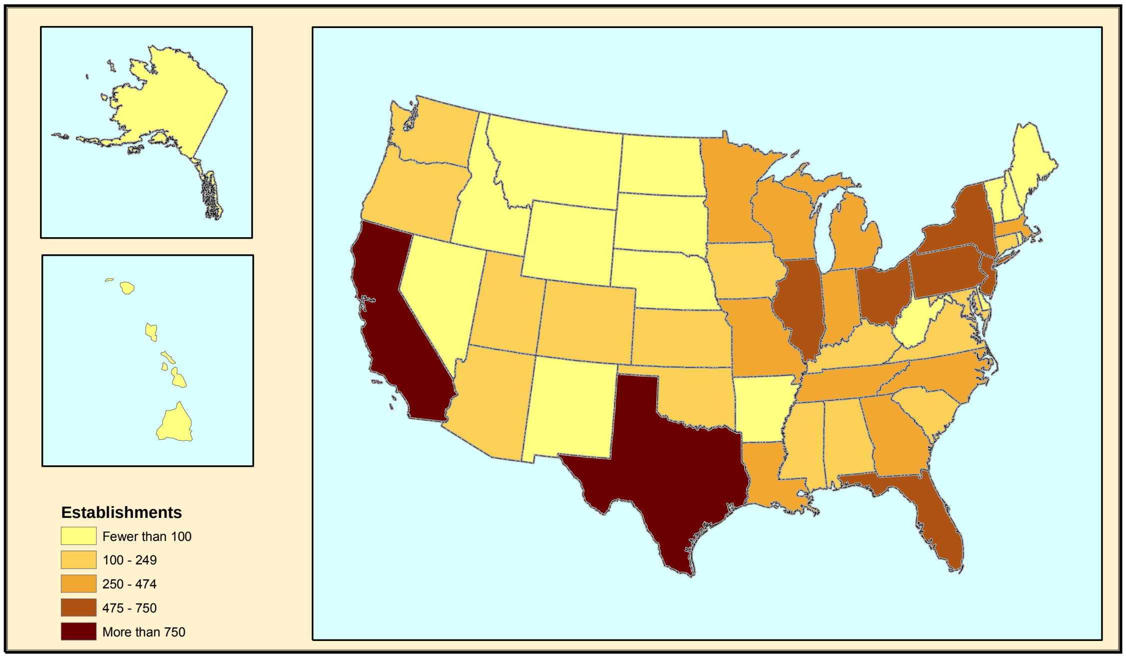


**Figure 2-34. Establishment Concentration in Chemical Manufacturing (NAICS 325): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

*2.4.3.2 Production Capacity and Utilization*

Capacity utilization of the chemical manufacturing industry has been broadly in line with the manufacturing sector (Figure 2-35). In the second half of 2005, the chemical manufacturing industry's capacity utilization fell dramatically because of the multiple hurricanes affecting the Gulf Coast states. The impact of the economic downturn in 2001 can be seen in the capacity utilization of both manufacturing and chemical manufacturing.

*2.4.3.3 Employment*

The geographic distribution of employment in chemical manufacturing differs largely among the different groups. In California, 52% of the chemical manufacturing employment comes from the pharmaceutical industry, while 60% of the chemical manufacturing employment in the Gulf Coast states comes from bulk chemicals manufacturing (Figure 2-36).

*2.4.3.4 Plants and Capacity*

Production capacity in chemical manufacturing has grown 33% since 1997. This growth, however, is 9% less than the growth rate for the manufacturing industry as a whole (Figure 2-37).

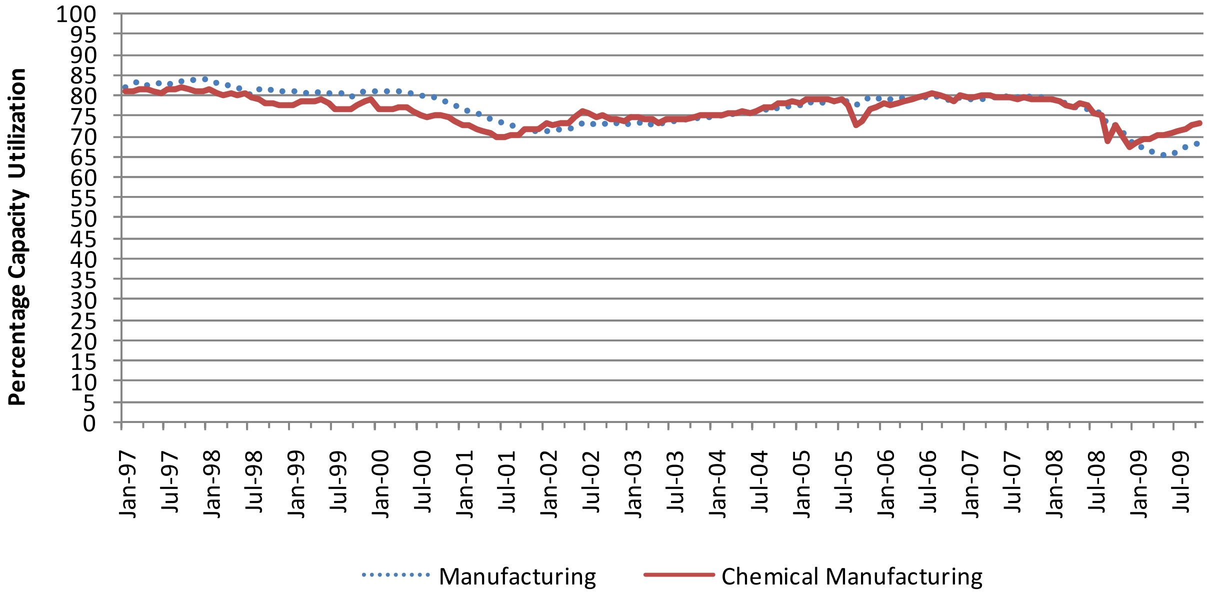


**Figure 2-35. Capacity Utilization Trends in Chemical Manufacturing (NAICS 325)**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G325.S. <http://www.federalreserve.gov/datadownload/>.

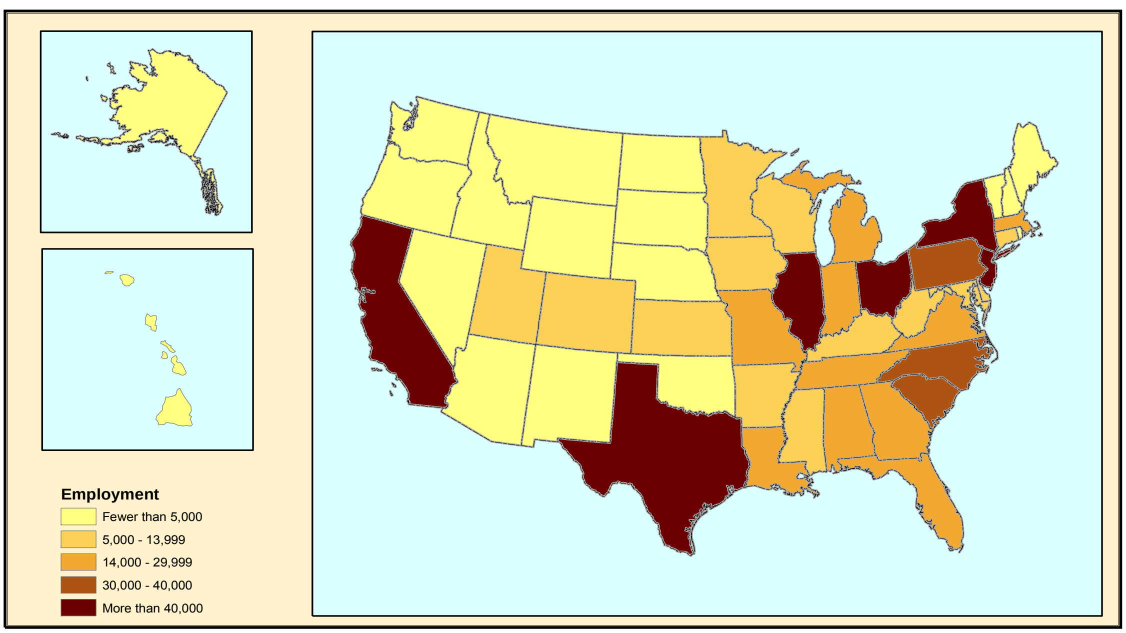


**Figure 2-36. Employment Concentration in Chemical Manufacturing (NAICS 325): 2002**

Source: U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

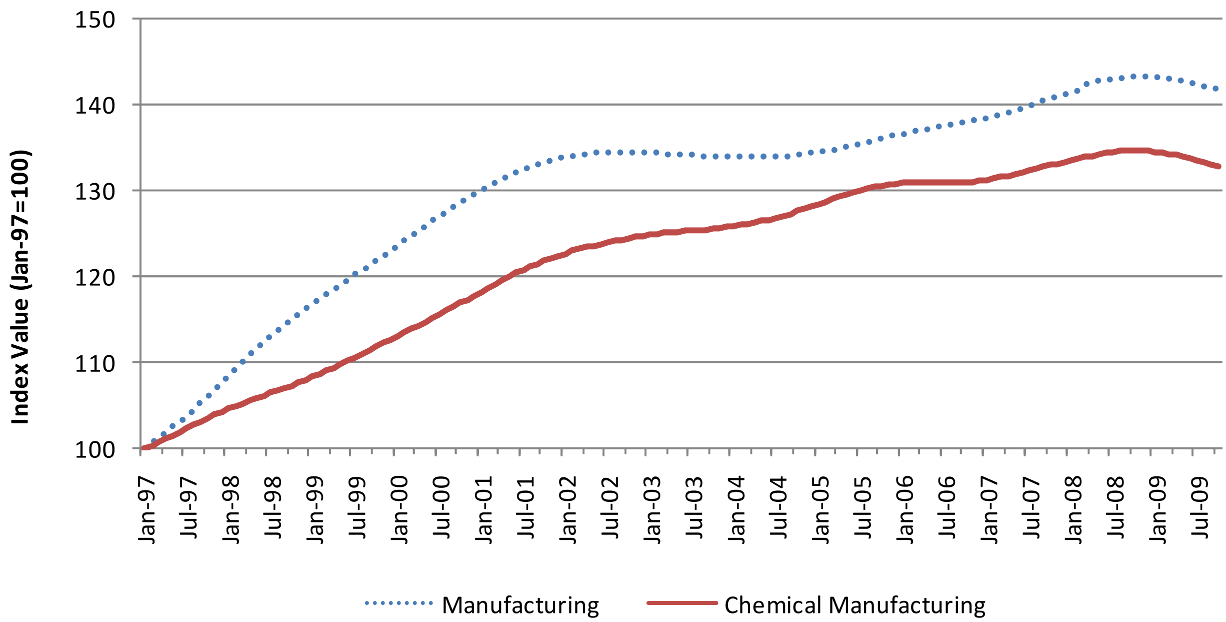


**Figure 2-37. Capacity Trends in Chemical Manufacturing (NAICS 325)**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G325.S. <http://www.federalreserve.gov/datadownload/>.

*2.4.3.5 Firm Characteristics*

In 2007, the top six companies by chemical sales had greater than $10 billion in sales. Together, their sales are greater than the next 44 highest chemical companies combined. These, however, are global companies, with a large portion of both sales and production coming from operations outside of the United States (Table 2-36). The largest chemical manufacturing company, Dow Chemicals, has 108 out of 150 manufacturing sites located outside of the United States (Dow Chemical Company, 2008).

In 2007, 58%of U.S. chemical manufacturing corporations generated net income. Including those with and without net income, chemical manufacturers had an average before-tax profit margin of 10.24%. Profitability is highest for pharmaceutical and medicine corporations (Table 2-37).

## Table 2-36. Top Chemical Producers: 2007

| | Chemical Sales ($millions) | % of Total Sales | % of Sales in United States |
|---|---|---|---|
| Dow Chemical | 53,513 | 100% | 35% |
| ExxonMobil | 36,826 | 9% | 38% |
| DuPont | 29,218 | 100% | 38% |
| Lyondell[a] | 16,165 | 57% | 80% |
| Chevron Phillips | 12,534 | 100% | 86% |
| PPG Industries[a] | 10,025 | 90% | 56% |
| Huntsman Chemical | 9,651 | 100% | 50% |
| Praxair | 9,402 | 100% | 43.5% |
| Air Products[a] | 8,820 | 88% | 51% |
| Rohm & Haas[b] | 7,837 | 88% | 49% |

[a] Percentage of sales in the United States calculated from total sales, not chemical sales.

[b] Percentage of sales in the United States is actually percentage of sales in North America.

Sources: O'Reilly, R. 2008. "Chemicals." *Standard and Poor's Industry Surveys*. 176(28).

## Table 2-37. 2007 Corporate Income and Profitability (NAICS 325)

| Industry | Number of Corporations | Number of Corporations with Net Income | Total Receipts ($thousands) | Business Receipts ($thousands) | Before-Tax Profit Margin | After-Tax Profit Margin |
|---|---|---|---|---|---|---|
| Basic chemical | 1,244 | 757 | $195,022,700 | $178,019,490 | 5.07% | 4.10% |
| Resin, synthetic rubber, and artificial synthetic fibers and filaments | 1,067 | 648 | $44,692,366 | $40,078,009 | 8.06% | 6.33% |
| Pharmaceutical and medicine | 1,034 | 611 | $381,339,258 | $317,414,432 | 15.63% | 11.66% |
| Paint, coating, and adhesive | 1,411 | 1,260 | $51,778,868 | $49,486,744 | 5.39% | 4.02% |
| Soap, cleaning compound, and toilet preparation | 1,862 | 463 | $150,506,485 | $139,836,602 | 9.07% | 7.51% |
| Other chemical product and preparation | 2,946 | 1,773 | $89,014,032 | $84,062,534 | 6.71% | 5.27% |
| **Chemical manufacturing** | **9,564** | **5,512** | **$912,353,710** | **$808,897,810** | **10.24%** | **7.89%** |

Source: Internal Revenue Service, U.S. Department of Treasury. 2008. "Corporation Source Book: Data File 2007." <http://www.irs.gov/taxstats/article/0,,id=167415,00.html>; (January, 15, 2010).

*2.4.3.6 Size Distribution*

The primary criterion for categorizing a business as small is number of employees, using definitions by the SBA for regulatory flexibility analyses. The data describing size standards are provided in Table 2-38. In 2002, enterprises with fewer than 500 employees accounted for 27% of employment and 15% of receipts within the chemical manufacturing industry).

*2.4.3.7 Domestic Production*

In the late 1990s, overall manufacturing production was growing much faster than the chemical manufacturing component (Figure 2-38). Following the recession of 2001, however, the components have moved broadly in line with one another, except for the drop in chemical manufacturing production caused by the hurricane season of 2005.

*2.4.3.8 International Trade*

In the year 2000, the United States moved from having a trade surplus to a trade deficit in chemical manufacturing products (Figure 2-39). This change occurred because the trade deficit in pharmaceutical manufacturing, currently at $35 billion, overwhelmed the trade surplus of bulk chemicals and other chemical manufacturing combined, currently at $22 billion.

*2.4.3.9 Market Prices*

Prices of goods in chemical manufacturing have accelerated rapidly in the last 2 years, having outpaced overall manufacturing since 2002 (Figure 2-40). Much of this recent acceleration seen in the industry PPI is due to the bulk chemicals segment, largely reflecting the rapid increase in fertilizer prices.

## Table 2-38. Small Business Size Standards: Chemical Manufacturing (NAICS 325)

| NAICS | Description | Employees |
|---|---|---|
| 325110 | Petrochemical Manufacturing | 1,000 |
| 325120 | Industrial Gas Manufacturing | 1,000 |
| 325131 | Inorganic Dye and Pigment Manufacturing | 1,000 |
| 325132 | Synthetic Organic Dye and Pigment Manufacturing | 750 |
| 325181 | Alkalies and Chlorine Manufacturing | 1,000 |
| 325182 | Carbon Black Manufacturing | 500 |
| 325188 | All Other Basic Inorganic Chemical Manufacturing | 1,000 |
| 325191 | Gum and Wood Chemical Manufacturing | 500 |
| 325192 | Cyclic Crude and Intermediate Manufacturing | 750 |
| 325193 | Ethyl Alcohol Manufacturing | 1,000 |
| 325199 | All Other Basic Organic Chemical Manufacturing | 1,000 |
| 325211 | Plastics Material and Resin Manufacturing | 750 |
| 325212 | Synthetic Rubber Manufacturing | 1,000 |
| 325221 | Cellulosic Organic Fiber Manufacturing | 1,000 |
| 325222 | Noncellulosic Organic Fiber Manufacturing | 1,000 |
| 325311 | Nitrogenous Fertilizer Manufacturing | 1,000 |
| 325312 | Phosphatic Fertilizer Manufacturing | 500 |
| 325314 | Fertilizer (Mixing Only) Manufacturing | 500 |
| 325320 | Pesticide and Other Agricultural Chemical Manufacturing | 500 |
| 325411 | Medicinal and Botanical Manufacturing | 750 |
| 325412 | Pharmaceutical Preparation Manufacturing | 750 |
| 325413 | In-Vitro Diagnostic Substance Manufacturing | 500 |
| 325414 | Biological Product (except Diagnostic) Manufacturing | 500 |
| 325510 | Paint and Coating Manufacturing | 500 |
| 325520 | Adhesive Manufacturing | 500 |
| 325611 | Soap and Other Detergent Manufacturing | 750 |
| 325612 | Polish and Other Sanitation Good Manufacturing | 500 |
| 325613 | Surface Active Agent Manufacturing | 500 |
| 325620 | Toilet Preparation Manufacturing | 500 |
| 325910 | Printing Ink Manufacturing | 500 |
| 325920 | Explosives Manufacturing | 750 |
| 325991 | Custom Compounding of Purchased Resins | 500 |
| 325992 | Photographic Film, Paper, Plate and Chemical Manufacturing | 500 |
| 325998 | All Other Miscellaneous Chemical Product and Preparation Manufacturing | 500 |

Source: U. S. Small Business Administration (SBA). 2008. “Table of Small Business Size Standards Matched to North American Industry Classification System Codes.” Effective August 22, 2008. <http://www.sba.gov/services/contractingopportunities/sizestandardstopics/size/index.html>.

**Table 2-39. Distribution of Economic Data by Enterprise Size: Chemical Manufacturing (NAICS 325)**

| Variable | Total | Enterprises with 1 to 20 Employees[a] | 20 to 99 Employees | 100 to 499 Employees | 500 to 749 Employees | 750 to 999 Employees | 1,000 to 1,499 Employees |
|---|---|---|---|---|---|---|---|
| Firms | 9,341 | 5,413 | 1,974 | 790 | 95 | 56 | 71 |
| Establishments | 13,096 | 5,433 | 2,208 | 1,352 | 250 | 185 | 276 |
| Employment | 827,430 | 34,838 | 78,090 | 113,326 | 28,025 | 18,119 | 28,338 |
| Receipts ($millions) | $468,211 | $9,631 | $21,394 | $39,111 | $12,217 | $7,324 | $14,762 |
| Receipts/firm ($thousands) | $50,124 | $1,779 | $10,838 | $49,507 | $128,603 | $130,779 | $207,913 |
| Receipts/establishment ($thousands) | $35,752 | $1,773 | $9,689 | $28,928 | $48,869 | $39,587 | $53,485 |
| Receipts/employment ($) | $565,862 | $276,464 | $273,971 | $345,117 | $435,942 | $404,195 | $520,920 |

[a] Excludes SUSB employment category for zero employees. These entities only operated for a fraction of the year.

Source: U.S. Census Bureau. 2008. "Firm Size Data from the Statistics of U.S. Businesses: U.S. Detail Employment Sizes: 2002." <http://www.census.gov/csd/susb/download_susb02.htm>.

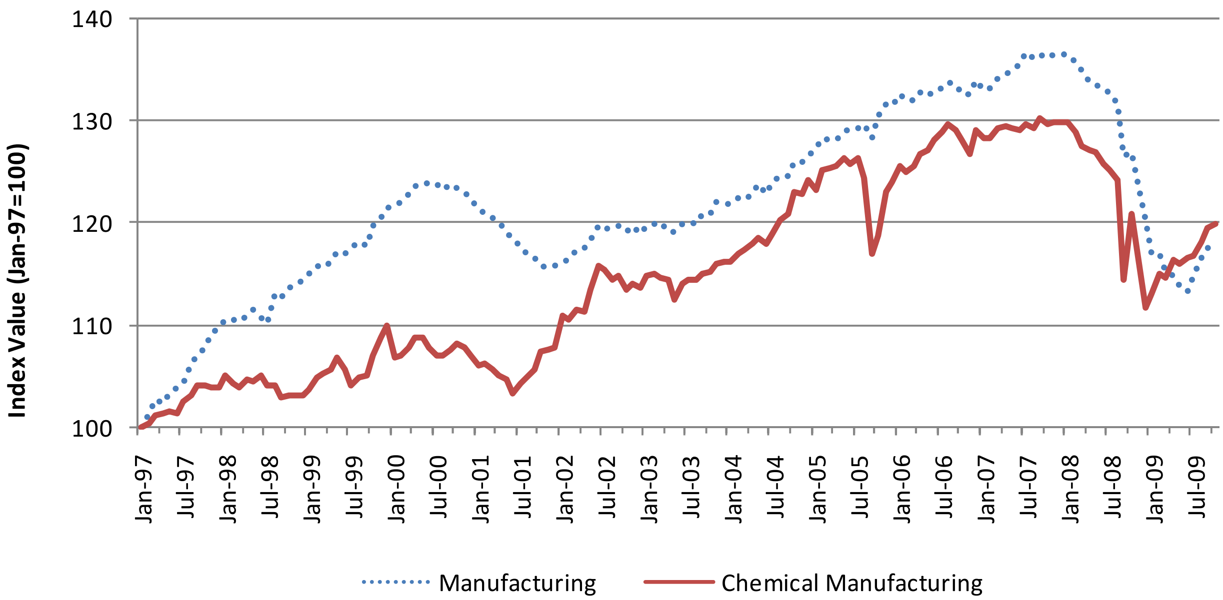


**Figure 2-38. Industrial Production Trends in Chemical Manufacturing (NAICS 325)**

Source: Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G325.S. <http://www.federalreserve.gov/datadownload/>.

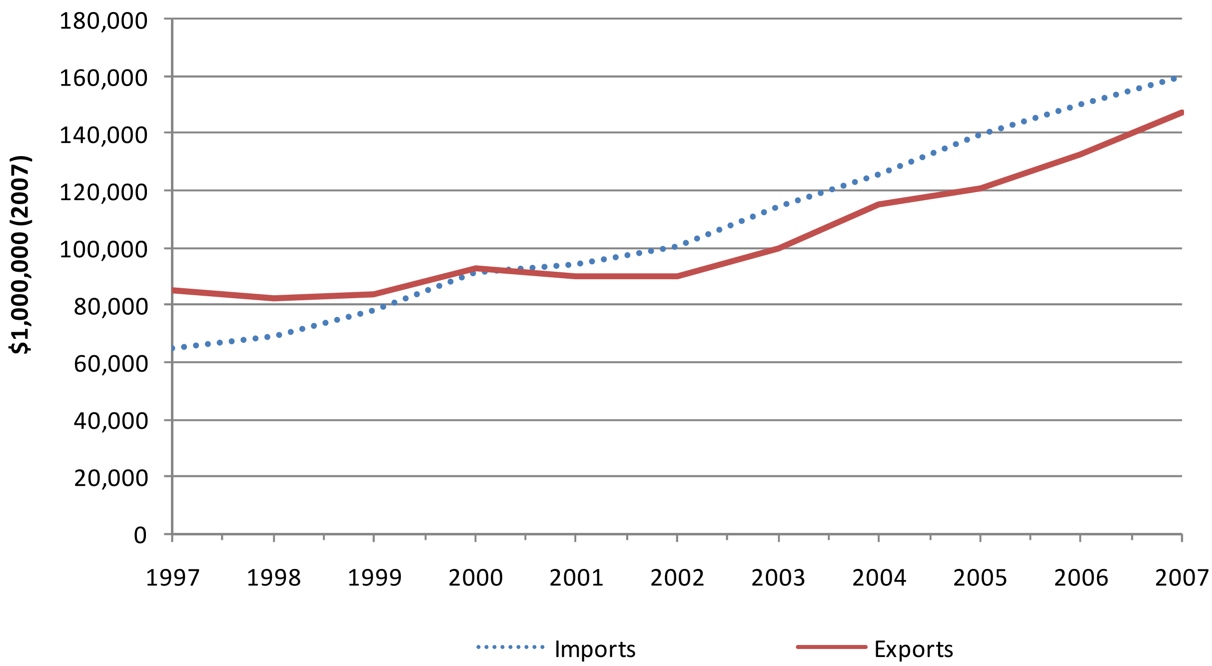


**Figure 2-39. International Trade Trends in Chemical Manufacturing (NAICS 325)**

Source: U.S. International Trade Commission. 2008a. "U.S. Domestic Exports" & "U.S. Imports for Consumption." <http://dataweb.usitc.gov/scripts/user_set.asp>.

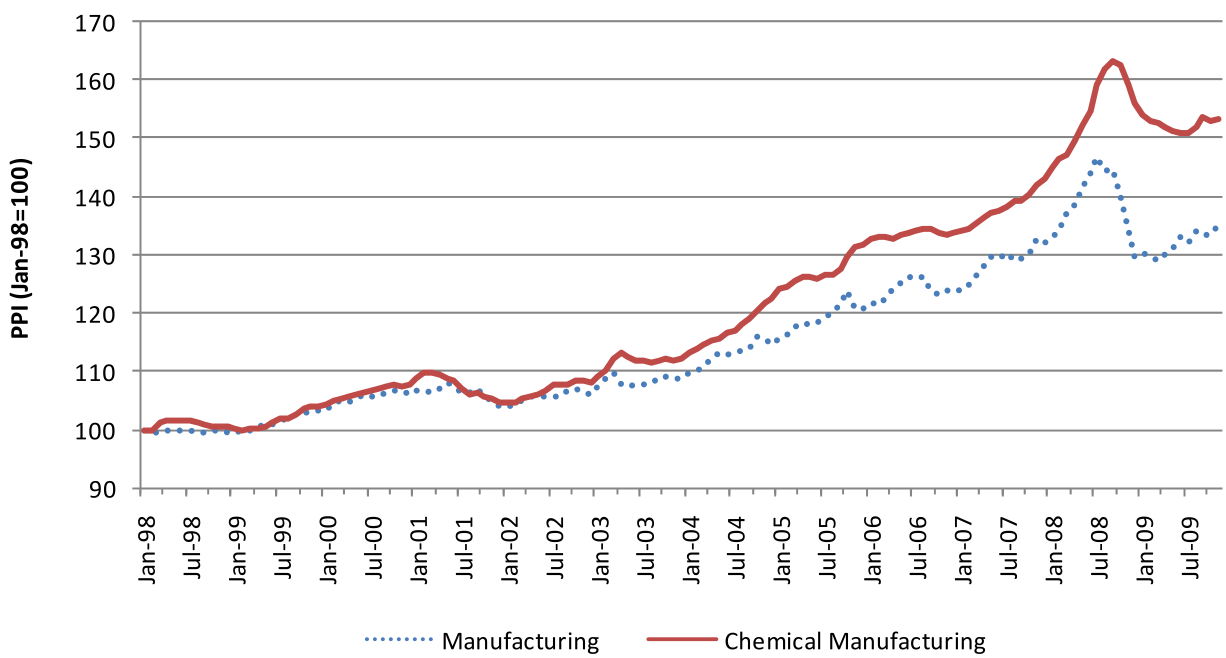


**Figure 2-40. Producer Price Trends in Chemical Manufacturing (NAICS 325)**

Source: U.S. Bureau of Labor Statistics (BLS). 2009. Producer Price Index. Series ID: PCU325—325—&PCUOMFG—OMFG—. <http://www.bls.gov/ppi/home.htm>.

# SECTION 3
# ENGINEERING COST ANALYSIS

We provide an overview of the engineering cost analysis used to estimate the additional private expenditures industry may make in order to comply with the rule. A detailed discussion of the methodology used to estimate cost impacts is presented in Appendices C and D.

## 3.1 Major Sources

To estimate the national cost impacts of the proposed rule for existing sources, EPA developed average baseline emission factors for each fuel type/control device combination based on the emission data obtained and contained in the Boiler MACT emission database. If a unit reported emission data, we assigned its unit-specific emission data as its baseline emissions. For units that did not report emission data, we assigned the appropriate emission factors to each existing unit in the inventory database, based on the average emission factors for boilers with similar fuel, design, control devices. We then compared each unit's baseline emission factors to the proposed MACT floor emission limit to determine if control devices were needed to meet the emission limits. The control analysis considered fabric filters, carbon bed adsorbers, and activated carbon injection to be the primary control devices for mercury control, electrostatic precipitators for units meeting mercury limits but requiring additional control to meet the PM limits, wet scrubbers to meet the HCl limits, tune-ups, replacement burners, and combustion controls for CO and organic HAP control, and carbon injection for dioxin/furan control. We identified where one control device could achieve reductions in multiple pollutants, for example a fabric filter was expected to achieve both PM and mercury control in order to avoid overestimating the costs. We also included costs for testing and monitoring requirements contained in the proposed rule. The resulting total national cost impact of the proposed rule is 10.0 billion dollars in capital expenditures and 3.2 billion dollars per year in total annual costs. Considering estimated fuel savings resulting from work practice standards and combustion controls, the total annualized costs are reduced to 2.9 billion. The total capital and annual costs include costs for control devices, work practices, testing and monitoring. Table 3-1 of this shows the capital and annual cost impacts for each subcategory. Costs include testing and monitoring costs, but not recordkeeping and reporting costs.

**Table 3-1. Summary of Capital and Annual Costs for New and Existing Major Sources**

| Source | Subcategory | Estimated/ Projected No. of Affected Units | Capital Costs (million) | Annualized Cost (million per yr) |
|---|---|---|---|---|
| Existing Units | Coal units | 578 | $4,500 | $1,600 |
| | Biomass units | 420 | $2,000 | $600 |
| | Liquid units | 826 | $1,400 | $500 |
| | Gas (NG/RG) units | 11,532 | $60 | $30 |
| | Gas (other) units | 199 | $1,600 | $500 |
| Energy Audit | ALL | | | 26 |
| New Units | Coal units | 0 | 0 | 0 |
| | Biomass units | 0 | 0 | 0 |
| | Liquid units | 11 | 12 | 6.1 |
| | Gas (NG/RG) units | 33 | 0.2 | 0.01 |
| | Gas (other) units | 2 | 5.5 | 1.7 |

Using Department of Energy projections on fuel expenditures, the number of additional boilers that could be potentially constructed was estimated. The resulting total national cost impact of the proposed rule in the 3rd year is 17 million dollars in capital expenditures and 6.2 million dollars per year in total annual costs, when considering a 1 percent fuel savings.

A discussion of the methodology used to estimate cost impacts is presented in "Methodology and Results of Estimating the Cost of Complying with the Industrial, Commercial, and Institutional Boiler and Process Heater NESHAP (2010)" in the Docket.

### 3.2 Area Sources

To estimate the national cost impacts of the proposed rule for existing sources, EPA developed several model boilers and determined the cost of control for these model boilers. The EPA assigned a model boiler to each existing unit based on the fuel, size, and current controls. The analysis considered all air pollution control equipment currently in operation at existing boilers. Model costs were then assigned to all existing units that could not otherwise meet the proposed standards. The resulting total national cost impact of the proposed rule for existing units is $279 million dollars in total annualized costs after considering fuel savings from efficiency improvements. The total annualized costs for installing controls, conducting an annual tune-up and an energy assessment, and implementing testing and monitoring requirements, is $696 million. Table 3-2 of this preamble shows the total annualized cost impacts for each subcategory.

**Table 3-2. Summary of Annual Costs for New and Existing Area Sources**

| Source | Subcategory | Estimated/ Projected No. of Affected Units | Total Annualized Cost (million per yr)[a] |
|---|---|---|---|
| **Existing Units** | Coal | 3,710 | $160 |
| | Biomass | 10,958 | $47 |
| | Oil | 168,003 | $436 |
| **Facility Energy Audit** | All | | $52 |
| **New Units[b]** | Coal | 155 | $54 |
| | Biomass | 200 | $13 |
| | Oil | 6,424 | $244 |

[a] TAC does not include fuel savings from improving combustion efficiency.
[b] Impacts for new units assume the number of units online in the first 3 years of this rule (2010 to 2013).

EPA also estimated the number of additional boilers that could be potentially constructed. The resulting total national cost impact of the proposed rule on new sources by the 3rd year, 2013, is $311 million dollars in total annualized costs. When accounting for a 1 percent fuel savings resulting from improvements to combustion efficiency, the total national cost impact on new sources is $260 million.

# SECTION 4
# ECONOMIC IMPACT ANALYSIS

EPA prepares an RIA to provide decision makers with a measure of the social costs of using resources to comply with a program (EPA, 2000). The social costs can then be compared with estimated social benefits (as presented in Section 6). As noted in EPA's (2000) *Guidelines for Preparing Economic Analyses*, several tools are available to estimate social costs and range from simple direct compliance cost methods to the development of a more complex market analysis that estimates market changes (e.g., price and consumption) and economic welfare changes (e.g., changes in consumer and producer surplus).

The Office of Air Quality Planning and Standards (OAQPS) adopted a standard market analysis as described in the Office's resource manual (EPA, 1999). The approach uses a single-period multimarket partial equilibrium model to compare pre-policy market baselines with expected post-policy market outcomes. The analysis' time horizon is the intermediate run; some production factors are fixed and some are variable and is distinguished from the very short run where all factors are fixed and producers cannot adjust inputs or outputs (EPA, 1999, 5-6). The intermediate time horizon allows us to capture important transitory stakeholder outcomes. Key measures in this analysis include industry-level changes in price levels, production and consumption, jobs, international trade, and social costs (changes in producer and consumer surplus).

## 4.1 Partial Equilibrium Analysis (Multiple Markets)

The partial equilibrium analysis develops a market model that simulates how stakeholders (consumers and industries) might respond to the additional regulatory program costs. In this section, we provide an overview of the economic model. Appendix A provides additional details on the behavioral assumptions, data, parameters, and model equations.

### *4.1.1 Overview*

Although several tools are available to estimate social costs, current EPA guidelines suggest that multimarket models "…are best used when potential economic impacts and equity effects on related markets might be considerable" and modeling using a computable general equilibrium model is not available or practical (EPA, 2000, p. 146). Other guides for environmental economists offer similar advice (Berck and Hoffmann, 2002; Just, Hueth, and Schmitz, 2004). Multimarket models focus on "short-run" time horizons and measure a policy's near-term or transition costs (EPA, 1999). The multimarket model contains the following features:

- Industry sectors and benchmark data set
  - 100 industry sectors
  - a single benchmark year (2010)
  - estimates of industry employment
- Economic behavior
  - industries respond to regulatory costs by changing production rates
  - market prices rise and fall to reflect higher energy and other non-energy material costs and changes in demand
  - customers respond to these price increases and consumption falls
- Model scope
  - 100 sectors are linked with each other based on their use of energy and other non-energy materials. For example, the construction industry is linked with the petroleum, cement, and steel industries and is influenced by price changes that occur in each sector. The links allow EPA to account for indirect effects the regulation has on related markets.
  - production adjustments influence employment levels
  - international trade (imports/exports) responds to domestic price changes
- Model time horizon ("short run") for a single period (2013)
  - fixed production resources (e.g., capital) lead to an upward-sloping industry supply function
  - firms cannot alter input mixes; there is no substitution among production inputs (capital, labor, energy intermediates, and other intermediate goods and services)
  - price of labor (i.e., wage) is fixed
  - investment and government expenditures are fixed

### *4.1.2 Economic Impact Analysis Results*

#### *4.1.2.1 Market-Level Results*

Market-level impacts include price and quantity adjustments including the changes in international trade (Figure 4-1). Under the proposed major source NESHAP, the Agency's economic model suggests the average national prices for industrial sectors could be 0.01% higher with the NESHAP, while average annual domestic production may fall by about 0.01%. Because of higher domestic prices, imports rise by 0.01% per year. Market-level effects for the proposed area source NESHAP are smaller when compared to the proposed major source rule; average

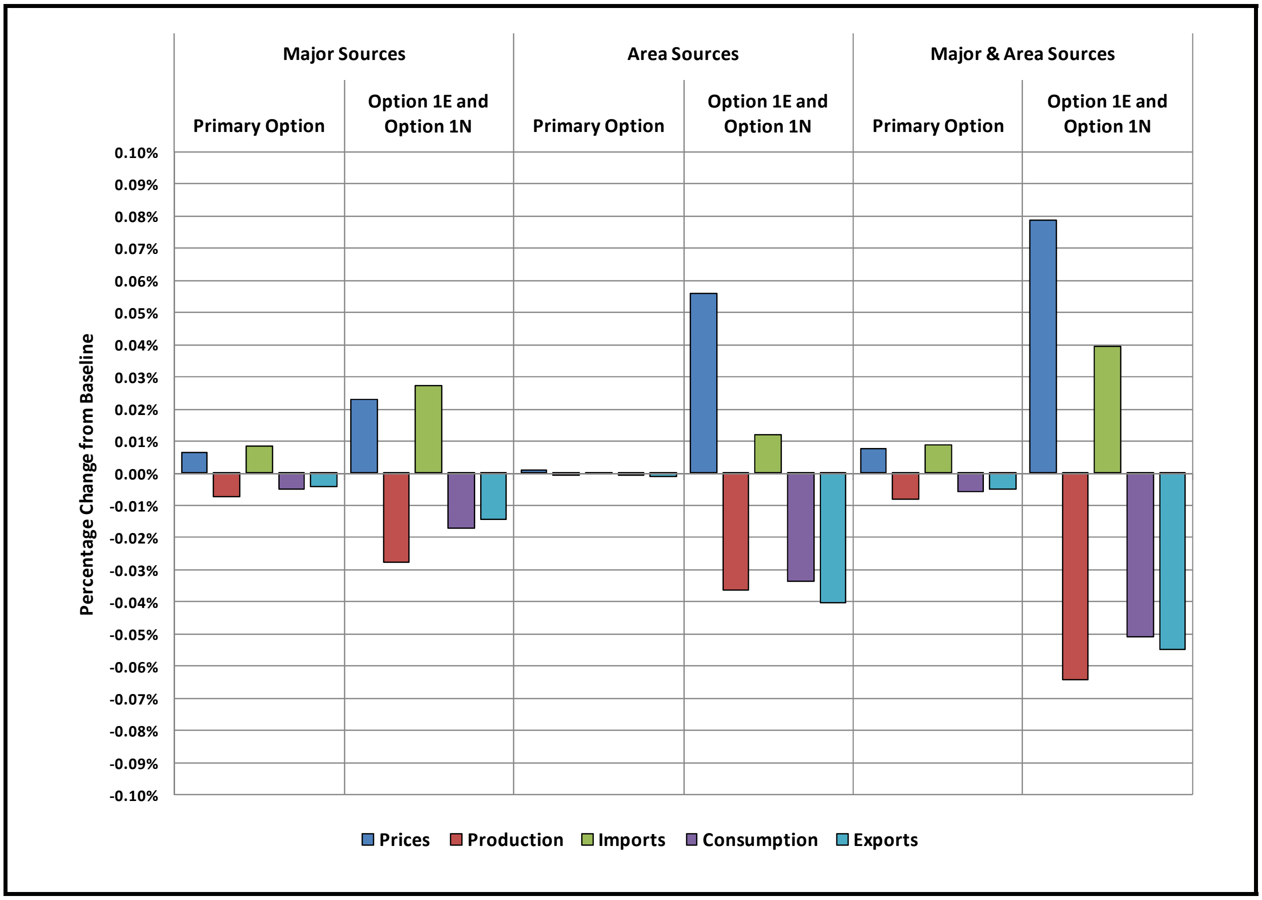


**Figure 4-1. Market-Level Changes by Source and Option**

price, production, and import changes are less than 0.01%. Industrial sector details are provided in Appendix B.

