Climate Policy and Energy-Intensive Manufacturing

Impacts and Options

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Acknowledgements

Authors Note

Most of our research and much of the writing of this report occurred prior to the current worldwide financial crisis and economic recession. We have attempted to incorporate some of these trends in our models, and whenever possible address their implications in our industry analyses. However, the report primarily focuses on the long-standing economic challenges that have faced the industries analyzed, and on their future opportunities to offset potential negative impacts of climate legislation. Despite the crisis, we believe the overall direction and general conclusions of the report remain valid, if they are not even more relevant to understanding the future competitiveness of U.S. manufacturing in a carbon-constrained world.

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Executive Summary

The Obama administration and Congress have begun to grapple with crafting legislation that addresses the looming threat of global warming while reducing America's dependency on foreign sources of energy. As attention turns to this debate, however, policymakers are confronting the challenge of how to design policies that maintain and enhance the competitiveness of America's manufacturing industries by promoting improvements in energy efficiency, while also reducing greenhouse gas emissions. Meeting this challenge is especially important if the United States is going to preserve its capacity in critical energy-intensive industries—such as iron and steel, aluminum, paper, and chemicals—which form the cornerstone of the nation's industrial base. These basic industries supply the materials used in almost every sector of the economy, from construction and transportation to a myriad of industrial and consumer products. They are also among the most sensitive industries to rising energy costs and international competition.

The story of the Flambeau Rivers Paper, a paper mill located in the heart of a Northern Wisconsin forest, both exemplifies this challenge and illustrates the real potential for successfully addressing it. In 2006, the town of Park Falls, with 3,000 residents, was in trouble. Its major employer, a paper and pulp mill located along the Flambeau River, closed, costing 300 workers their jobs. Originally built in 1896, the plant's equipment was antiquated and it used an expensive and outmoded process to make pulp. In recent years, higher energy prices combined with rising international competition and stagnant demand forced the owners of this mill to declare bankruptcy.

Two years later, with the help of state loans and private investors, the mill reopened, its restart enabled by investments in new biomass-energy boilers, making it the first fossil-fuel free, energy independent, integrated pulp and paper mill in North America. It also reemployed almost all of the workers originally laid-off at the same previous pay and benefits. Moreover, the Flambeau River mill is moving towards becoming the first modern U.S.-based pulp mill biorefinery to produce cellulosic ethanol. Not only would the new biorefinery have

a positive carbon impact of about 140,000 tons per year, it would create an additional 100 new jobs in the Park Falls area.[1]

Like many other American manufacturers, the Flambeau River mill faced volatile energy prices, intense international competition, a lack of capital, and aging equipment. Nevertheless, its success in turning itself into an energy-efficient, carbon-free competitive enterprise illustrates that new opportunities are being created as well. This suggests that policies requiring mandatory reductions in greenhouse gas (GHG) emissions, such as a cap-and-trade program, need not have devastating effects on American manufacturing, as some fear.

Indeed, a climate policy that puts on a price on carbon dioxide (CO$_2$) and other greenhouse gas emissions could promote energy efficiency gains throughout economy, as well spawn new industries and generate new jobs. However, making the transition to a low-carbon economy will not be without costs. Moreover, it would require the right kinds of supporting public policies and serious industry commitments to invest in such transformations.

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[1] Glenn Ostle, "Reopened Flambeau River Papers targets energy independence," *Paper360°,* December 1, 2006, 12-16; "Flambeau River BioFuels Gets OK for Biorefinery Project," *PaperAge,* July 15, 2008, http://www.paperage.com/2008news/07_15_2008flambeau_river.html.

Climate Policy and Manufacturing Study

The study presented in this report, conducted by High Road Strategies, LLC in collaboration with the Millennium Institute (referred to as the "HRS-MI study"), was undertaken to better understand the implications of enacting a climate policy for the energy-intensive manufacturing sector. Specifically, our objective was to examine the impacts of energy price changes resulting from CO_2-pricing policies on the competitiveness of five energy-intensive industries—iron and steel, aluminum, paper and paperboard, chlor-alkali, and petrochemicals—that are among the largest industrial consumers of fossil fuels in the American economy. We also did a preliminary evaluation of potential options to mitigate these impacts, including energy-saving and low-carbon technology investments and cost-mitigating policy measures.