### *4.1.2.2 Social Cost Estimates Major Source Rule*

In the near term, the Agency's economic model suggests that industries are able to pass on $0.8 billion (2008$) of the proposed area source rule's costs to U.S. households in the form of higher prices (Table 4-1). Existing U.S. industries' surplus falls by $2.5 billion and the net loss in aggregate is $3.3 billion. As U.S. prices rise, other countries are affected through international trade relationships. The price of goods produced in the United States increase slightly and domestic production declines, replaced to a certain degree by imports; the model estimates a net gain of $0.1 billion to foreign companies. After accounting for international trade effects, the Agency's economic model projects the net surplus loss associated with the proposed rule is $3.2 billion. As shown in Figure 4-2, the surplus losses are concentrated in other services (20 percent); lumber, paper, and printing (19 percent); and chemicals (16 percent)

**Table 4-1. Distribution of Social Costs Major Sources (billion, 2008$): 2013**

| Approach | Primary Option | Option 1E and Option 1N |
|---|---|---|
| **Partial Equilibrium Model (Multiple Markets)** | | |
| Change in U.S. consumer surplus | −$0.8 | −$3.8 |
| Change in U.S. producer surplus | −$2.5 | −$8.9 |
| Change in U.S. surplus | −$3.3 | −$12.7 |
| Net change in rest of world surplus | $0.1 | $0.5 |
| Net change in total surplus | −$3.2 | −$12.2 |
| **Direct Compliance Costs Method** | | |
| Total annualized costs, new major sources (not modeled) | Less than −$0.1 | Less than −$0.1 |
| Fuel savings, existing major sources (not modeled) | $0.4 | $0.3 |
| Fuel savings, new major sources (not modeled) | Less than $0.1 | Less than $0.1 |
| **Change in Total Surplus** | −$2.9 | −$11.9 |

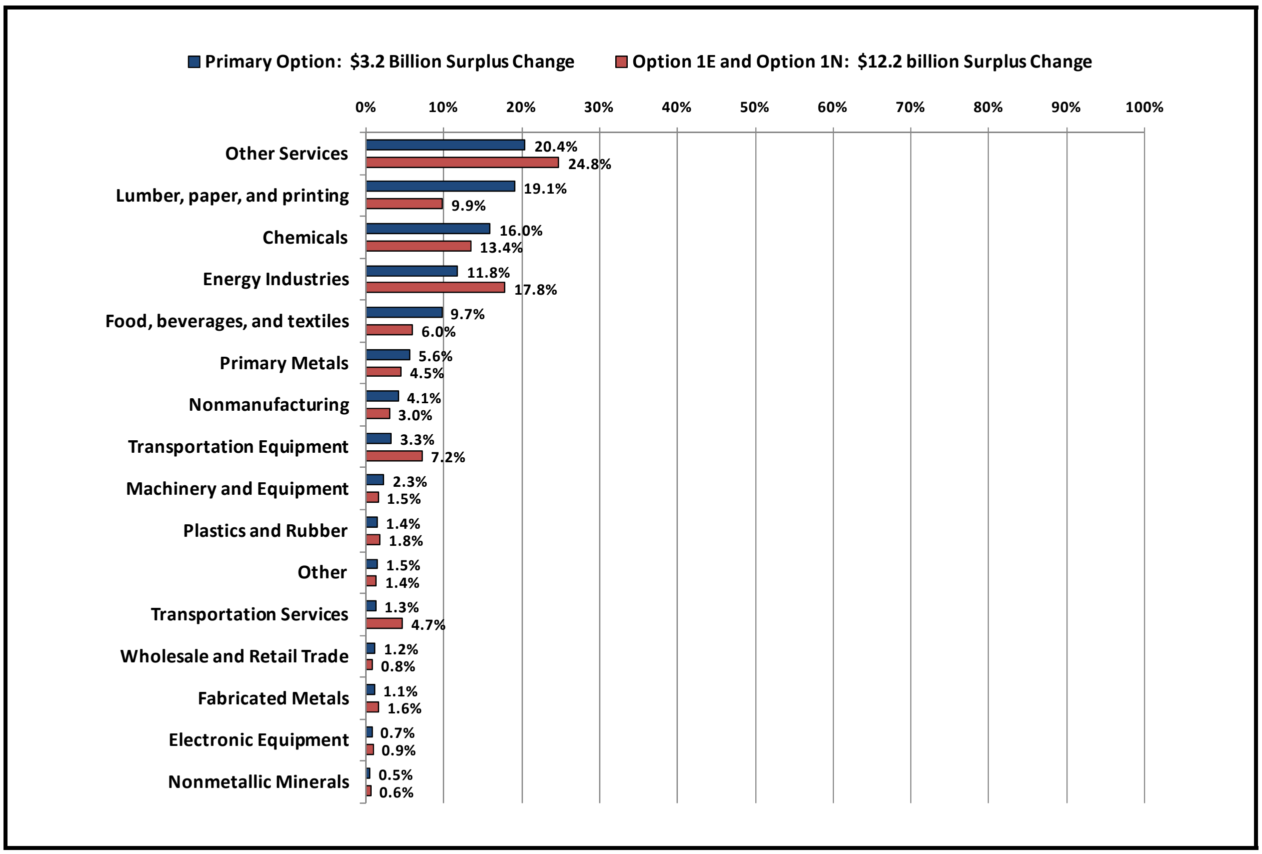


**Figure 4-2. Distribution of Total Surplus Changes by Sector: Major Sources**

The Agency also considered other elements of the engineering cost analysis that could not be modeled within the multimarket model (e.g., fuel savings benefits [existing and new major sources] and total annualized compliance costs [new major sources]). The net effect of the adjustments is a total surplus loss estimate of $2.9 billion.

*4.1.2.3 Social Cost Estimates Area Source Rule*

In the near term, the Agency's economic model suggests that industries are able to pass on $0.3 billion (2008$) of the proposed area source rule's costs to U.S. households in the form of higher prices (Table 4-2). Existing U.S. industries' surplus falls by $0.3 billion and the net loss for U.S. stakeholders is $0.6 billion. As U.S. prices rise, other countries are affected through international trade relationships. Households that buy U.S. exports pay higher prices and purchase fewer U.S. produced goods. Other countries that that sell goods to the United States benefit; the model estimates a net rest of the world gain of less than $0.1 billion. After accounting for international trade effects, the Agency's economic model projects the net surplus (consumer and producer) loss associated with the proposed rule is $0.6 billion. As shown in Figure 4-3, the surplus losses are concentrated in the other services (86 percent ).

**Table 4-2. Distribution of Social Costs Area Sources (billion, 2008$): 2013**

| Approach | Primary Option | Option 1E and Option 1N |
|---|---|---|
| **Partial Equilibrium Model (Multiple Markets)** | | |
| Change in U.S. consumer surplus | −$0.3 | −$16.5 |
| Change in U.S. producer surplus | −$0.3 | −$16.5 |
| Change in U.S. surplus | −$0.6 | −$33.1 |
| Net change in rest of world surplus | Less than $0.1 | −$0.1 |
| Net change in total surplus | −$0.6 | −$33.2 |
| **Direct Compliance Costs Method** | | |
| Total annualized costs, unknown existing area sources (not modeled) | Less than $0.1 | −$0.3 |
| Total annualized costs, new area sources (not modeled) | −$0.3 | −$2.3 |
| Fuel savings, existing area sources (not modeled) | $0.4 | $0.4 |
| Fuel savings, new area sources (not modeled) | Less than $0.1 | Less than $0.1 |
| **Change in Total Surplus** | −$0.5 | −$35.3 |

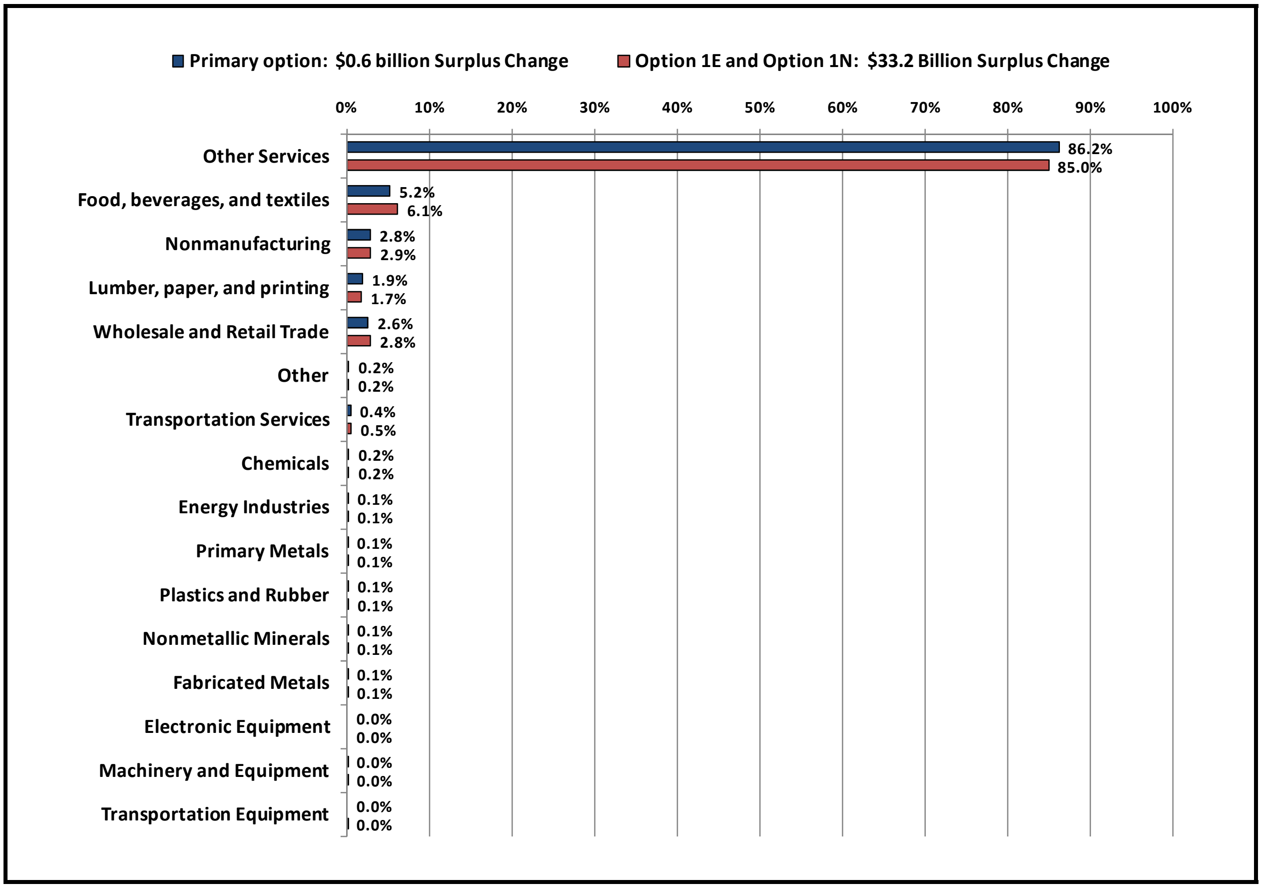


**Figure 4-3. Distribution of Total Surplus Changes by Sector: Area Sources**

The Agency also considered other elements of the engineering cost analysis that could not be modeled within the multimarket model (e.g., fuel-savings benefits [existing and new area sources] and total annualized compliance costs [unknown existing and new area sources]). The net effect of the adjustments is a total surplus loss estimate of $0.5 billion.

*4.1.2.4 Job Effects*

Precise job effect estimates cannot be estimated with certainty. Morgenstern et al. (2002) identify three economic mechanisms by which pollution abatement activities can indirectly influence jobs:

- higher production costs raise market prices, higher prices reduce consumption, and employment within an industry falls ("demand effect");
- pollution abatement activities require additional labor services to produce the same level of output ("cost effect"); and

- post regulation production technologies may be more or less labor intensive (i.e., more/less labor is required per dollar of output) ("factor-shift effect").

Several empirical studies, including Morgenstern et al. (2002), suggest the net employment decline is zero or economically small (e.g., Cole and Elliot, 2007; Berman and Bui, 2001). However, others show the question has not been resolved in the literature (Henderson, 1996; Greenstone, 2002). Morgenstern et al. use a six-year panel (U.S. Census data for plant-level prices, inputs (including labor), outputs, and environmental expenditures) to econometrically estimate the production technologies and industry-level demand elasticities. Their identification strategy leverages repeat plant-level observations over time and uses plant-level and year fixed effects (e.g., plant and time dummy variables). After estimating their model, Morgenstern show and compute the change in employment associated with an additional $1 million ($1987) in environmental spending. Their estimates cover four manufacturing industries (pulp and paper, plastics, petroleum, and steel) and Morgenstern, et al. present results separately for the cost, factor shift, and demand effects, as well as the net effect. They also estimate and report an industry-wide average parameter that combines the four industry-wide estimates and weighting them by each industry's share of environmental expenditures.

EPA has most often estimated employment changes associated with plant closures due to environmental regulation or changes in output for the regulated industry (EPA, 1999a; EPA, 2000). This analysis goes beyond what EPA has typically done in two ways. First, because the multimarket model provides estimates for changes in output for sectors not directly regulated, we were able to estimate a more comprehensive "demand effect." Secondly, parameters estimated in the Morgenstern paper were used to estimate all three effects ("demand," "cost," and "factor shift"). This transfer of results from the Morgenstern study is uncertain but avoids ignoring the "cost effect" and the "factor-shift effect."

We calculated "demand effect" employment changes by assuming that the number of jobs declines proportionally with multi-market model's simulated output changes. These results were calculated for all sectors in the EPA model that show a change in output.

We also calculated a similar "demand effect" estimate that used the Morgenstern paper. EPA selected this paper because the parameter estimates (expressed in jobs per million ($1987) of environmental compliance expenditures) provide a transparent and tractable way to transfer estimates for an employment effects analysis. Similar estimates were not available from other studies. To do this, we multiplied the point estimate for the total demand effect (−3.56 jobs per million ($1987) of environmental compliance expenditure) by the total environmental compliance expenditures used in the partial equilibrium model. For example, the jobs effect estimate for the Major Source Rule is estimated to be 7,000 jobs (−3.56× \$3.2 billion × 0.60).[1] Demand effect results are provided in Figure 4-4.

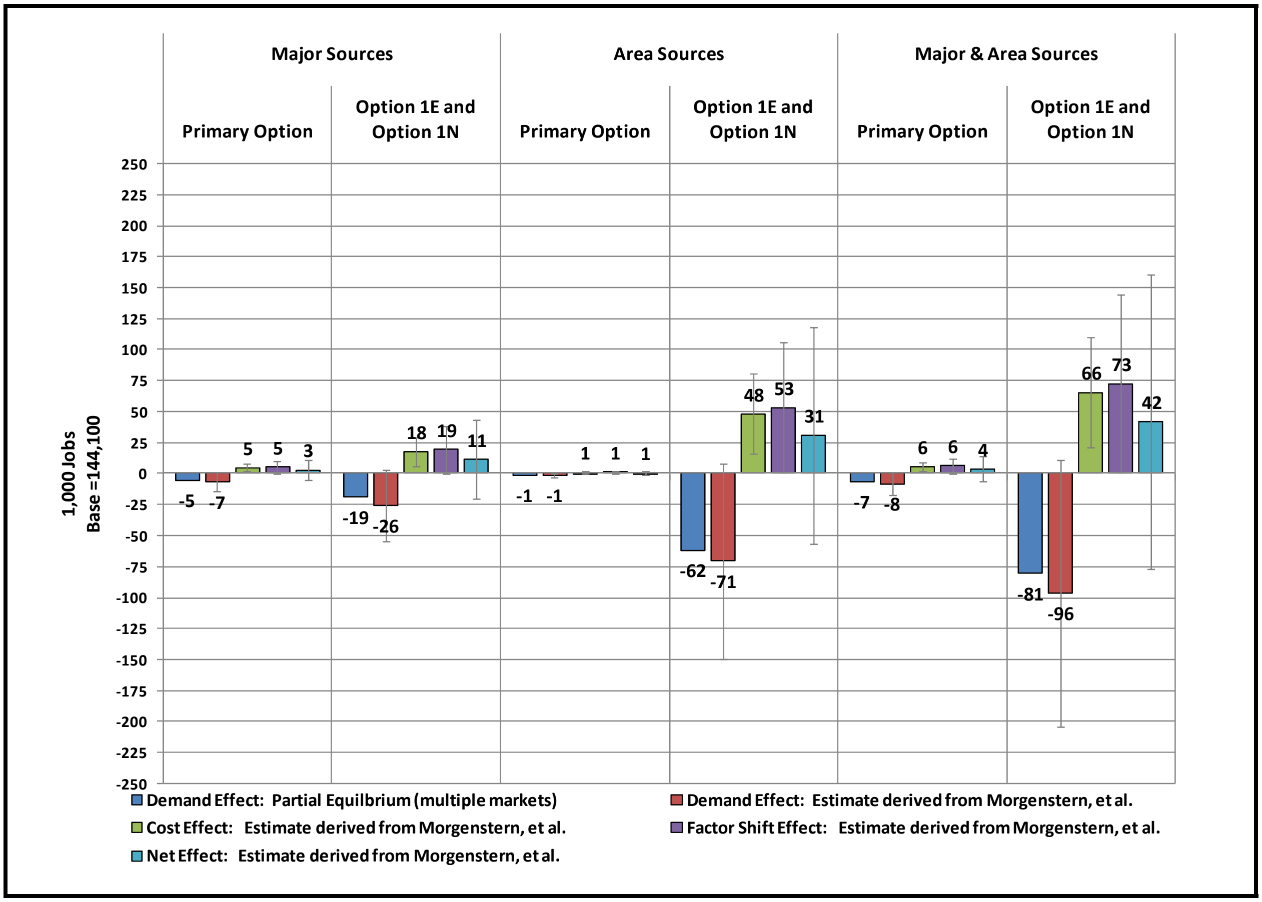


**Figure 4-4. Job Losses/Gains Associated with the Proposed Rules: 2013**

We also present the results of using the Morgenstern paper to estimate employment "cost" and "factor-shift" effects. Although using the Morgenstern parameters to estimate these "cost" and "factor-shift" employment changes is uncertain, it is helpful to compare the potential job gains from these effects to the job losses associated with the "demand" effect. Figure 4-4 shows that using the Morgenstern point estimates of parameters to estimate the "cost" and "factor shift" employment gains may be greater than the employment losses using either of the two ways of estimating "demand" employment losses. The 95% confidence intervals are shown for all of the

[1] Since Morgenstern's analysis reports environmental expenditures in \$1987, we make an inflation adjustment the engineering cost analysis using GDP implicit price deflator (64.76/108.48) = 0.60)

estimates based on the Morgenstern parameters. As shown, at the 95% confidence level, we cannot be certain if net employment changes are positive or negative.

Although the Morgenstern paper provides additional information about the potential job effects of environmental protection programs, there are several qualifications EPA considered as part of the analysis. First, EPA has used the weighted average parameter estimates for a narrow set of manufacturing industries (pulp and paper, plastics, petroleum, and steel). Absent other data and estimates, this approach seems reasonable and the estimates come from a respected peer-reviewed source. However, EPA acknowledges the proposed rule covers a broader set of industries not considered in original empirical study. By transferring the estimates to other industrial sectors, we make the assumption that estimates are similar in size. In addition, EPA assumes also that Morgenstern et al.'s estimates derived from the 1979-1991 still applicable for policy taking place in 2013, almost 20 years later. Second, the multi-market model only considers near term employment effects in a U.S. economy where production technologies are fixed. As a result, the modeling system places more emphasis on the short term "demand effect" whereas the Morgenstern paper emphasizes other important long term responses. For example, positive job gains associated with "factor shift effects" are more plausible when production choices become more flexible over time and industries can substitute labor for other production inputs. Third, the Morgenstern paper estimates rely on sector demand elasticities that are different from the demand elasticity parameters used in the multi-market model. As a result, the demand effects are not directly comparable with the demand effects estimated by the multi-market model. Fourth, Morgenstern identifies the industry average as economically and statistically insignificant effect (i.e., the point estimates are small, measured imprecisely, and not distinguishable from zero.) EPA acknowledges this fact and has reported the 95 percent confidence intervals in Figure 4-4. Fifth, Morgenstern's methodology assumes large plants bear most of the regulatory costs. By transferring the estimates, EPA assumes a similar distribution of regulatory costs by plant size and that the regulatory burden does not disproportionately fall on smaller plants.

# SECTION 5
# SMALL ENTITY ANALYSES

The RFA as amended by SBREFA generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute, unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities (SISNOSE). Small entities include small businesses, small governmental jurisdictions, and small not-for-profit enterprises. EPA assessed the potential small entity economic impacts using a screening analysis. After reviewing screening analysis results, EPA has determined it cannot certify that the proposed rules will not have a SISNOSE and presumes that both proposed rules are not eligible for certification under the RFA as amended by SBREFA. As a result, EPA has prepared and included an IRFA that discusses alternative regulatory or policy options that minimize the rules' small entity impacts. It includes information about key results from the SBAR panel.

## 5.1 Small Entity Screening Analysis

### *5.1.1 Small Businesses*

The sectors covered by the rule were identified through lists of small entities at major and area sources provided by the engineering analysis. Table 5-1 provides a list of the sectors affected (3-digit NAICS) and the range of SBA size definitions.

#### *5.1.1.1 Representative Small Business Analysis Using Census Statistics of U.S. Businesses*

For each 3-digit NAICS code, the SUSB provides national information on the distribution of economic variables by industry and enterprise size (U.S. Census, 2008). The Census Bureau and the Office of Advocacy of the SBA supported and developed these files for use in a broad range of economic analyses.[1] Statistics include the total number of establishments and receipts for all entities within an industry; however, only a subset of entities will be covered by the proposed rule. SUSB also provides statistics by enterprise employment and receipt size.

The Census Bureau's definitions used in the SUSB are as follows:

- *Establishment*: An establishment is a single physical location where business is conducted or where services or industrial operations are performed.

1 See http://www.census.gov/csd/susb/ and http://www.sba.gov/advo/research/data.html for additional details.

**Table 5-1. Affected Sectors and Size Standards**

| 2007 NAICS | Description | Size Standard (Effective August 22, 2008) |
|---|---|---|
| 211 | Oil and Gas Extraction | 500 employees |
| 212 | Mining (except Oil and Gas) | 500 employees |
| 221 | Utilities | [a] |
| 311 | Food Manufacturing | 500 to 1,000 employees |
| 312 | Beverage and Tobacco Product Manufacturing | 500 to 1,000 employees |
| 313 | Textile Mills | 500 to 1,000 employees |
| 321 | Wood Product Manufacturing | 500 employees |
| 322 | Paper Manufacturing | 500 to 750 employees |
| 323 | Printing and Related Support Activities | 500 employees |
| 324 | Petroleum and Coal Products Manufacturing | Typically 500 to 1,500 employees |
| 325 | Chemical Manufacturing | 500 to 1,000 employees |
| 326 | Plastics and Rubber Products Manufacturing | Typically 500 to 1,000 employees |
| 327 | Nonmetallic Mineral Product Manufacturing | 500 to 1,000 employees |
| 331 | Primary Metal Manufacturing | 500 to 1,000 employees |
| 332 | Fabricated Metal Product Manufacturing | 500 to 1,500 employees |
| 335 | Electrical Equipment Manufacturing | 500 to 1,000 employees |
| 336 | Transportation Equipment Manufacturing | 500 to 1,000 employees |
| 337 | Furniture and Related Product Manufacturing | 500 employees |
| 339 | Miscellaneous Manufacturing | 500 employees |
| 423 | Merchant Wholesalers, Durable Goods | 100 employees |
| 493 | Warehousing and Storage | $25.5 million in annual receipts |
| 562 | Waste Management and Remediation Services | Typically $7 to $14 million in annual receipts |
| 611 | Educational Services | Typically $7 to $35.5 million in annual receipts |

[a] NAICS codes 221111, 221112, 221113, 221119, 221121, 221122: A firm is small if, including its affiliates, it is primarily engaged in the generation, transmission, and/or distribution of electric energy for sale and its total electric output for the preceding fiscal year did not exceed 4 million megawatt hours.

- *Receipts*: Receipts (net of taxes) are defined as the revenue for goods produced, distributed, or services provided, including revenue earned from premiums, commissions and fees, rents, interest, dividends, and royalties. Receipts exclude all revenue collected for local, state, and federal taxes.
- *Enterprise*: An enterprise is a business organization consisting of one or more domestic establishments that were specified under common ownership or control. The enterprise and the establishment are the same for single-establishment firms. Each multi-establishment company forms one enterprise—the enterprise employment and annual payroll are summed from the associated establishments. Enterprise size designations are determined by the total employment of all associated establishments.

Because the SBA's business size definitions (SBA, 2008) apply to an establishment's "ultimate parent company," we assumed in this analysis that the "enterprise" definition above is consistent with the concept of ultimate parent company that is typically used for SBREFA screening analyses, and the terms are used interchangeably.

The analysis generated a set of establishment sales tests (represented as cost-to-receipt ratios) for NAICS codes associated with sectors listed in Table 5-2. Although the appropriate SBA size definition should be applied at the parent company (enterprise) level, we can only compute and compare ratios for a model establishment owned by an enterprise within an SUSB size range (employment or receipts). Using the SUSB size range helps us account for receipt differences between establishments owned by large and small enterprises and also allows us to consider the variation in small business definitions across affected industries. Using establishment receipts is also a conservative approach, because an establishment's parent company (the "enterprise") may have other economic resources that could be used to cover the costs of the regulatory program.

For each representative establishment in the SUSB data, we developed a range of facility-level cost numerators based on the engineering cost analysis. For major sources, we used the maximum and minimum small entity facility-level costs observed within each 3-digit NAICS code. For area sources, we were limited to two representative small entity facility-level costs (approximately \$26,000,000 to \$1.4 million)[1]. Using these cost data and the Census estimates of average establishment receipts, a substantial number of SUSB NAICS/enterprise categories have ratios over 3% (Figure 5-1).

1 Prior to computing the cost-to-receipt ratios, we adjusted the engineering compliance costs to reflect 2002 dollars using the implicit price deflators for gross domestic product (GDP). The values used are 2002 = 92.118 and 2008 = 108.483 (U.S. BEA, 2010).

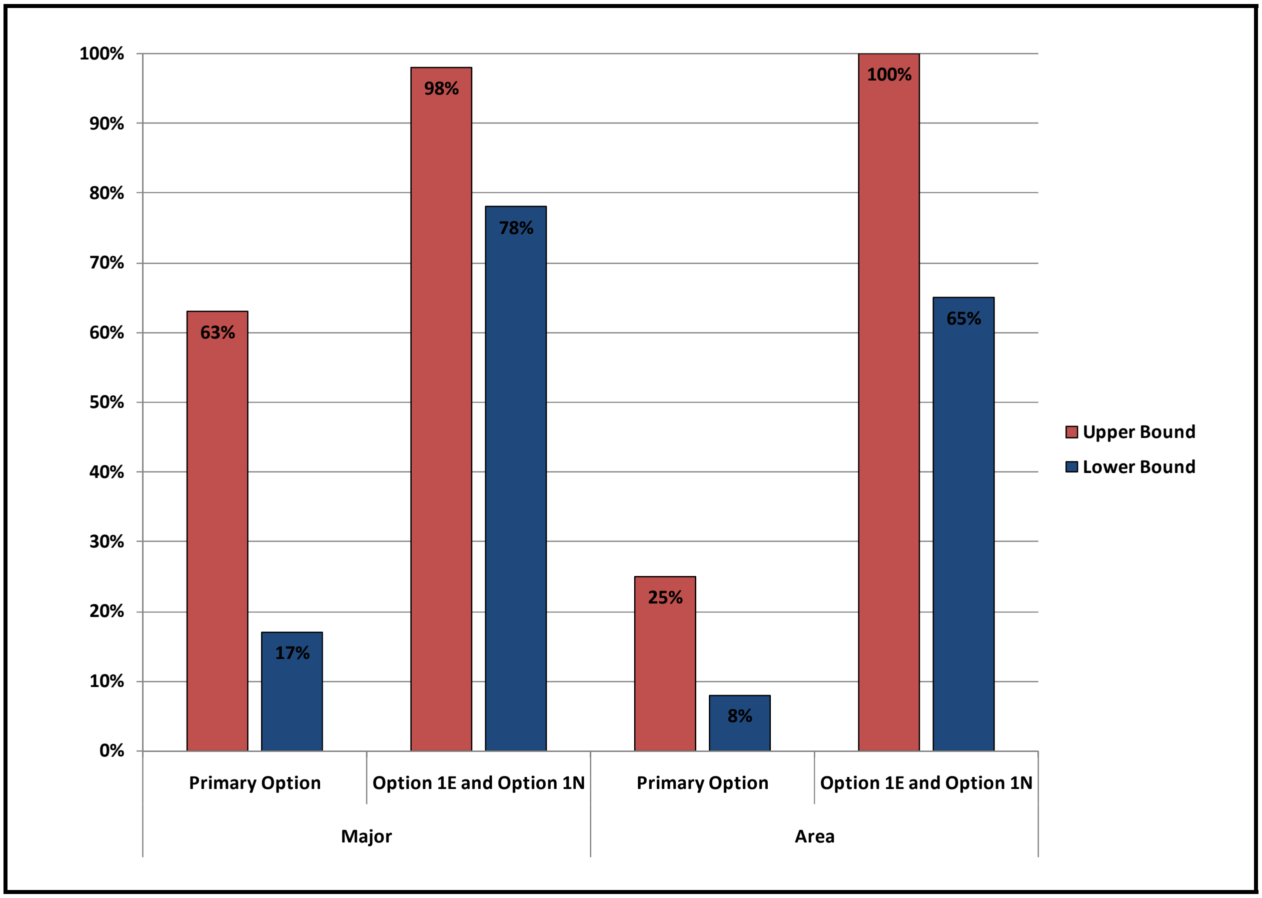


**Figure 5-1. Share of NAICS/Enterprise Employment Categories (<500 employees) with Sales Tests Exceeding 3%**

*5.1.1.2 Additional Small Business Analysis Using Sample of Small Businesses Identified in Combustion Facility Survey*

Next, we performed a more detailed analysis that compares the Census SUSB representative small entity results with a firm-specific sample of major small private enterprises. In this approach, we identified a sample of survey facility names listed as small, traced the ultimate parent company name to verify the facility was owned by a small business, and collected the most recent parent company sales and employment figures. As Table 5-2 shows, the average cost-to-sales ratios for small major source companies are above 5%. The median ratios are below one percent for the primary option and above 5 percent for Option 1E.

**Table 5-2. Major Sources: Sales Tests Using Small Companies Identified in the Combustion Survey**

| Sample Statistic | Primary Option | Option 1E |
|---|---|---|
| Mean | 4.9% | 15.6% |
| Median | 0.4% | 5.3% |
| Maximum | 72.9% | 100.0% |
| Minimum | <0.1% | <0.1% |
| Ultimate parent company observations | 50 | 50 |
| Ultimate parent companies with sale tests exceeding 3% | 14 | 30 |

### *5.1.2 Small Governmental Jurisdictions and Not-for--Profit Enterprises*

In addition to the private sector, this rule also covers sectors that include entities owned by small and large governments and not-for-profit enterprises. Given the uncertainty and data limitations associated with identifying and appropriately classifying these entities, we computed a "revenue" test, where the annualized compliance cost is a percentage of annual revenues (U.S. Census, 2005a and b).

Compliance costs were estimated for model facilities for major and area sources for multiple options. A summary of the compliance costs used for the small entity analysis follows:

Major Sources:

- *Primary option*: $3.0 million (median cost small public facility)
- *Option 1E and 1N*: $4.5 million (median cost small public facility)

Area Sources:

- Primary option:
  - Other public: $3.0 million
  - Hospital: $11,300
  - Schools: $4,500
  - Churches: $2,200

- Option 1E and Option 1N:
  - Other public: $2.9 million
  - Hospital: $141,000
  - Schools: $346,000
  - Churches: $45,000

From the 2002 Census (in 2008 dollars), the average revenue for small governments (counties and municipalities with populations fewer than 10,000) are $3 million per entity, and the average revenue for local governments with populations fewer than 50,000 is $7 million per entity. Churches are assumed to have an operation budget of $150,000.

The analysis shows that small major source public facilities would have cost-to-revenue ratios that exceed 10% under the both regulatory options. The following small area source facilities would have cost-to-revenue ratios exceeding 1 percent:

- Primary option: other public (ratio > 10 percent) and churches (ratio = 1.5 percent)
- Option 1E and Option 1N: other public (ratio > 10 percent), hospitals (ratio > 3 percent), schools (ratio > 10 percent), and churches (ratio >10 percent).

## 5.2 Initial Regulatory Flexibility Analysis (IFRA)

An IRFA illustrates how EPA considered the proposed rule's small entity effects before a rule is finalized and provides information about how the objectives of the rule were achieved while minimizing significant economic impacts on small entities. We provide a summary of IRFA elements; the preambles for each rule provide additional details.

### *5.2.1 Reasons Why Action Is Being Considered*

In 2004, EPA promulgated national emission NESHAP for new and existing industrial/commercial/institutional boilers and process heaters. However, in 2007, the U.S. Court of Appeals for the District of Columbia Circuit (DC Circuit) vacated the NESHAP for industrial/commercial/institutional boilers and process heaters. The proposed action provides EPA's proposed rule in response to the court's vacatur. Under authority of section 112 of the Clean Air Act (CAA), EPA is also proposing a NESHAP for two area source categories: industrial boilers and institutional/commercial boilers.

### *5.2.2 Statement of Objectives and Legal Basis of Proposed Rules*

The proposed rules would protect air quality and promote public health by reducing emissions of the HAPs. Section 112(d) of the CAA requires EPA to establish NESHAPs for both major and area sources of HAPs that are listed for regulation under CAA section 112(c). A major source emits or has the potential to emit 10 tons per year (tpy) or more of any single HAP or 25 tpy or more of any combination of HAP. An area source is a stationary source that is not a major source.

### *5.2.3 Description and Estimate of the Number of Small Entities*

The sectors covered by the rule were identified through lists of small entities at major and area sources included in the survey. A listing of the sectors affected (3-digit NAICS) and the range of SBA size definitions are provided in Table 5-1. EPA believes a substantial number of small entities will be affected by the proposed rules, but data limitations preclude us from providing precise estimates of the number of small entities affected.

### *5.2.4 Description and Compliance Costs*

#### *5.2.4.1 Major Sources*

A discussion of the methodology used to estimate cost impacts is presented in "Methodology and Results of Estimating the Cost of Complying with the Industrial, Commercial, and Institutional Boiler and Process Heater NESHAP" in the Docket and Section 4 of the RIA.

#### *5.2.4.2 Area Sources*

A detailed discussion of the methodology used to estimate cost impacts is presented in the memorandum "Estimation of Impacts for Industrial, Commercial, and Institutional Boilers Area Source NESHAP" in the Docket and Section 4 of the RIA.

### *5.2.5 Description of Federal Rules that May Overlap or Conflict with Proposed Rules*

The proposed major source rule regulates source categories covering industrial boilers, institutional boilers, commercial boilers, and process heaters that may include combustion units that are already regulated by other MACT standards. Therefore, EPA proposes to exclude any boiler or process heater that is already or will be subject to regulation under another MACT standard. Boilers located at area source facilities may be regulated pursuant to CAA section 129. Section 129(h) states that no unit subject to standards under section 129 shall be subject to standards under section 112(d) of the CAA. As a result, EPA proposes to exclude any boiler that is subject to regulation under section 129. EPA has codified new source performance standards (NSPS) for industrial boilers (40 CFR 60, subparts Db and Dc), but the NSPS does not regulate sources of HAPs. As a result, sources subject to the NSPS will still be subject to the proposed rules. However, EPA has minimized the monitoring requirements, testing requirements, and recordkeeping requirements to avoid duplicating NSPS requirements.

### *5.2.6 Description of Regulatory Alternatives that Minimize Significant Economic Impacts on Small Entities*

As required by section 609(b) of the RFA, as amended by SBREFA, EPA has conducted outreach to small entities and convened a SBAR Panel to obtain advice and recommendation of representatives of the small entities that potentially would be subject to the requirements of this rule. On January 22, 2009, EPA's Small Business Advocacy Chairperson convened a Panel under section 609(b) of the RFA. In addition to the Chair, the Panel consisted of the Director of the Sector Policies and Programs Division within EPA's Office of Air and Radiation, the Chief Counsel for Advocacy of the SBA, and the Administrator of the Office of Information and Regulatory Affairs within the Office of Management and Budget.

As part of the SBAR Panel process, we conducted outreach with representatives from 14 various small entities that would be affected by this rule. The small entity representatives (SERs) included associations representing schools, churches, hotels/motels, wood product facilities, and manufacturers of home furnishings. We met with these SERs to discuss the potential rulemaking approaches and potential options to decrease the impact of the rulemaking on their industries/sectors. We distributed outreach materials to the SERs; these materials included background on the rulemaking, possible regulatory approaches, preliminary cost and economic impacts, and possible rulemaking alternatives. The Panel met with SERs from the industries that will be directly affected by this rule on February 10, 2009, to discuss the outreach materials and receive feedback on the approaches and alternatives detailed in the outreach packet. (EPA also met with SERs on November 13, 2008, for an initial outreach meeting.) The Panel received written comments from the SERs following the meeting in response to discussions at the meeting and the questions posed to the SERs by the Agency. The SERs were specifically asked to provide comment on regulatory alternatives that could help minimize the rules' impact on small businesses.

#### *5.2.6.1 Panel Recommendations for Small Business Flexibilities*

The Panel recommended that EPA consider and seek comment on a wide range of regulatory alternatives to mitigate the impacts of the rulemaking on small businesses, including those flexibility options described below. The following section summarizes the SBAR Panel recommendations. EPA has proposed provisions consistent with four of the Panel's recommendations.

Consistent with the RFA/SBREFA requirements, the Panel evaluated the assembled materials and small-entity comments on issues related to elements of the IRFA. A copy of the Final Panel Report (including all comments received from SERs in response to the Panel's outreach meeting), as well as summaries of both outreach meetings that were held with the SERs, is included in the docket for the proposed rules. A summary of the Panel recommendations is detailed below. The proposals include proposed provisions for all but one of the Panel recommendations.

***5.2.6.1.1 Work Practice Standards.*** The panel recommended that EPA consider requiring annual tune-ups, including standardized criteria outlining proper tune-up methods targeted at smaller boiler operators. The panel further recommended that EPA take comment on the efficacy of energy assessments/audits at improving combustion efficiency and the cost of performing the audits, especially to smaller boiler operators.

A work practice standard, instead of MACT emission limits, may be proposed if it can be justified under section 112(h) of the CAA, that is, it is impracticable to enforce the emission standards due to technical or economic limitations. Work practice standards could reduce fuel use and improve combustion efficiency, which would result in reduced emissions.

In general, SERs commented that a regulatory approach to improve combustion efficiency, such as work practice standards, would have positive impacts with respect to the environment and energy use and save on compliance costs. The SERs were concerned with work practice standards that would require energy audits and implementation of audit findings. The basis of these concerns rested on the uncertainty that there is no guarantee that there are available funds to implement a particular audit's findings.

***5.2.6.1.2 Subcategorization.*** The Panel recommended that EPA allow subcategorizations suggested by the SERs, unless EPA finds that a subcategorization is inconsistent with the CAA.

SERs commented that subcategorization is a key concept that could ensure that like boilers are compared with similar boilers so that MACT floors are more reasonable and could be achieved by all units within a subcategory using appropriate emission reduction strategies. SERs commented that EPA should subcategorize based on fuel type, boiler type, duty cycle, and location.

***5.2.6.1.3 Health Based Compliance Alternatives (HBCA).*** The Panel recommended that EPA adopt the HBCA as a regulatory flexibility option for the boiler MACT rulemaking. The panel recognized, however, that EPA has concerns about its legal authority to provide an HBCA under the CAA, and EPA may ultimately determine that this flexibility is inconsistent with the CAA.

SERs commented that adopting an HBCA would perhaps be the most important step EPA could take to mitigate the serious financial harm the boiler MACT would otherwise inflict on small entities using solid fuels nationwide; therefore, HBCA should be a critical component of any future rule to lessen the impact on small entities.

***5.2.6.1.4 Emissions Averaging.*** The Panel recommended that EPA consider a provision for emission averaging and long averaging times for the proposed emission limits.

SERs commented that a measure EPA should consider to lessen the regulatory burden of complying with the boiler MACT is to allow emissions averaging at sources with multiple regulated units. SERs commented that another approach that can aide small entity compliance is to set longer averaging times (i.e., 30 days or more) rather than looking at a mere 3-run (hour) average for performance. Given the inherent variability in boiler performance, an annual or quarterly averaging period for all HAP would prevent a single spike in emissions from throwing a unit into noncompliance.

***5.2.6.1.5 Compliance Costs.*** The Panel recommended that EPA carefully weigh the potential burden of compliance requirements and consider for small entities options, such as emission averaging within the facility, reduced monitoring/testing requirements, or allowing more time for compliance.

SERs noted that recordkeeping activities, as written in the vacated boiler MACT, would be especially challenging for small entities that do not have a dedicated environmental affairs department.

## SECTION 6
## HUMAN HEALTH BENEFITS OF EMISSIONS REDUCTIONS

### 6.1 Synopsis

In this section, we provide an estimate of the monetized benefits associated with reducing particulate matter (PM) for the proposed Boiler MACT Rule and Boiler Area Source Rule. For these rules, the PM reductions are the result of emission limits on PM (as a surrogate for metals) as well as emission limits on other HAPs. The total $PM_{2.5}$ reductions are the consequence of the technologies installed to meet these multiple limits. These estimates reflect the monetized human health benefits of reducing cases of morbidity and premature mortality among populations exposed to the $PM_{2.5}$ precursors reduced by this rulemaking. Using a 3% discount rate, we estimate the total monetized benefits of the proposed Major and Area Source Boiler Rules to be $18 billion to $43 billion in the implementation year (2013). Using a 7% discount rate, we estimate the total monetized benefits of the proposed Major and Area Source Boiler Rules to be $16 billion to $39 billion in the implementation year. All estimates are in 2008$.

These estimates reflect EPA's most current interpretation of the scientific literature. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided in Figure 6-2. Data, resource, and methodological limitations prevented EPA from monetizing the benefits from several important benefit categories, including benefits from reducing hazardous air pollutants, ecosystem effects, and visibility impairment. The benefits from reducing hazardous air pollutants have not been monetized in this analysis, including reducing 370,000 tons of carbon monoxide, 37,000 tons of HCl, 1,000 tons of HF, 8.3 tons of mercury, 3,400 tons of other metals, and 1,200 grams of dioxins/furans each year.

### 6.2 Calculation of $PM_{2.5}$ Human Health Benefits

This rulemaking would reduce emissions of $PM_{2.5}$, $SO_2$, and VOCs. Because SOx and VOCs are also precursors to $PM_{2.5}$, reducing these emissions would also reduce $PM_{2.5}$ formation, human exposure, and the incidence of $PM_{2.5}$-related health effects. For these rules, the PM reductions are the result of emission limits on PM (as a surrogate for metals) as well as emission limits on other HAPs. The total $PM_{2.5}$ reductions are the consequence of the technologies installed to meet these multiple limits. Due to analytical limitations, it was not possible to provide a comprehensive estimate of $PM_{2.5}$-related benefits. Instead, we used the "benefit-per-ton" approach to estimate these benefits based on the methodology described in Fann et al. (2009). The key assumptions are described in detail below. These $PM_{2.5}$ benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of $PM_{2.5}$ from a specified source. EPA has used the benefit per-ton technique in several previous RIAs, including the recent $NO_2$ NAAQS RIA (U.S. EPA, 2010b). Table 6-1 shows the quantified and unquantified benefits captured in those benefit-per-ton estimates.

**Table 6-1. Human Health and Welfare Effects of $PM_{2.5}$**

| Pollutant / Effect | Quantified and Monetized in Primary Estimates | Unquantified Effects Changes in: |
|---|---|---|
| $PM_{2.5}$ | Adult premature mortality | Subchronic bronchitis cases |
| | Bronchitis: chronic and acute | Low birth weight |
| | Hospital admissions: respiratory and cardiovascular | Pulmonary function |
| | Emergency room visits for asthma | Chronic respiratory diseases other than chronic bronchitis |
| | Nonfatal heart attacks (myocardial infarction) | Non-asthma respiratory emergency room visits |
| | Lower and upper respiratory illness | Visibility |
| | Minor restricted-activity days | Household soiling |
| | Work loss days | |
| | Asthma exacerbations (asthmatic population) | |
| | Infant mortality | |

Consistent with the Portland Cement NESHAP (U.S. EPA, 2009a), the $PM_{2.5}$ benefits estimates utilize the concentration-response functions as reported in the epidemiology literature, as well as the 12 functions obtained in EPA's expert elicitation study as a sensitivity analysis.

- One estimate is based on the concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as reported in Pope et al. (2002), a study that EPA has previously used to generate its primary PM benefits estimate.

- One estimate is based on the C-R function developed from the extended analysis of the Harvard Six Cities cohort, as reported by Laden et al. (2006). This study, published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS, has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ benefits estimates in RIAs completed since the $PM_{2.5}$ NAAQS.

- Twelve estimates are based on the C-R functions from EPA's expert elicitation study (Roman et al., 2008) on the $PM_{2.5}$ -mortality relationship and interpreted for PM benefits analysis in EPA's final RIA for the $PM_{2.5}$ NAAQS. For that study, twelve experts (labeled A through L) provided independent estimates of the $PM_{2.5}$ -mortality concentration-response function. EPA practice has been to develop independent estimates of $PM_{2.5}$ -mortality estimates corresponding to the concentration-response function provided by each of the twelve experts, to better characterize the degree of variability in the expert responses.

The effect coefficients are drawn from epidemiology studies examining two large population cohorts: the American Cancer Society cohort (Pope et al., 2002) and the Harvard Six Cities cohort (Laden et al., 2006).[1] These are logical choices for anchor points in our presentation because, while both studies are well designed and peer reviewed, there are strengths and weaknesses inherent in each, which we believe argues for using both studies to generate benefits estimates. Previously, EPA had calculated benefits based on these two empirical studies, but derived the range of benefits, including the minimum and maximum results, from an expert elicitation of the relationship between exposure to $PM_{2.5}$ and premature mortality (Roman et al., 2008).[2] Within this assessment, we include the benefits estimates derived from the concentration-response function provided by each of the twelve experts to better characterize the uncertainty in the concentration-response function for mortality and the degree of variability in the expert responses. Because the experts used these cohort studies to inform their concentration-response functions, benefits estimates using these functions generally fall between results using these epidemiology studies (see Figure 6-2). In general, the expert elicitation results support the conclusion that the benefits of $PM_{2.5}$ control are very likely to be substantial.

Readers interested in reviewing the methodology for creating the benefit-per-ton estimates used in this analysis should consult Fann et al. (2009). As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates are developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (e.g., $SO_2$ emitted from electric generating units; $NO_2$ emitted from mobile sources). Our estimate of $PM_{2.5}$ control benefits is therefore based on the total $PM_{2.5}$ emissions controlled by sector and multiplied by this per-ton value.

The benefit-per-ton coefficients in this analysis were derived using modified versions of the health impact functions used in the PM NAAQS Regulatory Impact Analysis. Specifically, this analysis uses the benefit-per-ton method first applied in the Portland Cement NESHAP RIA (U.S. EPA, 2009a), which incorporated three updates: a new population dataset, an expanded geographic scope of the benefit-per-ton calculation, and the functions directly from the

[1] These two studies specify multi-pollutant models that control for $SO_2$, among other pollutants.
[2] Please see the Section 5.2 of the Portland Cement RIA in Appendix 5A for more information regarding the change in the presentation of benefits estimates.

epidemiology studies without an adjustment for an assumed threshold.[3] Removing the threshold assumption is a key difference between the method used in this analysis of PM benefits and the methods used in RIAs prior to Portland Cement, and we now calculate incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. Based on our review of the body of scientific literature, EPA applied the no-threshold model in this analysis. EPA's Integrated Science Assessment for Particulate Matter (U.S. EPA, 2009b), which was recently reviewed by EPA's Clean Air Scientific Advisory Committee (U.S. EPA-SAB, 2009a; U.S. EPA-SAB, 2009b), concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function.[4] In conjunction with the underlying scientific literature, this document provided a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs.[5]

As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve over time to reflect the Agency's most current interpretation of the scientific and economic literature. For a period of time (2004-2008), the Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature. The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$)[6] was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006) meta-analysis. However, the

[3] The benefit-per-ton estimates have also been updated since the Cement RIA to incorporate a revised VSL, as discussed on the next page.

[4] It is important to note that uncertainty regarding the shape of the concentration-response function is conceptually distinct from an assumed threshold. An assumed threshold (below which there are no health effects) is a discontinuity, which is a specific example of non-linearity.

[5] In the Portland Cement RIA (U.S. EPA, 2009a), EPA solicited comment on the use of the no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP closed on September 4, 2009 (Docket ID No. EPA–HQ–OAR–2002–0051 available at http://www.regulations.gov). EPA is currently reviewing those comments.

[6] In this analysis, we adjust the VSL to account for a different currency year (2008$) and to account for income growth to 2015. After applying these adjustments to the $5.5 million value, the VSL is $7.9m.

Agency neither changed its official guidance on the use of VSL in rule-makings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

During this time, the Agency continued work to update its guidance on valuing mortality risk reductions, including commissioning a report from meta-analytic experts to evaluate methodological questions raised by EPA and the SAB on combining estimates from the various data sources. In addition, the Agency consulted several times with the Science Advisory Board Environmental Economics Advisory Committee (SAB-EEAC) on the issue. With input from the meta-analytic experts, the SAB-EEAC advised the Agency to update its guidance using specific, appropriate meta-analytic techniques to combine estimates from unique data sources and different studies, including those using different methodologies (i.e., wage-risk and stated preference) (U.S. EPA-SAB, 2007).

Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore, the Agency has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[7] while the Agency continues its efforts to update its guidance on this issue. This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[8] The Agency is committed to using scientifically sound, appropriately reviewed evidence in valuing mortality risk reductions and has made significant progress in responding to the SAB-EEAC's specific recommendations. The Agency anticipates presenting results from this effort to the SAB-EEAC in Spring 2010 and that draft guidance will be available shortly thereafter.

Figure 6-1 illustrates the relative breakdown of the monetized $PM_{2.5}$ health benefits.

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[7] In the (draft) update of the Economic Guidelines (U.S. EPA, 2008), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. Therefore, this report does not represent final agency policy.

[8] In this analysis, we adjust the VSL to account for a different currency year (2008$) and to account for income growth to 2015. After applying these adjustments to the $6.3 million value, the VSL is $9.1m.

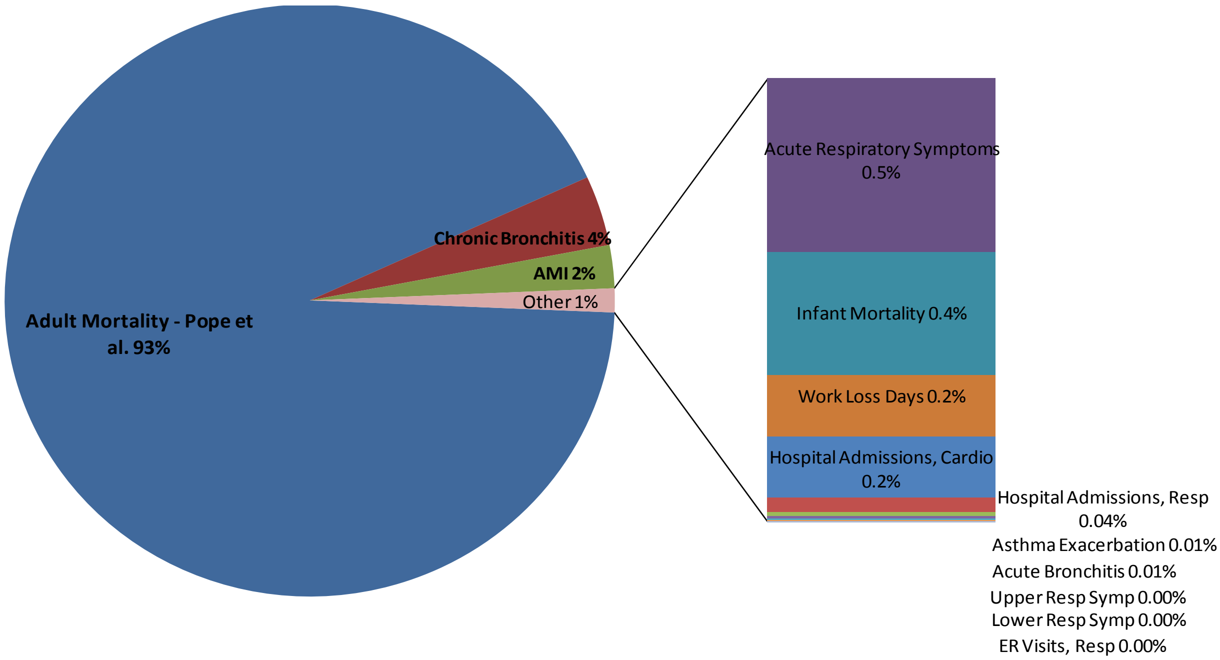


**Figure 6-1. Breakdown of Monetized $PM_{2.5}$ Health Benefits using Mortality Function from Pope et al. (2002)[a]**

[a] This pie chart breakdown is illustrative, using the results based on Pope et al. (2002) as an example. Using the Laden et al. (2006) function for premature mortality, the percentage of total monetized benefits due to adult mortality would be 97%. This chart shows the breakdown using a 3% discount rate, and the results would be similar if a 7% discount rate was used.

Tables 6-2 and 6-3 provide a general summary of the results by pollutant, including the emission reductions and monetized benefits-per-ton at discount rates of 3% and 7%.[9] Table 6-4 provides a summary of the reductions in health incidences as a result of the pollution reductions. In Table 6-5, we provide the benefits using our anchor points of Pope et al. and Laden et al. as well as the results from the expert elicitation on PM mortality. Figures 6-2 and 6-3 provide a visual representation of the range of benefits estimates and the pollutant breakdown of the monetized benefits of the proposed option.

[9] To comply with Circular A-4, EPA provides monetized benefits using discount rates of 3% and 7% (OMB, 2003). These benefits are estimated for a specific analysis year (i.e., 2013), and most of the PM benefits occur within that year with two exceptions: acute myocardial infarctions (AMIs) and premature mortality. For AMIs, we assume 5 years of follow-up medical costs and lost wages. For premature mortality, we assume that there is a "cessation" lag between PM exposures and the total realization of changes in health effects. Although the structure of the lag is uncertain, EPA follows the advice of the SAB-HES to assume a segmented lag structure characterized by 30% of mortality reductions in the first year, 50% over years 2 to 5, and 20% over the years 6 to 20 after the reduction in $PM_{2.5}$ (U.S. EPA-SAB, 2004). Changes in the lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths. Therefore, discounting only affects the AMI costs after the analysis year and the valuation of premature mortalities that occur after the analysis year. As such, the monetized benefits using a 7% discount rate are only approximately 10% less than the monetized benefits using a 3% discount rate.

## Table 6-2. Summary of Monetized Benefits Estimates for Boiler MACT (for Major Sources) in 2013 (2008$)[a]

| | Pollutant | Emissions Reductions (tons) | Benefit per ton (Pope, 3%) | Benefit per ton (Laden, 3%) | Benefit per ton (Pope, 7%) | Benefit per ton (Laden, 7%) | Total Monetized Benefits (millions 2008$ at 3%) | Total Monetized Benefits (millions 2008$ at 7%) |
|---|---|---|---|---|---|---|---|---|
| Option 1E and 1N | Direct $PM_{2.5\ Major}$ | 29,336 | $230,000 | $560,000 | $210,000 | $500,000 | $6,700 to $16,000 | $6,100 to $15,000 |
| | $PM_{2.5}$ Precursors | | | | | | | |
| | $SO_{2\ Major}$ | 347,114 | $29,000 | $72,000 | $27,000 | $65,000 | $10,000 to $25,000 | $9,300 to $23,000 |
| | VOC | 6,679 | $1,200 | $3,000 | $1,100 | $2,700 | $8.1 to $20.0 | $7.4 to $18.0 |
| | | | | | | **Total** | **$17,000 to $41,000** | **$15,000 to $37,000** |
| Primary Options | Direct $PM_{2.5\ Major}$ | 29,020 | $230,000 | $560,000 | $210,000 | $500,000 | $6,600 to $16,000 | $6,000 to $15,000 |
| | $PM_{2.5}$ Precursors | | | | | | | |
| | $SO_{2\ Major}$ | 339,996 | $29,000 | $72,000 | $27,000 | $65,000 | $10,000 to $25,000 | $9,100 to $22,000 |
| | VOC | 1,786 | $1,200 | $3,000 | $1,100 | $2,700 | $2.2 to $5.3 | $2.0 to $4.8 |
| | | | | | | **Total** | **$17,000 to $41,000** | **$15,000 to $37,000** |

[a] All estimates are for the implementation year (2013), and are rounded to two significant figures so numbers may not sum across columns. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary because each ton of precursor reduced has a different propensity to become $PM_{2.5}$. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. These estimates include 46 new major sources expected to be affected by 2013.

## Table 6-3. Summary of Monetized Benefits Estimates for Boiler Area Source Rule in 2013 (2008$)[a]

| | Pollutant | Emissions Reductions (tons) | Benefit per ton (Pope, 3%) | Benefit per ton (Laden, 3%) | Benefit per ton (Pope, 7%) | Benefit per ton (Laden, 7%) | Total Monetized Benefits (millions 2008$ at 3%) | Total Monetized Benefits (millions 2008$ at 7%) |
|---|---|---|---|---|---|---|---|---|
| Option 1E and 1N | Direct $PM_{2.5\ Area}$ | 22,920 | $360,000 | $880,000 | $330,000 | $790,000 | $8,200 to $20,000 | $7,500 to $18,000 |
| | $PM_{2.5}$ Precursors | | | | | | | |
| | $SO_{2\ Area}$ | 1,745 | $20,000 | $49,000 | $18,000 | $44,000 | $35 to $86 | $32 to $77 |
| | VOC | 2,119 | $1,200 | $3,000 | $1,100 | $2,700 | $2.6 to $6.3 | $2.3 to $5.7 |
| | | | | | | **Total** | **$8,300 to $20,000** | **$7,500 to $18,000** |
| Primary Options | Direct $PM_{2.5\ Area}$ | 2,682 | $360,000 | $880,000 | $330,000 | $790,000 | $960 to $2,400 | $880 to $2,100 |
| | $PM_{2.5}$ Precursors | | | | | | | |
| | $SO_{2\ Area}$ | 1,539 | $20,000 | $49,000 | $18,000 | $44,000 | $31 to $76 | $28 to $68 |
| | VOC | 1,179 | $1,200 | $3,000 | $1,100 | $2,700 | $1.4 to $3.5 | $1.3 to $3.2 |
| | | | | | | **Total** | **$1,000 to $2,400** | **$910 to $2,200** |

[a] All estimates are for the implementation year (2013), and are rounded to two significant figures so numbers may not sum across columns. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary because each ton of precursor reduced has a different propensity to become $PM_{2.5}$. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. These estimates include 6,779 new area sources expected to be affected by 2013.

### Table 6-4. Summary of Reductions in Health Incidences from $PM_{2.5}$ Benefits for the Proposed Major and Area Source Boiler Rules in 2013[a]

| | Boiler MACT (Major Sources) | | Boiler Area Source Rule | |
|---|---|---|---|---|
| | **Options 1E and 1N** | **Primary Options** | **Options 1E and 1N** | **Primary Options** |
| **Avoided Premature Mortality** | | | | |
| Pope et al. | 1,900 | 1,900 | 930 | 110 |
| Laden et al. | 4,900 | 4,800 | 2,400 | 300 |
| **Avoided Morbidity** | | | | |
| Chronic Bronchitis | 1,300 | 1,300 | 670 | 81 |
| Acute Myocardial Infarction | 3,000 | 3,000 | 1,500 | 190 |
| Hospital Admissions, Resp | 460 | 450 | 220 | 27 |
| Hospital Admissions, Cardio | 980 | 960 | 460 | 57 |
| Emergency Room Visits, Resp | 1,800 | 1,800 | 690 | 85 |
| Acute Bronchitis | 3,000 | 3,000 | 1,600 | 190 |
| Work Loss Days | 250,000 | 250,000 | 130,000 | 16,000 |
| Asthma Exacerbation | 33,000 | 33,000 | 17,000 | 2,100 |
| Acute Respiratory Symptoms | 1,500,000 | 1,500,000 | 780,000 | 95,000 |
| Lower Respiratory Symptoms | 36,000 | 36,000 | 19,000 | 2,300 |
| Upper Respiratory Symptoms | 27,000 | 27,000 | 14,000 | 1,700 |

[a] All estimates are for the analysis year (2013) and are rounded to whole numbers with two significant figures. All fine particles are assumed to have equivalent health effects, but each $PM_{2.5}$ precursor pollutant has a different propensity to form $PM_{2.5}$. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. These estimates include 46 new major sources and 6,779 new area sources expected to be affected by 2013.

**Table 6-5. All $PM_{2.5}$ Benefits Estimates for the Proposed Major and Area Source Boiler Rules at discount rates of 3% and 7% in 2013 (in millions of 2008$)[a]**

| | Options 1E and 1N | | Proposal Options | |
|---|---|---|---|---|
| | 3% | 7% | 3% | 7% |
| **Benefit-per-ton Coefficients Derived from Epidemiology Literature** | | | | |
| Pope et al. | $25,000 | $23,000 | $18,000 | $16,000 |
| Laden et al. | $62,000 | $56,000 | $43,000 | $39,000 |
| **Benefit-per-ton Coefficients Derived from Expert Elicitation** | | | | |
| Expert A | $8,100 | $7,300 | $46,000 | $41,000 |
| Expert B | $6,200 | $5,600 | $35,000 | $32,000 |
| Expert C | $6,200 | $5,600 | $35,000 | $31,000 |
| Expert D | $4,400 | $4,000 | $25,000 | $22,000 |
| Expert E | $10,000 | $9,100 | $57,000 | $51,000 |
| Expert F | $5,700 | $5,100 | $32,000 | $29,000 |
| Expert G | $3,700 | $3,400 | $21,000 | $19,000 |
| Expert H | $4,700 | $4,200 | $26,000 | $24,000 |
| Expert I | $6,100 | $5,500 | $34,000 | $31,000 |
| Expert J | $5,000 | $4,500 | $28,000 | $25,000 |
| Expert K | $1,200 | $1,100 | $6,900 | $6,300 |
| Expert L | $4,500 | $4,100 | $25,000 | $23,000 |

[a] All estimates are rounded to two significant figures. Estimates do not include confidence intervals because they were derived through the benefit-per-ton technique described above. The benefits estimates from the Expert Elicitation are provided as a reasonable characterization of the uncertainty in the mortality estimates associated with the concentration-response function. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. These estimates include 45 new major sources and 6,779 new area sources expected to be affected by 2013.

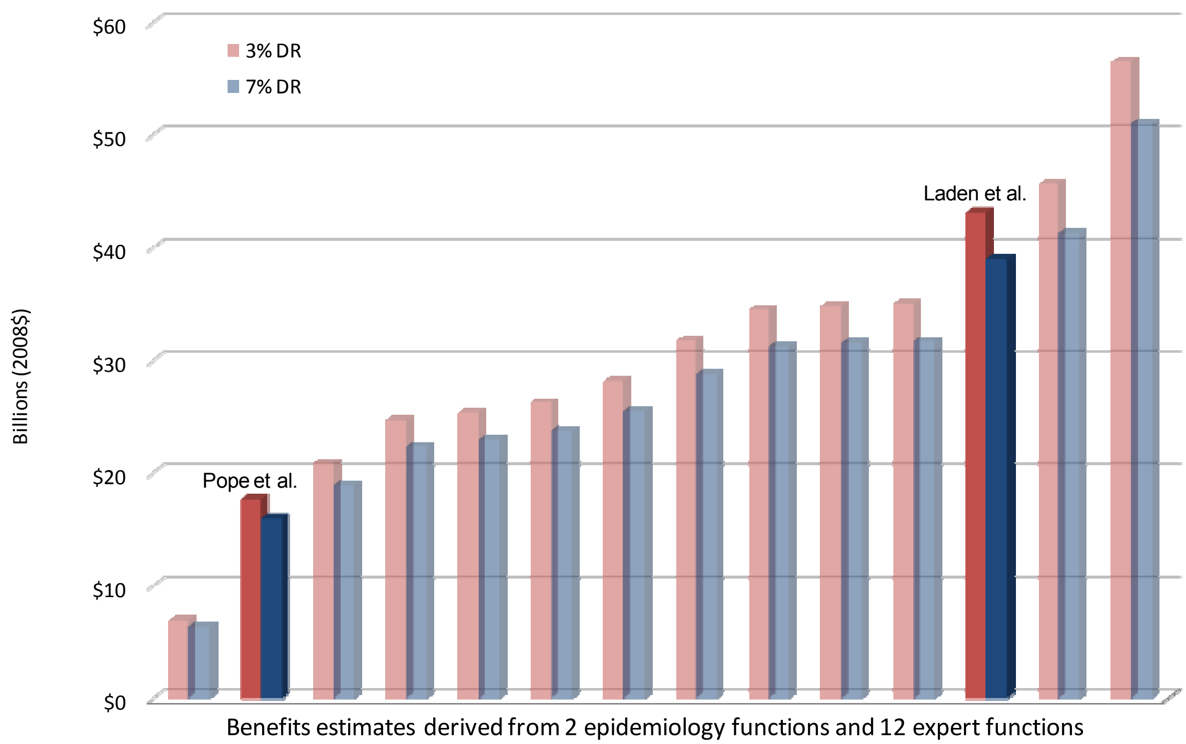


**Figure 6-2. Total Monetized $PM_{2.5}$ Benefits for the Proposed Major and Area Source Boiler Rules in 2013**

[a] This graph shows the estimated benefits at discount rates of 3% and 7% using effect coefficients derived from the Pope et al. study and the Laden et al. study, as well as 12 effect coefficients derived from EPA's expert elicitation on PM mortality. The results shown are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response function provided in those studies.

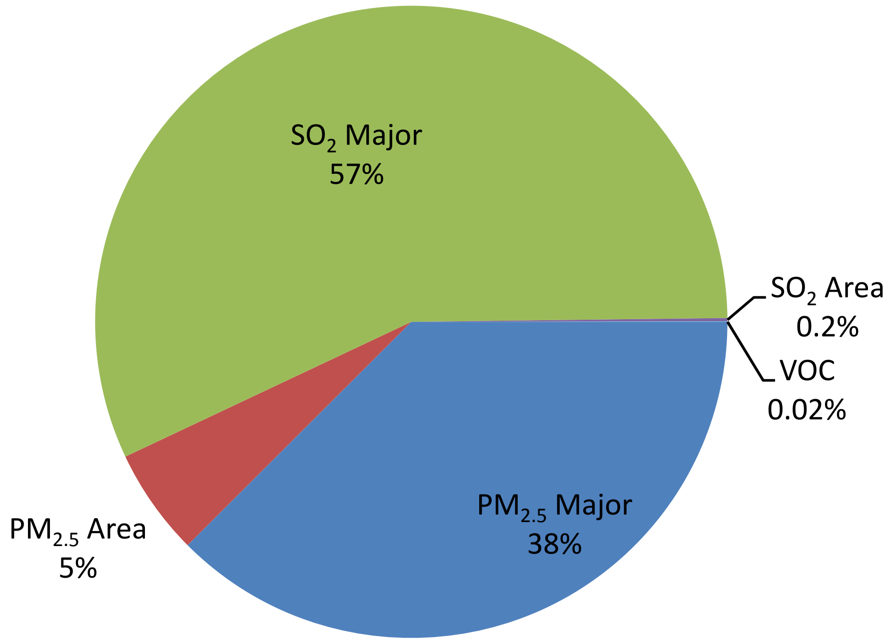


**Figure 6-3. Breakdown of Monetized Benefits for the Proposed Boiler Rules by $PM_{2.5}$ Precursor Pollutant and Source**

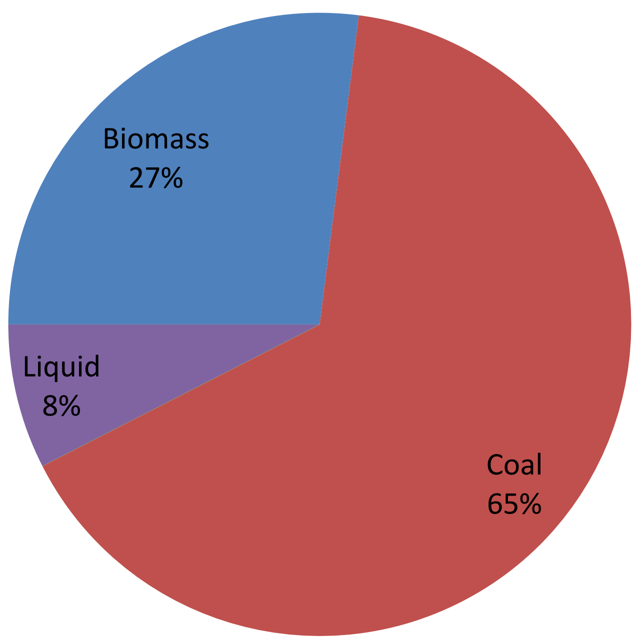


**Figure 6-4. Breakdown of Monetized Benefits for the Proposed Boiler MACT (Major Sources) by Fuel Type**

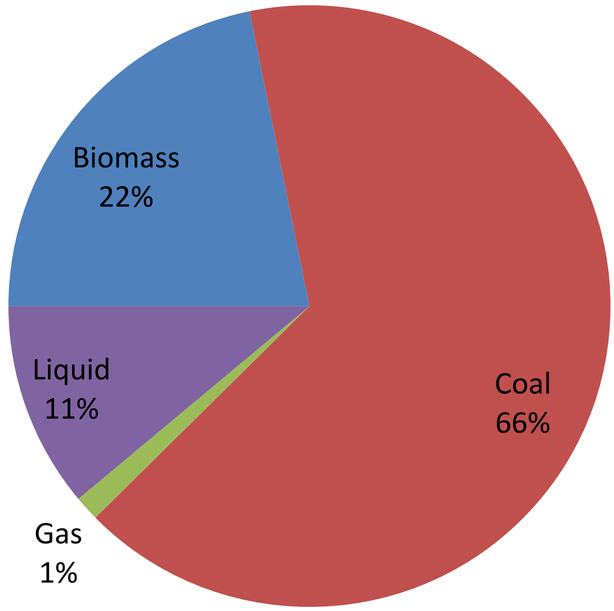


**Figure 6-5. Breakdown of Monetized Benefits for the Proposed Boiler Area Source Rule by Fuel Type**

## 6.3 Unquantified Benefits

The monetized benefits estimated in this RIA only reflect the portion of benefits attributable to the health effect reductions associated with ambient fine particles. Data, resource, and methodological limitations prevented EPA from quantifying or monetizing the benefits from several important benefit categories, including benefits from reducing toxic emissions, ecosystem effects, and visibility impairment. The health benefits from reducing thousands of tons of hazardous air pollutants (HAPs) and millions of tons of carbon monoxide each year have not been monetized in this analysis. In addition to being a $PM_{2.5}$ precursor, $SO_2$ emissions also contribute to adverse effects from acidic deposition in aquatic and terrestrial ecosystems, increase mercury methylation, as well as visibility impairment.

### *6.3.1 Carbon Monoxide Benefits*

Carbon monoxide (CO) exposure is associated with a variety of health effects. Without knowing the location of the emission reductions and the resulting ambient concentrations using fine-scale air quality modeling, we were unable to estimate the exposure to CO for nearby populations. Due to data, resource, and methodological limitations, we were unable to estimate the benefits associated with the 370,000 tons reductions in CO emissions that would occur as a result of this rule.

Carbon monoxide in ambient air is formed primarily by the incomplete combustion of carbon-containing fuels and photochemical reactions in the atmosphere. The amount of CO emitted from these reactions, relative to carbon dioxide ($CO_2$), is sensitive to conditions in the combustion zone, such as fuel oxygen content, burn temperature, or mixing time. Upon inhalation, CO diffuses through the respiratory system to the blood, which can cause hypoxia (reduced oxygen availability). Carbon monoxide can elicit a broad range of effects in multiple tissues and organ systems that are dependent upon concentration and duration of exposure.

The Integrated Science Assessment for Carbon Monoxide (U.S. EPA, 2010a) concluded that short-term exposure to CO is "likely to have a causal relationship" with cardiovascular morbidity, particularly in individuals with coronary heart disease. Epidemiologic studies associate short-term CO exposure with increased risk of emergency department visits and hospital admissions. Coronary heart disease includes those who have angina pectoris (cardiac chest pain), as well as those who have experienced a heart attack. Other subpopulations potentially at risk include individuals with diseases such as chronic obstructive pulmonary disease (COPD), anemia, or diabetes, and individuals in very early or late life stages, such as older adults or the developing young. The evidence is suggestive of a causal relationship between short-term exposure to CO and respiratory morbidity and mortality. The evidence is also suggestive of a causal relationship for birth outcomes and developmental effects following long-term exposure to CO, and for central nervous system effects linked to short- and long-term exposure to CO.

### *6.3.2 Other $SO_2$ Benefits*

In addition to being a precursor to $PM_{2.5}$, $SO_2$ emissions are also associated with a variety of respiratory health effects. Unfortunately, we were unable to estimate the health benefits associated with reduced $SO_2$ exposure in this analysis because we do not have air quality modeling data available. Without knowing the location of the emission reductions and the resulting ambient concentrations, we were unable to estimate the exposure to $SO_2$ for nearby populations. Therefore, this analysis only quantifies and monetizes the $PM_{2.5}$ benefits associated with the reductions in $SO_2$ emissions.

Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the Integrated Science Assessment (ISA) for Sulfur Dioxide concluded that there is a causal relationship between respiratory health effects and short-term exposure to $SO_2$ (U.S. EPA, 2008). The immediate effect of $SO_2$ on the respiratory system in humans is bronchoconstriction.

Asthmatics are more sensitive to the effects of $SO_2$ likely resulting from preexisting inflammation associated with this disease. A clear concentration-response relationship has been demonstrated in laboratory studies following exposures to $SO_2$ at concentrations between 20 and 100 ppb, both in terms of increasing severity of effect and percentage of asthmatics adversely affected. Based on our review of this information, we identified four short-term morbidity endpoints that the $SO_2$ ISA identified as a "causal relationship": asthma exacerbation, respiratory-related emergency department visits, and respiratory-related hospitalizations. The differing evidence and associated strength of the evidence for these different effects is described in detail in the $SO_2$ ISA. The $SO_2$ ISA also concluded that the relationship between short-term $SO_2$ exposure and premature mortality was "suggestive of a causal relationship" because it is difficult to attribute the mortality risk effects to $SO_2$ alone. Although the $SO_2$ ISA stated that studies are generally consistent in reporting a relationship between $SO_2$ exposure and mortality, there was a lack of robustness of the observed associations to adjustment for pollutants.

$SO_2$ emissions also contribute to adverse welfare effects from acidic deposition, visibility impairment, and enhanced mercury methylation. Deposition of sulfur causes acidification, which can cause a loss of biodiversity of fishes, zooplankton, and macro invertebrates in aquatic ecosystems, as well as a decline in sensitive tree species, such as red spruce (*Picea rubens*) and sugar maple (*Acer saccharum*) in terrestrial ecosystems. In the northeastern United States, the surface waters affected by acidification are a source of food for some recreational and subsistence fishermen and for other consumers and support several cultural services, including aesthetic and educational services and recreational fishing. Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity, which can cause reduced root growth, which restricts the ability of the plant to take up water and nutrients. These direct effects can, in turn, increase the sensitivity of these plants to stresses, such as droughts, cold temperatures, insect pests, and disease leading to increased mortality of canopy trees. Terrestrial acidification affects several important ecological services, including declines in habitat for threatened and endangered species (cultural), declines in forest aesthetics (cultural), declines in forest productivity (provisioning), and increases in forest soil erosion and reductions in water retention (cultural and regulating). (U.S. EPA, 2008d)

Reducing $SO_2$ emissions and the secondary formation of $PM_{2.5}$ would improve the level of visibility throughout the United States. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil (Sisler, 1996). These suspended particles and gases degrade visibility by scattering and absorbing light. Higher visibility impairment levels in the East are due to generally higher concentrations of fine particles, particularly sulfates, and higher average relative humidity levels. In fact, particulate sulfate is the largest contributor to regional haze in the eastern U.S. (i.e., 40% or more annually and 75% during summer). In the western U.S., particulate sulfate contributes to 20-50% of regional haze (U.S. EPA, 2009c). Visibility has direct significance to people's enjoyment of daily activities and their overall sense of wellbeing. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

### *6.3.3 HAP Benefits*

Due to data, resource, and methodology limitations, we were unable to estimate the benefits associated with the thousands tons of hazardous air pollutants that would be reduced as a result of this rule. Available emissions data show that several different HAPs are emitted from boilers, either contained within the fuel burned or formed during the combustion process.

Although numerous HAPs may be emitted from boilers, a few HAPs account for the majority of the total mass of HAPs emissions. See Table 6-6 for the list of the major HAPs for each fuel type. This rule is anticipated to reduce 370,000 tons of carbon monoxide, 37,000 tons of HCl, 1,000 tons of HF, 8.3 tons of mercury, and 3,400 tons of other metals, 1,200 grams of dioxins/furans each year from major and area sources. We discuss the health effects associated with these top HAPs as well as the HAPs for which we have emission reduction estimates.

**Table 6-6. Top HAPs by Mass from Boilers by Fuel Type**

| Coal | Gas | Biomass | Oil |
|---|---|---|---|
| 68% HCl | 44% Formaldehyde | 32% Acetaldehyde | 28% Nickel |
| 5% HF | 25% PAH | 28% HCl | 19% Manganese |
| | 3% Toluene | 25% Formaldehyde | |

#### *6.3.3.1 Mercury*

Mercury is a highly neurotoxic contaminant that enters the food web as a methylated compound, methylmercury (U.S. EPA, 2008d). The contaminant is concentrated in higher trophic levels, including fish eaten by humans. Experimental evidence has established that only inconsequential amounts of methylmercury can be produced in the absence of sulfate (U.S. EPA, 2008d). Current evidence indicates that in watersheds where mercury is present, increased sulfate deposition very likely results in methylmercury accumulation in fish (Drevnick et al., 2007; Munthe et al, 2007). The $SO_2$ ISA concluded that evidence is sufficient to infer a casual relationship between sulfur deposition and increased mercury methylation in wetlands and aquatic environments (U.S. EPA, 2008d).

In addition to the role of sulfate deposition on methylation, these proposed rules would also reduce mercury emissions. Mercury is emitted to the air from various man-made and natural sources. These emissions transport through the atmosphere and eventually deposit to land or water bodies. This deposition can occur locally, regionally, or globally, depending on the form of mercury emitted and other factors such as the weather. The form of mercury emitted varies depending on the source type and other factors. Available data indicate that the mercury emissions from these sources are a mixture of gaseous elemental mercury, inorganic ionic mercury, and particulate bound mercury. Gaseous elemental mercury can be transported very long distances, even globally, to regions far from the emissions source (becoming part of the global "pool") before deposition occurs. Inorganic ionic and particulate bound mercury have a shorter atmospheric lifetime and can deposit to land or water bodies closer to the emissions source. Furthermore, elemental mercury in the atmosphere can undergo transformation into ionic mercury, providing a significant pathway for deposition of emitted elemental mercury.

Major and area source boilers emitted about 16 tons of mercury in the air in 2008 in the U.S. Based on the EPA's National Emission Inventory, about 103 tons of mercury were emitted from all anthropogenic sources in the U.S. in 2005. Moreover, the United Nations has estimated that about 2,100 tons of mercury were emitted worldwide by anthropogenic sources in 2005. We believe that total mercury emissions in the U.S. and globally in 2008 were about the same magnitude in 2005. Therefore, we estimate that in 2008, these sources emitted about 16% of the total anthropogenic mercury emissions in the U.S. and about 0.8% of the global emissions. Overall, this rule would reduce mercury emissions by about 8.3 tons per year from current levels, and therefore, contribute to reductions in mercury exposures and health effects. Due to time and resource limitations, we were unable to model mercury dispersion, deposition, methylation, bioaccumulation in fish tissue, and human consumption of mercury-contaminated fish that would be needed in order to estimate the human health benefits from reducing mercury emissions.

Potential exposure routes to mercury emissions include both direct inhalation and consumption of fish containing methylmercury. The primary route of human exposure to mercury emissions from industrial sources is generally indirectly through the consumption of fish containing methylmercury. As described above, mercury that has been emitted to the air eventually settles into water bodies or onto land where it can either move directly or be leached into waterbodies. Once deposited, certain microorganisms can change it into methylmercury, a highly toxic form that builds up in fish, shellfish and animals that eat fish. Consumption of fish and shellfish are the main sources of methylmercury exposure to humans. Methylmercury builds up more in some types of fish and shellfish than in others. The levels of methylmercury in fish and shellfish vary widely depending on what they eat, how long they live, and how high they are in the food chain. Most fish, including ocean species and local freshwater fish, contain some methylmercury. For example, in recent studies by EPA and the U.S. Geological Survey (USGS) of fish tissues, every fish sampled contained some methylmercury.

The majority of fish consumed in the U.S. are ocean species. The methylmercury concentrations in ocean fish species are primarily influenced by the global mercury pool. However, the methylmercury found in local fish can be due, at least partly, to mercury emissions from local sources. Research shows that most people's fish consumption does not cause a mercury-related health concern. However, certain people may be at higher risk because of their routinely high consumption of fish (e.g., tribal and other subsistence fishers and their families who rely heavily on fish for a substantial part of their diet). It has been demonstrated that high levels of methylmercury in the bloodstream of unborn babies and young children may harm the developing nervous system, making the child less able to think and learn. Moreover, mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages.

Several studies suggest that the methylmercury content of fish may reduce these cardio-protective effects of fish consumption. Some of these studies also suggest that methylmercury may cause adverse effects to the cardiovascular system. For example, the NRC (2000) review of the literature concerning methylmercury health effects took note of two epidemiological studies that found an association between dietary exposure to methylmercury and adverse cardiovascular effects.[10] Moreover, in a study of 1,833 males in Finland aged 42 to 60 years, Solonen et al. (1995) observed a relationship between methylmercury exposure via fish consumption and acute myocardial infarction (AMI or heart attacks), coronary heart disease, cardiovascular disease, and all-cause mortality.[11] The NRC also noted a study of 917 seven year old children in the Faroe Islands, whose initial exposure to methylmercury was *in utero* although post natal exposures may have occurred as well. At seven years of age, these children exhibited an increase in blood

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[10] National Research Council (NRC). 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology. National Academies Press. Washington, DC. pp.168-173.

[11] Salonen, J.T., Seppanen, K. Nyyssonen et al. 1995. "Intake of mercury from fish lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular and any death in Eastern Finnish men." Circulation, 91 (3):645-655.

pressure and a decrease in heart rate variability.[12] Based on these and other studies, NRC concluded in 2000 that, while "the data base is not as extensive for cardiovascular effects as it is for other end points (i.e. neurologic effects) the cardiovascular system appears to be a target for methylmercury toxicity."[13]

Since publication of the NRC report there have been some 30 published papers presenting the findings of studies that have examined the possible cardiovascular effects of methylmercury exposure. These studies include epidemiological, toxicological, and toxicokinetic investigations. Over a dozen review papers have also been published. If there is a causal relationship between methylmercury exposure and adverse cardiovascular effects, then reducing exposure to methylmercury would result in public health benefits from reduced cardiovascular effects.