Employing the *Integrated Industry-Climate Policy Model* (II-CPM), a computer-based system dynamics model developed by the HRS-MI team—supplemented by econometric and qualitative analyses—we investigated three questions:

- How will climate policy-driven energy price increases affect the production costs of manufacturers in energy-intensive manufacturing sectors?

- In the face of energy-driven cost increases, and constraints on manufacturers' ability to pass these costs along to consumers, how will international competition affect the industry's competitiveness (i.e., profitability and market share)?

- How will manufacturers respond to the energy price increases and possible threats to their competitiveness? For example, would firms adopt new energy-saving practices and technologies, expand or reduce production capacity, or move operations or plants offshore?

How will climate policy-driven energy price increases affect the production costs of manufacturers in energy-intensive manufacturing sectors?

Climate Change and Competitiveness

A number of proposals aimed at reducing GHG emissions in the U.S. have been introduced and debated in Congress over the past few years. Under these proposals, a mandatory cap would be placed on the total amount of greenhouse gases that could be emitted, generally tightening over time to meet long-term emission reduction goals.

The resulting increase in fossil fuels prices would prompt a shift towards the use of lower-carbon fuels, especially in electricity generation and in industrial processes. It would also encourage energy-efficiency gains in all sectors of the economy, thereby lowering GHG emissions.

But these gains would not come without transitional costs, especially in the sectors most heavily reliant on carbon-based fuels. Of particular concern are what impacts these policies would have on the U.S. manufacturing base, which has undergone significant capacity and job losses for well over a decade, accompanied by a growing trade deficit.

Industry groups and labor unions have raised concerns about the competitive disadvantages a climate policy might impose on U.S. manufacturing—especially energy intensive sectors. For example, iron and steel industry groups have argued that American manufacturing is at "a distinct disadvantage in global competition... due to dramatically rising costs associated with energy."[1] They warn that a mandatory cap-and-trade program would consequently hurt the competitiveness and viability of the domestic steel industry. Some worry that their industry is approaching the physical limits of energy efficiency for the processes it operates today. To adjust to rising energy prices, it would need to adopt costly "new and transformational steelmaking technologies to achieve major additional reductions."[2]

Similarly, although most labor unions today favor enacting a comprehensive climate policy, industry impacts and international competition remain under scrutiny. Labor leaders have longstanding concerns about the impacts of policies on the competitiveness of our economy and especially on workers involved in the manufacturing of energy-intensive industry products. They argue that climate policies should not encourage off-shoring of manufacturing or the sale of assets, and warn against "carbon leakage", which results when companies move their production to regions of the world without comparable GHG emissions reduction commitments. As Robert Baugh, executive director of the American Federation of Labor-Congress of Industrial Organizations (AFL-CIO) Industrial Union Council (IUC) and co-chair of the AFL-

CIO Energy Task Force, testified before the U.S. Senate Environment and Public Works Committee in 2007, "it is not in our national interest to see our efforts to reduce carbon emissions become yet another advantage that a developing nation uses to attract business."[3]

In recent years the attention devoted to climate change and its impacts, as well as the consequences of the financial and economic crisis currently underway, have contributed to change the way labor unions, industries, and policymakers approach climate policies. They all are concerned about reviving the U.S. manufacturing sector and keeping domestic jobs. But they now see an opportunity to modernize and make U.S. industries more energy efficient under a set of comprehensive and fair domestic and international climate policies.

THE ATTENTION DEVOTED TO CLIMATE CHANGE AND ITS IMPACTS HAVE CONTRIBUTED TO CHANGE THE WAY LABOR UNIONS, INDUSTRIES, AND POLICYMAKERS APPROACH CLIMATE POLICIES.