In early 2010, EPA sponsored a workshop in which a group of experts were asked to assess the plausibility of a causal relationship between methylmercury exposure and cardiovascular health effects and to advise EPA on methodologies for estimating population level cardiovascular health impacts of reduced methylmercury exposure. The report from that workshop is in preparation.

#### *6.3.3.2 Hydrogen Chloride (HCl)* [14]

Hydrogen chloride gas is intensely irritating to the mucous membranes of the nose, throat, and respiratory tract. Brief exposure to 35 ppm causes throat irritation, and levels of 50 to 100 ppm are barely tolerable for 1 hour. The greatest impact is on the upper respiratory tract; exposure to high concentrations can rapidly lead to swelling and spasm of the throat and suffocation. Most seriously exposed persons have immediate onset of rapid breathing, blue coloring of the skin, and narrowing of the bronchioles. Patients who have massive exposures may develop an accumulation of fluid in the lungs. Exposure to hydrogen chloride can lead to Reactive Airway Dysfunction Syndrome (RADS), a chemically- or irritant-induced type of asthma. Children may be more vulnerable to corrosive agents than adults because of the relatively smaller diameter of their airways. Children may also be more vulnerable to gas exposure because of increased minute

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[12] Sorensen, N, K. Murata, E. Budtz-Jorgensen, P. Weihe, and Grandjean, P., 1999. "Prenatal Methylmercury Exposure As A Cardiovascular Risk Factor At Seven Years of Age", Epidemiology, pp370-375.

[13] National Research Council (NRC). 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology. National Academies Press. Washington, DC. p. 229.

[14] All health effects language for this section came from: Agency for Toxic Substances and Disease Registry (ATSDR). Medical Management Guidelines for Hydrogen Chloride (HCl). CAS#: 7647-01-0. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available on the Internet at <http://www.atsdr.cdc.gov/Mhmi/mmg173.html>.

ventilation per kg and failure to evacuate an area promptly when exposed. Hydrogen chloride has not been classified for carcinogenic effects.

*6.3.3.3 Chlorine gas ($Cl_2$)* [15]

Chlorine gas is irritating and corrosive to the eyes, skin, and respiratory tract. Exposure to chlorine may cause burning of the eyes, nose, and throat; cough as well as constriction and edema of the airway and lungs can occur.

*6.3.3.4 Hydrogen cyanide (HCN)* [16]

Hydrogen cyanide is highly toxic by all routes of exposure and may cause abrupt onset of profound central nervous system, cardiovascular, and respiratory effects, leading to death within minutes. Exposure to lower concentrations of hydrogen cyanide may produce eye irritation, headache, confusion, nausea, and vomiting followed in some cases by coma and death. Hydrogen cyanide acts as a cellular asphyxiant. By binding to mitochondrial cytochrome oxidase, it prevents the utilization of oxygen in cellular metabolism. The central nervous system and myocardium are particularly sensitive to the toxic effects of cyanide.

*6.3.3.5 Hydrogen Fluoride (HF)* [17]

Acute (short-term) inhalation exposure to gaseous hydrogen fluoride can cause severe respiratory damage in humans, including severe irritation and pulmonary edema. Chronic (long-term) exposure to fluoride at low levels has a beneficial effect of dental cavity prevention and may also be useful for the treatment of osteoporosis. Exposure to higher levels of fluoride may cause dental fluorosis. One study reported menstrual irregularities in women occupationally exposed to fluoride. The EPA has not classified hydrogen fluoride for carcinogenicity.

[15] All health effects language for this section came from: Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Medical Management Guidelines for Chlorine (CAS 7782-50-5; UN 1017). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available on the Internet at http://www.atsdr.cdc.gov/MHMI/mmg172.html#bookmark02.

[16] All health effects language for this section came from: Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Medical Management Guidelines for Hydrogen Cyanide (HCN) (CAS#: 7782-50-5). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available on the Internet at http://www.atsdr.cdc.gov/Mhmi/mmg8.html#bookmark02.

[17] All health effects language for this section came from: U.S. EPA, "National Emission Standards for Hazardous Air Pollutants for Industrial/Commercial/Institutional Boilers and Process Heaters; Proposed Rule," 68 Federal Register 8 (January 13, 2003). pp. 1664-1665. Available on the internet at http://www.epa.gov/ttn/atw/boiler/fr13ja03.pdf

### *6.3.3.6 Toluene*[18]

Toluene is found in evaporative as well as exhaust emissions from motor vehicles. Under the 2005 Guidelines for Carcinogen Risk Assessment, there is inadequate information to assess the carcinogenic potential of toluene because studies of humans chronically exposed to toluene are inconclusive, toluene was not carcinogenic in adequate inhalation cancer bioassays of rats and mice exposed for life, and increased incidences of mammary cancer and leukemia were reported in a lifetime rat oral bioassay.

The central nervous system (CNS) is the primary target for toluene toxicity in both humans and animals for acute and chronic exposures. CNS dysfunction (which is often reversible) and narcosis have been frequently observed in humans acutely exposed to low or moderate levels of toluene by inhalation; symptoms include fatigue, sleepiness, headaches, and nausea. Central nervous system depression has been reported to occur in chronic abusers exposed to high levels of toluene. Symptoms include ataxia, tremors, cerebral atrophy, nystagmus (involuntary eye movements), and impaired speech, hearing, and vision. Chronic inhalation exposure of humans to toluene also causes irritation of the upper respiratory tract, eye irritation, dizziness, headaches, and difficulty with sleep.

Human studies have also reported developmental effects, such as CNS dysfunction, attention deficits, and minor craniofacial and limb anomalies, in the children of women who abused toluene during pregnancy. A substantial database examining the effects of toluene in subchronic and chronic occupationally exposed humans exists. The weight of evidence from these studies indicates neurological effects (i.e., impaired color vision, impaired hearing, decreased performance in neurobehavioral analysis, changes in motor and sensory nerve conduction velocity, headache, dizziness) as the most sensitive endpoint.

### *6.3.3.7 Formaldehyde*

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[19] EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic

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[18] All health effects language for this section came from: U.S. EPA. 2005. "Full IRIS Summary for Toluene (CASRN 108-88-3)" Environmental Protection Agency, Integrated Risk Information System (IRIS), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. Available on the Internet at <http://www.epa.gov/iris/subst/0118.htm>.

[19] U.S. EPA. 1987. Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde, Office of Pesticides and Toxic Substances, April 1987.

malignancies such as leukemia among workers exposed to formaldehyde.[20,21] In an analysis of the lymphohematopoietic cancer mortality from an extended follow-up of these workers, NCI confirmed an association between lymphohematopoietic cancer risk and peak exposures.[22] A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[23] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[24]

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[25,26,27] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. However, it should be noted that recent research published by EPA indicates that when two-stage modeling assumptions are varied, resulting dose-response estimates can vary by several orders of magnitude.[28,29,30,31] These findings are not supportive of interpreting the CIIT model results as providing a

[20] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615-1623.

[21] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117-1130.

[22] Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751-761.

[23] Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193-200.

[24] Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608-1615.

[25] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2003. Biologically motivated computational modeling of formaldehyde carcinogenicity in the F344 rat. Tox Sci 75: 432-447.

[26] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2004. Human respiratory tract cancer risks of inhaled formaldehyde: Dose-response predictions derived from biologically-motivated computational modeling of a combined rodent and human dataset. Tox Sci 82: 279-296.

[27] Chemical Industry Institute of Toxicology (CIIT).1999. Formaldehyde: Hazard characterization and dose-response assessment for carcinogenicity by the route of inhalation. CIIT, September 28, 1999. Research Triangle Park, NC.

[28] U.S. EPA. Analysis of the Sensitivity and Uncertainty in 2-Stage Clonal Growth Models for Formaldehyde with Relevance to Other Biologically-Based Dose Response (BBDR) Models. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-08/103, 2008

[29] Subramaniam, R; Chen, C; Crump, K; .et .al. (2008) Uncertainties in biologically-based modeling of formaldehyde-induced cancer risk: identification of key issues. Risk Anal 28(4):907-923.

[30] Subramaniam, R; Chen, C; Crump, K; .et .al. (2007). Uncertainties in the CIIT 2-stage model for formaldehyde-induced nasal cancer in the F344 rat: a limited sensitivity analysis-I. Risk Anal 27:1237

[31] Crump, K; Chen, C; Fox, J; .et .al. (2008) Sensitivity analysis of biologically motivated model for formaldehyde-induced respiratory cancer in humans. Ann Occup Hyg 52:481-495.

conservative (health protective) estimate of human risk.[32] EPA research also examined the contribution of the two-stage modeling for formaldehyde towards characterizing the relative weights of key events in the mode-of-action of a carcinogen. For example, the model-based inference in the published CIIT study that formaldehyde's direct mutagenic action is not relevant to the compound's tumorigenicity was found not to hold under variations of modeling assumptions.[33]

Based on the developments of the last decade, in 2004, the working group of the IARC concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals - a higher classification than previous IARC evaluations. After reviewing the currently available epidemiological evidence, the IARC (2006) characterized the human evidence for formaldehyde carcinogenicity as "sufficient," based upon the data on nasopharyngeal cancers; the epidemiologic evidence on leukemia was characterized as "strong."[34] EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation – including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.[35,36]

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[32] Crump, K; Chen, C; Fox, J; .et .al. (2008) Sensitivity analysis of biologically motivated model for formaldehyde-induced respiratory cancer in humans. Ann Occup Hyg 52:481-495.
[33] Subramaniam, R; Chen, C; Crump, K; .et .al. (2007). Uncertainties in the CIIT 2-stage model for formaldehyde-induced nasal cancer in the F344 rat: a limited sensitivity analysis-I. Risk Anal 27:1237
[34] International Agency for Research on Cancer (2006) Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Monographs Volume 88. World Health Organization, Lyon, France.
[35] Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/toxprofiles/tp111.html
[36] WHO (2002) Concise International Chemical Assessment Document 40: Formaldehyde. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva.

*6.3.3.8 Polycyclic Aromatic Hydrocarbons (PAHs)*

At least seven PAH compounds are classified by EPA as probable human carcinogens based on animal data, including benzo(a)anthracene[37], benzo(b)fluoranthene[38], benzo(k)fluoranthene[39], benzo(a)pyrene[40], chrysene[41], dibenz(a,h)anthracene[42], and indeno(1,2,3-cd)pyrene[43]. Recent studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development at age three.[44,45] EPA has not yet evaluated these recent studies.

*6.3.3.9 Acetaldehyde*

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[46] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the

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[37] U.S. EPA (1997). Integrated Risk Information System File of benzo(a)anthracene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0454.htm.

[38] U.S. EPA (1997). Integrated Risk Information System File of benzo(b)fluoranthene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0453.htm.

[39] U.S. EPA (1997). Integrated Risk Information System File of benzo(k)fluoranthene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0452.htm.

[40] U.S. EPA (1998). Integrated Risk Information System File of benzo(a)pyrene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0136.htm.

[41] U.S. EPA (1997). Integrated Risk Information System File of chrysene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0455.htm

[42] U.S. EPA (1997). Integrated Risk Information System File of dibenz(a,h)anthracene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0456.htm.

[43] U.S. EPA (1997). Integrated Risk Information System File of indeno(1,2,3-cd)pyrene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/ncea/iris/subst/0457.htm.

[44] Perera, F.P.; Rauh, V.; Tsai, W-Y.; et al. (2002) Effect of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. Environ Health Perspect. 111: 201-205.

[45] Perera, F.P.; Rauh, V.; Whyatt, R.M.; Tsai, W.Y.; Tang, D.; Diaz, D.; Hoepner, L.; Barr, D.; Tu, Y.H.; Camann, D.; Kinney, P. (2006) Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ Health Perspect 114: 1287-1292.

[46] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.

IARC.[47,48] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[49] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[50] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[51] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

*6.3.3.10 Nickel*[52]

Nickel is an essential element in some animal species, and it has been suggested it may be essential for human nutrition. Nickel dermatitis, consisting of itching of the fingers, hand and forearms, is the most common effect in humans from chronic (long-term) skin contact with nickel. Respiratory effects have also been reported in humans from inhalation exposure to nickel. No information is available regarding the reproductive or developmental effects of nickel in humans, but animal studies have reported such effects. Human and animal studies have reported an increased risk of lung and nasal cancers from exposure to nickel refinery dusts and nickel subsulfide. Animal studies of soluble nickel compounds (i.e., nickel carbonyl) have reported lung tumors. The EPA has classified nickel refinery subsulfide as Group A, human carcinogens and nickel carbonyl as a Group B2, probable human carcinogen.

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[47] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[48] International Agency for Research on Cancer (IARC). 1999. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France.

[49] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.

[50] Appleman, L.M., R.A. Woutersen, and V.J. Feron. (1982). Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. Toxicology. 23: 293-297.

[51] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. (1993) Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. Am. Rev. Respir.Dis.148(4 Pt 1): 940-943.

[52] All health effects language for this section came from: U.S. EPA, "National Emission Standards for Hazardous Air Pollutants for Industrial/Commercial/Institutional Boilers and Process Heaters; Proposed Rule," 68 Federal Register 8 (January 13, 2003). pp. 1664-1665. Available on the internet at http://www.epa.gov/ttn/atw/boiler/fr13ja03.pdf

*6.3.3.11 Manganese*[53]

Health effects in humans have been associated with both deficiencies and excess intakes of manganese. Chronic (long-term) exposure to low levels of manganese in the diet is considered to be nutritionally essential in humans, with a recommended daily allowance of 2 to 5 milligrams per day. Chronic exposure to high levels of manganese by inhalation in humans results primarily in CNS effects. Visual reaction time, hand steadiness, and eye-hand coordination were affected in chronically-exposed workers. Manganism, characterized by feelings of weakness and lethargy, tremors, a masklike face, and psychological disturbances, may result from chronic exposure to higher levels. Impotence and loss of libido have been noted in male workers afflicted with manganism attributed to inhalation exposures. The EPA has classified manganese in Group D, not classifiable as to carcinogenicity in humans.

*6.3.3.12 Dioxins (Chlorinated dibenzodioxins (CDDs)*[54]

A number of effects have been observed in people exposed to 2,3,7,8-TCDD levels that are at least 10 times higher than background levels. The most obvious health effect in people exposure to relatively large amounts of 2,3,7,8-TCDD is chloracne. Chloracne is a severe skin disease with acne-like lesions that occur mainly on the face and upper body. Other skin effects noted in people exposed to high doses of 2,3,7,8-TCDD include skin rashes, discoloration, and excessive body hair. Changes in blood and urine that may indicate liver damage also are seen in people. Alterations in the ability of the liver to metabolize (or breakdown) hemoglobin, lipids, sugar, and protein have been reported in people exposed to relatively high concentrations of 2,3,7,8-TCDD. Most of the effects are considered mild and were reversible. However, in some people these effects may last for many years. Slight increases in the risk of diabetes and abnormal glucose tolerance have been observed in some studies of people exposed to 2,3,7,8-TCDD. We do not have enough information to know if exposure to 2,3,7,8-TCDD would result in reproductive or developmental effects in people, but animal studies suggest that this is a potential health concern.

In certain animal species, 2,3,7,8-TCDD is especially harmful and can cause death after a single exposure. Exposure to lower levels can cause a variety of effects in animals, such as weight

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[53] All health effects language for this section came from: U.S. EPA, "National Emission Standards for Hazardous Air Pollutants for Industrial/Commercial/Institutional Boilers and Process Heaters; Proposed Rule," 68 Federal Register 8 (January 13, 2003). pp. 1664-1665. Available on the internet at http://www.epa.gov/ttn/atw/boiler/fr13ja03.pdf

[54] All health effects language for this section came from: Agency for Toxic Substances and Disease Registry (ATSDR). 1999. ToxFAQs for Chlorinated Dibenzo-p-dioxins (CDDs) (CAS#: 2,3,7,8-TCDD 1746-01-6). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available on the Internet at http://www.atsdr.cdc.gov/tfacts104.html.

loss, liver damage, and disruption of the endocrine system. In many species of animals, 2,3,7,8-TCDD weakens the immune system and causes a decrease in the system's ability to fight bacteria and viruses at relatively low levels (approximately 10 times higher than human background body burdens). In other animal studies, exposure to 2,3,7,8-TCDD has caused reproductive damage and birth defects. Some animal species exposed to CDDs during pregnancy had miscarriages and the offspring of animals exposed to 2,3,7,8-TCDD during pregnancy often had severe birth defects including skeletal deformities, kidney defects, and weakened immune responses. In some studies, effects were observed at body burdens 10 times higher than human background levels.

*6.3.3.13 Furans (Chlorinated dibenzofurans (CDFs))* [55]

Most of the information on the adverse health effects comes from studies in people who were accidentally exposed to food contaminated with CDFs. The amounts that these people were exposed to were much higher than are likely from environmental exposures or from a normal diet. Skin and eye irritations, especially severe acne, darkened skin color, and swollen eyelids with discharge, were the most obvious health effects of the CDF poisoning. CDF poisoning also caused vomiting and diarrhea, anemia, more frequent lung infections, numbness, effects on the nervous system, and mild changes in the liver. Children born to exposed mothers had skin irritation and more difficulty learning, but it is unknown if this effect was permanent or caused by CDFs alone or CDFs and polychlorinated biphenyls in combination.

Many of the same effects that occurred in people accidentally exposed also occurred in laboratory animals that ate CDFs. Animals also had severe weight loss, and their stomachs, livers, kidneys, and immune systems were seriously injured. Some animals had birth defects and testicular damage, and in severe cases, some animals died. These effects in animals were seen when they were fed large amounts of CDFs over a short time, or small amounts over several weeks or months. Nothing is known about the possible health effects in animals from eating CDFs over a lifetime.

*6.3.3.14 Other Air Toxics*

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from boilers would be affected by this rule. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[56]

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[55] All health effects language for this section came from: Agency for Toxic Substances and Disease Registry (ATSDR). 1995. ToxFAQs™ for Chlorodibenzofurans (CDFs). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available on the Internet at <http://www.atsdr.cdc.gov/tfacts32.html>.

[56] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris

## 6.4 Characterization of Uncertainty in the Monetized $PM_{2.5}$ Benefits

In any complex analysis, there are likely to be many sources of uncertainty. Many inputs are used to derive the final estimate of economic benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of concentration-response (C-R) functions, estimates of values, population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the necessary information is not available.

The annual benefit estimates presented in this analysis are also inherently variable due to the processes that govern pollutant emissions and ambient air quality in a given year. Factors such as hours of equipment use and weather are constantly variable, regardless of our ability to measure them accurately. As discussed in the $PM_{2.5}$ NAAQS RIA (Table 5.5) (U.S. EPA, 2006), there are a variety of uncertainties associated with these PM benefits. Therefore, the estimates of annual benefits should be viewed as representative of the magnitude of benefits expected, rather than the actual benefits that would occur every year.

We performed a couple of sensitivity analyses on the benefits results to assess the sensitivity of the primary results to various data inputs and assumptions. We then changed each default input one at a time and recalculated the total monetized benefits to assess the percent change from the default. We present the results of this sensitivity analysis in Table 6-7. We indicated each input parameter, the value used as the default, and the values for the sensitivity analyses, and then we provide the total monetary benefits for each input and the percent change from the default value for the proposed option.

Above we present the estimates of the total monetized benefits, based on our interpretation of the best available scientific literature and methods and supported by the SAB-HES and the NAS (NRC, 2002). The benefits estimates are subject to a number of assumptions and uncertainties. For example, for key assumptions underlying the estimates for premature mortality, which typically account for at least 90% of the total monetized benefits, we were able to quantify include the following:

**Table 6-7. Sensitivity Analyses for Monetized $PM_{2.5}$ Health Benefits (in millions of 2008$)**

| | | Total $PM_{2.5}$ Benefits | % Change from Default |
|---|---|---|---|
| **Threshold Assumption (with Epidemiology Study)** | No Threshold (Pope) | $18,000 | N/A |
| | No Threshold (Laden) | $43,000 | N/A |
| | Threshold (Pope) | $13,810 | -23% |
| | Threshold (Laden) | $31,000 | -28% |
| **Discount Rate (with Epidemiology Study)** | 3% (Pope) | $18,000 | N/A |
| | 3% (Laden) | $43,000 | N/A |
| | 7% (Pope) | $16,000 | -11% |
| | 7% (Laden) | $39,000 | -9% |

1. $PM_{2.5}$ benefits were derived through benefit per-ton estimates, which do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an over-estimate or under-estimate of the actual benefits of controlling directly emitted fine particulates.

2. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.

3. We assume that the health impact function for fine particles is linear down to the lowest air quality levels modeled in this analysis. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.

4. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality (which typically accounts for 85% to 95% of total monetized benefits), we include a set of twelve estimates based on results of the expert elicitation study in addition to our core estimates. Even these multiple characterizations omit the uncertainty in air quality estimates, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the $PM_{2.5}$ estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis. For more information on the uncertainties associated with $PM_{2.5}$ benefits, please consult the $PM_{2.5}$ NAAQS RIA (Table 5-5).

This RIA does not include the type of detailed uncertainty assessment found in the PM NAAQS RIA because we lack the necessary air quality input and monitoring data to run the benefits model. Moreover, it was not possible to develop benefit-per-ton metrics and associated estimates of uncertainty using the benefits estimates from the PM RIA because of the significant differences between the sources affected in that rule and those regulated here. However, the results of the Monte Carlo analyses of the health and welfare benefits presented in Chapter 5 of the PM NAAQS RIA can provide some evidence of the uncertainty surrounding the benefits results presented in this analysis.

It is important to note that the monetized benefit-per-ton estimates used here reflect specific geographic patterns of emissions reductions and specific air quality and benefits modeling assumptions. For example, these estimates do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors. Use of these $/ton values to estimate benefits associated with different emission control programs (e.g., for reducing emissions from large stationary sources like EGUs) may lead to higher or lower benefit estimates than if benefits were calculated based on direct air quality modeling. Great care should be taken in applying these estimates to emission reductions occurring in any specific location, as these are all based on national or broad regional emission reduction programs and therefore represent average benefits-per-ton over the entire United States. The benefits- per-ton for emission reductions in specific locations may be very different than the estimates presented here.

## 6.5 Comparison of Benefits and Costs

Using a 3% discount rate, we estimate the total combined monetized benefits of the proposed Boiler MACT and Area Source Rule to be $18 billion to $45 billion in the implementation year (2013). Using a 7% discount rate, we estimate the total monetized benefits of the proposed Boiler MACT and Area Source Rule to be $17 billion to $40 billion. The combined annualized social costs of the proposed Boiler MACT and Area Source Rule are $3.4 billion at a 7% interest rate.[57] Thus, the combined net benefits are $15 billion to $41 billion at a 3% discount rate and $13 billion to $37 billion at a 7% discount rate. All estimates are in 2008$ for the year 2013.

The annualized social costs of the proposed Boiler MACT only are $2.9 billion, and the annualized social costs of the proposed Area Source Rule are $500 million at a 7% discount rate. The net benefits for the proposed Boiler MACT for major sources only are $14 billion to $38

[57] For more information on the annualized social costs, please refer to Section 4 of this RIA.

billion and $12 billion to $34 billion, at 3% and 7% discount rates, respectively. The net benefits for the Boiler Area Source rule only are $500 million to $1.9 billion and $410 million to $1.7 billion, at 3% and 7% discount rates, respectively. All estimates are in 2008$ for the year 2013.

Tables 6-8 and 6-9 show a summary of the monetized benefits, social costs, and net benefits for the proposed options and the alternative options for the Boiler MACT for Major Sources and for the Boiler Area Source Rule, respectively. Figures 6-4 and 6-5 show the full range of net benefits estimates (i.e., annual benefits minus annualized costs) utilizing the 14 different $PM_{2.5}$ mortality functions at discount rates of 3% and 7%. In addition, the benefits from reducing 370,000 tons of carbon monoxide, 37,000 tons of HCl, 1,000 tons of HF, 8.3 tons of mercury, 3,400 tons of other metals, and 1,200 grams of dioxins/furans each year from major and area sources have not been included in these estimates. EPA believes that the benefits are likely to exceed the costs under this rulemaking even when taking into account uncertainties in the cost and benefit estimates.

**Table 6-8. Summary of the Monetized Benefits, Social Costs, and Net Benefits for the Boiler MACT (Major Sources) in 2013 (millions of 2008$)[1]**

| | | |
|---|---|---|
| | **Proposed Option** | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[2] | $17,000 to $41,000 | $15,000 to $37,000 |
| Total Social Costs[3] | $2,900 | $2,900 |
| Net Benefits | $14,000 to $38,000 | $12,000 to $34,000 |
| | **Option 1N and 1E** | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[4] | $17,000 to $41,000 | $15,000 to $37,000 |
| Total Social Costs[3] | $12,000 | $12,000 |
| Net Benefits | $5,000 to $30,000 | $3,500 to $26,000 |

[1]All estimates are for the implementation year (2013), and are rounded to two significant figures.

[2] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 29,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 1,700 tons of VOC and 340,000 tons of $SO_2$. The benefits from reducing 340,000 tons of carbon monoxide, 37,000 tons of HCl, 1,000 tons of HF, and 7.5 tons of mercury, 3,200 tons of other metals, and 720 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

[3] The methodology used to estimate social costs for one year in the multimarket model using surplus changes results in the same social costs for both discount rates.

[4] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 29,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 6,700 tons of VOC and 350,000 tons of $SO_2$. The benefits from reducing 390,000 tons of carbon monoxide, 42,000 tons of HCl, 8,600 tons of HF, and 8.1 tons of mercury, 3,200 tons of other metals, and 760 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

**Table 6-9. Summary of the Monetized Benefits, Social Costs, and Net Benefits for the Boiler Area Source Rule in 2013 (millions of 2008$)[1]**

| | | |
|---|---|---|
| **Proposed Option** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[2] | $1,000 to $2,400 | $910 to $2,200 |
| Total Social Costs[3] | $500 | $500 |
| Net Benefits | $500 to $1,900 | $410 to $1,700 |
| **Option 1N and 1E** | | |
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[4] | $8,300 to $20,000 | $7,500 to $18,000 |
| Total Social Costs[3] | $35,000 | $35,000 |
| Net Benefits | $-27,000 to $-15,000 | $-28,000 to $-17,000 |

[1] All estimates are for the implementation year (2013), and are rounded to two significant figures.

[2] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 2,700 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 1,200 tons of VOC and 1,500 tons of $SO_2$. The benefits from reducing 40,000 tons of carbon monoxide, 130 tons of HCl, 5 tons of HF, and 0.75 tons of mercury, 250 tons of other metals, and 470 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

[3] The methodology used to estimate social costs for one year in the multimarket model using surplus changes results in the same social costs for both discount rates.

[4] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 23,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 2,100 tons of VOC and 1,700 tons of $SO_2$. The benefits from reducing 58,000 tons of carbon monoxide, 140 tons of HCl, 6.4 tons of HF, and 1.5 tons of mercury, 6,200 tons of other metals, and 530 grams of dioxins/furans each year are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

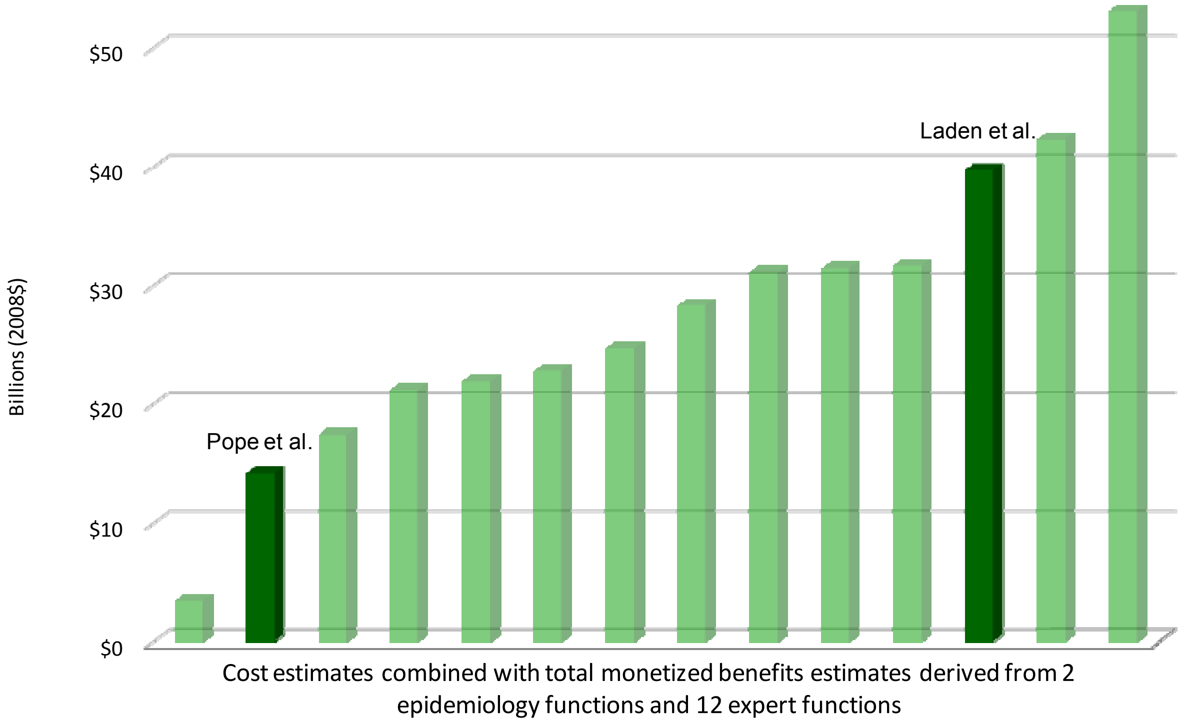


**Figure 6-6. Net Benefits for the Proposed Major and Area Source Boiler Rules at 3% Discount Rate[a]**

[a] Net Benefits are quantified in terms of $PM_{2.5}$ benefits for implementation year (2013). This graph shows 14 benefits estimates combined with the cost estimate. All combinations are treated as independent and equally probable. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary because each ton of precursor reduced has a different propensity to become $PM_{2.5}$. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles.

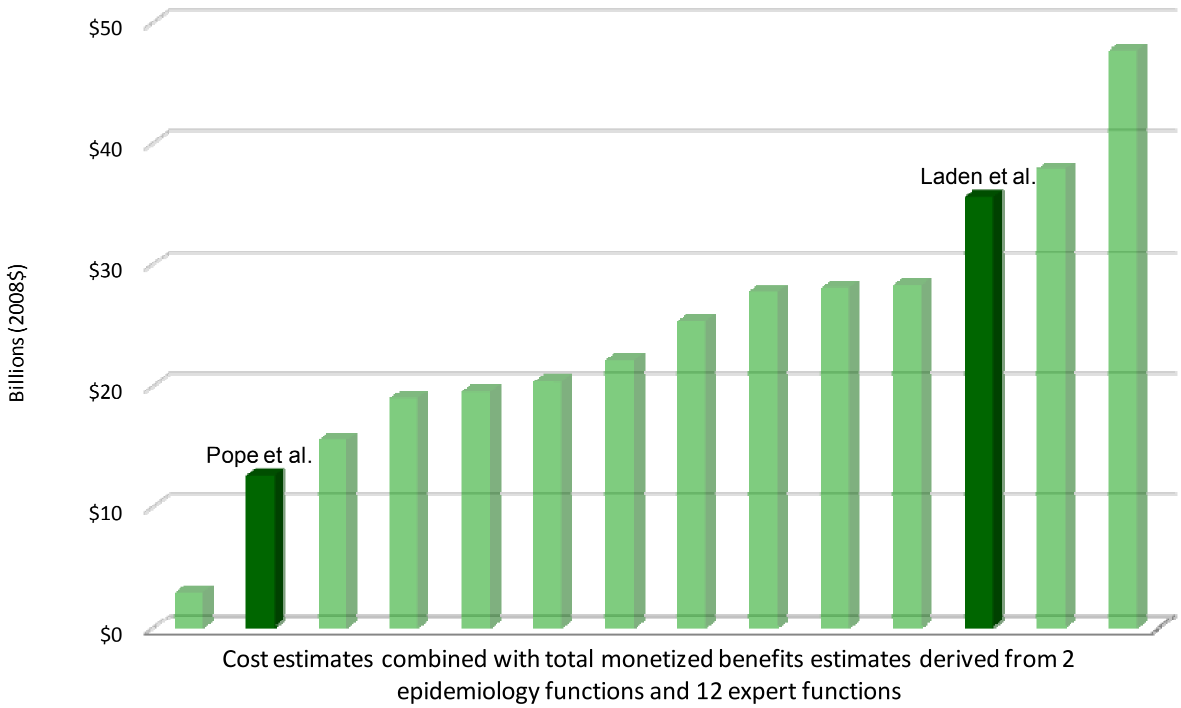


**Figure 6-7. Net Benefits for the Proposed Major and Area Source Boiler Rules at 7% Discount Rate[a]**

[a] Net Benefits are quantified in terms of $PM_{2.5}$ benefits for implementation year (2013). This graph shows 14 benefits estimates combined with the cost estimate. All combinations are treated as independent and equally probable. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary because each ton of precursor reduced has a different propensity to become $PM_{2.5}$. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles.

# SECTION 7
# SUPPLEMENTAL ECONOMIC ANALYSES FOR NON-HAZARDOUS SOLID WASTE DEFINITION

EPA also considered an economic analysis for an alternate approach for defining non-hazardous solid waste. Under the alternative approach, the universe of sources in the energy recovery and waste burning cement kiln subcategories would change while the number of sources in the remaining three subcategories (i.e., incinerators, burn-off ovens, and small, remote incinerators) does not change. This section provides an overview of the results.

## 7.1 Economic Impact Analysis Results

### *7.1.1 Market-Level Results*

Market-level impacts include price and quantity adjustments including the changes in international trade (Table 7-1). The Agency's economic model suggests the average national market-level variables (prices, production-levels, consumption, and international trade) will not significantly change (e.g., are less than 0.5%).

### *7.1.2 Social Cost Estimates*

In the near term, the Agency's economic model suggests that industries are able to pass on $0.7 billion (2008$) of the costs to U.S. households in the form of higher prices (Table 7-2). Existing U.S. industries' surplus falls by $2.0 billion, and the net loss for U.S. stakeholders is $2.7 billion. Households that buy U.S. exports pay higher prices and purchase fewer U.S. produced goods. Other countries that that sell goods to the United States benefit; the model estimates a net rest of the world gain of $0.1 billion. After accounting for international trade effects, the Agency's economic model projects the net surplus loss associated with the proposed rule is $2.6 billion. The Agency also considered other elements of the engineering cost analysis that could not be modeled within the multimarket model (e.g., 0.4 billion in fuel savings) which reduces the social cost estimate to 2.2 billion.

### *7.1.3 Job Effects*

Near-term employment changes associated with the proposed rule are estimated to be less than 5,000 job losses; over a longer time period, net employment effects could range between 4,000 job losses to 9,000 job gains. Additional details and caveats associated with these estimates are present in section 4.

**Table 7-1. Market-Level Price and Quantity Changes: 2013 (Alternate Definition)**

| Industry Sector | Prices | Production | Imports | Consumption | Exports |
|---|---|---|---|---|---|
| ***Energy*** | 0.04% | -0.01% | 0.07% | less than 0.01% | less than 0.01% |
| ***Nonmanufacturing*** | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| ***Manufacturing*** | | | | | |
| Food, beverages, and textiles | 0.02% | -0.02% | 0.02% | -0.01% | -0.01% |
| Lumber, paper, and printing | 0.14% | -0.06% | 0.14% | -0.03% | -0.09% |
| Chemicals | 0.02% | -0.03% | 0.02% | -0.02% | -0.02% |
| Plastics and Rubber | less than 0.01% | -0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| Nonmetallic Minerals | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| Primary Metals | 0.04% | -0.04% | 0.04% | -0.02% | -0.04% |
| Fabricated Metals | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| Machinery and Equipment | 0.01% | -0.01% | less than 0.01% | less than 0.01% | -0.02% |
| Electronic Equipment | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| Transportation Equipment | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| Other | less than 0.01% | -0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| ***Wholesale and Retail Trade*** | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| ***Transportation Services*** | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |
| ***Other Services*** | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% | less than 0.01% |

## Table 7-2. Distribution of Social Costs (million, 2008$): 2013

| Method | Alternate Definition |
|---|---|
| **Partial Equilibrium Model (Multiple Markets)** | |
| Change in U.S. consumer surplus | −$0.7 |
| Change in U.S. producer surplus | −$2.0 |
| Change in U.S. surplus | −$2.7 |
| Net change in rest of world surplus | $0.1 |
| Net change in total surplus | −$2.6 |
| **Direct Compliance Costs Method** | |
| Fuel savings (not modeled) | $0.4 |
| **Change in Total Surplus** | −$2.2 |

## Table 7-3. Employment Changes: 2013

| Method | 1,000 Jobs |
|---|---|
| **Partial equilibrium model (multiple markets) (demand effect only)** | **−4.2** |
| **Estimate Derived from Morgenstern, et al. (net effect [A + B +C below])** | **+2.4 (−4.4 to +9.2)** |
| *A. Estimate Derived from Morgenstern, et al: Demand effect* | −5.5 (−11.6 to 0.6) |
| *B. Estimate Derived from Morgenstern, et al: Cost effect* | +3.7 (+1.2 to +6.2) |
| *C. Estimate Derived from Morgenstern, et al: Factor shift effect* | +4.1 (+0.1 to +8.2) |

Note: Totals may not add due to independent rounding. 95 percent confidence intervals are shown in parenthesis.

## 7.2 Benefits Analysis Results

Table 7-4 provides a general summary of the alternate approach results by pollutant, including the emission reductions and monetized benefits-per-ton at discount rates of 3% and 7%. These estimates reflect EPA's most current interpretation of the scientific literature. Higher or lower estimates of benefits are possible using other assumptions, but most expert-derived estimates fall within these estimates. Data, resource, and methodological limitations prevented EPA from monetizing the benefits from several important benefit categories, including benefits from reducing hazardous air pollutants, ecosystem effects, and visibility impairment. The benefits from reducing hazardous air pollutants have not been monetized in this analysis, including reducing 280,000 tons of carbon monoxide, 5,100 tons of HCl, 1,100 tons of HF, and 7.1 tons of mercury, and 290 grams of dioxins/furans from major sources each year. Tables 7-5 shows a summary of the monetized benefits, social costs, and net benefits for the alternative definition for the Boiler MACT for existing major sources.

**Table 7-4. Summary of Monetized Benefits for the Boiler MACT for Existing Major Sources in 2013 (2008$) (Alternate Approach)***

| Pollutant | Emissions Reductions (tons) | Benefit per ton (Pope, 3%) | Benefit per ton (Laden, 3%) | Benefit per ton (Pope, 7%) | Benefit per ton (Laden, 7%) | Total Monetized Benefits (millions 2008$ at 3%) | Total Monetized Benefits (millions 2008$ at 7%) |
|---|---|---|---|---|---|---|---|
| Direct $PM_{2.5\ Major}$ | 8,040 | $230,000 | $560,000 | $210,000 | $500,000 | $1,800 to $4,500 | $1,700 to $4,100 |
| $PM_{2.5}$ Precursors | | | | | | | |
| $SO_{2\ Major}$ | 44,092 | $29,000 | $72,000 | $27,000 | $65,000 | $1,300 to $3,200 | $1,200 to $2,900 |
| VOC | 4,703 | $1,200 | $3,000 | $1,100 | $2,700 | $5.7 to $14.0 | $5.2 to $13.0 |
| | | | | | **Total** | **$3,100 to $7,700** | **$2,800 to $6,900** |

*All estimates are for the implementation year (2013), and are rounded to two significant figures so numbers may not sum across columns. All fine particles are assumed to have equivalent health effects, but the benefit per ton estimates vary because each ton of precursor reduced has a different propensity to form $PM_{2.5}$. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles.

**Table 7-5. Summary of the Monetized Benefits, Social Costs, and Net Benefits for the Boiler MACT (Major Sources) in 2013 (millions of 2008$)[1]**

| Proposed Option with Alternate Solid Waste Definition | | |
|---|---|---|
| | 3% Discount Rate | 7% Discount Rate |
| Total Monetized Benefits[2] | $3,100 to $7,700 | $2,800 to $6,900 |
| Total Social Costs[3] | $2,200 | $2,200 |
| Net Benefits | $930 to $5,500 | $640 to $4,700 |

[1]All estimates are for the implementation year (2013), and are rounded to two significant figures.
[2] The total monetized benefits reflect the human health benefits associated with reducing exposure to $PM_{2.5}$ through reductions of 8,000 tons of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors such as 4,700 tons of VOC and 44,000 tons of $SO_2$. The benefits from reducing 280,000 tons of carbon monoxide, 5,100 tons of HCl, 1,100 tons of HF, and 7.1 tons of mercury, 1,600 tons of other metals, and 290 grams of dioxins/furans each year from major sources are not included in these estimates. In addition, the benefits from reducing ecosystem effects and visibility impairment are not included.

## REFERENCES


Benwart, S.J. 2006. “Paper & Forest Products. Standard and Poor’s Industry Surveys.” 176 (28).

Broda, C., N. Limao, and D. Weinstein. 2008a. “Export Supply Elasticities.” http://faculty.chicagobooth.edu/christian.broda/website/research/unrestricted/TradeElasticities/TradeElasticities.html. Accessed September 2009.

Broda, C., N. Limao, and D.E. Weinstein. 2008b. “Optimal Tariffs and Market Power: The Evidence.” *American Economic Review* 98(5):2032-2065.

Berck, P., and S. Hoffmann. 2002. “Assessing the Employment Impacts of Environmental and Natural Resource Policy.” *Environmental and Resource Economics* 22(1):133-156.

Berman, E. and L. T. M. Bui. 2001. Environmental regulation and labor demand: Evidence from the south coast air basin. *Journal of Public Economics* 79(2):265-295.

Cole, M. A. and R. J. Elliott. 2007. Do environmental regulations cost jobs? An industry-level analysis of the UK. *B E Journal of Economic Analysis & Policy* 7(1) (Topics), Article 28..

Dow Chemical Company. 2008. “Transforming: The Dow Chemical Company 2007 10-K and Stockholder Summary.” <http://www.dow.com/financial/2007ann/>.

Drevnick, P.E., D.E. Canfield, P.R. Gorski, A.L.C. Shinneman, D.R. Engstrom, D.C.G. Muir, G.R. Smith, P.J. Garrison, L.B. Cleckner, J.P. Hurley, R.B. Noble, R.R. Otter, and J.T.Oris. 2007. Deposition and cycling of sulfur controls mercury accumulation in Isle Royale fish. Environmental Science and Technology 41(21):7266-7272.

Dun & Bradstreet. 2007. *2007 D&B Million Dollar Directory*. Pennsylvania: Dun & Bradstreet Inc.

Dun & Bradstreet Small Business Solutions. 2008. Small Business Database. <http://smallbusiness.dnb.com/default.asp?bhcd2=1107465546>.

Edison Electric Institute. “Income Statement: Q4 2008 Financial Update. Quarterly Report of the U.S. Shareholder-Owned Electric Utility Industry.” <http://www.eei.org>.

Fann, N., C.M. Fulcher, B.J. Hubbell. 2009. The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health (2009) 2:169-176.

Federal Reserve Board. 2008. “Industrial Production and Capacity Utilization: Capacity Utilization.” Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G311.S. <http://www.federalreserve.gov/datadownload/>. (Food).

Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G311.S. <http://www.federalreserve.gov/datadownload/>. (Food).

Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G311.S. <http://www.federalreserve.gov/datadownload/>. (Food).

Federal Reserve Board. 2008. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G311.S. <http://www.federalreserve.gov/datadownload/>. (Food).

Federal Reserve Board. 2009. "Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.G324.S & G17/KW/KW.GMF.S. <http://www.federalreserve.gov/datadownload/>. (Petroleum).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity" Series ID: G17/CAP/CAP.G324.S & G17/CAP/CAP.GMF.S. <http://www.federalreserve.gov/datadownload/>. (Petroleum).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_DURABLE_GOODS_DETAIL/IP.G324.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S. <http://www.federalreserve.gov/datadownload/>. (Petroleum).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.G324.S & G17/CAPUTL/CAPUTL.GMF.S. <http://www.federalreserve.gov/datadownload/>. (Petroleum).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G322.S. <http://www.federalreserve.gov/datadownload>. (Paper).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G322.S. <http://www.federalreserve.gov/datadownload/>. (Paper).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G322.S. <http://www.federalreserve.gov/datadownload/>. (Paper).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G322.S. <http://www.federalreserve.gov/datadownload/>. (Paper).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.G2211.S. <http://www.federalreserve.gov/datadownload/>. Last released January 15, 2010. (Electric Utilities).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.G2211.S. <http://www.federalreserve.gov/datadownload/>. Last released January 15, 2010. (Electric Utilities).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MINING_AND_UTILITY_DETAIL/IP.G2211.S. <http://www.federalreserve.gov/datadownload/>. Last released January 15, 2010. (Electric Utilities).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G321.S. <http://www.federalreserve.gov/datadownload/>. (Wood Products).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009. (Wood Products).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009. (Wood Products).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Production." Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G321.S. <http://www.federalreserve.gov/datadownload/>. Accessed on December 15, 2009. (Wood Products).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Capacity Utilization." Series ID: G17/CAPUTL/CAPUTL.GMF.S & G17/CAPUTL/CAPUTL.G325.S. <http://www.federalreserve.gov/datadownload/>. (Chemicals).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Electric Power Use: Manufacturing and Mining." Series ID: G17/KW/KW.GMF.S & G17/KW/KW.G325.S. <http://www.federalreserve.gov/datadownload/>. (Chemicals).

Federal Reserve Board. 2009. "Industrial Production and Capacity Utilization: Industrial Capacity." Series ID: G17/CAP/CAP.GMF.S & G17/CAP/CAP.G325.S. <http://www.federalreserve.gov/datadownload/>. (Chemicals).

Federal Reserve Board. 2009. “Industrial Production and Capacity Utilization: Industrial Production.” Series ID: G17/IP_MAJOR_INDUSTRY_GROUPS/IP.GMF.S & G17/IP_MAJOR_INDUSTRY_GROUPS/IP.G325.S. <http://www.federalreserve.gov/datadownload/>. (Chemicals).

Gale Research Inc. 2007. *Ward’s Business Directory of U.S. Private and Public Companies*. Detroit: Gale Research.

Graves, T. 2008. “Foods and Nonalcoholic Beverages.” *Standard and Poor’s Industry Surveys*. 176 (25).

Greenstone, M. 2002. “The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures.” *Journal of Political Economy* 110(6):1175-1219.

Henderson, J. V. 1996. “Effects of Air Quality Regulation.” *American Economic Review* 86(4):789-813.

Ho, M.S., R. Morgenstern, and J.S. Shih. 2008. “Impact of Carbon Price Policies on US Industry.” RFF Discussion Paper 08-37. http://www.Rff.Org/Publications/Pages/Publicationdetails.Aspx?. Publicationid=20680. Accessed August 2009.

Hoovers. 2007. Free Content, Company Information. <http://www.hoovers.com/free/>.

Internal Revenue Service, U.S. Department of Treasury. 2008. “Corporation Source Book: Data File 2005.” <http://www.irs.gov/taxstats/article/0,,id=167415,00.html>; (January, 14 2009).

Internal Revenue Service, U.S. Department of Treasury. 2008. “Corporation Source Book: Data File 2007.” <http://www.irs.gov/taxstats/article/0,,id=167415,00.html>; (January, 15, 2010).

Just, R.E., D.L. Hueth, and A. Schmitz. 2004. *The Welfare Economics of Public Policy*. Northampton, MA: Edward Elgar.

Kochi, I., B. Hubbell, and R. Kramer. 2006. “An Empirical Bayes Approach to Combining Estimates of the Value of Statistical Life for Environmental Policy Analysis.” *Environmental and Resource Economics* 34:385-406.

Kraft Foods Inc. 2008. Form 10-K, Period ending December 31, 2007. <http://www.kraft.com/Investor/sec-filings-annual-report/>.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. “Reduction in Fine Particulate Air Pollution and Mortality.” *American Journal of Respiratory and Critical Care Medicine* 173:667-672.

Morgenstern, R. D., W. A. Pizer, and J. S. Shih. 2002. "Jobs versus the Environment: An Industry-Level Perspective." *Journal of Environmental Economics and Management* 43(3):412-436.

Mrozek, J.R., and L.O. Taylor. 2002. "What Determines the Value of Life? A Meta-Analysis." *Journal of Policy Analysis and Management* 21(2):253-270.

Munthe, J., R.A. Bodaly, B.A. Branfireun, C.T. Driscoll, C.C. Gilmour, R. Harris, M. Horvat, M. Lucotte, and O. Malm. 2007. "Recovery of Mercury-Contaminated Fisheries." *AMBIO: A Journal of the Human Environment* 36:33-44.

National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press.

O'Reilly, R. 2008. "Chemicals." *Standard and Poor's Industry Surveys*. 176 (28).

Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *Journal of the American Medical Association* 287:1132-1141.

Roman, H.A., K.D. Walker, T.L. Walsh, L. Conner, H.M. Richmond, .J. Hubbell, and P.L. Kinney. 2008. "Expert Judgment Assessment of the Mortality Impact of Changes in Ambient Fine Particulate Matter in the U.S." *Environ. Sci. Technol*. 42(7):2268-2274.

Shoven, J.B., and J. Whalley. 1995. *Applying General Equilibrium*. New York: Cambridge University Press.

U.S. Bureau of Economic Analysis (BEA). 2008. "2002 Benchmark Input-Output Accounts: 2002 Standard Make and Use Tables at the Summary Level." Table 2. Washington, DC: BEA.

U.S. Bureau of Economic Analysis (BEA). 2010. Table 1.1.9. Implicit Price Deflators for Gross Domestic Product. Accessed January 20, 2010. http://www.bea.gov/national/nipaweb/SelectTable.asp?Selected=N.

U.S. Bureau of Labor Statistics (BLS). 2009. Producer Price Index. Series ID:PCU321—321—& PCUOMFG—OMFG—<http://www.bls.gov/ppi/home.htm>. (Data accessed on January 8, 2010).

U.S. Bureau of Labor Statistics (BLS). 2009. Producer Price Index. Series ID:PCU322–322– & PCUOMFG–OMFG–. <http://www.bls.gov/ppi/home.htm>.

U.S. Bureau of Labor Statistics (BLS). 2009. Producer Price Index. Series ID:PCU325—325—& PCUOMFG—OMFG—<http://www.bls.gov/ppi/home.htm>.

U.S. Bureau of Labor Statistics (BLS). 2009. "Producer Price Index." Series ID: PCU3313–3313– & PCUOMFG–OMFG–. <http://www.bls.gov/ppi/home.htm>.

U.S. Census Bureau. 1997. “1997 Economic Census: Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau. 2001. 1997 Census NAICS Definitions. <http://www.census.gov/epcd/ec97/industry/E322.HTM#def>.

U.S. Census Bureau. 2002. “2002 Economic Census: Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis.” <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau. 2002. “2002 Economic Census: Sector 22: Utilities: Geographic Area Series: Summary Statistics: 2002.” <http://factfinder.census.gov>; (November 10, 2008).

U.S. Census Bureau. 2005a. *2002 Census of Governments, Volume 4, Number 3, Finances of County Governments: 2002 GC02(4)-3*. U.S. Washington, DC: Government Printing Office. Table 12.

U.S. Census Bureau. 2005b. *2002 Census of Governments, Volume 4, Number 4, Finances of Municipal and Township Governments: 2002 GC02(4)-4*. Washington, DC: Government Printing Office. Table 13.

U.S. Census Bureau. 2008a. “Exclusions from the Economic Census.” <http://www.census.gov/econ/census02/guide/excluded.htm>; (January 14, 2009).

U.S. Census Bureau. 2008b. “Firm Size Data from the Statistics of U.S. Businesses: U.S. Detail Employment Sizes: 2002.” <http://www.census.gov/csd/susb/download_susb02.htm>.

U.S. Census Bureau. 2009a. “2002 NAICS Definition.” <http://www.census.gov/cgi-bin/sssd/naics/naicsrch?code=324&search=2002%20NAICS%20Search>. (January 9, 2009).

U.S. Census Bureau. 2009b. “Sector 00: All Sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997.”

U.S. Census Bureau. 2009c. Generated by RTI International; using American FactFinder; “Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005.” <http://factfinder.census.gov>.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder, “Sector 00: EC0700A1: All sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007 .” <http://factfinder.census.gov>.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder, “Sector 00: EC0700A1: All sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007.” <http://factfinder.census.gov>. Accessed on January 6, 2010.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 00: EC0700A1: All sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." Accessed on December 27, 2009.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder, "Sector 00: EC0700A1: All sectors: Geographic Area Series: Economy-Wide Key Statistics: 2007." <http://factfinder.census.gov>. Accessed on December 28, 2009.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the U.S.: 2007. http://factfinder.census.gov. Accessed on December 27, 2009.

U.S. Census Bureau; generated by Kapur Energy and Environment: using American FactFinder; "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." <http://factfinder.census.gov>. Accessed on December 27, 2009.

U.S. Census Bureau; generated by Kapur Energy and Environment; using American FactFinder, "Sector 31: EC0731I1: Manufacturing: Industry Series: Detailed Statistics by Industry for the United States: 2007." <http://factfinder.census.gov>. Accessed on December 28, 2009.

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (1997 NAICS Basis): 2002 and 1997." <http://factfinder.census.gov>; (July 8, 2008.

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 00: All sectors: Core Business Statistics Series: Comparative Statistics for the United States and the States (2007 NAICS Basis): 2002 and 2007." <http://factfinder.census.gov>; (January 4, 2010).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Annual Survey of Manufactures: General Statistics: Statistics for Industry Groups and Industries: 2006 and 2005." <http://factfinder.census.gov>; (July 8, 2008).

U.S. Census Bureau; generated by RTI International; using American FactFinder; "Sector 31: Manufacturing: Geographic Area Series: Industry Statistics for the States, Metropolitan and Micropolitan Statistical Areas, Counties, and Places: 2002." <http://factfinder.census.gov>; (July 23, 2008).

U.S. Department of Energy, Energy Information Administration (EIA). 1996–2008. "Petroleum Supply Annuals, Volume 1." <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_supply_annual/psa_volume1/psa_volume1.htmls>. Accessed on December 28, 2009.

U.S. Department of Energy, Energy Information Administration (EIA). 1999. U.S. Environmental Protection Agency (EPA). 2008. "Regulatory Impact Analysis for the Petroleum Refineries NSPS." <http://www.epa.gov/ttn/ecas/regdata/RIAs/ finalpetroleumrefineriesnspsria43008.pdf>.

U.S. Department of Energy, Energy Information Administration. 2007. "2002 Energy Consumption by Manufacturers—Data Tables." Tables 3.2, N3.2 and 5.2. Washington, DC: DOE. <http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html>.

U.S. Department of Energy, Energy Information Administration. 2007a. "2006 Annual Electric Generator Report—Generator (Existing) File."

U.S. Department of Energy, Energy Information Administration. 2007b. "2006 Energy Consumption by Manufacturers—Data Tables." Table 3.1. http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html.

U.S. Department of Energy, Energy Information Administration. 2007c. "State Electricity Profiles 2007." DOE/EIA-0348(01)/2. p. 314. <http://www.eia.doe.gov/cneaf/electricity/st_profiles/sep2007.pdf>. (Data accessed on January 6, 2010)

U.S. Department of Energy, Energy Information Administration. 2008. "Assumptions to the Annual Energy Outlook 2008: With Projections for 2030." <http://www.eia.doe.gov/oiaf/aeo/assumption/>.

U.S. Department of Energy, Energy Information Administration. 2009a. "2006 Energy Consumption by Manufacturers—Data Tables." Table 3.1. Washington, DC: DOE. <http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html>.

U.S. Department of Energy, Energy Information Administration. 2009b. "Current and Historical Monthly Retail Sales, Revenues and Average Revenue per Kilowatt hour by State and by Sector (Form EIA-826)." <http://www.eia.doe.gov/cneaf/electricity/epm/table5_5_b.html>; (January 21, 2010 and February 16, 2010).

U.S. Department of Energy, Energy Information Administration. 2009c. "Electric Power Annual 2007: Table 6.3." DOE/EIA-0348(2007).

U.S. Department of Energy, Energy Information Administration. 2009d. "Official Energy Statistics from the U.S. Government: Glossary." <http://www.eia.doe.gov/glossary/ index.html>; (January 29, 2009).

U.S. Department of Energy, Energy Information Administration (EIA). 2009e. "Refinery Capacity Report 2009." <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/ref capacity.html >. Released on June 25, 2009.

U.S. Department of Energy, Energy Information Administration. 2009f. "Status of Electricity Restructuring by State." <http://www.eia.doe.gov/cneaf/electricity/page/restructuring/restructure_elect.html>; (February 3, 2009).

U.S. Department of Energy, Energy Information Administration. 2010a. "Annual Energy Outlook 2010 Reference Case Table A8." <http://www.eia.doe.gov/oiaf/aeo/pdf/appa.pdf>.

U.S. Department of Energy, Energy Information Administration. 2010b. "Electric Power Annual 2008: Table 1.1." Accessed on January 29, 2010.

U.S. Department of Energy, Energy Information Administration. 2010c. "Electric Power Annual 2008: Table 2.1." Accessed on January 29, 2010.

U.S. Department of Energy, Energy Information Administration. 2010d. "Electric Power Annual 2008: Table 8.1, Table 8.3, Table 8.4, Table 8.5, Table 8.6." DOE/EIA-0348 (2008).

U.S. Department of Labor, Occupational Safety and Health Administration (OSHA). 2003. OSHA Technical Manual, Section IV: Chapter 2, Petroleum Refining Processes. TED 01-00-015. Washington, DC: U.S. DOL. <http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html>. As obtained on October 23, 2006.

U.S. Department of Labor; Bureau of Labor Statistics. 2010. Producer Price Indexes. <http://www.bls.gov/pPI/Series Id: PCU311—311—Food Manufacturing & PCUOMFG–OMFG–Total Manufacturing>.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. 1999. *OAQPS Economic Analysis Resource Document*. http://www.epa.gov/ttn/ecas/analguid.html.

U.S. Environmental Protection Agency. September 2000. *Guidelines for Preparing Economic Analyses*. EPA 240-R-00-003. Washington, DC: EPA. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html. Accessed August 2009.

U.S. Environmental Protection Agency. 2002. "Profile of the Pulp and Paper Industry." *Sector Notebook Project*. <http://www.epa.gov/Compliance/resources/publications/assistance/sectors/notebooks/index.html>.

U.S. Environmental Protection Agency. 2008. *Regulatory Impact Analysis for the Petroleum Refineries NSPS, Chapter 3*. Available at< http://www.epa.gov/ttn/ecas/regdata/RIAs/finalpetroleumrefineriesnspsria43008.pdf>.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. March 2008. *EMPAX-CGE Model Documentation.* http://pubweb.epa.gov/ttn/ecas/models/empax_model_documentation.pdf.

U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>.

U.S. Environmental Protection Agency. 2006. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for Particulate Matter, Chapter 5. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf >.

U.S. Environmental Protection Agency (U.S. EPA). 2008. Guidelines for Preparing Economic Analyses: External Review Draft. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available at <http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2008b. *Integrated Science Assessment for Sulfur Oxides—Health Criteria* (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. Available at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843>.

U.S. Environmental Protection Agency (U.S. EPA). 2008c. *Guidelines for Preparing Economic Analyses: External Review Draft.* National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. Available at <http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2008d. *Integrated Science Assessment for Oxides of Nitrogen and Sulfur–Ecological Criteria National* (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.

U.S. Environmental Protection Agency (U.S. EPA). 2009a. *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf >.

U.S. Environmental Protection Agency (U.S. EPA). 2009b. *Proposed $SO_2$ NAAQS Regulatory Impact Analysis (RIA)*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. November. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/pso2full11-16-09.pdf >.

U.S. Environmental Protection Agency (U.S. EPA). 2009c. *Integrated Science Assessment for Particulate Matter* (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

U.S. Environmental Protection Agency (U.S. EPA). 2010a. *Integrated Science Assessment for Carbon Monoxide*. National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-09/019F. January. Available at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686>.

U.S. Environmental Protection Agency (U.S. EPA). 2010b. *Final Regulatory Impact Analysis (RIA) for the* $NO_2$ *National Ambient Air Quality Standards (NAAQS)*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. January. Available at < http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf>.

U.S. Environmental Protection Agency—Science Advisory Board (U.S. EPA-SAB). 2007. *SAB Advisory on EPA's Issues in Valuing Mortality Risk Reductio*n. EPA-SAB-08-001. October. Available at <http://yosemite.epa.gov/sab/sabproduct.nsf/4128007E7876B8F0852573760058A978/$File/sab-08-001.pdf >.

U.S. Environmental Protection Agency—Science Advisory Board (U.S. EPA-SAB). 2009a. *Review of EPA's Integrated Science Assessment for Particulate Matter* (First External Review Draft, December 2008). EPA-COUNCIL-09-008. May. Available at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf>.

U.S. Environmental Protection Agency—Science Advisory Board (U.S. EPA-SAB). 2009b. *Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment*. EPA-COUNCIL-09-009. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf>.

U.S. International Trade Commission. 2008a. "U.S. Domestic Exports" & "U.S. Imports for Consumption." <http://dataweb.usitc.gov/scripts/user_set.asp>.

U.S. International Trade Commission. 2008b. "U.S. Total Exports" & "U.S. Imports for Consumption." <http://dataweb.usitc.gov/scripts/user_set.asp>.

U.S. International Trade Commission. 2009. "U.S. Domestic Exports" & "U.S. Imports for Consumption." <http://www.federalreserve.gov/datadownload/>.

U.S. Small Business Administration (SBA). 2008. "Table of Small Business Size Standards Matched to North American Industry Classification System Codes." Effective August 22, 2008. <http://www.sba.gov/services/contractingopportunities/sizestandardstopics/size/index.html>.

Viscusi, V.K., and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." *Journal of Risk and Uncertainty* 27(1):5-76.

# APPENDIX A

# OAQPS MULTIMARKET MODEL TO ASSESS THE ECONOMIC IMPACTS OF ENVIRONMENTAL REGULATION

## A.1 Introduction

An economic impact analysis (EIA) provides information about a policy's effects (i.e., social costs); emphasis is also placed on how the costs are distributed among stakeholders (EPA, 2000). In addition, large-scale policies require additional analysis to better understand how costs are passed across the economy. Although several tools are available to estimate social costs, current EPA guidelines suggest that multimarket models "…are best used when potential economic impacts and equity effects on related markets might be considerable" and modeling using a computable general equilibrium model is not available or practical (EPA, 2000, p. 146). Other guides for environmental economists offer similar advice (Berck and Hoffmann, 2002; Just, Hueth, and Schmitz, 2004).

Multimarket models focus on "short-run" time horizons and measure a policy's near term or transition costs (EPA, 1999). Recent studies suggest short-run analyses can complement full dynamic general equilibrium analysis.

The multimarket model described in this appendix is a new addition to the Office of Air Quality Planning and Standards' (OAQPS's) economic model tool kit; it is designed to be used as a transparent tool that can respond quickly to requests about how stakeholders in 100 U.S. industries might respond to new environmental policy. Next, we provide an overview of the model, data, and parameters.

## A.2 Multimarket Model

The multimarket model contains the following features:

- Industry sectors and benchmark data set
  - 100 industry sectors
  - a single benchmark year (2010)
  - estimates of industry carbon dioxide ($CO_2$) emissions
  - estimates of industry employment
- Economic behavior
  - industries respond to regulatory costs by changing production rates
  - market prices rise to reflect higher energy and other nonenergy material costs
  - customers respond to these price increases and consumption falls
- Model scope

- 100 sectors are linked with each other based on their use of energy and other nonenergy materials. For example, the construction industry is linked with the petroleum, cement, and steel industries and is influenced by price changes that occur in each sector. The links allow EPA to account for indirect effects the regulation has on related markets.
  - Links come from input-output information used from OAQPS's computable general equilibrium model (EMPAX)
  - production adjustments influence employment levels
  - international trade (imports/exports) behavior considered
- Model time horizon ("short-run")
  - fixed production resources (e.g., capital) leads to an upward-sloping industry supply function
  - firms cannot alter input mixes; there is no substitution among production inputs (capital, labor, energy intermediates, and other intermediates)
  - price of labor (i.e., wage) is fixed
  - investment and government expenditures are fixed

### *A.2.1 Industry Sectors and Benchmark Data Set*

The multimarket model includes 100 industries. For the benchmark year, the model uses information from OAQPS's computable general equilibrium model's balanced social accounting matrix (SAM) and the following accounting identity holds (EPA, 2008):

$$\text{Output} + \text{Imports} = \text{Consumption} + \text{Investment} + \text{Government} + \text{Exports} \qquad (A.1)$$

If we abstract and treat each industry as a national market, the identity represents the prepolicy market-clearing condition, or benchmark "equilibrium"; supply equals demand in each market. In Table A-1, we identify the 100 industries for the multimarket model; Table A-2 provides the 2010 benchmark data set. Since the benchmark data are reported in value terms, we also use the common "Harberger convention" and choose units where are all prices are one in the benchmark equilibrium (Shoven and Whalley, 1995).

## Table A-1. Industry Sectors Included in Multimarket Model

| Industry Label | Description | Representative NAICS[a] |
|---|---|---|
| **Energy Industries** | | |
| COL | Coal | 2121 |
| CRU | Crude Oil Extraction | 211111 (exc. nat gas) |
| ELE | Electric Generation | 2211 |
| GAS | Natural Gas | 211112 2212 4862 |
| OIL | Refined Petroleum | 324 |
| **Nonmanufacturing** | | |
| AGR | Agricultural | 11 |
| MIN | Mining | 21 less others |
| CNS | Construction | 23 |
| **Manufactured Goods** | | |
| ***Food, beverages, and textiles*** | | |
| ANM | Animal Foods | 3111 |
| GRN | Grain Milling | 3112 |
| SGR | Sugar | 3113 |
| FRU | Fruits and Vegetables | 3114 |
| MIL | Dairy Products | 3115 |
| MEA | Meat Products | 3116 |
| SEA | Seafood | 3117 |
| BAK | Baked Goods | 3118 |
| OFD | Other Food Products | 3119 |
| BEV | Beverages and Tobacco | 312 |
| TEX | Textile Mills | 313 |
| TPM | Textile Product Mills | 314 |
| WAP | Wearing Apparel | 315 |
| LEA | Leather | 316 |
| ***Lumber, paper, and printing*** | | |
| SAW | Sawmills | 3211 |
| PLY | Plywood and Veneer | 3212 |
| LUM | Other Lumber | 3219 |
| PAP | Pulp and Paper Mills | 3221 |
| CPP | Converted Paper Products | 3222 |
| PRN | Printing | 323 |
| ***Chemicals*** | | |
| CHM | Chemicals and Gases | 3251 |
| RSN | Resins | 3252 |
| FRT | Fertilizer | 3253 |
| MED | Drugs and Medicine | 3254 |
| PAI | Paints and Adhesives | 3255 |
| SOP | Soap | 3256 |
| OCM | Other Chemicals | 3259 |

(continued)

## Table A-1. Industry Sectors Included in Multimarket Model (continued)

| Industry Label | Description | Representative NAICS[a] |
|---|---|---|
| ***Plastics and Rubber*** | | |
| PLS | Plastic | 3261 |
| RUB | Rubber | 3262 |
| ***Nonmetallic Minerals*** | | |
| CLY | Clay | 3271 |
| GLS | Glass | 3272 |
| CEM | Cement | 3273 |
| LIM | Lime and Gypsum | 3274 |
| ONM | Other Non-Metallic Minerals | 3279 |
| ***Primary Metals*** | | |
| I_S | Iron and Steel | 3311 3312 33151 |
| ALU | Aluminum | 3313 331521 331524 |
| OPM | Other Primary Metals | 3314 331522 331525 331528 |
| ***Fabricated Metals*** | | |
| FRG | Forging and Stamping | 3321 |
| CUT | Cutlery | 3322 |
| FMP | Fabricated Metals | 3323 |
| BOI | Boilers and Tanks | 3324 |
| HRD | Hardware | 3325 |
| WIR | Springs and Wires | 3326 |
| MSP | Machine Shops | 3327 |
| EGV | Engraving | 3328 |
| OFM | Other Fabricated Metals | 3329 |
| ***Machinery and Equipment*** | | |
| CEQ | Construction and Agricultural Equipment | 3331 |
| IEQ | Industrial Equipment | 3332 |
| SEQ | Service Industry Equipment | 3333 |
| HVC | HVAC Equipment | 3334 |
| MEQ | Metalworking Equipment | 3335 |
| EEQ | Engines | 3336 |
| GEQ | General Equipment | 3339 |
| ***Electronic Equipment*** | | |
| CPU | Computers | 3341 |
| CMQ | Communication Equipment | 3342 |
| TVQ | TV Equipment | 3343 |
| SMI | Semiconductor Equipment | 3344 |
| INS | Instruments | 3345 |
| MGT | Magnetic Recording Equipment | 3346 |
| LGT | Lighting | 3351 |
| APP | Appliances | 3352 |

(continued)

## Table A-1. Industry Sectors Included in Multimarket Model (continued)

| Industry Label | Description | Representative NAICS[a] |
|---|---|---|
| ***Electronic Equipment (continued)*** | | |
| ELQ | Electric Equipment | 3353 |
| OEQ | Other Electric Equipment | 3359 |
| ***Transportation Equipment*** | | |
| M_V | Motor Vehicles | 3361 |
| TKB | Truck Bodies | 3362 |
| MVP | Motor Vehicle Parts | 3363 |
| ARC | Aircraft | 3364 |
| R_R | Rail Cars | 3365 |
| SHP | Ships | 3366 |
| OTQ | Other Transport Equipment | 3369 |
| Other | | |
| FUR | Furniture | 337 |
| MSC | Miscellaneous Manufacturing | 339 |
| **Services** | | |
| ***Wholesale and Retail Trade*** | | |
| WHL | Wholesale Trade | 42 |
| RTL | Retail Trade | 44-45 |
| ***Transportation Services*** | | |
| ATP | Air Transportation | 481 |
| RTP | Railroad Transportation | 482 |
| WTP | Water Transportation | 483 |
| TTP | Freight Truck Transportation | 484 |
| PIP | Pipeline Transport | 486 |
| OTP | Other Transportation Services | 485 487 488 |
| ***Other Services*** | | |
| INF | Information | 51 |
| FIN | Finance and Insurance | 52 |
| REL | Real Estate | 53 |
| PFS | Professional Services | 54 |
| MNG | Management | 55 |
| ADM | Administrative Services | 56 |
| EDU | Education | 61 |
| HLT | Health Care | 62 |
| ART | Arts | 71 |
| ACM | Accommodations | 72 |
| OSV | Other Services | 81 |
| PUB | Public Services | 92 |

[a] NAICS = North American Industry Classification System. Industry assignments are based on data used in the EMPAX-modeling system, which relies on the commodity code system used in IMPLAN.

**Table A-2. 2010 Benchmark Data Set (billion 2006$)**

| Industry Label | Industry Description | Output | Imports | Consumption | Investment and Government | Exports |
|---|---|---|---|---|---|---|
| ACM | Accommodations | $828 | $6 | $816 | $17 | $1 |
| ADM | Administrative Services | $795 | $37 | $771 | $61 | Less than $1 |
| AGR | Agricultural | $314 | $53 | $333 | $5 | $29 |
| ALU | Aluminum | $65 | $17 | $70 | $4 | $8 |
| ANM | Animal Foods | $45 | Less than $1 | $36 | Less than $1 | $9 |
| APP | Appliances | $25 | $19 | $35 | $6 | $3 |
| ARC | Aircraft | $217 | $60 | $58 | $120 | $98 |
| ART | Arts | $252 | Less than $1 | $246 | $3 | $3 |
| ATP | Air Transportation | $154 | $28 | $91 | $32 | $59 |
| BAK | Baked Goods | $61 | $3 | $61 | $2 | Less than $1 |
| BEV | Beverages and Tobacco | $133 | $54 | $186 | Less than $1 | $1 |
| BOI | Boilers and Tanks | $27 | $2 | $19 | $9 | $2 |
| CEM | Cement | $52 | Less than $1 | $47 | $3 | $2 |
| CEQ | Construction and Agricultural Equipment | $70 | $24 | $47 | $33 | $14 |
| CHM | Chemicals and Gases | $284 | $75 | $300 | $10 | $49 |
| CLY | Clay | $8 | $4 | $10 | $1 | $2 |
| CMQ | Communication Equipment | $73 | $40 | $47 | $56 | $11 |
| CNS | Construction | $983 | $77 | $594 | $465 | Less than $1 |
| COL | Coal | $44 | $2 | $42 | Less than $1 | $4 |
| CPP | Converted Paper Products | $52 | $2 | $43 | $6 | $6 |
| CPU | Computers | $145 | $76 | $132 | $52 | $37 |
| CRU | Crude Oil Extraction | $67 | $189 | $255 | Less than $1 | Less than $1 |
| CUT | Cutlery | $11 | $5 | $9 | $5 | $2 |
| EDU | Education | $970 | Less than $1 | $257 | $701 | $13 |
| EEQ | Engines | $36 | $14 | $30 | $6 | $13 |
| EGV | Engraving | $21 | Less than $1 | $9 | $5 | $7 |
| ELE | Electric Generation | $317 | Less than $1 | $287 | $31 | Less than $1 |
| ELQ | Electric Equipment | $33 | $16 | $23 | $17 | $10 |
| FIN | Finance and Insurance | $2,015 | $106 | $1,972 | $43 | $106 |
| FMP | Fabricated Metals | $66 | $1 | $58 | $7 | $2 |
| FRG | Forging and Stamping | $20 | Less than $1 | $17 | $1 | $2 |
| FRT | Fertilizer | $42 | $5 | $33 | $4 | $10 |

(continued)

**Table A-2. 2010 Benchmark Data Set (billion 2006$) (continued)**

| Industry Label | Industry Description | Output | Imports | Consumption | Investment and Government | Exports |
|---|---|---|---|---|---|---|
| FRU | Fruits and Vegetables | $74 | $12 | $76 | $4 | $5 |
| FUR | Furniture | $66 | $38 | $84 | $17 | $2 |
| GAS | Natural Gas | $139 | $32 | $160 | $6 | $6 |
| GEQ | General Equipment | $54 | $32 | $47 | $25 | $14 |
| GLS | Glass | $30 | Less than $1 | $18 | $2 | $10 |
| GRN | Grain Milling | $77 | $9 | $74 | $2 | $10 |
| HLT | Health Care | $1,863 | Less than $1 | $1,823 | $20 | $20 |
| HRD | Hardware | $8 | $4 | $5 | $4 | $3 |
| HVC | HVAC Equipment | $34 | $9 | $26 | $10 | $6 |
| I_S | Iron and Steel | $125 | $42 | $143 | $10 | $13 |
| IEQ | Industrial Equipment | $26 | $14 | $16 | $14 | $11 |
| INF | Information | $1,305 | $77 | $1,217 | $154 | $11 |
| INS | Instruments | $112 | $44 | $71 | $65 | $20 |
| LEA | Leather | $4 | $26 | $29 | Less than $1 | $1 |
| LGT | Lighting | $12 | $11 | $16 | $5 | $1 |
| LIM | Lime and Gypsum | $7 | Less than $1 | $1 | Less than $1 | $5 |
| LUM | Other Lumber | $41 | $2 | $32 | $9 | $2 |
| M_V | Motor Vehicles | $272 | $190 | $313 | $106 | $43 |
| MEA | Meat Products | $174 | $9 | $169 | $5 | $10 |
| MED | Drugs and Medicine | $258 | $102 | $316 | $18 | $27 |
| MEQ | Metalworking Equipment | $24 | $11 | $16 | $14 | $4 |
| MGT | Magnetic Recording Equipment | $15 | $2 | $13 | $2 | $2 |
| MIL | Dairy Products | $87 | $3 | $84 | $4 | $2 |
| MIN | Mining | $53 | $2 | $30 | $15 | $11 |
| MNG | Management | $469 | Less than $1 | $378 | Less than $1 | $92 |
| MSC | Miscellaneous Manufacturing | $178 | $129 | $189 | $73 | $46 |
| MSP | Machine Shops | $38 | $2 | $32 | $5 | $2 |
| MVP | Motor Vehicle Parts | $220 | $75 | $226 | $17 | $52 |
| OCM | Other Chemicals | $45 | $2 | $23 | $9 | $15 |
| OEQ | Other Electric Equipment | $31 | $16 | $28 | $7 | $11 |
| OFD | Other Food Products | $92 | $7 | $90 | $2 | $7 |
| OFM | Other Fabricated Metals | $56 | $28 | $50 | $22 | $12 |

(continued)

**Table A-2. 2010 Benchmark Data Set (billion 2006$) (continued)**

| Industry Label | Industry Description | Output | Imports | Consumption | Investment and Government | Exports |
|---|---|---|---|---|---|---|
| OIL | Refined Petroleum | $415 | $106 | $462 | $12 | $47 |
| ONM | Other Non-Metallic Minerals | $13 | $5 | $15 | $1 | $2 |
| OPM | Other Primary Metals | $40 | $27 | $52 | $2 | $12 |
| OSV | Other Services | $2,321 | Less than $1 | $1,479 | $598 | $244 |
| OTP | Other Transportation Services | $245 | Less than $1 | $202 | $22 | $22 |
| OTQ | Other Transport Equip | $23 | $10 | $14 | $13 | $5 |
| PAI | Paints and Adhesives | $36 | $1 | $28 | $3 | $6 |
| PAP | Pulp and Paper Mills | $131 | $21 | $133 | $5 | $14 |
| PFS | Professional Services | $2,103 | $84 | $1,715 | $461 | $10 |
| PIP | Pipeline Transport | $37 | $83 | $20 | $98 | $1 |
| PLS | Plastic | $145 | $14 | $139 | $4 | $15 |
| PLY | Plywood and Veneer | $19 | $8 | $25 | $1 | $1 |
| PRN | Printing | $51 | $1 | $34 | $11 | $6 |
| PUB | Public Services | $1,099 | $22 | $355 | $766 | Less than $1 |
| R_R | Rail Cars | $11 | $2 | $6 | $6 | $2 |
| REL | Real Estate | $2,719 | $2 | $2,559 | $131 | $31 |
| RSN | Resins | $107 | $23 | $98 | $6 | $26 |
| RTL | Retail Trade | $1,440 | $53 | $1,412 | $82 | Less than $1 |
| RTP | Railroad Transportation | $70 | Less than $1 | $42 | $18 | $11 |
| RUB | Rubber | $38 | $20 | $36 | $15 | $6 |
| SAW | Sawmills | $29 | $9 | $36 | $1 | $1 |
| SEA | Seafood | $13 | $3 | $14 | $1 | $1 |
| SEQ | Service Industry Equipment | $29 | $23 | $22 | $24 | $6 |
| SGR | Sugar | $34 | $6 | $36 | $2 | $3 |
| SHP | Ships | $36 | $6 | $13 | $29 | Less than $1 |
| SMI | Semiconductor Equipment | $141 | $69 | $157 | $12 | $41 |
| SOP | Soap | $82 | $5 | $74 | $3 | $9 |
| TEX | Textile Mills | $29 | $9 | $31 | $1 | $6 |
| TKB | Truck Bodies | $58 | $12 | $34 | $32 | $5 |
| TPM | Textile Product Mills | $27 | $19 | $37 | $7 | $2 |
| TTP | Freight Truck Transportation | $301 | Less than $1 | $211 | $39 | $51 |

(continued)

**Table A-2. 2010 Benchmark Data Set (billion 2006$) (continued)**

| Industry Label | Industry Description | Output | Imports | Consumption | Investment and Government | Exports |
|---|---|---|---|---|---|---|
| TVQ | TV Equipment | $19 | $37 | $50 | $3 | $3 |
| WAP | Wearing Apparel | $25 | $94 | $117 | $1 | Less than $1 |
| WHL | Wholesale Trade | $1,309 | $22 | $1,021 | $172 | $138 |
| WIR | Springs and Wires | $5 | | $2 | $1 | $3 |
| WTP | Water Transportation | $45 | | $14 | $12 | $19 |

*A.2.1.2 Employment Data*

The model includes employment forecasts for each of the 100 sectors. Employment estimates are based on data from three sources: the AEO 2009 estimates of employment (AEO supplemental Table 126 and indicators of Macroeconomic Activity), and Global Insights, Inc., and the Bureau of Labor Statistics (BLS) 2008 end-of year-employment (Current Employment Statistics—CES [National]). Typically, 3-digit NAICS sectors' employment estimates are either directly reported in the updated AEO 2009 release or Global Insights For multimarket industries with finer NAICs detail, estimates were calculated by selecting a primary NAICS supersector estimate (AEO or Global Insights) and distributing total employment from the larger NAICS supersectors across more detailed NAICS sectors within the super-sector. The distributions were determined using observed 2008 BLS employment data. In the last step, In order to match aggregate U.S. employment numbers reported in the AEO 2009 release (140.1 million), a single adjustment factor was applied to all sectors that use Global Insights' supersector data.[1] Table A-4 reports the baseline employment for each of the 100 sectors.

### *A.2.2 Economic Behavior*

*A.2.2.1 U.S. Supply*

In a postpolicy scenario, industry responds to changes in the new market-clearing "net" price for the good or service sold:

$$\%\Delta\text{"net" price} = \%\Delta\text{ market price} - \%\Delta\text{ direct costs} - \%\Delta\text{ indirect costs} \qquad \text{(A.2)}$$

The %Δ direct costs are approximated using the engineering cost analysis and baseline value of output. For example, a \$1 billion increase in compliance costs for the electricity sector (ELE) would be represented in the model as follows:

$$\%\Delta\text{ direct costs} = \$1/\$317 = 0.03\% \qquad \text{(A.3)}$$

As shown in Figure A-1, the cost change provides the industry with incentives to alter production rates at current market prices; market prices must rise to maintain the original prepolicy production levels (Q).