RESEARCH APPROACH

To carry out the HRS-MI study, we developed detailed economic and energy profiles of several manufacturing industries, entailing the collection and processing of historical economic data. We then constructed system dynamics models, supported by stakeholder group modeling sessions, to simulate the impacts of a climate policy on these sectors.

Specifically, the study compared the *Lieberman-Warner America's Climate Security Act of 2008* (S. 2192), referred to in the report as the "Mid-CO$_2$ Price Policy," to a Business As Usual (BAU) case that assumed

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[2] The American Iron and Steel Institute (AISI), the Steel Manufacturers Association (SMA) and the Specialty Steel Industry of North America (SSINA), "Submission On behalf of Our U.S. Member Companies, To The U.S. Department of Commerce (DOC), In Connection with The DOC's Review of U.S. Manufacturing and The Need to Develop and Implement A Pro-Manufacturing Policy Agenda," Washington, D.C., August 15, 2003.

[3] American Iron and Steel Institute (AISI), "Climate Change Priorities" *2007 Public Policy Agenda,* Washington, DC, February 22, 2007, 8-10.

[4] Robert C. Baugh, "A 21st Century Energy Policy for Environmental and Economic Progress, Testimony Before the Environment and Public Works Committee for the U.S. Senate," July 25, 2007.

therefore are indicators of an industry's profitability (see Box ES-I).

Cost Pass-Along Scenarios.

According to economic studies and industry experts, the ability of these industries to pass along policy-driven costs is generally constrained, especially in the short-to-medium run, depending on economic conditions and the strength of market demand. Indeed, the evidence suggests that the no cost pass along scenarios would more realistically represent the energy-intensive industries' market situation under a climate policy. Nevertheless, to provide a full spectrum of possible industry responses to energy costs increases, we simulated the Mid-CO_2 Price Policy relative to BAU assuming that the 100 percent of the additional energy costs are passed along by industries (the "cost-pass-along" scenario, or CPA). The model outputs included production costs, operating surpluses and margins, and domestic and import market shares and production outputs.

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no climate policies are enacted into law throughout the study period (1992-2030). The EIA's analysis of the Lieberman-Warner bill projects the inflation-adjusted (USD 2006) allowance price to be $30 per metric ton of CO_2-equivalent by 2020 and $61 by 2030.[5] The policy case was assumed not to go into effect until 2012. The energy price projections used in this study—for electricity and five fuel types, (metallurgical coal, natural gas, liquid petroleum gas, residual fuel and distillate fuel)—correspond to the EIA's Lieberman-Warner analysis (see Table ES-A).

Core Scenarios. Using the II-CPM, we conducted simulations estimating the impacts of the Mid-CO_2 Price Policy relative to BAU on six industries (primary and secondary aluminum, iron and steel and ferroalloy products, paper and paperboard, petrochemicals, and chlor-alkali), with the assumption that the industries did not pass additional energy costs along to their customers (the "no cost pass-along" scenario, or NCPA). In addition to measuring energy and production cost impacts in the simulations, we defined two new variables: the *operating surplus,* to serve as a proxy for an industry's profits, and the *operating margin,* as a proxy for its profit margin, and

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[5] U.S Department of Energy, Energy Information Administration (EIA), *Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007* [SR/OIAF/2008-01] (Washington, DC, April 2008), xii, table ES3.

Carbon-Based Fuels and Electricity Price Scenarios Mid-CO_2 Price and BAU Cases

($2000/MBtu and % above BAU)

Energy Source	Real Energy Prices ($2000)		
	BAU 2006	Mid-CO_2 Price	
		2020	2030
Electricity	15.42	16.09	17.11
Percent above BAU	—	*8.6*	*13.1*
Natural Gas	6.57	6.51	8.69
Percent above BAU	—	*22.2*	*39.0*
Metallurgical Coal	3.04	6.01	8.65
Percent above BAU	—	*104.7*	*180.0*
Liquefied Petroleum Gas	16.91	14.48	15.25
Percent above BAU	—	*0.5*	*-0.1*
Coal Coke	9.11	18.02	25.94
Percent above BAU	—	*104.7*	*180.0*
Residual Fuel	7.77	9.01	11.81
Percent above BAU	—	*26.7*	*43.1*
Distillate Fuel	13.15	14.31	17.30
Percent above BAU	—	*14.1*	*24.0*