1 This step is required because Global Insight's data used by EPA are an older vintage than the forecasts used in the AEO.

## Table A-4. 2010 U.S. Employment Projections

| Industry Label | Industry Description | Projected Employment (1,000) |
|---|---|---|
| ACM | Accommodations | 11,239 |
| ADM | Administrative Services | 9,274 |
| AGR | Agricultural | 1,607 |
| ALU | Aluminum | 87 |
| ANM | Animal Foods | 45 |
| APP | Appliances | 33 |
| ARC | Aircraft | 449 |
| ART | Arts | 1,939 |
| ATP | Air Transportation | 506 |
| BAK | Baked Goods | 247 |
| BEV | Beverages and Tobacco | 92 |
| BOI | Boilers and Tanks | 67 |
| CEM | Cement | 164 |
| CEQ | Construction and Agricultural Equipment | 176 |
| CHM | Chemicals and Gases | 147 |
| CLY | Clay | 38 |
| CMQ | Communication Equipment | 73 |
| CNS | Construction | 7,446 |
| COL | Coal | 79 |
| CPP | Converted Paper Products | 306 |
| CPU | Computers | 104 |
| CRU | Crude Oil Extraction | 384 |
| CUT | Cutlery | 34 |
| EDU | Education | 2,892 |
| EEQ | Engines | 75 |
| EGV | Engraving | 100 |
| ELE | Electric Generation | 219 |
| ELQ | Electric Equipment | 72 |
| FIN | Finance and Insurance | 6,051 |
| FMP | Fabricated Metals | 285 |
| FRG | Forging and Stamping | 75 |
| FRT | Fertilizer | 35 |
| FRU | Fruits and Vegetables | 153 |
| FUR | Furniture | 327 |

(continued)

**Table A-4. 2010 U.S. Employment Projections (continued)**

| Industry Label | Industry Description | Projected Employment (1,000) |
|---|---|---|
| GAS | Natural Gas | 98 |
| GEQ | General Equipment | 198 |
| GLS | Glass | 71 |
| GRN | Grain Milling | 55 |
| HLT | Health Care | 15,190 |
| HRD | Hardware | 20 |
| HVC | HVAC Equipment | 109 |
| I_S | Iron and Steel | 205 |
| IEQ | Industrial Equipment | 88 |
| INF | Information | 2,939 |
| INS | Instruments | 250 |
| LEA | Leather | 3 |
| LGT | Lighting | 26 |
| LIM | Lime and Gypsum | 10 |
| LUM | Other Lumber | 216 |
| M_V | Motor Vehicles | 170 |
| MEA | Meat Products | 450 |
| MED | Drugs and Medicine | 279 |
| MEQ | Metalworking Equipment | 139 |
| MGT | Magnetic Recording Equipment | 20 |
| MIL | Dairy Products | 113 |
| MIN | Mining | 599 |
| MNG | Management | 1,732 |
| MSC | Miscellaneous Manufacturing | 180 |
| MSP | Machine Shops | 251 |
| MVP | Motor Vehicle Parts | 485 |
| OCM | Other Chemicals | 92 |
| OEQ | Other Electric Equipment | 63 |
| OFD | Other Food Products | 144 |
| OFM | Other Fabricated Metals | 196 |
| OIL | Refined Petroleum | 70 |
| ONM | Other Non-metallic Minerals | 61 |
| OPM | Other Primary Metals | 87 |
| OSV | Other Services | 5,271 |
| OTP | Other Transportation Services | 1,064 |

(continued)

**Table A-4. 2010 U.S. Employment Projections (continued)**

| Industry Label | Industry Description | Projected Employment (1,000) |
|---|---|---|
| OTQ | Other Transport Equipment | 36 |
| PAI | Paints and Adhesives | 60 |
| PAP | Pulp and Paper Mills | 121 |
| PFS | Professional Services | 18,989 |
| PIP | Pipeline Transport | 43 |
| PLS | Plastic | 473 |
| PLY | Plywood and Veneer | 74 |
| PRN | Printing | 248 |
| PUB | Public Services | 21,787 |
| R_R | Rail Cars | 25 |
| REL | Real Estate | 2,158 |
| RSN | Resins | 102 |
| RTL | Retail Trade | 15,283 |
| RTP | Railroad Transportation | 236 |
| RUB | Rubber | 117 |
| SAW | Sawmills | 84 |
| SEA | Seafood | 36 |
| SEQ | Service Industry Equipment | 77 |
| SGR | Sugar | 62 |
| SHP | Ships | 140 |
| SMI | Semiconductor Equipment | 245 |
| SOP | Soap | 104 |
| TEX | Textile Mills | 110 |
| TKB | Truck Bodies | 126 |
| TPM | Textile Product Mills | 32 |
| TTP | Freight Truck Transportation | 1,429 |
| TVQ | TV Equipment | 15 |
| WAP | Wearing Apparel | 153 |
| WHL | Wholesale Trade | 5,869 |
| WIR | Springs and Wires | 36 |
| WTP | Water Transportation | 67 |
| Total | | 144,100 |

The multimarket model also simultaneously considers how the policy influences other important production costs (via changes in energy and other intermediate material prices). As a result, the multimarket model can provide additional information about how policy costs are transmitted through the economy. As shown in Figure A-2, the indirect cost change provides the industry with additional incentives to alter production rates at current market prices.

The %Δ indirect effects associated with each input are approximated using an input "use" ratio and the price change that occurs in the input market.

$$\%\Delta \text{ indirect costs} = \text{input use ratio} \times \%\Delta \text{ input price} \tag{A.4}$$

The social accounting matrix provides an internally consistent estimate of the use ratio and describes the dollar amount of an input that is required to produce a dollar of output. Higher ratios suggest strong links between industries, while lower ratios suggest weaker links. Given the short time horizon, we assume the input use ratio is fixed and cannot adjust their input mix; this is a standard assumption in public and commercial input-output (IO) and SAM multiplier models (Berck and Hoffmann, 2002). Morgenstern and colleagues (2004) and Ho and colleagues (2008) also use this assumption when examining near-term effects of environmental policy.

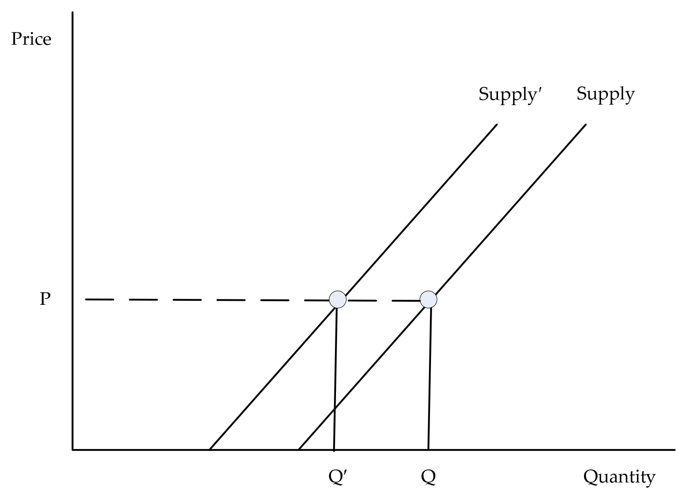


**Figure A-1. Direct Compliance Costs Reduce Production Rates at Benchmark Prices**

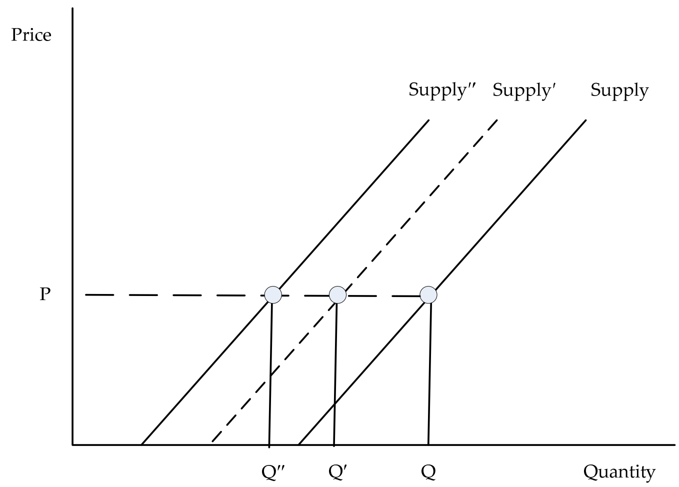


**Figure A-2. Indirect Costs Further Reduce Production Rates at Benchmark Prices**

Following guidance in the OAQPS economic resource manual (OAQPS, 1999), we use a general form for the U.S. industry supply function:

$$Q'_g = b\left(P'_g - t - \sum_{i=1}^{n} \alpha_{gi}(P'_i - P_i)\right)^{\varepsilon_g} \tag{A.5}$$

where

$Q'_g$ = with-policy supply quantity (g)

$b$ = calibrated scale parameter for the supply price relationship

$P'_g$ = with-policy price for output (g)

$t$ = direct compliance costs per unit of supply

$\alpha_{gi}$ = input use ratio (g using input i)

$P'_i$ = with-policy input (i) price

$P_i$ = benchmark input (i) price

$\varepsilon_g$ = price elasticity of supply for output (g)

The key supply parameter that controls the industry production adjustments is the price elasticity of supply ($\varepsilon_g$). To our knowledge, there is no existing empirical work that estimates short-run supply elasticities for all industry groups used in the multimarket model. As a result, we assume the U.S. supply elasticities are a function of econometrically estimated rest-of-world (ROW) export supply elasticities (see discussion in the next section). We report the values currently available in the model in Table A-5.

*A.2.2.2 International Competition*

International competition is captured by a single ROW supply function:

$$Q'_g = c\left(P'_g\right)^{\varepsilon_g^{ROW}} \tag{A.6}$$

where

| | | |
|---|---|---|
| $Q'_g$ | = | with-policy supply quantity (g) |
| c | = | calibrated scale parameter for the supply and price relationship |
| $P'_g$ | = | with-policy U.S. price for output (g) |
| $\varepsilon_g^{ROW}$ | = | price elasticity of supply of goods from the ROW to the United States (imports) (g) |

The key supply parameter that controls the ROW supply adjustments is the price elasticity of supply ( $\varepsilon_g^{ROW}$ ). We obtained these estimates for a variety of industry groups from a recently published article by Broda and colleagues (2008b).

*A.2.2.3 Price Elasticity of Supply: Rest of World (ROW)*

Broda and colleagues (2008) provide an empirical basis for the multimarket model supply elasticities. Broda et al. provide over 1,000 inverse elasticities that RTI organized to be comparable with the 100-sector model. The first step was to match the Harmonized Trade System (HS) elasticities estimated in the article to the appropriate NAICS codes. Many of the HS codes correspond with a detailed NAICS codes (5- and 6-digit level), while the multimarket sector industries typically correspond with more aggregated sectors (NAICS 2-, 3-, or 4-digit levels). To adapt these labels to our model, we combined the 5- and 6- digit NAICS under their 3- and 4-digit codes and calculated an average inverse elasticity value for codes that fell within the multimarket model's aggregate industrial sectors. This gives a crude way to account for the variety of products detailed in the original data set. We also restricted the elasticity sample to those that Broda et al. classify as "medium" and "low" categories; these categories tend to have lower elasticity values that are consistent with the multimarket model's modeling horizon (i.e., in the short run importers are likely to have less flexibility to respond to price changes and elasticities are low).[1]

1 Broda et al.'s intent was to use these categories to describe or proxy for domestic market power.

## Table A-5. Supply Elasticities

| Industry Label | Industry Description | Rest of World (ROW) | U.S. |
|---|---|---|---|
| ACM | Accommodations | 0.7 | 0.7 |
| ADM | Administrative Services | 0.7 | 0.7 |
| AGR | Agricultural | 1.0 | 1.0 |
| ALU | Aluminum | 0.8 | 0.5 |
| ANM | Animal Foods | 1.1 | 0.8 |
| APP | Appliances | 0.9 | 0.8 |
| ARC | Aircraft | 0.9 | 0.6 |
| ART | Arts | 0.7 | 0.7 |
| ATP | Air Transportation | 0.7 | 0.7 |
| BAK | Baked Goods | 0.8 | 0.7 |
| BEV | Beverages and Tobacco | 2.9 | 2.9 |
| BOI | Boilers and Tanks | 1.1 | 0.8 |
| CEM | Cement | 0.9 | 0.7 |
| CEQ | Construction and Agricultural Equipment | 0.8 | 0.6 |
| CHM | Chemicals and Gases | 1.1 | 0.8 |
| CLY | Clay | 0.8 | 0.6 |
| CMQ | Communication Equipment | 2.5 | 1.0 |
| CNS | Construction | 0.7 | 0.7 |
| COL | Coal | 2.2 | 2.2 |
| CPP | Converted Paper Products | 0.9 | 0.7 |
| CPU | Computers | 1.0 | 0.7 |
| CRU | Crude Oil Extraction | 3.7 | 3.7 |
| CUT | Cutlery | 1.4 | 1.1 |
| EDU | Education | 0.7 | 0.7 |
| EEQ | Engines | 1.2 | 1.0 |
| EGV | Engraving | 1.1 | 0.8 |
| ELE | Electric Generation | 2.0 | 2.0 |
| ELQ | Electric Equipment | 0.8 | 0.6 |
| FIN | Finance and Insurance | 0.7 | 0.7 |
| FMP | Fabricated Metals | 1.2 | 1.1 |
| FRG | Forging and Stamping | 1.6 | 1.5 |

(continued)

**Table A-5. Supply Elasticities (continued)**

| Industry Label | Industry Description | Rest of World (ROW) | U.S. |
|---|---|---|---|
| FRT | Fertilizer | 1.0 | 0.7 |
| FRU | Fruits and Vegetables | 1.0 | 0.7 |
| FUR | Furniture | 1.9 | 1.9 |
| GAS | Natural Gas | 12.2 | 12.2 |
| GEQ | General Equipment | 1.0 | 0.7 |
| GLS | Glass | 0.8 | 0.6 |
| GRN | Grain Milling | 1.7 | 1.5 |
| HLT | Health Care | 0.7 | 0.7 |
| HRD | Hardware | 1.1 | 0.8 |
| HVC | HVAC Equipment | 0.9 | 0.6 |
| I_S | Iron and Steel | 1.0 | 0.6 |
| IEQ | Industrial Equipment | 0.9 | 0.6 |
| INF | Information | 0.7 | 0.7 |
| INS | Instruments | 0.9 | 0.6 |
| LEA | Leather | 0.9 | 0.7 |
| LGT | Lighting | 1.1 | 0.7 |
| LIM | Lime and Gypsum | 0.9 | 0.7 |
| LUM | Other Lumber | 0.9 | 0.7 |
| M_V | Motor Vehicles | 1.3 | 0.7 |
| MEA | Meat Products | 1.2 | 3.9 |
| MED | Drugs and Medicine | 1.3 | 1.0 |
| MEQ | Metalworking Equipment | 0.7 | 0.5 |
| MGT | Magnetic Recording Equipment | 1.0 | 0.7 |
| MIL | Dairy Products | 1.1 | 0.9 |
| MIN | Mining | 2.2 | 2.2 |
| MNG | Management | 0.7 | 0.7 |
| MSC | Miscellaneous Manufacturing | 1.0 | 0.8 |
| MSP | Machine Shops | 1.1 | 0.8 |
| MVP | Motor Vehicle Parts | 0.9 | 0.6 |
| OCM | Other Chemicals | 1.1 | 0.6 |
| OEQ | Other Electric Equipment | 1.0 | 0.7 |
| OFD | Other Food Products | 1.1 | 0.7 |

(continued)

**Table A-5. Supply Elasticities (continued)**

| Industry Label | Industry Description | Rest of World (ROW) | U.S. |
|---|---|---|---|
| OFM | Other Fabricated Metals | 0.9 | 0.6 |
| OIL | Refined Petroleum | 1.0 | 0.7 |
| ONM | Other Non-metallic Minerals | 1.5 | 0.7 |
| OPM | Other Primary Metals | 0.7 | 0.5 |
| OSV | Other Services | 0.7 | 0.7 |
| OTP | Other Transportation Services | 0.7 | 0.7 |
| OTQ | Other Transport Equipment | 1.0 | 0.7 |
| PAI | Paints and Adhesives | 1.0 | 0.7 |
| PAP | Pulp and Paper Mills | 1.1 | 0.7 |
| PFS | Professional Services | 0.7 | 0.7 |
| PIP | Pipeline Transport | 2.0 | 2.0 |
| PLS | Plastic | 1.0 | 0.7 |
| PLY | Plywood and Veneer | 1.3 | 1.3 |
| PRN | Printing | 1.0 | 0.7 |
| PUB | Public Services | 0.7 | 0.7 |
| R_R | Rail Cars | 1.8 | 0.7 |
| REL | Real Estate | 0.7 | 0.7 |
| RSN | Resins | 1.0 | 0.7 |
| RTL | Retail Trade | 0.7 | 0.7 |
| RTP | Railroad Transportation | 0.7 | 0.7 |
| RUB | Rubber | 1.3 | 1.1 |
| SAW | Sawmills | 0.8 | 0.6 |
| SEA | Seafood | 1.1 | 0.8 |
| SEQ | Service Industry Equipment | 0.8 | 0.6 |
| SGR | Sugar | 1.1 | 0.8 |
| SHP | Ships | 1.0 | 0.7 |
| SMI | Semiconductor Equipment | 1.2 | 1.0 |
| SOP | Soap | 0.8 | 0.6 |
| TEX | Textile Mills | 1.0 | 0.7 |
| TKB | Truck Bodies | 3.2 | 3.1 |
| TPM | Textile Product Mills | 0.8 | 0.6 |
| TTP | Freight Truck Transportation | 0.7 | 0.7 |
| TVQ | TV Equipment | 5.8 | 5.4 |

(continued)

**Table A-5. Supply Elasticities (continued)**

| Industry Label | Industry Description | Rest of World (ROW) | U.S. |
|---|---|---|---|
| WAP | Wearing Apparel | 1.2 | 0.8 |
| WHL | Wholesale Trade | 0.7 | 0.7 |
| WIR | Springs and Wires | 1.9 | 0.8 |
| WTP | Water Transportation | 0.7 | 0.7 |

Note: RTI mapped Broda et al. data for their industry aggregation to the multimarket model's 100 industries. Domestic supply elasticities are typically assumed to be within one standard deviation of the sample of supply elasticities used for the ROW. In selected cases where this information is not available, the U.S. supply elasticity is set equal to the ROW.

Source: Broda, C., N. Limao, and D. Weinstein. 2008a. "Export Supply Elasticities." http://faculty.chicagobooth.edu/christian.broda/website/research/unrestricted/TradeElasticities/TradeElasticities.html. Accessed September 2009.

Our ideal preference was to use an exact 3- or 4-digit match from the medium category if one was available. If the multimarket model had a 4-digit code for which there was no direct match, we aggregated up a level and applied the relevant 3-digit elasticity. If a multimarket code was not covered in the medium set of elasticities, we used the low elasticity category. This method was sufficient for mapping the majority of the sectors in the model. After applying our inverse elasticity values to the multimarket sectors, we calculated the inverse of the value to arrive at the actual supply elasticity. Since Broda et al.'s article focused on industrial production goods, some of the multimarket sectors were not covered in the elasticity data. These sectors included mainly service industries, transportation, and energy sources.

In order to fill these gaps, we turned to the source substitution elasticities from Purdue University's Global Trade Analysis Project (GTAP)[1]. Although the elasticities in the GTAP model are a different type of international trade elasticity and cannot be directly applied in the multimarket model (e.g., they are based on the Armington structure[2]), the parameters provide us with some additional information about the relative trade elasticity differences between industry sectors. To use the GTAP information to develop assumptions about the multimarket model sectors with missing elasticities, we chose a base industrial sector (iron and steel) for which we had parameter value from Broda et al. Next, we developed industry-specific ratios for missing industries using the corresponding GTAP sector trade elasticities and the GTAP iron and steel

[1] See Chapter 14 of the GTAP 7 Database Documentation for the full description of the parameters at https://www.gtap.agecon.purdue.edu/resources/download/4184.pdf; see Table 14.2 for elasticities.

[2] Detailed documentation of the entire GTAP 7 Database is available at https://www.gtap.agecon.purdue.edu/databases/v7/v7_doco.asp. The GTAP also uses a unique system of categorizing commodities that does not match the NAICS or HS system exactly.

sector. We multiplied the resulting ratio by the Broda et al. iron and steel parameter (1.0). For example, the GTAP trade elasticity for coal (6.10) is approximately 2.2 times the trade elasticity for iron and steel (2.95). As a result, the multimarket import supply elasticity for coal is computed as 2.2 (2.2 x 1.0).

*A.2.2.4 Price Elasticity of Supply: United States*

We also used Broda et al.'s elasticities to derive a set of domestic supply elasticities for the model. We have assumed that a product's domestic supply would be equal to or less elastic than other countries' supply of imports. When we aggregated and averaged the original elasticities to the 3- and 4- digit NAICS level for our foreign supply elasticities, we also calculated the standard deviation of each 3- and 4-digit NAICS sample. By adding the standard deviation to the corresponding foreign supply and then taking the inverse, we were able to calculate a domestic supply elasticity for each sector that was lower than its foreign counterpart while maintaining the structure of the original elasticities. For sectors in which no standard deviation was available,[1] we used professional judgment to apply the closest available substitute from a similar industry. Without a comparable way of scaling our foreign elasticities for the sectors in which we used the GTAP elasticities, we elected to keep the domestic and foreign supply elasticities the same.

*A.2.2.5 Demand*

Uses for industry output are divided into three groups: investment/government use, domestic intermediate uses, and other final use (domestic and exports). Given the short time horizon, investment/government does not change. Intermediate use is determined by the input use ratios and the industry output decisions.

$$Q_i' = \alpha_{gi} Q_g' \tag{A.7}$$

$Q_i'$ = with-policy input demand quantity (i)

$\alpha_{gi}$ = input use ratio (g using input i)

$Q_g'$ = with-policy output quantity (g)

Other final use does respond to market price changes. Following guidance in the OAQPS economic resource manual (OAQPS, 1999), we use a general form for the U.S. industry demand function:

[1] No standard deviations were calculated for the 3- and 4-digit codes that had only one observation (i.e., Broda et al.'s model used the exact 3- or 4-digit code).

$$Q'_g = a\left(P'_g\right)^{\eta_g} \tag{A.8}$$

where

$Q'_g$ = with-policy demand quantity (g)

$a$ = calibrated scale parameter for the demand and price relationship

$P'_g$ = with-policy price for output (g)

$\eta_g$ = price elasticity of demand (g)

The key parameter that controls consumption adjustments is the price elasticity of demand ($\eta_g$). To approximate the response, we use demand elasticities that were simulated with a general equilibrium model (Ho, Morgenstern, and Shih, 2008). Table A-6 reports the values currently available in the model.

*A.2.2.6 Model Scope*

The multimarket model includes 100 sectors covering energy, manufacturing, and service applications. Each sector's production technology requires the purchase of energy and other intermediate goods made by other sectors included in the model. Linking the sectors in this manner allows the model to trace direct and indirect policy effects across different sectors. Therefore, it is best used when potential economic impacts and equity effects on related markets might be important to stakeholders not directly affected by an environmental policy. However, the model can also be run in single-market partial equilibrium mode to support and provide insights for other types of environmental policies.

*A.2.2.7 Model Time Horizon*

The model is designed to address short-run and transitional effects associated with environmental policy. Production technologies are fixed; the model does not assess substitution among production inputs (labor, energy intermediates, and other intermediates) and assumes each investment cannot be changed during the time frame of the analysis. These issues are better addressed using other frameworks such as computable general equilibrium modeling. Similarly, government purchases from each sector do not adjust in response to changes in goods/service prices. Although, employment levels (number of jobs) adjust as production levels change, wages are assumed to be fixed.

## Table A-6. U.S. Demand Elasticities

| Industry Label | Industry Description | Demand Elasticity $\eta_g$ |
|---|---|---|
| ACM | Accommodations | −0.7 |
| ADM | Administrative Services | −0.7 |
| AGR | Agricultural | −0.8 |
| ALU | Aluminum | −1.0 |
| ANM | Animal Foods | −0.6 |
| APP | Appliances | −2.6 |
| ARC | Aircraft | −2.5 |
| ART | Arts | −0.7 |
| ATP | Air Transportation | −0.8 |
| BAK | Baked Goods | −0.6 |
| BEV | Beverages and Tobacco | −0.6 |
| BOI | Boilers and Tanks | −0.5 |
| CEM | Cement | −0.8 |
| CEQ | Construction and Agricultural Equipment | −1.7 |
| CHM | Chemicals and Gases | −1.0 |
| CLY | Clay | −0.8 |
| CMQ | Communication Equipment | −2.6 |
| CNS | Construction | −0.8 |
| COL | Coal | −0.1 |
| CPP | Converted Paper Products | −0.7 |
| CPU | Computers | −2.6 |
| CRU | Crude Oil Extraction | −0.3 |
| CUT | Cutlery | −0.5 |
| EDU | Education | −0.7 |
| EEQ | Engines | −1.7 |
| EGV | Engraving | −0.5 |
| ELE | Electric Generation | −0.2 |
| ELQ | Electric Equipment | −2.6 |
| FIN | Finance and Insurance | −0.7 |
| FMP | Fabricated Metals | −0.5 |
| FRG | Forging and Stamping | −0.5 |
| FRT | Fertilizer | −1.0 |
| FRU | Fruits and Vegetables | −0.6 |
| FUR | Furniture | −0.7 |

(continued)

## Table A-6. U.S. Demand Elasticities (continued)

| Industry Label | Industry Description | Demand Elasticity $\eta_g$ |
|---|---|---|
| GAS | Natural Gas | −0.3 |
| GEQ | General Equipment | −1.7 |
| GLS | Glass | −0.8 |
| GRN | Grain Milling | −0.6 |
| HLT | Health Care | −0.7 |
| HRD | Hardware | −0.5 |
| HVC | HVAC Equipment | −1.7 |
| I_S | Iron and Steel | −1.0 |
| IEQ | Industrial Equipment | −1.7 |
| INF | Information | −0.7 |
| INS | Instruments | −2.6 |
| LEA | Leather | −1.1 |
| LGT | Lighting | −2.6 |
| LIM | Lime and Gypsum | −0.8 |
| LUM | Other Lumber | −0.7 |
| M_V | Motor Vehicles | −2.5 |
| MEA | Meat Products | −0.6 |
| MED | Drugs and Medicine | −1.0 |
| MEQ | Metalworking Equipment | −1.7 |
| MGT | Magnetic Recording Equipment | −2.6 |
| MIL | Dairy Products | −0.6 |
| MIN | Mining | −0.6 |
| MNG | Management | −0.7 |
| MSC | Miscellaneous Manufacturing | −1.7 |
| MSP | Machine Shops | −0.5 |
| MVP | Motor Vehicle Parts | −2.5 |
| OCM | Other Chemicals | −1.0 |
| OEQ | Other Electric Equipment | −2.6 |
| OFD | Other Food Products | −0.6 |
| OFM | Other Fabricated Metals | −0.5 |
| OIL | Refined Petroleum | −0.1 |
| ONM | Other Non-metallic Minerals | −0.8 |
| OPM | Other Primary Metals | −1.0 |
| OSV | Other Services | −0.7 |
| OTP | Other Transportation Services | −0.8 |

(continued)

**Table A-6. U.S. Demand Elasticities (continued)**

| Industry Label | Industry Description | Demand Elasticity $\eta_g$ |
|---|---|---|
| OTQ | Other Transport Equip | −2.5 |
| PAI | Paints and Adhesives | −1.0 |
| PAP | Pulp and Paper Mills | −0.7 |
| PFS | Professional Services | −0.7 |
| PIP | Pipeline Transport | −0.8 |
| PLS | Plastic | −1.0 |
| PLY | Plywood and Veneer | −0.7 |
| PRN | Printing | −0.7 |
| PUB | Public Services | −0.7 |
| R_R | Rail Cars | −2.5 |
| REL | Real Estate | −0.7 |
| RSN | Resins | −1.0 |
| RTL | Retail Trade | −0.7 |
| RTP | Railroad Transportation | −0.8 |
| RUB | Rubber | −1.0 |
| SAW | Sawmills | −0.7 |
| SEA | Seafood | −0.6 |
| SEQ | Service Industry Equipment | −1.7 |
| SGR | Sugar | −0.6 |
| SHP | Ships | −2.5 |
| SMI | Semiconductor Equipment | −2.6 |
| SOP | Soap | −1.0 |
| TEX | Textile Mills | −1.1 |
| TKB | Truck Bodies | −2.5 |
| TPM | Textile Product Mills | −1.1 |
| TTP | Freight Truck Transportation | −0.8 |
| TVQ | TV Equipment | −2.6 |
| WAP | Wearing Apparel | −2.4 |
| WHL | Wholesale Trade | −0.7 |
| WIR | Springs and Wires | −0.5 |
| WTP | Water Transportation | −0.8 |

Note: RTI assigned an elasticity using the most similar industry from Ho and colleagues' industry aggregation.

Source: Ho, M. S, R. Morgenstern, and J. S. Shih. 2008. "Impact of Carbon Price Policies on US Industry." RFF Discussion Paper 08-37. Http://Www.Rff.Org/Publications/Pages/Publicationdetails.Aspx?. Publicationid=20680. Accessed August 2009. Table B.6.

# APPENDIX B
# DETAILED ECONOMIC MODEL RESULTS BY SECTOR

**Table B-1. Prices (Percentage Change from Benchmark): Industry Detail**

| | Major | | Area | |
|---|---|---|---|---|
| | Primary Option | Option 1E | Primary Option | Option 1N |
| Energy | 0.04% | 0.18% | 0.00% | −0.01% |
| Nonmanufacturing | 0.00% | 0.01% | 0.00% | 0.02% |
| Manufacturing | | | | |
| Food, beverages, and textiles | 0.02% | 0.05% | 0.00% | 0.14% |
| Lumber, paper, and printing | 0.22% | 0.42% | 0.01% | 0.31% |
| Chemicals | 0.02% | 0.07% | 0.00% | −0.02% |
| Plastics and rubber | 0.01% | 0.08% | 0.00% | −0.04% |
| Nonmetallic minerals | 0.01% | 0.06% | 0.00% | −0.02% |
| Primary metals | 0.04% | 0.10% | 0.00% | −0.01% |
| Fabricated metals | 0.01% | 0.07% | 0.00% | −0.02% |
| Machinery and equipment | 0.01% | 0.02% | 0.00% | −0.01% |
| Electronic equipment | 0.00% | 0.00% | 0.00% | −0.01% |
| Transportation equipment | 0.00% | 0.02% | 0.00% | 0.00% |
| Other | 0.01% | 0.03% | 0.00% | 0.01% |
| Wholesale and retail trade | 0.00% | −0.01% | 0.00% | 0.01% |
| Transportation services | 0.00% | 0.02% | 0.00% | 0.00% |
| Other services | 0.00% | 0.00% | 0.00% | 0.08% |

**Table B-2. Production (Percentage Change from Benchmark): Industry Detail**

| | Major | | Area | |
|---|---|---|---|---|
| | Primary Option | Option 1E | Primary Option | Option 1N |
| Energy | −0.01% | −0.12% | 0.00% | −0.01% |
| Nonmanufacturing | −0.01% | −0.02% | 0.00% | −0.04% |
| Manufacturing | | | | |
| Food, beverages, and textiles | −0.02% | −0.05% | 0.00% | −0.11% |
| Lumber, paper, and printing | −0.10% | −0.18% | 0.00% | −0.16% |
| Chemicals | −0.04% | −0.12% | 0.00% | −0.01% |
| Plastics and rubber | −0.02% | −0.08% | 0.00% | −0.02% |
| Nonmetallic minerals | −0.01% | −0.03% | 0.00% | −0.01% |
| Primary metals | −0.04% | −0.13% | 0.00% | 0.00% |
| Fabricated metals | −0.01% | −0.04% | 0.00% | −0.01% |
| Machinery and equipment | −0.01% | −0.04% | 0.00% | 0.00% |
| Electronic equipment | 0.00% | −0.02% | 0.00% | 0.00% |
| Transportation equipment | −0.01% | −0.06% | 0.00% | 0.00% |
| Other | −0.02% | −0.06% | 0.00% | −0.04% |
| Wholesale and retail trade | 0.00% | −0.01% | 0.00% | −0.02% |
| Transportation services | 0.00% | −0.07% | 0.00% | −0.01% |
| Other services | 0.00% | −0.01% | 0.00% | −0.04% |

## Table B-3. Consumption (Percentage Change from Benchmark): Industry Detail

| | Major | | Area | |
|---|---|---|---|---|
| | Primary Option | Option 1E | Primary Option | Option 1N |
| Energy | −0.01% | −0.05% | 0.00% | −0.01% |
| Nonmanufacturing | −0.01% | −0.01% | 0.00% | −0.04% |
| Manufacturing | | | | |
| Food, beverages, and textiles | −0.01% | −0.03% | 0.00% | −0.08% |
| Lumber, paper, and printing | −0.06% | −0.11% | 0.00% | −0.06% |
| Chemicals | −0.02% | −0.08% | 0.00% | −0.01% |
| Plastics and rubber | −0.01% | −0.05% | 0.00% | −0.02% |
| Nonmetallic minerals | −0.01% | −0.02% | 0.00% | −0.02% |
| Primary metals | −0.02% | −0.07% | 0.00% | −0.01% |
| Fabricated metals | −0.01% | −0.03% | 0.00% | −0.01% |
| Machinery and equipment | −0.01% | −0.02% | 0.00% | −0.01% |
| Electronic equipment | 0.00% | −0.01% | 0.00% | 0.00% |
| Transportation equipment | 0.00% | −0.03% | 0.00% | 0.00% |
| Other | −0.01% | −0.02% | 0.00% | −0.02% |
| Wholesale and retail trade | 0.00% | −0.01% | 0.00% | −0.02% |
| Transportation services | 0.00% | −0.02% | 0.00% | −0.01% |
| Other Services | 0.00% | −0.01% | 0.00% | −0.04% |

## Table B-4. Imports (Percentage Change from Benchmark): Industry Detail

| | Major | | Area | |
|---|---|---|---|---|
| | Primary Option | Option 1E | Primary Option | Option 1N |
| Energy | 0.08% | 0.28% | 0.00% | −0.01% |
| Nonmanufacturing | 0.00% | 0.01% | 0.00% | 0.01% |
| Manufacturing | | | | |
| Food, beverages, and textiles | 0.03% | 0.06% | 0.00% | 0.16% |
| Lumber, paper, and printing | 0.23% | 0.42% | 0.01% | 0.32% |
| Chemicals | 0.02% | 0.08% | 0.00% | −0.02% |
| Plastics and rubber | 0.01% | 0.09% | 0.00% | −0.04% |
| Nonmetallic minerals | 0.00% | 0.02% | 0.00% | −0.01% |
| Primary metals | 0.04% | 0.10% | 0.00% | −0.01% |
| Fabricated metals | 0.01% | 0.07% | 0.00% | −0.02% |
| Machinery and equipment | 0.01% | 0.02% | 0.00% | −0.01% |
| Electronic equipment | 0.00% | 0.00% | 0.00% | −0.01% |
| Transportation equipment | 0.00% | 0.03% | 0.00% | 0.00% |
| Other | 0.01% | 0.05% | 0.00% | 0.02% |
| Wholesale and retail trade | 0.00% | −0.01% | 0.00% | 0.00% |
| Transportation services | 0.00% | 0.02% | 0.00% | 0.00% |
| Other services | 0.00% | 0.00% | 0.00% | 0.01% |

### Table B-5. Exports (Percentage Change from Benchmark): Industry Detail

| | Major | | Area | |
|---|---|---|---|---|
| | Primary Option | Option 1E | Primary Option | Option 1N |
| Energy | −0.01% | −0.02% | 0.00% | 0.00% |
| Nonmanufacturing | 0.00% | −0.01% | 0.00% | −0.01% |
| Manufacturing | | | | |
| Food, beverages, and textiles | −0.01% | −0.03% | 0.00% | −0.09% |
| Lumber, paper, and printing | −0.16% | −0.29% | 0.00% | −0.22% |
| Chemicals | −0.02% | −0.07% | 0.00% | 0.02% |
| Plastics and rubber | −0.01% | −0.08% | 0.00% | 0.04% |
| Nonmetallic minerals | 0.00% | −0.05% | 0.00% | 0.02% |
| Primary metals | −0.04% | −0.10% | 0.00% | 0.01% |
| Fabricated metals | 0.00% | −0.03% | 0.00% | 0.01% |
| Machinery and equipment | −0.02% | −0.03% | 0.00% | 0.02% |
| Electronic equipment | 0.00% | 0.01% | 0.00% | 0.02% |
| Transportation equipment | −0.01% | −0.06% | 0.00% | 0.01% |
| Other | −0.01% | −0.03% | 0.00% | 0.01% |
| Wholesale and retail trade | 0.00% | 0.01% | 0.00% | 0.00% |
| Transportation services | 0.00% | −0.02% | 0.00% | 0.00% |
| Other services | 0.00% | 0.00% | 0.00% | −0.06% |

# APPENDIX C
# MAJOR SOURCES COST AND EMISSIONS MEMORANDUM

MEMORANDUM

TO: Jim Eddinger, U.S. Environmental Protection Agency, OAQPS/SPPD

FROM: Susan McClutchey, Amanda Singleton, and Graham Gibson, ERG

DATE: 15 April 2010

SUBJECT: Methodology for Estimating Cost and Emissions Impacts for Industrial, Commercial, Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants – Major Source

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## 1.0 INTRODUCTION

The purpose of this memorandum is to discuss the methodology used to estimate the costs, emission reductions, and secondary impacts from industrial, commercial, and institutional boilers at major sources of hazardous air pollutants (HAP). These impacts were calculated for existing units and new units projected to be operational by the year 2013, three years after the rule is expected to be promulgated. The results of the impacts analysis are presented for both the most stringent regulatory option evaluated and the regulatory option contained in the proposed rule. The development of the maximum achievable control technology (MACT) floor level of control, projection of new units, and a detailed description of the cost equations used to estimate costs for various control technologies is presented in other memoranda.[1,2,3] This memorandum is organized as follows:

1.0 Introduction
2.0 Overview of Regulatory Options
3.0 Estimating Cost Impacts
4.0 Methodology for Estimating Emission Reductions
5.0 Methodology for Estimating Secondary Impacts
6.0 References

# 2.0 OVERVIEW OF REGULATORY OPTIONS

Five control options were considered for existing boilers and process heaters at major sources of HAP. A description of the six options is included in this section.

## *2.1 Existing Units*

- Option 1E represents the option where all boilers, regardless of fuel type or size, must meet PM, HCl, mercury, CO, and D/F numerical emission limits.

- Option 2E uses the same control device and testing, and monitoring cost estimation logic outlined above for option 1E, except that it does not estimate ACI for units exceeding the MACT floor emission limit for dioxin/furan. Instead, it is estimated that most units, when testing for dioxin/furan will be below detection levels without installing any additional control devices.

- Option 3E uses the same control device and testing, and monitoring cost estimation logic outlined above for option 4E below, but it does not include the cost of an annual energy audit.

- Option 4E represents the primary proposed option discussed in the preamble. In this option all boilers and process equal to or greater than or equal to 10 mmBtu/hr must meet PM, HCl, mercury, CO, and D/F numerical emission limits, except for units in the natural gas/refinery gas and Metallurgical Process Furnace subcategories. All boilers and process heaters less than 10 mmBtu/hr must meet a work practice standard of a biennial boiler tune-up. All large units greater than or equal to 10 mmBtu/hr in the natural gas/refinery gas and Metallurgical Process Furnace subcategories must meet a work practice standard of an annual boiler tune-up. All major source facilities with a boiler or process heater must conduct an energy audit.

- Option 5E uses the same control device and testing, and monitoring cot estimation logic outlined above for option 4E above for all units except for refinery gas units. Units firing refinery gas will have a separate numerical emission limit for mercury.

- A revised definition of solid waste is being proposed parallel with this proposed rulemaking effort. The solid waste definitional rulemaking proposal includes both a primary and alternative definition of solid waste for consideration during the public comment period. Options 1E through 5E analyze the regulatory impacts with respect to the primary proposed definition of solid waste. However, to compare the impacts of both definitions of solid waste, the cost and emission impacts of regulatory option 4E discussed above were applied to the inventory of units that were not classified as waste burning units under the alternative solid waste definition.

## 2.2 New Units

Three control options were considered for existing boilers and process heaters at major sources of HAP. A description of the three options is included in this section.

- Option 1N represents the option where all new boilers, regardless of fuel type or size, must meet PM, HCl, mercury, CO, and D/F numerical emission limits.
- Option 2N uses the same control device and testing, and monitoring cost estimation logic outlined above for option 1N, except that it does not estimate ACI for units exceeding the MACT floor emission limit for dioxin/furan. Instead, it is estimated that most units, when testing for dioxin/furan will be below detection levels without installing any additional control devices.
- Option 4N represents the primary proposed option discussed in the preamble. In this option all boilers and process, regardless of size, meet PM, HCl, mercury, CO, and D/F numerical emission limits, except for units in the natural gas/refinery gas and Metallurgical Process Furnace subcategories. All units in the natural gas/refinery gas and Metallurgical Process Furnace subcategories must meet a work practice standard of an annual boiler tune-up.

# 3.0 ESTIMATING COST IMPACTS

For each option, the cost impacts analysis compares the baseline emissions for each unit to the corresponding MACT floor emission limit for the unit's subcategory. A control device was applied to the unit if its baseline emissions exceeded their applicable MACT floor emission limit. A comparison of the overall capital and annualized costs of the proposed options 4E and Option 4N are presented in Table 1. The detailed equations used to estimate the control, testing, monitoring, and work practice costs are discussed in another memorandum.[2] The following logic was used to apply control, testing, and monitoring costs to each boiler or process heater:

## 3.1 Option 1E/1N

### Control Cost Impacts

*Mercury Control*

- A new fabric filter installation was expected to achieve the Hg emission limits in the proposed rule. Where baseline Hg emissions were found to be greater than the MACT floor, the cost of a fabric filter was estimated for an individual boiler or process heater, unless the unit already had a fabric filter installed. A new fabric filter was estimated to be installed at 12,138 existing boilers and process heaters. In the case of a unit with a fabric filter emitting Hg above the MACT floor emission limit, the incremental Hg removal efficiency required to meet the MACT floor was calculated, and then the costs to install activated carbon injection (ACI) technology on the boiler were estimated. If the unit had a packed bed scrubber and did not meet the MACT floor for Hg, a fabric filter was installed if no other control was in place. Incremental ACI equipment was installed for 155 existing boilers and process heaters.

- Wet scrubbers—the technology selected for the cost analysis to reduce emissions of hydrogen chloride (HCl)—are also capable of achieving modest reductions in Hg. Literature suggests that these scrubbers can achieve a 10-percent reduction in Hg emissions. If a scrubber was being installed for HCl, and baseline Hg emissions were within 10 percent of the MACT floor, the wet scrubber was expected to achieve this level of emission reduction without installing a fabric filter.

*Particulate Matter Control*

- When baseline particulate (PM) emissions exceeded the MACT floor, the cost of an ESP was estimated, unless a fabric filter had already been included in the cost analysis for Hg reduction. ESP technology was estimated to be installed at 397 existing boilers and process heaters.
- Wet scrubbers are also capable of achieving a modest reduction in PM. Literature suggests that these scrubbers can achieve an 85-percent reduction in PM emissions. If a scrubber was being installed for HCl, and baseline PM emissions were within 85 percent of the MACT floor for PM, the wet scrubber was expected to achieve this level of emission reduction without installing an ESP.

*Hydrogen Chloride Control*

- When HCl baseline emissions were greater than the MACT floor, the cost of adding a packed bed scrubber was estimated. If the boiler already reported to have a scrubber installed and the baseline emissions still exceeded the floor, the incremental required HCl removal efficiency was calculated and the then the cost to increase the sorbent injection rate in the scrubber was estimated in the cost analysis. Wet scrubbers were identified to be necessary to control HCl emissions at 13,269 existing boilers and process heaters

*Dioxin/Furan Control*

- Where dioxin/furans exceeded the MACT floor, the required removal efficiencies of dioxin/furans was calculated, and the costs to install ACI were included in the cost analysis. If ACI had was previously included in the cost analysis for incremental Hg control, the ACI costs based on the highest required removal efficiency were used in the cost analysis. For example, if a boiler required 90 percent reduction in Hg and 98 percent reduction in dioxin/furan, the higher ACI costs associated with the 98 percent reduction of dioxin/furan were used in the cost analysis. ACI technology was estimated to be required at 2,538 existing boilers and process heaters for either Hg or dioxin/furan control.

*Carbon Monoxide and Organic HAP Control*

- Organic HAP and carbon monoxide can be controlled by either improving the combustion efficiency of the unit, or installing an oxidation catalyst on the exhaust of a combustion unit. The control strategy necessary to meet the MACT floor emission limit will vary depending on the magnitude between the baseline emissions and the CO MACT floor. A step function was used to delineate what type of control strategy should be analyzed in the cost impacts analysis:

    - Most boilers (other than Dutch ovens and PC-coal boilers discussed below) are designed to operate with CO emissions at or near 400 parts per million (ppm). A boiler tune-up, was estimated in the cost impacts analysis if the unit's baseline emissions exceeded the floor for carbon monoxide (CO), but were less than or equal to 400 ppm @ 3% $O_2$.
    - If the baseline CO emissions were between 400 and 1000 ppm @ 3% $O_2$ for boilers and process heaters designed to burn liquid and gaseous fuels, the cost of a replacement low-NOx burner was estimated to achieve the MACT floor emission limits.
    - Since stokers, fuel cells, or fluidized bed unit do not have replaceable burners, a linkageless boiler management system (LBMS) was the technology estimated to achieve the MACT floor when baseline CO emissions exceeded the floor and were between 400 and 1000 ppm @ 3% $O_2$.

- For boilers and process heaters designed to burn gas and liquids, as well as stokers, fuel cells, and fluidized bed boilers and process heaters design to burn solid fuels, the cost impacts analysis estimated that a CO Oxidation catalyst would be required to meet MACT floor limits if a unit's baseline CO emissions were above 1,000 ppm @ 3% $O_2$ and exceeded the MACT floor.
- Similar to stokers, Dutch oven and suspension-fired boilers and process heaters do not have replaceable burners. The design of the Dutch oven/suspension burner combustion system and the high moisture content of the fuels used in Dutch ovens typically cause elevated CO levels compared to other combustor designs. A tune-up was estimated in the cost analysis for any Dutch oven/suspension burner with a baseline of less than 5,000 ppm @ 3% $O_2$. LBMS costs were estimated for any Dutch oven boiler with baseline CO between 5,000 – 12,500 ppm @ 3% $O_2$. If the baseline CO emissions at Dutch oven/suspension-fired units exceeded 12,500 ppm @ 3% $O_2$, the cost of adding catalytic oxidation was estimated for the cost impacts analysis.
- For PC-boilers, a tune-up was estimated in the cost analysis for any unit with a baseline of less than 1200 ppm @ 3% $O_2$. The cost of a replacement LNB was estimated if CO emissions were between 1200 – 3000 ppm @ 3% $O_2$ and catalytic oxidation was estimated if CO baseline was greater than 3000 ppm @ 3% $O_2$.

Option 1E of the cost impacts analysis estimated 11,013 existing boilers and process heaters would meet the CO MACT floor with a tune-up, an additional 1,073 existing units would install a LBMS, 1 existing boiler would replace their existing burner with a LNB, and 482 existing units would install a CO oxidation catalyst.

## Testing and Monitoring Cost Impacts

Testing and monitoring requirements varied depending on the equipment installed on the unit to control emissions, the design capacity of the unit, and the fuel category the unit was assigned to.

*Testing Costs*

All boilers and process heaters designed to burn solid and gaseous fuels were expected to conduct an annual compliance test for PM, HCl, Hg, D/F, and CO. The cost to conduct stack tests for these five pollutants was estimated to be $44,000 per year. Combustion units greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM, HCl, Hg, and D/F was estimated to be $37,000 per year.

Boilers and process heaters designed to burn liquid fuels were expected to conduct an annual compliance test for PM, D/F, and CO. In lieu of a stack test boilers designed to burn liquid fuels were expected to conduct fuel analysis, or report fuel analyses received from a fuel supplier for chlorine and Hg. Conducting stack tests for PM, D/F, and CO and fuel analysis for chlorine and Hg was estimated to be $16,000 per year. Combustion units greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM and D/F and fuel analysis for chlorine and Hg was estimated to be $10,000 per year. Although other fuels are eligible to comply with the proposed rule through fuel analysis in lieu of stack testing, this cost estimate conservatively assumed that only units designed to fire liquid fuels would use this compliance alternative. The methods and data sources used to estimate testing and monitoring costs are discussed in other memoranda.[2]

Small boilers often exhaust to small diameter stacks that do not have any test ports or test platforms installed. For these small units, we estimated the additional costs to these costs to construct or rent scaffolding and install test ports. The costs include installation of 4 test ports, 90 degrees opposed to each other, and five weeks rental of temporary scaffolding. EPA estimates that these small sources would incur an additional $185 million to install test ports and rent temporary scaffolding. Many establishments in each industry, commercial, or institutional sector are associated with multiple (as many as a 700) small units. A summary of the costs by fuel category is shown in Table 1 below.

**Table 1. Cost Estimate for Renting Scaffolding and Constructing Test Ports at Small Boilers and Process Heaters**

| Fuel Category | Number of Small Boilers and Process Heaters (less than 10 mmBtu/hr) | Port Costs ($2008) | Renting Temporary Scaffolding ($2008) | Total Costs ($2008) |
|---|---|---|---|---|
| Coal | 3 | 32,944 | 42,000 | 74,944 |
| Biomass | 26 | 285,517 | 364,000 | 649,517 |
| Natural Gas/ Refinery Gas | 7138 | 78,385,476 | 99,932,000 | 178,317,476 |
| Other Process Gases | 2 | 21,963 | 28,000 | 49,963 |
| Liquid | 238 | 2,613,581 | 3,332,000 | 5,945,581 |
| **Total** | **7,407** | **81,339,482** | **103,698,000** | **185,037,482** |

*Monitoring Costs*

Various monitor configurations were installed based on the size of the unit and the pollution control devices expected to be installed to achieve the MACT floor emission limits. For units expected to install packed bed wet scrubbers, an annualized cost of $5,600 for a scrubber parametric monitor was included in the cost analysis. For units expected to install a fabric filter, an annualized cost of $9,700 for a bag leak detection monitor was included in the cost analysis. If a unit was expected to install ACI, the cost to monitor the carbon injection rate was included in the analysis, based on the unit's hours of operation. For units greater than 100 mmBtu/hr, an annualized cost of $53,300 for a CO CEMS was included in the cost analysis, and for units greater than 250 mmBtu/hr an annualized cost of $56,100 was used in the cost analysis. For units that did not install a PM CEMS and did not install a scrubber to meet HCl limits, an annualized cost of $14,660 for an opacity monitor was included in the cost analysis. No PM CEMS or opacity monitors were assumed for boilers and process heaters designed to gaseous fuels.

## Fuel Savings Impacts

This cost analysis includes an estimate of energy savings for every unit that is expected to install controls to improve combustion, or conduct an annual tune-up or energy audit. The Department of Energy has conducted energy assessments at selected manufacturing facilities and reports that facilities can reduce fuel/energy use by 10 to 15 percent by using best practices to increase their energy efficiency. Many best practices are considered pollution prevention because they reduce the amount of fuel combusted which results in a corresponding reduction in emissions from the fuel combustion. Further boiler tune-ups have been shown to improve the efficiency of a boiler between 1 and 5 percent, depending on the age of the unit and the time lapse since the previous tune-up. Other combustion controls such as upgrading burners and installation of an LBMS are also expected to improve the efficiency of the unit, thus reducing fuel consumption. This cost analysis assumes an annual fuel savings of 1 percent. The energy savings is estimated using the Equation 1:

$$\text{Annual Fuel Savings (mmBtu/yr)} = DC * CF * Op_{hours} * EG \qquad \textbf{(Equation 1)}$$

*Where:*

DC = unit design capacity (mmBtu/hr)
CF = capacity factor, 90% of design capacity
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)
EG = Efficiency gain, estimated to be 1%

After the fuel savings for each boiler and process heater was calculated, the both industrial and commercial prices for coal, #2 distillate fuel oil, #6 residual fuel oil, and natural gas were obtain from the EIA.[3] The EIA data reported fuel prices as $/ton for coal, $/thousand cubic feet for natural gas, and cents per gallon for fuel oil. The higher heating values were obtained from Table C-1 of the EPA Mandatory Reporting Rule (40 CFR part 98 subpart C) and the higher heating values were used to convert the fuel prices to a standard unit of measure, $ per mmBtu. Using the NAICS code reported by each facility and the fuel category assigned to each combustion unit, the appropriate fuel price was multiplied by the calculated fuel savings. This cost analysis only estimates the fuel savings from units in the coal, liquid and natural gas and other gaseous fuel categories. A fuel savings was not estimated for units in the biomass fuel category since the price of biomass fuels is variable, and often biomass is an on-site industrial byproduct instead of a purchased fuel.

## *3.2 Option 2E/2N*

Option 2E uses the same control device and testing, and monitoring cost estimation logic outlined above for option 1E, except that it does not estimate ACI for units exceeding the MACT floor emission limit for dioxin/furan. Instead, it is estimated that most units, when testing for dioxin/furan will be below detection levels without installing any additional control devices.

## 3.3 Option 3E

Option 3E follows the same logic for estimating control costs as option 2E outlined above, with the exception of small units (less than 10 mmBtu/hr) and units in the natural gas/refinery gas and natural gas-fired metallurgical process furnace subcategories. In option 3E, the only cost estimated for small units is the cost of an annual tune-up for each boiler or process heater. For all units firing natural gas or refinery gas, regardless of the size of the unit, the only cost estimated is the cost of an annual tune-up for each boiler or process heater.

Unlike option 2E, there are no testing and monitoring costs are associated with small units or units of any size designed to burn natural gas, refinery gas, or natural gas-fired metallurgical process furnaces.

## 3.4 Option 4E

Option 4E includes control device and testing/monitoring cost estimation logic identical to Option 3E outlined above, except for the addition of the estimated cost of one facility-wide energy audit for each facility, annualized over 5 years. As discussed in the memorandum for Estimating Control Costs from Major Source Boilers and Process Heaters, the cost of an energy audit ranges from $75,000 for industrial-scale energy audits to between $2,000 and $5,000 per energy audit for institutional and commercial-scale audits.[2] The cost of each type of audit was annualized over 5 years at 7 percent to obtain an annualized cost estimate. For the cost impacts analysis, 1,608 facilities are expected to conduct an audit, 197 facilities are commercial or institutional and 1,411 facilities are industrial.

## 3.5 Option 5E

For refinery gas units, option 5E includes a cost estimate to install a carbon adsorption system to filter the refinery gas prior to combustion. Carbon adsorption is expected to remove trace contaminants in the gas, such as Hg. When this option was initially considered, the baseline emission factor for mercury from refinery gas units was estimated to be 1.07E-07 lb per mmBtu. Since that analysis was completed, the baseline emissions from refinery gas units were reviewed and an outlier from a 1990 test, on the order of $10^{-5}$ was identified to be biasing the baseline emission averages toward a higher average. This test occurred at Facility ID: CAExxonMobil-Torrance (unit ID 75-F-1) and only one test run was available. Several additional mercury tests at other units firing refinery gas at the same facility in the same year were reported two be two orders of magnitude lower than the test reported for 75-F-1. After removing the outlier emissions, the baseline emissions of mercury from refinery gas were comparable to those of natural gas, and a combined average mercury baseline emission factor of 7.28E-07 lb/mmBtu was used for both refinery gas and natural gas.

For analyzing the cost impacts of option 5E EPA estimated one carbon adsorption system for each facility with refinery gas boilers and process heaters. EPA expected that a centralized adsorption system would provide economies of scale and would treat all the gas prior to the refinery gas being used in the combustion equipment. The cost impacts assumption estimates that 73 different facilities would install a carbon adsorption system to treat refinery gas. Since the revised estimate of mercury baseline emissions estimated from refinery gas units had decreased substantially as a result of adjusting the baseline emission factor, the cost to install carbon adsorption was no longer cost effective and the beyond the floor mercury control option from refinery gas units was not included in the proposal. However, the estimated costs of installing carbon adsorbers at refineries are included in Appendix A for reference.

### 3.6 Option 4N

Option 4N follows the same logic for estimating control costs as option 2E/2N outlined above, with the exception of units in the natural gas/refinery gas and natural gas-fired metallurgical process furnace subcategories. In option 4N, the only cost estimated for units firing natural gas or refinery gas, regardless of the size of the unit, the only cost estimated is the cost of an annual tune-up for each boiler or process heater.

Unlike option 2E/2N, there are no testing and monitoring costs are associated units of any size designed to burn natural gas, refinery gas, or natural gas-fired metallurgical process furnaces.

### 3.7 Impacts Considering the Alternative Solid Waste Definition

The impacts of the alternative solid waste definition follows the identical logic for estimating control costs as option 4E discussed in Section 3.4 above. Under this option, there are13,275 boilers identified as not burning waste materials, compared to a total of 13,555 boilers and process heaters under the primary definition of solid waste. The remainders of these units are analyzed under the parallel rulemaking effort for Commercial Industrial Solid Waste Incinerators if the units are located in the private sector. Should the alternative definition of solid waste become the final promulgated definition, the additional waste burning units located in the public sector will be analyzed under the forthcoming Other Solid Waste Incinerator rulemaking.

## *3.8 Summary of Cost Impacts*

Option 4E is the proposed option for existing boilers and process heaters and option 4N is the proposed option for new boilers and process heaters. Tables 1 and 2 summarize the costs of the proposed option for new and existing units. Appendix A of this memorandum provides a detailed summary of the costs according to boiler size, boiler fuel category, and individual control device costs. Appendix A also includes a summary of the costs on existing units under the alternative definition of solid waste.

**Table 1: Summary of Costs of Proposed Options**
**Costs shown in $\$10^6$ (2008) with capital recovery estimated at 7%**

| Type of Unit | Option | Number of Units | TAC | TAC considering fuel savings | Testing & Monitoring TAC | Control TAC | Control TCI |
|---|---|---|---|---|---|---|---|
| New | 4N | 46 | $7.9 | $6.2 | $0.6 | $7.2 | $17.3 |
| Existing | 4E | 13,555 | $3,248 | $2,871 | $136 | $3,086 | $9,489 |

**Table 2: Summary of Costs by Control Type for Existing Units under Option 4E**
**Costs shown in $\$10^6$ (2008) with capital recovery estimated at 7%**

| Number of Boilers | Fabric Filter | | ESP | | Wet Scrubber | | Increased Caustic Rate | Combustion Controls and Oxidation Catalysts | | Activated Carbon Injection | | Energy Audit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TCI | TAC | TCI | TAC | TCI | TAC | TAC | TCI | TAC | TCI | TAC | TAC |
| 13,555 | 5,154 | 1,198 | 953 | 161 | 3,281 | 1,630 | 2.4 | 13.9 | 2.9 | 9.5 | 56.9 | 26.0 |

# 4.0 METHODOLOGY FOR ESTIMATING EMISSION REDUCTIONS

This section discusses the methodology used to estimate emission reductions from boilers and process heaters at both existing and new facilities and it presents a summary of the results for the regulatory options 1E/1N and 4E/4N.

## *4.1 Emission Reductions from Existing Boilers and Process Heaters*

The emission reductions analysis for existing combustion units was done for each boiler and process heater in the major source inventory. There are a total of 13,555 boilers and process heaters at major sources that reported data in the 2008 questionnaire (ICR No. 2286.01). Each combustion unit was assigned a unit-specific or average baseline emission factor, depending on the availability of emission data reported for the unit. A detailed discussion of the procedures and results of the baseline emissions analysis is presented in another memorandum.[4]

*Emission Reductions for Option 1E*

Emission reductions for PM, HCl, Hg, CO, and dioxins/furans were calculated on a ton per year basis by subtracting the baseline emissions assigned to each unit from the MACT floor emission limits corresponding to each unit's subcategory. A detailed discussion of the procedures and results of the MACT floor analysis is presented in another memorandum.[1] For each combustion unit, a percent reduction in CO was calculated. It was assumed that each combustion unit would achieve an identical percent reduction from baseline emissions for THC and VOC as was achieved for CO. Similarly, a percent reduction was also calculated for HCl. It was assumed that each combustion unit would achieve an identical percent reduction from baseline emissions for HF as was achieved for HCl. A combustion unit is required to install a scrubber for HCl control if it is not currently meeting the HCl floor limit, and if it doesn't already have a scrubber installed. For units required to install a scrubber, it was assumed that the scrubber will achieve a 95 percent reduction from baseline for SO2. To calculate emission reductions for SO2, baseline emissions were multiplied by a factor of 0.95. A percent reduction in PM was calculated in order to estimate total metals reductions. It was assumed that each combustion unit would achieve an identical percent reduction from baseline emissions for each non-Hg metallic HAP as was achieved for PM. PM2.5 emissions were assumed to be a fraction of total filterable PM emissions based on fuel and control device configuration installed on the unit. The methods used to derive the contribution of PM2.5 to overall filterable PM are presented in other memoranda.[4] To calculate emission reductions for PM2.5, the emission reductions for PM were multiplied by the applicable PM2.5 fraction. Emission reductions for all pollutants for which there was no floor value were calculated on a ton per year basis.

To convert emission reductions from an emission rate on a heat input basis to an annual emission rate, Equation 2 was used:

$$\text{Annual Emission Rate (tpy)} = ER_{HI} * 0.0005 * Op_{hours} \qquad \textbf{(Equation 2)}$$

*Where:*

$ER_{HI}$ = emission rate (lb/mmBtu)
0.0005 = conversion factor, lbs per ton
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)

To convert emission reductions from a concentration basis to an annual emission rate, Equations 3 and 4 were used:

$$\text{Annual Emission Rate (tpy)} = ER_C * 0.000001 * \rho_{air} * Q_S * 60 * Op_{hours} * 0.0005 * (20.946 - O_2) / (20.946 - \text{Std } O_2) \qquad \textbf{(Equation 3)}$$

*Where:*

$ER_C$ = emission concentration (ppm @ 3% $O_2$)
0.000001 = conversion factor, ppm to parts
$\rho_{air}$ = density of air, 0.0749 lb/dscf
$Q_S$ = exhaust flowrate (dscfm)
60 = conversion factor, minutes to hours
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)
0.0005 = conversion factor, lb per ton
20.946 = percentage of oxygen in ambient air
$O_2$ = percentage of oxygen assumed in exhaust gas
Std. $O_2$ = 3 percent oxygen in standardized emission concentration for proposed rule.

Annual Emission Rate (tpy) = $ER_C$ * 0.0283 * $Q_S$ * 60 * $Op_{hours}$ * 0.000000001 * 0.0022 * 0.0005 * (20.946 – $O_2$) / (20.946 – Std $O_2$) **(Equation 4)**

*Where:*

$ER_C$ = emission concentration (ng/dscm @ 7% $O_2$)
0.0283 = conversion factor, dry standard cubic meter per dry std. cubic foot
$Q_S$ = exhaust flowrate (dscfm)
60 = conversion factor, minutes per hour
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)
0.000000001 = conversion factor, ng to g
0.0022 = conversion factor, g per lb
0.0005 = conversion factor, lb per ton
20.946 = percentage of oxygen in ambient air
$O_2$ = percentage of oxygen assumed in exhaust gas
Std $O_2$ = 7 percent oxygen in standardized emission concentration for proposed rule.

Converting concentrations to an annual emission rate required an oxygen concentration and exhaust flowrate estimated for each specific fuel type. The development of these assumptions and estimates is presented in other memoranda.[2] All conversions required the annual operating hours for each combustion unit reported in the 2008 survey. If no operating hours were reported, the unit was assumed to operate for 8,400 hours per year (two weeks of downtime).

*Emission Reductions for Option 4E*

The same calculations discussed for estimating emission reductions for option 1E were applied to all units except small units (less than 10 mmBtu/hr) and units of any size firing natural gas or refinery gas. For small units firing any type of fuel and units in the natural gas/refinery gas and natural gas metallurgical process furnace subcategories, the emission reductions were based on a one percent gain in efficiency expected from the annual tune-up work practice standard. Efficiency gains reduce fuel use, and in turn, emissions of hazardous air pollutants. A one percent reduction in all types of emissions was estimated by multiplying the baseline emissions for each unit by a factor of 0.01.

*Emission Reductions under the Alternative Solid Waste Definition*

The same calculations discussed for estimating emission reductions for option 4E were applied to all units that were identified as not burning waste under the alternative solid waste definition. In this case, the baseline emissions were compared to the MACT floor emission limits calculated for units not burning solid waste under the alternative definition. A discussion of the methodology used to calculate the MACT floor emission limits under the alternative solid waste definition is discussed in another memorandum.[1]

*Incremental Emission Reductions if Energy Audit Findings are Implemented*

We evaluated the potential additional reductions and fuel savings that could occur as a result of implementing certain cost-effective energy efficiency improvements identified during the audit. Using the Department of Energy references of a 10 to 15 percent improvement in efficiency, a range of incremental emission reductions was estimated considering efficiency gains between 5 and 10 percent. We applied the control efficiency ranges of 5 and 10 percent reduction to the emissions remaining after MACT level of controls were installed on the unit to identify the potential for additional emission reductions if the findings of an energy audit were implemented. Table 3 summarizes the potential additional emission reductions that could occur under a beyond the floor option of implementing any findings in the audit with a short term payback. The fuel savings were estimated using Equation 1 described in 3.1 of this memo was used to estimate fuel savings. In this case the efficiency gain term was modified to be between 5 and 10 percent.

A summary of the estimated emission reductions at existing units for options 1E, the proposed option 4E, as well as the reductions from units considering the alternative proposed solid waste definition are located in **Appendix B**.

**Table 3. Emission Reductions and Energy Savings Resulting from Implementing Cost Effective Findings of an Energy Audit**

| | Assuming a Five Percent Efficiency Gain From Implementing Audit Findings | | | | | | |
|---|---|---|---|---|---|---|---|
| **Emission Reductions and Energy Savings Per Facility** | **HCl Emission Reductions (tpy)** | **Filterable PM Emission Reductions (tpy)** | **Non-Hg Metals Emission Reductions (tpy)** | **Hg Emission Reductions (tpy)** | **VOC Emission Reductions (tpy)** | **Energy Saved (mmBtu/yr)** | **Annual Fuel Savings ($/yr)** |
| Min | 1.23E-07 | 1.23E-06 | 1.49E-07 | 2.55E-10 | 2.13E-10 | 2.05E-01 | $ - |
| Max | 6.85E+00 | 2.02E+01 | 4.98E+00 | 2.95E-03 | 2.80E+01 | 6.31E+06 | $ 58,771,608 |
| Average | 1.76E-01 | 8.55E-01 | 5.07E-02 | 8.53E-05 | 2.84E-01 | 1.69E+05 | $ 1,290,803 |
| Median | 1.57E-02 | 1.95E-01 | 2.97E-03 | 1.68E-05 | 5.17E-02 | 4.50E+04 | $ 255,301 |
| TOTAL (all 1,608 facilities) | 282 | 1,375 | 81 | 0 | 457 | 271,172,354 | 2,075,611,566 |
| | **Assuming a 10 Percent Efficiency Gain From Implementing Audit Findings** | | | | | | |
| **Emission Reductions and Energy Savings Per Facility** | **HCl Emission Reductions (tpy)** | **Filterable PM Emission Reductions (tpy)** | **Non-Hg Metals Emission Reductions (tpy)** | **Hg Emission Reductions (tpy)** | **VOC Emission Reductions (tpy)** | **Energy Saved (mmBtu/yr)** | **Annual Fuel Savings ($/yr)** |
| **Min** | 2.46E-07 | 2.46E-06 | 2.99E-07 | 5.09E-10 | 4.26E-10 | 4.10E-01 | $ - |
| **Max** | 1.37E+01 | 4.04E+01 | 9.97E+00 | 5.89E-03 | 5.60E+01 | 1.26E+07 | $ 117,543,216 |
| **Average** | 3.51E-01 | 1.71E+00 | 1.01E-01 | 1.71E-04 | 5.69E-01 | 3.37E+05 | $ 2,581,606 |
| **Median** | 3.14E-02 | 3.91E-01 | 5.93E-03 | 3.36E-05 | 1.03E-01 | 8.99E+04 | $ 510,601 |
| **TOTAL** (all 1,608 facilities) | 565 | 2,749 | 163 | 0 | 914 | 542,344,709 | 4,151,223,131 |

* Although the energy savings in mmBtu/yr are calculated for all fuels, additional fuel savings in $/yr consider only units in the coal, liquid and gas 1 fuel types. Biomass and process gases are industrial byproducts and were not assigned a purchase price.

## *4.2 Emission Reductions from New Boilers and Process Heaters*

Based on industrial and commercial fuel consumption projections from the EIA, there are 46 new boilers and process heaters expected to come on-line by 2013.[5] a discussion of the methodology used to project new boilers and process heaters is discussed in another memorandum.[3]

The New Source Performance Standards for Industrial, Commercial and Institutional Boilers (40 CFR part 60, subparts Db, Dc) (NSPS), was reviewed to identify the expected baseline level of control for projected new units. It was determined that new boilers and process heaters larger than 30 mmBtu/hr and combusting biomass would install an ESP. This technology selection is based on the analysis used to establish the PM NSPS limit for biomass boilers. New coal units larger than 75 mmBtu/hr would have a fabric filter and wet scrubber installed, while coal new units between 30 and 75 mmBtu/hr would only have a fabric filter installed and would meet the SO2 limits in the NSPS by using coals with a low sulfur content. New units larger than 30 mmBtu/hr and combusting liquid fuel would have a fabric filter installed. All new units less than 30 mmBtu/hr would have no add-on controls and liquid fuels were expected to meet the NSPS So2 limits using low sulfur fuel oils. Gas-fired units of all sizes were not expected to install controls to meet any of the NSPS limits. For this impacts analysis, it was assumed that all new solid fuel units would be stokers, since stoker boilers are the most common type of solid fuel boilers and all new units would have NOx control installed as a baseline control, regardless of fuel.

*Emission Reductions for Option 1N*

After an appropriate baseline level of control was determined for each model unit, an average baseline emission factor calculated for existing units within the same fuel category and having the same level of control was assigned to each model boiler. The NSPS specifies PM and SO2 limits for new solid- and liquid-fired combustion units based on heat input. It was assumed that all new solid and liquid units would be constructed to meet these limits, so they were used as baseline emission values where applicable. The baseline emissions for each unit were subtracted from the new source MACT floor emission limit corresponding to each unit's subcategory. The same calculations discussed in Section 3.1 of this memo were used to estimate the reductions for new units.

*Emission Reductions for Option 4N*

Similar to the methods discussed in Section 4.1 of this memorandum, the emission reductions for new units under regulatory option 4N were calculated by subtracting the baseline emissions assigned to each unit from the MACT floor emission limits corresponding to each unit's subcategory, except for units firing natural gas or refinery gas. For any size natural gas or refinery gas-fired units, the emission reductions were estimated base on a 1 percent reduction in emissions, as a result of implementing a tune-up work practice. A summary of the estimated emission reductions at existing units for both option 1 and option 4 are located in **Appendix B-1**.

# 5.0 SECONDARY IMPACTS

Secondary impacts include the solid waste, water, wastewater, and electricity required to operate air pollution control devices, as well as the additional energy savings resulting from improved combustion controls or work practices required by the NESHAP. This section documents the inputs and equations used to estimate these secondary impacts, and it summarizes the impacts at existing units under proposed regulatory option 4 and new units under proposed regulatory option 1. Table 4-1 summarizes the cost, emission, and secondary impacts of this proposed NESHAP. Appendices C-1 and C-2 present a detailed breakdown of the secondary waste, water, and energy impacts from each subcategory of new and existing boilers and process heaters, respectively.

**Table 4-1. Summary of Secondary Impacts**

| Impact | New Units (proposed regulatory Option 4N) | Existing Units (proposed regulatory Option 4E) |
|---|---|---|
| Water (gal/yr) | 197,200 | 2.4 billion |
| Wastewater (gal/yr) | 142,300 | 730 million |
| Solid Waste (tons/yr) | 149,800 | 81,400 |
| Purchased Electricity (kW-hr/yr) | 11.2 | 2.9 billion |
| Energy Savings* (trillion Btu/yr) | 0.1 | 41.7 |

* Energy savings is calculated for units in the coal, liquid and gas subcategories.

The secondary impacts were calculated using algorithms and assumptions described in another memorandum.[2] These algorithms and assumptions were applied to the existing boiler and process heaters, where the baseline emissions for each unit exceeded the proposed MACT floor emission limit except for small units (<10 mmBtu/hr) and units firing natural gas or refinery gas. A one percent energy savings was calculated for all units, including the small and gas-fired units since these units are expected to conduct a tune-up. For new units, the algorithms and assumptions were applied to model units representing units expected to come online between 2010 and 2013, when the baseline emissions for each model exceeded the proposed MACT floor emission limit for new units except for units firing natural gas and refinery gas. Natural gas and refinery gas are not required to meet a numerical emission limit, and therefore not expected to incur any secondary waste, water, or electricity impacts from these controls. A 1 percent energy savings from natural gas and refinery gas units are included in the energy savings estimate in Table 4-1 since these units are expected to conduct a tune-up. The methodology used to assign baseline emission factors to new and existing units are discussed in another memorandum.[4]

## *5.1 Wastewater and Water Impacts*

The water required to create a slurry in the packed scrubber and the wastewater generated by the effluent of a packed bed scrubber was calculated for every unit expected to install a scrubber to meet the HCl limits in the proposed rule. Both the water and wastewater calculations required the use of several constants and variables. The constants including the density of gas, moles of salt needed per mole of hydrogen chloride in the exhaust gas, the molecular weight of the salt used, the fraction of the waste stream treated, operating hours per year and the molecular weight of the gas. The data sources for these constants are provided in another memorandum.[2] The variables used to estimate the quantity of water required and wastewater generated were calculated based on characteristics reported for each existing unit in the 2008 survey and for the characteristics assigned to each new model unit. The variables included: exhaust flow rate from the combustion unit to the control device in actual cubic feet per minute, the inlet loading of hydrogen chloride to the control device (mole fraction), and the efficiency of the control device in removing hydrogen chloride from the exhaust gas (percent reduction). The calculations used to estimate each variable are provided in another memorandum.[2] The total national water and wastewater amounts in Table 4.1 were determined by adding the per unit water and wastewater estimates for all new and existing units, respectively.

## *5.2 Solid Waste Impacts*

Solid waste is generated from collecting dust and fly ash in fabric filters or ESP control devices, spent carbon associated with ACI or the installation of a carbon bed adsorber, or spent caustic from increasing the caustic injection rate. Solid waste impacts were estimated for every unit expected to install a fabric filter, ACI or carbon bed adsorber to meet mercury emission limits, or install an ESP to meet PM emission limits. The total national solid waste amounts in Table 4.1 were determined by adding the per unit solid waste estimates for all new and existing units, respectively. To estimate the solid waste contribution from each of these control devices, the variables were calculated based on characteristics reported for each existing unit in the 2008 survey and for the characteristics assigned to each new model unit. The calculations used to estimate each variable and the quantity of solid waste generated are provided in another memorandum.[2]

The solid waste (dust, fly ash) generated by the use of an electrostatic precipitator was calculated when an electrostatic precipitator was determined to be necessary to meet the NESHAP emission limits for PM. Estimates of the solid waste collected in an ESP was based on several variables including: exhaust flow rate from the combustion unit to the control device (acfm); the inlet loading of particulate matter to the control device (gr/acfm); operating hours (hr/year) and the efficiency of the control device required to meet the PM emission limits in the proposed NESHAP.

The solid waste generated from the collection of dust and fly ash in a fabric filter was calculated when a fabric filter was determined to be necessary to meet the proposed NESHAP emission limits for particulate matter and/or mercury. The calculation required the use of three variables, including: exhaust flow rate from the combustion unit to the control device (dscfm); operating hours (hr/year) and the inlet loading of particulate matter to the control device (gr/acfm).

For this analysis, the spent carbon collected from units with ACI is assumed to be disposed of instead of being re-generated. The amount of spent carbon created from ACI was calculated when ACI was expected to be necessary to meet the proposed NESHAP emission limits for mercury or dioxin/furan. The calculation required the use of six variables, including: exhaust flow rate from the combustion unit to the control device (dscfm); operating hours (hr/year), required removal efficiency for mercury and dioxin/furan, and an adjustment factor based required removal efficiency of mercury or dioxin /furan.

The solid waste generated by the use of increased caustic was calculated for those units where additional caustic was expected to achieve the proposed NESHAP emission limits for HCl. The calculation required the use of three variables, including: exhaust flow rate from the combustion unit to the control device (dscfm); operating hours (hr/year), and the required removal efficiency for HCl.

## 5.3 Electricity Impacts

The amount of electricity required to operate a control device was calculated for a packed scrubber, electrostatic precipitator, and fabric filter, CO oxidation catalyst and the fans for the ductwork associated with this equipment. These impacts were assessed for every unit that was estimated to require hydrogen chloride and/or particulate matter control. Electricity requirements are one output of the cost algorithms used in the analyses, so no additional calculations were necessary. For some units, an electrical demand from multiple control devices was estimated. The total national electricity demand in Table 4.1 was determined by adding the per unit solid waste estimates for all new and existing units, respectively. To estimate the electricity demand from each of these control devices, a set of variables were calculated based on characteristics reported for each existing unit in the 2008 survey and for the characteristics assigned to each new model unit. The constants, variables, and calculations used to estimate each variable and the electricity demand to operate the control devices are provided in another memorandum.[2]

## 5.4 Energy Savings Impacts

The energy savings from combustion controls such as low NOx burners or linkageless boiler management systems, and work practice standards, including a tune-up, and implementing the energy audit findings with a short-term payback can improvements in efficiency, thereby reducing fuel consumption. Although these combustion improvements have been documented to achieve efficiency gains between 5 and 10 percent from the baseline operating conditions, this secondary impacts analysis estimates a 1 percent efficiency gain, to be conservative and consistent with the assumptions made in Section 3.1 of this memorandum. Quantifying the exact gains in efficiency from each of these work practice standards is difficult, and may depend on the baseline operating efficiency of each unit.

Section 3.1 discusses the fuel savings impacts in terms of annualized cost savings to each boiler or process heater, and the national energy savings presented in Table 4.1 of this section follows the same methodology as was discussed in Section 3.1 and reflect the savings from boilers in the coal, gas, and liquid fuel categories only.

## 5.5 Estimating Secondary Impacts for Regulatory Options 4E/4N

Regulatory Options 4E for existing and 4N for new units are both described in detail in Section 3 of this memorandum. For the secondary impacts analysis at existing units under option

4E, the water, wastewater, solid waste, and electricity impacts were only assessed for large units, (those greater than or equal to 10 mmBtu/hr) that are in the coal, biomass, liquids, or other process gas subcategories. Secondary impacts of water, wastewater, solid waste, and electricity were not assessed for natural gas or refinery gas units or units in the natural gas metallurgical process furnace subcategory. Energy savings were estimated for all units firing anything other than biomass since all units were expected to conduct an energy audit.

For new units under option 4N, the water, wastewater, solid waste, and electricity impacts were assessed for any size unit firing coal, biomass, liquid, or other process gases. Secondary impacts of water, wastewater, solid waste, and electricity were not assessed for natural gas or refinery gas units or units in the natural gas metallurgical process furnace subcategory. A one percent energy savings was estimated for all units firing coal, liquids or gases that were estimated to require a tune-up or the installation of combustion control equipment to meet the CO limits from new boilers. Both tune-ups and combustion controls improve the efficiency of the unit, thereby reducing energy consumption.

# 6.0 REFERENCES


1. Singleton, Amanda. ERG. MACT Floor Methodology for Major Source Boilers and Process Heaters. April 2010.

2. Singleton, Amanda and S. McClutchey. ERG. Methodology for Estimating Control Costs for the Major Source Industrial, Commercial and Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants. April 2010.

3. Gibson, Graham. ERG. New Unit Analysis for Industrial, Commercial, and Institutional Boilers and Process Heaters at Major Sources. April 2010.

4. U.S. Department of Energy, EIA. 2008 Delivered Fuel Prices to Industrial and Commercial Clients. http://www.eia.doe.gov/

5. Gibson, G. ERG. Development of Baseline Emission Factors for Boilers and Process Heaters at Commercial, Industrial, and Institutional Facilities. April 2010.

6. U.S. Department of Energy, EIA. Annual Energy Outlook 2009. Table 2. Energy Consumption by Sector and Source. http://www.eia.doe.gov/

# APPENDIX D

# AREA SOURCES COST AND EMISSIONS MEMORANDUM

MEMORANDUM

TO: Jim Eddinger, U.S. Environmental Protection Agency, OAQPS/SPPD

FROM: Graham Gibson, Susan McClutchey, and Amanda Singleton, ERG

DATE: April 2010

SUBJECT: DRAFT Methodology for Estimating Impacts from Industrial, Commercial, Institutional Boilers at Area Sources of Hazardous Air Pollutant Emissions

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## 1.0 INTRODUCTION

The purpose of this memorandum is to discuss the methodology used to estimate the costs, emission reductions, and secondary impacts from industrial, commercial, and institutional boilers at area sources of hazardous air pollutants (HAP). These impacts were calculated for existing units and new units projected to be operational by the year 2013, three years after the rule is expected to be promulgated. The results of the impacts analysis are presented for both the most stringent regulatory option evaluated and the regulatory option contained in the proposed rule. The development of the maximum achievable control technology (MACT) floor and Generally Achievable Control Technology (GACT) level of control, projection of new units, and a detailed description of the cost equations used to estimate costs for various control technologies is presented in other memoranda.[1,2,3] This memorandum is organized as follows:

1.0 Introduction
2.0 Overview of Regulatory Options
3.0 Estimating Cost Impacts
4.0 Methodology for Estimating Emission Reductions
5.0 Methodology for Estimating Secondary Impacts
6.0 References

# 2.0 OVERVIEW OF REGULATORY OPTIONS

Three control options were considered for existing boilers at area sources of HAP. A description of the three options is described below.

## 2.1 Existing Units

- Option 1E represents the option where all boilers, regardless of fuel type or size, must meet mercury and CO numerical emission limits based on MACT and PM numerical emission limits based on GACT. PM GACT was identified to be a multiclone for existing units.

- Option 2E represents the same emission limits as discussed in 1E above for large units (equal to or greater than 10 mmBtu/hr). Small units are exempt from numerical limits and instead are required to meet a work practice standard of a biennial tune-up. All facilities are required to conduct an energy audit.

- Option 3E represents the primary proposed option discussed in the preamble. In this option, all coal boilers equal to or greater than 10 mmBtu/hr must meet mercury and CO numeric emission limits based on MACT. All biomass and liquid boilers equal to or greater than 10 mmBtu/hr must meet a CO numerical emission limit, based on MACT. All facilities with a large boiler are required to conduct an energy audit. Small boilers are exempt from numeric emission limits for all pollutants, but are required to meet a work practice standard of a biennial tune-up. There are no numerical emission limits for PM under this option for any size or type of unit.

## 2.2 New Units

Three control options were considered for new boilers at area sources of HAP. A detailed description of the three options is described below.

- Option 1N represents the option where all boilers, regardless of fuel type or size, must meet mercury and CO limits based on MACT and PM numerical emission limits based on GACT. GACT for new units is based on PM limits in the New Source Performance Standards (NSPS) for Industrial, Commercial, and Institutional Boilers (40 CFR part 60 subparts Db, Dc).

- Option 2N represents the same emission limits as discussed in 1N above for large units (equal to or greater than 10 mmBtu/hr). Small units are exempt from numerical emission limits and instead are required to meet a work practice standard of a biennial tune-up.

- Option 3N represents the primary proposed option discussed in the preamble. In this option, all coal boilers, regardless of size, must meet mercury and CO limits based on MACT and PM numerical emission limits based on GACT. All biomass and liquid boilers, regardless of size, must meet CO limits based on MACT and PM numerical emission limits based on GACT.

# 3.0 ESTIMATING COST IMPACTS

For each option, a percentage of units in each model unit were assumed to require control devices in order to meet the limit when the baseline emissions for the model unit exceeded the MACT floor emission limit applicable to each model. A detailed description of the three options is described below. A summary table comparing the overall capital and annualized costs of option 3E for existing units and option 3N for new units is presented in Table 1. The equations used to estimate the control, testing, monitoring, and work practice costs are discussed in another memorandum.[3] The following logic was used to apply control, testing, and monitoring costs to each boiler:

## *3.1 Option 1E*

### Control Cost Impacts

*Mercury Control*

A new fabric filter installation was expected to achieve the mercury emission limits in the proposed rule. Where baseline mercury emissions were found to be greater than the MACT floor, the cost of a fabric filter was estimated for a portion of the boilers represented by the model unit. Based on the data used in the MACT floor analysis, a fraction of units in each subcategory meeting the MACT floor for Hg was estimated. For boilers designed to burn biomass one of the boilers was meeting the floor and the other unit was not meeting the floor. In the cost impacts analysis, 50 percent of the biomass units were estimated to install a fabric filter to meet the floor. For boilers designed to burn coal, 44 percent of units were achieving the proposed MACT floor emission limit for coal, so a new fabric filter was estimated to be installed at 56 percent of the existing coal-fired boilers. For liquid fuel units, there were no area source boilers with emission test data available for mercury. In the absence of other information about the distribution of units that would require a fabric filter to be installed, this cost impacts analysis assumes that 50 percent of the liquid fuel units would install a fabric filter to meet the mercury limit.

*CO/Organic HAP Control*

Organic HAP and carbon monoxide can be controlled by either improving the combustion efficiency of the unit, or installing an oxidation catalyst on the exhaust of a combustion unit. The control strategy necessary to meet the MACT floor emission limit will vary depending on the magnitude between the baseline emissions and the CO MACT floor.

Most boilers (other than Dutch ovens and PC-coal boilers) are designed to operate with CO emissions at or near 400 parts per million (ppm). A boiler tune-up was estimated in the cost impacts analysis if the unit's baseline emissions exceeded the floor for carbon monoxide (CO), but were less than or equal to 400 ppm @ 3% $O_2$. The combustor design of the boilers in the area source inventory is not known and this impacts analysis assumes that all areas source boilers firing solid fuels have a stoker combustor design since this is the predominant combustor design in the major source boiler inventory. The baseline emissions for area source boilers in all fuel categories are less than 400 ppm, and so it is assumed that combustion controls, either a basic tune-up or a more advanced burner replacement or installation of a linkageless boiler management system, can achieve the proposed MACT floor emission limits. No oxidation catalysts are estimated to be required to meet the MACT floor emission limits.

Based on the emission test data used to calculate the MACT floor for CO, 29 percent of units burning coal are meeting the MACT floor and these units would be expected to install a linkageless boiler management system to comply with the CO limits. For units burning biomass, 72 percent of the units are exceeding the MACT floor emission limits, and so 72 percent of the units are estimated to install a linkageless boiler management system. For units burning liquids, 86 percent of the units are exceeding the floor and this cost impacts analysis assumes these units will install a new low NOx replacement burner in order to meet the CO limits. The units not expected to install these advanced controls are expected to conduct an annual tune-up to maintain in compliance with the proposed CO limit overtime.

*Particulate Matter Control*

For all units that were not expected to install a fabric filter for mercury control, the cost impacts analysis for this option assumes that the unit would install a multiclone to achieve the GACT emission limits for PM. Based on the current MACT floor analysis, 44 percent of coal units and 50 percent of liquid units would install a multiclone. Existing biomass units not expected to install a fabric filter would also install a multiclone. Base on the current MACT floor analysis, 50 percent of existing biomass units would install a multiclone.

## Testing and Monitoring Cost Impacts

Testing and monitoring requirements varied depending on the equipment installed on the unit to control emissions, the design capacity of the model unit, and the fuel category of the model unit.

*Testing Costs*

All boilers designed to burn solid fuels were expected to conduct an annual compliance test for PM, Hg, and CO. The cost to conduct stack tests for these three pollutants was estimated to be $15,000 per year. Boilers greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM and Hg was estimated to be $12,000 per year.

Boilers designed to burn liquid fuels were expected to conduct an annual compliance test for PM and CO. In lieu of a stack test boilers designed to burn liquid fuels were expected to conduct fuel analysis, or report fuel analyses received from a fuel supplier for chlorine and Hg. Conducting stack tests for PM and CO was estimated to be $13,000 per year and the cost to conduct fuel analysis for Hg was estimated to be $600 per year. Combustion units greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM and fuel analysis for Hg was estimated to be $8,600 per year. Although solid fuels are eligible to comply with the proposed rule through fuel analysis in lieu of stack testing, when the mercury content of the fuel is below the MACT floor emission limit, this cost estimate conservatively assumed that only units designed to fire liquid fuels would use this compliance alternative. The methods and data sources used to estimate testing and monitoring costs are discussed in other memoranda.[3]

*Monitoring Costs*

Various monitor configurations were installed based on the size of the unit and the pollution control devices expected to be installed to achieve the MACT floor emission limits. For units expected to install a fabric filter, an annualized cost of $9,700 for a bag leak detection monitor was included in the cost analysis. For units greater than 100 mmBtu/hr, an annualized cost of $53,300 for a CO CEMS was included in the cost analysis. For units that did not install a bag leak detector, an annualized cost of $14,660 for an opacity monitor was included in the cost analysis.

## Fuel Savings Impacts

This cost analysis includes an estimate of energy savings for every unit that is expected to install controls to improve combustion, or conduct an annual tune-up or energy audit. The Department of Energy has conducted energy assessments at selected manufacturing facilities and reports that facilities can reduce fuel/energy use by 10 to 15 percent by using best practices to increase their energy efficiency. Many best practices are considered pollution prevention because they reduce the amount of fuel combusted which results in a corresponding reduction in emissions from the fuel combustion. Further boiler tune-ups have been shown to improve the efficiency of a boiler between 1 and 5 percent, depending on the age of the unit and the time lapse since the previous tune-up. Other combustion controls such as upgrading burners and installation of an LBMS are also expected to improve the efficiency of the unit, thus reducing fuel consumption. This cost analysis assumes an annual fuel savings of 1 percent. The energy savings is estimated using Equation 1:

Annual Fuel Savings (mmBtu/yr) = $DC * CF * Op_{hours} * EG$ **(Equation 1)**

*Where:*

DC = unit design capacity (mmBtu/hr)

$Op_{hours}$ = annual operating hours, assumed 8400 (hours/year)

EG = Efficiency gain, estimated to be 1%

CF = annual average capacity factor, 0.5 for liquid and 0.65 for coal and biomass

After the fuel savings for each boiler was calculated, the both industrial and commercial prices for coal, #2 distillate fuel oil, and #6 residual fuel oil were obtained from the EIA.[3] The EIA data reported fuel prices as $/ton for coal, and cents per gallon for fuel oil. The higher heating values were obtained from Table C-1 of the EPA Mandatory Reporting Rule (40 CFR part 98 subpart C) and the higher heating values were used to convert the fuel prices to a standard unit of measure, $ per mmBtu. Using the distribution of SIC codes reported in the 13-state boiler inspector inventory, the model units were distributed to an industrial or commercial sector, and then the appropriate fuel price was multiplied by the calculated fuel savings. This cost analysis only estimates the fuel savings from units in the coal and liquid fuel categories. A fuel savings was not estimated for units in the biomass fuel category since the price of biomass fuels is variable, and often biomass is an on-site industrial byproduct instead of a purchased fuel.

## 3.2 Option 2E

Option 2E follows the same logic for estimating control costs as option 1E outlined above, with the exception of small units (less than 10 mmBtu/hr). In option 2E, the only cost estimated for small units is the cost of an annual tune-up for each boiler. No testing and monitoring costs were included in option 2E for small units. Option 2E also includes the cost of an energy audit at every area source facility, approximately 91,339 facilities. As discussed in the memorandum for Estimating Control Costs from Major Source Boilers and Process heaters, the cost of an energy audit ranges from $75,000 for industrial-scale energy audits to between $2,000 and $5,000 per energy audit for institutional and commercial-scale audits.[4] The facility's classification of either an industrial or commercial facility was assigned using the distribution of SIC codes in the 13-state boiler inspector inventory. The cost of each type of audit was annualized over 5 years at 7 percent to obtain an annualized cost estimate.

## 3.3 Option 3E

The proposed option 3E includes control device and testing/monitoring cost estimation for mercury and CO from large coal units. As mentioned in option 1E, 56 percent of large coal units, or 321 boilers are expected to install a fabric filter in order to meet the mercury limit. In addition, 29 percent of large coal units are expected to install advanced combustion controls in order to meet the CO limit. This analysis uses the cost of a linkageless boiler management system to estimate the costs of advanced combustion control. The remaining 71 percent of large coal units are expected to meet the CO limit with a tune-up. The testing and monitoring costs for large coal units include a test for CO and mercury, as well as a bag leak detection system for the 321 boilers that are expected to install a fabric filter. There are no proposed numerical PM emission limits under this option, and so no additional testing costs for PM or opacity monitoring costs were assessed in the cost impacts analysis for this option.

Under option 3E liquid and biomass boilers are not subject to numerical emission limits for mercury and there are no costs included in the impacts analysis to install fabric filters or conduct mercury fuel analysis or stack testing. Large liquid and biomass boilers are subject to numerical emission limits for CO. This cost impacts analysis estimates that all the biomass and liquid fuel units can meet the CO emission limits by conducting an annual tune-up. These large units must also conduct testing and monitoring activities for CO to demonstrate compliance with the numerical emission limits.

Option 3E exempts small boilers from numerical emission limits. Instead these units must conduct a work practice standard of a biennial tune-up. The cost impacts analysis does not include any additional testing and monitoring requirements for these small boilers.

Finally, option 3E proposes that all facilities with large boilers conduct an energy audit. For this cost impacts analysis one large boiler per facility was assumed, or 13,268 facilities estimated to conduct an audit. Similar to the discussion under option 2E, the cost of the audit ranged from $75,000 for industrial-scale energy audits to between $2,000 and $5,000 per energy audit for institutional and commercial-scale audits.[2]

## 3.4 Option 1N

New area source boilers are subject to an NSPS (40 CFR part 60 subparts Db, Dc) to regulate emissions of PM, NOx and SO2. The cost impacts analysis considered controls that would likely be installed to comply with the NSPS and includes an estimate of any additional control, testing and monitoring costs that would not be already conducted to meet the requirements of the NSPS. Based on a review of the NSPS, this analysis assumes all biomass boilers greater than 30 mmBtu/hr will have an ESP control installed as the baseline to meet the NSPS PM limits; all coal boilers greater than 75 will have an FF and wet scrubber installed to meet PM and SO2 limits; all coal boilers between 30 and 75 will have a Fabric Filter and use low sulfur coal to meet PM and SO2 limits, and all liquid boilers greater than 30 will have an FF installed to meet PM limits. The NSPS does not regulate PM for units less than 30 mmBtu/hr.

*Mercury Control*

A new fabric filter installation was expected to achieve the mercury emission limits in the proposed rule. Where baseline mercury emissions were found to be greater than the MACT floor, the cost of a fabric filter was estimated for a portion of the boilers represented by the model unit. All new boilers, regardless of size or fuel, were expected to install a fabric filter in order to meet the mercury limits under this option. Comparing these mercury control requirement to the expected controls under the NSPS, all biomass boilers are expected to install a fabric filter to meet the mercury limit and all liquid and coal boilers less than or equal to 30 mmBtu/hr are expected to install a fabric filter to meet the mercury limit.

*CO/Organic HAP Control*

New boilers are expected to be equipped with new and efficient burners, and it was assumed that an annual tune-up could achieve the CO numeric emission limit for all sizes and types of boilers. Other advanced combustion controls were not considered as a control alternative for new boilers. As mentioned under 1E, the control strategy necessary to meet the MACT floor emission limit will vary depending on the magnitude between the baseline emissions and the CO MACT floor.

*Particulate Matter Control*

Under this option all units are expected to install a fabric filter for mercury control, which has a co-benefit of reducing PM emissions, as well as other non-mercury metallic HAP. No additional control costs were estimated for PM control at new boilers.

## Testing and Monitoring Cost Impacts

Testing and monitoring requirements varied depending on the equipment installed on the unit to control emissions, the design capacity of the model unit, and the fuel category of the model unit.

*Testing Costs*

All boilers designed to burn solid fuels were expected to conduct an annual compliance test for PM, Hg, and CO. The cost to conduct stack tests for these three pollutants was estimated to be $15,000 per year. Combustion units greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM and Hg was estimated to be $12,000 per year.

Boilers designed to burn liquid fuels were expected to conduct an annual compliance test for PM and CO. In lieu of a stack test boilers designed to burn liquid fuels were expected to conduct fuel analysis, or report fuel analyses received from a fuel supplier for chlorine and Hg. Conducting stack tests for PM and CO was estimated to be $13,000 per year and the cost to conduct fuel analysis for Hg was estimated to be $600 per year. Combustion units greater than 100 mmBtu/hr were expected to install CO CEMS in lieu of conducting a CO stack test and the cost to conduct tests on PM and fuel analysis for Hg was estimated to be $8,600 per year. Although solid fuels are eligible to comply with the proposed rule through fuel analysis in lieu of stack testing, when the mercury content of the fuel is below the MACT floor emission limit, this cost estimate conservatively assumed that only units designed to fire liquid fuels would use this compliance alternative. The methods and data sources used to estimate testing and monitoring costs are discussed in other memoranda.[3]

*Monitoring Costs*

Various monitor configurations were installed based on the size of the unit and the pollution control devices expected to be installed to achieve the MACT floor emission limits. For units expected to install a fabric filter, an annualized cost of $9,700 for a bag leak detection monitor was included in the cost analysis. For units greater than 100 mmBtu/hr, an annualized cost of $53,300 for a CO CEMS was included in the cost analysis. For units that did not install a bag leak detector, an annualized cost of $14,660 for an opacity monitor was included in the cost analysis.

## 3.5 Option 2N

Option 2N follows the same logic for estimating control costs as option 1N outlined above, with the exception of small units (less than 10 mmBtu/hr). In option 2N, the only cost estimated for small units is the cost of an annual tune-up for each boiler. No testing and monitoring costs were included in option 2N for small units

## 3.6 Option 3N

The proposed option 3N includes identical requirement for coal units as outlined under option 1N. Under option 3N liquid and biomass boilers are not subject to numerical emission limits for mercury and there are no costs included in the impacts analysis to install fabric filters for mercury control or conduct mercury fuel analysis or stack testing. Liquid and biomass boilers are subject to numerical emission limits for CO. This cost impacts analysis estimates that all the biomass and liquid fuel units can meet the CO emission limits by conducting an annual tune-up. These units must also conduct testing and monitoring activities for CO to demonstrate compliance with the numerical emission limits.

Option 3N also includes a numerical PM emission limit for coal, biomass, and liquid boilers, based on the NSPS limits applicable to each of these categories. Since all coal units are subject to mercury emission limits, they are expected to meet a PM GACT limit of 0.051 lb/mmBtu without any additional control requirements. The NSPS PM limit for biomass is 0.1 lb/mmBtu, which is based on the performance of an electrostatic precipitator (ESP). Since biomass units greater than 30 mmBtu/hr are already subject to this limit under the NSPS, this cost analysis applies the costs for an ESP to units less than or equal to 30 mmBtu/hr. The NSPS PM limit for liquids is also 0.051 lb/mmBtu. Based on the calculated average baseline emission factors analysis distillate liquids are expected to meet that limit without any additional control.[5] However residual liquid units are expected to install a fabric filter to meet the PM emission limit.

Under option 3N, all boilers less than or equal to 30 mmBtu/hr are estimated to incur costs to test for PM and CO, at an estimate cost of $14,000 per year. Boilers greater than 30 mmBtu/hr will incur PM stack testing costs under the NSPS. Coal boilers are estimated to incur additional costs to test for mercury and the cost to conduct tests for PM, CO, and Hg is estimated to be $19,000 per year.

## 3.7 Summary of Cost Impacts

Option 3E is the proposed option for existing boilers and option 3N is the proposed option for new boilers. Since new boilers and their exhaust stacks can be designed to allow for stack testing, the tune-up work practice standard does not apply to new small units. Table 1 summarizes the costs of the proposed option for new and existing boilers at area sources of HAP. Appendix A of this memorandum provides a detailed summary of the costs for each model unit.

**Table 1: Summary of Costs of Proposed Options**
**Costs shown in $\$10^6$ (2008) with capital recovery estimated at 7%**

| Type of Unit | Option | Number of Boilers | TAC | TAC considering fuel savings | Testing & Monitoring TAC | Control TAC | Control TCI |
|---|---|---|---|---|---|---|---|
| New | 3N | 6,779 | $311 | $260 | $193 | $117 | $343 |
| Existing | 3E | 182,671 | $696 | $279 | $94 | $550 | $1,792 |

# 4.0 METHODOLOGY FOR ESTIMATING EMISSION REDUCTIONS

This section discusses the methodology used to estimate emission reductions from boilers at both existing and new facilities and it presents a summary of the results for the regulatory options 1E/1N and 3E/3N.

## *4.1 Emission Reductions from Existing Boilers*

Each model area source boiler was assigned baseline emissions based on the calculated baseline averages for existing major source combustion units in the same size and fuel subcategory. The development of area source model units and the procedures and results of the baseline emissions analysis is presented in other memoranda.[5-6]

*Emission Reductions for Option 1E*

Emission reductions for all pollutants were calculated on a ton per year basis. Emission reductions of Hg and CO were calculated by subtracting the baseline emissions assigned to each model unit from the MACT floor (or GACT) emission limits corresponding to the subcategory for each model boiler. A detailed discussion of the procedures and results of the MACT floor analysis is presented in another memorandum.[1]

For all units expected to install a fabric filter to meet the mercury MACT floor emission limits, this fabric filter achieves a co-benefit of reducing emissions of PM and non-mercury metallic HAP. To calculate the PM emission reductions from units expected to install a fabric filter, the baseline emissions assigned to each model boiler were subtracted from the calculated average baseline emission factor corresponding to a fabric filter level of control in the same fuel category. For example, the PM baseline emission factor for uncontrolled or multiclone-equipped biomass boilers is 0.26 lb/mmBtu, and the calculated baseline emission factors for biomass boilers equipped with a fabric filter is 0.01 lb/mmBtu. The emission reductions were estimated using the difference of these two factors, or 0.25 lb/mmBtu. The methodology used to calculate average baseline emission factors for different fuel and control configurations is discussed in another memorandum.[5] It was assumed that the remaining boilers that did not install a fabric filter will install a cyclone or multiclone to reduce PM emissions. Multiclones were identified as a GACT level of control for PM. Emission reductions for units expected to install a multiclone were estimated by multiplying the baseline emissions of each model unit by the expected PM control efficiency of a multiclone, a 75 percent reduction. These control efficiencies for various control devices are detailed in another memorandum.[5] Model units with a design capacity greater than 10 mmBtu/hr were expected to already have a multiclone installed as a baseline level of control, so no additional PM emission reductions were estimated from these units, unless the unit installed a fabric filter for mercury control.

To estimate the reductions in other non-mercury metallic HAP, the percent reduction in filterable PM was calculated for each model boiler expected to install a fabric filter for mercury control. This percent reduction was multiplied by the baseline emissions for each of the non-mercury metallic HAP. Since fabric filters capture fine particulate, this analysis assumes that each model boiler would achieve an identical percent reduction from baseline emissions for each non-mercury metallic HAP as was achieved for PM. For model boilers that were expected to install a multiclone to meet the PM GACT limit, a 10 percent reduction was estimated for non-mercury metallic HAP.

PM2.5 emissions comprise a fraction of total filterable PM emissions depending on the fuel combusted and control device configuration installed on the unit. The methods used to derive the contribution of PM2.5 to overall filterable PM are presented in other memoranda.[5] To calculate emission reductions for PM2.5 for each model boiler, the emission reductions for PM were multiplied by the applicable PM2.5 fraction.

For any boiler conducting a tune-up or installing advanced combustion controls such as a replacement burner or linkageless boiler management system, a one percent gain in combustion efficiency was estimated, resulting in an estimated one percent emissions reduction of all pollutants. Efficiency gains reduce fuel use, and in turn, emissions of hazardous air pollutants.[8] A one percent reduction in emissions for these pollutants was estimated by multiplying the baseline emissions for each unit by a factor of 0.01.

To convert emission reductions from an emission rate on a heat input basis to an annual emission rate, Equation 2 was used:

Annual Emission Rate (tpy) = $ER_{HI}$ * 0.0005 * $Op_{hours}$ * CF **(Equation 2)**

*Where:*

$ER_{HI}$ = emission rate (lb/mmBtu)
0.0005 = conversion factor, lbs per ton
$Op_{hours}$ = annual operating hours, assumed 8760 (adjusted using capacity factor)
CF = annual average capacity factor, 0.5 for liquid and 0.65 for coal and biomass

To convert emission reductions from a concentration basis to an annual emission rate, Equations 3 and 4 were used:

Annual Emission Rate (tpy) = $ER_C$ * 0.000001 * $\rho_{air}$ * $Q_S$ * 60 * $Op_{hours}$ * 0.0005 * (20.946 – $O_2$) / (20.946 – Std $O_2$) * CF **(Equation 3)**

*Where:*

$ER_C$ = emission concentration (ppm @ 3% $O_2$)
0.000001 = conversion factor, ppm to parts
$\rho_{air}$ = density of air, 0.0749 lb/dscf
$Q_S$ = exhaust flowrate (dscfm)
60 = conversion factor, minutes to hours
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)
0.0005 = conversion factor, lb per ton
20.946 = percentage of oxygen in ambient air
$O_2$ = percentage of oxygen assumed in exhaust gas
Std. $O_2$ = 3 percent oxygen in standardized emission concentration for proposed rule.
CF = annual average capacity factor, 0.5 for liquid and 0.65 for coal and biomass

Annual Emission Rate (tpy) = $ER_C$ * 0.0283 * $Q_S$ * 60 * $Op_{hours}$ * 0.000000001 * 0.0022 * 0.0005 * (20.946 – $O_2$) / (20.946 – Std $O_2$) * CF **(Equation 4)**

*Where:*

$ER_C$ = emission concentration (ng/dscm @ 7% $O_2$)
0.0283 = conversion factor, dscm to dscf
$Q_S$ = exhaust flowrate (dscfm)
60 = conversion factor, minutes to hours
$Op_{hours}$ = annual operating hours reported in 2008 survey (hours/year)
0.000000001 = conversion factor, ng to g
0.0022 = conversion factor, g per lb
0.0005 = conversion factor, lb per ton
20.946 = percentage of oxygen in ambient air
$O_2$ = percentage of oxygen assumed in exhaust gas
Std $O_2$ = 7 percent oxygen in standardized emission concentration for proposed rule.
CF = annual average capacity factor, 0.5 for liquid and 0.65 for coal and biomass

Converting concentrations to an annual emission rate required an oxygen concentration and exhaust flowrate estimated for each specific fuel type. The development of these assumptions and estimates is presented in another memorandum.[4]

*Emission Reductions for Option 3E*

The same calculations discussed for estimating emission reductions for option 1E were applied to all large coal boilers. For small model boilers, the emission reductions were based on a one percent gain in efficiency expected from the biennial tune-up work practice standard. For large biomass and liquid units no add-on controls for PM or mercury are expected since these units are not subject to numerical emission limits for PM or Hg. Instead, a similar one percent gain in efficiency is expected to occur as a result of conducting an annual tune-up or installing advanced combustion controls necessary to meet the CO numerical limit in each category. Efficiency gains reduce fuel use, and in turn, emissions of hazardous air pollutants. A one percent reduction in all types of emissions was estimated by multiplying the baseline emissions for each unit by a factor of 0.01. A summary of the estimated emission reductions at existing units for both option 1 and option 2a are located in **Appendix B-1**.

## 4.2 Emission Reductions from New Boilers

Based on industrial and commercial fuel consumption projections from the EIA and a history of boiler installation dates in the boiler inspector inventory, there are 6,779 new area source boilers expected to come on-line by 2013.[7] These new projected boilers are expected to fire biomass, coal, and liquid fuels. An average (mean) design capacity of area source boilers firing similar fuel type, in the same size category, and in the same sector (industrial or commercial) was estimated to develop new model units representative of the existing boiler inventory. New model units were assigned baseline emissions in the same manner as existing area source model units. The projection of new model area source boilers and the procedures and results of the baseline emissions analysis is presented in other memoranda.[2]

As discussed in Section 3.4, the NSPS for Industrial, Commercial and Institutional Boilers (40 CFR part 60, subparts Db, Dc) (NSPS) were reviewed to identify the expected baseline level of control for projected new units. Then, the average baseline emission factor corresponding to the expected level of control and fuel category was assigned to each new model boiler. New biomass boilers larger than 30 mmBtu/hr were expected to install an ESP; new coal boilers larger than 75 mmBtu/hr were expected to install a fabric filter and wet scrubber; new coal boilers between 30 and 75 mmBtu/hr would only have a fabric filter installed and were expected to meet the SO2 limits in the NSPS by using coals with a low sulfur content; new boilers larger than 30 mmBtu/hr and combusting liquid fuels were expected to install a fabric filter. All new boilers less than 30 mmBtu/hr would have no add-on controls. For this impacts analysis, it was assumed that all new solid fuel units would be stokers, since stoker boilers are the most common type of solid fuel boilers and all new units would have NOx control installed as a baseline control, regardless of fuel. Based on the EIA fuel projections, all new coal boilers are projected to be less than 10 mmBtu/hr and the only 49 model boilers firing biomass are expected to exceed 30 mmBtu/hr.

*Emission Reductions for Option 1N*

After an appropriate baseline level of control was determined for each model unit, an average baseline emission factor was calculated for existing units within the same fuel category and having the same level of control was assigned to each model boiler. The NSPS specifies PM and SO2 limits for new solid- and liquid-fired combustion units based on heat input. It was assumed that all new solid and liquid units would be constructed to meet these limits and those limits were used as baseline emission values, where applicable. For units less than 30 mmBtu/hr, the baseline emissions for PM were estimated assuming the unit was uncontrolled and the target PM emission limit from the NSPS was used as the GACT level of control. The baseline emissions for each unit were subtracted from the new source MACT floor for Hg and CO and GACT emission limit for PM corresponding to each unit's subcategory. The same calculations discussed in Section 4.1 of this memo were used to estimate the reductions for new units.

*Emission Reductions for Option 3N*

For new coal boilers, the emission reductions were calculated using the same methods discussed for Option 1N above. For new biomass boilers less than 30 mmBtu/hr, emission reductions for PM were calculated by subtracting the PM NSPS emission limits from a baseline emission factor representing uncontrolled units. Since an ESP is not expected to be very effective at capturing mercury emissions, mercury emissions reductions from all biomass units were estimated based on a one percent efficiency improvement, resulting from annual tune-ups or other combustion controls expected to occur in order to demonstrate compliance with CO emission limits. For new biomass boilers greater than or equal to 30 mmBtu/hr, there were no estimated additional PM or non-Hg metallic HAP emission reductions since these larger biomass boilers are already expected to be in compliance with a PM NSPS limit using an ESP.

New residual liquid boilers less than 30 mmBtu/hr were expected to install a fabric filter to meet the PM emission limit. Since a fabric filter is effective at capturing fine particulate, additional emission reductions for mercury were calculated by subtracting the average baseline emission factor for heavy liquid boilers equipped with a fabric filter from the average baseline emission factor corresponding to an uncontrolled heavy liquid unit.

The average baseline emission factor for PM at uncontrolled distillate liquid units is less than the NSPS emission limit for liquid units. As a result, no additional PM, Hg, or non-Hg metallic HAP emission reductions were estimated from installing additional PM controls. Instead, these reductions were estimated based on a one percent efficiency improvement, resulting from annual tune-ups or other combustion controls expected to occur in order to demonstrate compliance with CO emission limits.

Under this proposed option, new small units do not qualify for the same tune-up work practice standards that apply to existing units since it is expected that new units can be designed to allow for stack test diameters that would be compatible with EPA test methods. As a result, new A summary of the estimated emission reductions at existing units for both option 1N and the proposed option 3N are located in **Appendix B-2**.

*Incremental Emission Reductions if Energy Audit Findings are Implemented*

We evaluated the potential additional reductions and fuel savings that could occur as a result of implementing certain cost-effective energy efficiency improvements identified during the audit. Using the Department of Energy references of a 10 to 15 percent improvement in efficiency, a range of incremental emission reductions was estimated considering efficiency gains between 5 and 10 percent. We applied the control efficiency ranges of 5 and 10 percent reduction to the emissions remaining after MACT level of controls were installed on the unit to identify the potential for additional emission reductions if the findings of an energy audit were implemented. Table 3 summarizes the potential additional emission reductions that could occur under a beyond the floor option of implementing any findings in the audit with a short term payback. The fuel savings were estimated using Equation 1 described in 3.1 of this memo that was used to estimate fuel savings. In this case the efficiency gain term was modified to be between 5 and 10 percent. A summary of the estimated incremental emission reduction and fuel savings is shown in Table 3.

A summary of the estimated emission reductions at existing area source boilers for options 1E, 2E, and the proposed option 3E are located in **Appendix B-1**. A summary of the estimated emission reductions at new area source boilers for options 1N, 2N, and the proposed option 3N are located in **Appendix B-2**.

**Table 3. Emission Reductions and Energy Savings Resulting from Implementing Cost Effective Findings of an Energy Audit at Facilities with Large (≥10 mmBtu/hr) Boilers**

| | Assuming a Five Percent Efficiency Gain From Implementing Audit Findings | | | | | | |
|---|---|---|---|---|---|---|---|
| **Emission Reductions and Energy Savings Per Facility** | **HCl Emission Reductions (tpy)** | **Filterable PM Emission Reductions (tpy)** | **Non-Hg Metals Emission Reductions (tpy)** | **Hg Emission Reductions (tpy)** | **VOC Emission Reductions (tpy)** | **Energy Saved (mmBtu/yr)** | **Annual Fuel Savings ($/yr)** |
| **Min** | 3.92E-03 | 3.01E-02 | 1.12E-03 | 9.21E-07 | 3.59E-04 | 3.85E+03 | $0 |
| **Max** | 2.40E-01 | 3.11E+00 | 1.64E-01 | 3.28E-05 | 2.93E-02 | 3.80E+04 | $860,704 |
| **Average** | 1.73E-02 | 1.74E-01 | 1.98E-02 | 4.64E-06 | 1.86E-03 | 6.15E+03 | $95,279 |
| **Median** | 3.92E-03 | 3.01E-02 | 2.39E-02 | 3.45E-06 | 4.20E-04 | 5.54E+03 | $125,613 |
| **TOTAL** (13,268 facilities with a large boiler) | 2.29E+02 | 2.31E+03 | 2.63E+02 | 6.16E-02 | 2.47E+01 | 8.16E+07 | $1,264,161,683 |
| | **Assuming a 10 Percent Efficiency Gain From Implementing Audit Findings** | | | | | | |
| **Emission Reductions and Energy Savings Per Facility** | **HCl Emission Reductions (tpy)** | **Filterable PM Emission Reductions (tpy)** | **Non-Hg Metals Emission Reductions (tpy)** | **Hg Emission Reductions (tpy)** | **VOC Emission Reductions (tpy)** | **Energy Saved (mmBtu/yr)** | **Annual Fuel Savings ($/yr)** |
| **Min** | 7.84E-03 | 6.02E-02 | 2.25E-03 | 1.84E-06 | 7.18E-04 | 7.69E+03 | $0 |
| **Max** | 4.80E-01 | 6.23E+00 | 3.28E-01 | 6.56E-05 | 5.87E-02 | 7.60E+04 | $1,721,408 |
| **Average** | 3.45E-02 | 3.48E-01 | 3.96E-02 | 9.28E-06 | 3.73E-03 | 1.23E+04 | $190,558 |
| **Median** | 7.84E-03 | 6.02E-02 | 4.79E-02 | 6.89E-06 | 8.40E-04 | 1.11E+04 | $251,226 |
| **TOTAL** (13,268 facilities with a large boiler) | 4.58E+02 | 4.62E+03 | 5.26E+02 | 1.23E-01 | 4.94E+01 | 1.63E+08 | $2,528,323,367 |

* Although the energy savings in mmBtu/yr are calculated for all fuels, additional fuel savings in $/yr consider only units in the coal and liquid categories. Biomass is often an industrial byproducts and was not assigned a purchase price.

# 5.0 METHODOLOGY FOR ESTIMATING SECONDARY IMPACTS

Secondary impacts include the solid waste and electricity required to operate air pollution control devices, as well as the additional energy savings resulting from improved combustion controls or work practices required by the NESHAP. This section documents the inputs and equations used to estimate these secondary impacts, and it summarizes the impacts at existing units under proposed regulatory option 3E and new units under proposed regulatory option 3N. Table 5-1 summarizes the secondary impacts of this proposed NESHAP. Appendices C-1 and C-2 present a detailed breakdown of the secondary waste and energy impacts from each subcategory of existing and new boilers, respectively.

**Table 5-1: Summary of Secondary Impacts**

| Impact | New Units (proposed regulatory Option 4N) | Existing Units (proposed regulatory Option 4E) |
|---|---|---|
| Solid Waste (tons/yr) | 1,800 | 14,300 |
| Purchased Electricity (kW-hr/yr) | 22 million | 206 million |
| Energy Savings* (tBtu/yr) | 2.34 | 19.6 |

* Energy savings is calculated for units in the coal and liquid subcategories.

The secondary impacts were calculated using algorithms and assumptions described in another memorandum.[3] These algorithms and assumptions were applied to the existing boilers, where the baseline emissions for each unit exceeded the proposed MACT floor emission limit. For new units, the algorithms and assumptions were applied to model units representing units expected to come online between 2010 and 2013, when the baseline emissions for each model exceeded the proposed MACT floor or GACT emission limit for new units. The methodology used to assign baseline emission factors to new and existing units are discussed in another memorandum.[5]

## *5.1 Solid Waste Impacts*

Solid waste is generated from collecting dust and fly ash in fabric filters or ESP control devices. Solid waste impacts were estimated for every unit expected to install a fabric filter to meet mercury emission limits, or install an ESP to meet PM emission limits. The total national solid waste amounts in Table 5-1 were determined by adding the per unit solid waste estimates for all new and existing units, respectively. To estimate the solid waste contribution from each of these control devices, the variables were calculated based on characteristics reported for each model unit. The calculations used to estimate each variable and the quantity of solid waste generated are provided in another memorandum.[3]

The solid waste (dust, fly ash) generated by the use of an electrostatic precipitator was calculated when an electrostatic precipitator was determined to be necessary to meet the GACT emission limits for PM. Estimates of the solid waste collected in an ESP was based on several variables including: exhaust flow rate from the combustion unit to the control device (acfm); the inlet loading of particulate matter to the control device (gr/acfm); operating hours (hr/year) and the efficiency of the control device required to meet the PM emission limits in the proposed NESHAP.

The solid waste generated from the collection of dust and fly ash in a fabric filter was calculated when a fabric filter was determined to be necessary to meet the proposed NESHAP emission limits for particulate matter and/or mercury. The calculation required the use of three variables, including: exhaust flow rate from the combustion unit to the control device (dscfm); operating hours (hr/year) and the inlet loading of particulate matter to the control device (gr/acfm).

## 5.2 Electricity Impacts

The amount of electricity required to operate a control device was calculated for an electrostatic precipitator and fabric filter. These impacts were assessed for every unit that was estimated to require particulate matter control. Electricity requirements are one output of the cost algorithms used in the analyses, so no additional calculations were necessary. For some units, an electrical demand from multiple control devices was estimated. The total national electricity demand in Table 5-1 was determined by adding the per unit solid waste estimates for all new and existing units, respectively. To estimate the electricity demand from each of these control devices, a set of variables were calculated based on characteristics assigned to each model unit. The constants, variables, and calculations used to estimate each variable and the electricity demand to operate the control devices are provided in another memorandum.[3]

## 5.3 Energy Savings Impacts

The energy savings from combustion controls such as low NOx burners or linkageless boiler management systems, and work practice standards, including a tune-up, and implementing the energy audit findings with a short-term payback can improvements in efficiency, thereby reducing fuel consumption. Although these combustion improvements have been documented to achieve efficiency gains between 5 and 10 percent from the baseline operating conditions, this secondary impacts analysis estimates a 1 percent efficiency gain, to be conservative and consistent with the assumptions made in Section 3.1 of this memorandum. Quantifying the exact gains in efficiency from each of these work practice standards is difficult, and may depend on the baseline operating efficiency of each unit.

Section 3.1 discusses the fuel savings impacts in terms of annualized cost savings to each boiler, and the national energy savings presented in Table 5-1 of this section follows the same methodology as was discussed in Section 3.1 and reflect the savings from boilers in the coal and liquid fuel categories only.

## 5.4 Estimating Secondary Impacts for Regulatory Options 3E/3N

Regulatory Options 3E for existing and 3N for new units are both described in detail in Section 2 of this memorandum. For the secondary impacts analysis at existing units under option 3E, the waste and electricity impacts were only assessed for large units (those greater than or equal to 10 mmBtu/hr) that are in the coal subcategory. Secondary impacts of solid waste and electricity were not assessed for the liquid and biomass subcategories because these boilers were not subject to PM or Hg numerical emission limits and were not expected to install add-on controls. Energy savings were estimated for all units firing anything other than biomass since all units were expected to conduct a tune-up or install combustion controls.

For new units under option 3N, the solid waste and electricity impacts were assessed for any size unit firing coal, liquid, or biomass. A one percent energy savings was estimated for all units firing coal or liquids that were estimated to require a tune-up to meet the CO limits from new boilers. Both tune-ups and combustion controls improve the efficiency of the unit, thereby reducing energy consumption.

## 6.0 REFERENCES


1. Singleton, A., ERG. MACT Floor Analysis for the Industrial, Commercial, Institutional Boilers National Emission Standards for Hazardous Air Pollutants – Area Source. April, 2010.

2. Singleton, A., ERG. New Unit Analysis Industrial, Commercial, and Institutional Boilers National Emission Standards for Hazardous Air Pollutants – Area Source. April, 2010.

3. Singleton, A., ERG. Methodology for Estimating Control Costs for Industrial, Commercial, Institutional Boilers National Emission Standards for Hazardous Air Pollutants – Area Source. April, 2010.

4. Singleton, A., ERG. Methodology for Estimating Control Costs for Industrial, Commercial, Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants – Major Source. April, 2010.

5. Gibson, G. and A. Singleton, ERG. Development of Baseline Emission Factors for Boilers and Process Heaters at Commercial, Industrial and Institutional Facilities. April, 2010.

6. Singleton, A., ERG. Methodology for Developing Model Units for Industrial, Commercial, and Institutional Boilers National Emission Standards for Hazardous Air Pollutants – Area Source. April, 2010.

7. U.S. Department of Energy. Energy Information Administration. Annual Energy Outlook 2006 (Early Release) with Projections to 2030. Figure 3. Energy Consumption by Fuel, 1980-2030 (quadrillion Btu).

8. Delta Institute. Sector-*Based Based Pollution Prevention: Toxic Reductions through Energy Efficiency and Conservation Among Industrial Boilers.* July 2002. Located online at http://www.delta-institute.org/publications/boilers/SectorBasedP2.pdf