Source: EIA, HRS-MI

Operating Surplus and Operating Margin Defined

At the unit of production level, the **operating surplus** is defined as the difference between an industry's aggregate market price and its unit production cost. For each industry, the II-CPM generated operating surplus and margin projections for the climate policy case and the BAU scenario. At the industry output level, the total operating surplus was calculated by subtracting total production costs from total industry revenues for a given year.[6] The **operating margin** is defined as the ratio of an industry's total operating surplus and total revenues.

The operating surplus includes several overhead-related costs (such as sales, general and administrative (SG&A) costs), depreciation, interest on capital, and other expenses that could be considered part of the industry's fixed production costs, and profits and taxes not yet paid out. When a firm's operating surplus and margin is reduced as a result of increased production costs, this generally leads to lower profits, at least over the short-run unless administrative costs are reduced, as well.

[6] Total production costs equals total production output multiplied by unit production costs. Total industry revenues equals production output multiplied by market price.

These results were used to inform preliminary analyses of investment and policy options for the different industries. Although investment options were not directly modeled, we calculated energy-efficiency improvements needed to offset the increasing energy costs from a climate policy. We also modeled an allowance allocation scenario, wherein allowances are distributed to energy-intensive industries to mitigate a portion of the increased energy prices. This work included the following assessments:

Energy-efficiency requirements—for each industry, estimates of the energy efficiency gains required to offset increased energy costs under a climate policy.

Technology investment options—review of the principal near-, mid- and long-term technology options available to reduce energy use, improve efficiency, and offset higher production costs arising from a climate policy.

Ninety percent allocation policy option—simulations of a policy option that would allocate to each of the industries allowances mitigating 90 percent of the additional costs incurred as a result of a climate policy.

Additional scenarios and sensitivity analyses were simulated to examine changes in the II-CPM outputs resulting from variations in key assumptions, under different economic conditions and scenarios.

SUMMARY OF FINDINGS

The results of the HRS-MI study show that climate change policies that put a price on CO_2 and other greenhouse gas emissions in the economy, when applied only in the United States and with no relevant energy efficiency investments, could have substantial impacts on the competitiveness of U.S. energy-intensive manufacturing industries over the next two decades. On the other hand, we also found that technology investment and policy options exist that could mitigate the industries' policy-related cost increases, improve their

energy-efficiency, and ultimately enhance their economic performance. More research is needed, however, to further explore and analyze these options, as well as other policies that could preserve and strengthen this vital part of the nation's manufacturing base while reducing the threat of global warming.

Our findings support the following general conclusions:

Climate policies that impose a modest to high cost on carbon-based energy sources would increase most of the energy-intensive industries' production costs, reduce their operating surpluses and margins, and shrink their domestic market shares. This assumes that no investments or actions are made to mitigate or offset the additional cost impacts. These results also are contingent on each industry's future energy mix and reliance on fossil fuels.

Since these industries typically are constrained in their ability to pass along domestic policy-driven energy costs (because of international competition, market conditions, the nature of their markets, and other factors), **they likely would feel increasing pressure to take actions to reduce their costs and prevent their profitability from decreasing to undesired levels.**

The adoption of both readily available and more cutting-edge technology, and the achievement of high energy efficiency at a large scale could offset increased costs and generate additional profits. All the industries investigated are exploring a range of energy-saving technologies that could help mitigate these impacts, but face financial, technological, and other limitations (such as the age and sunk costs of their existing equipment) on their ability to successfully invest and adopt these alternatives over the short-to-mid-term.

An allowance allocation policy that substantially offsets energy cost impacts, at least through 2025, could buy time for these industries to make the adjustments and energy-saving technology investments required for maintaining their domestic production capacity and competitiveness. On the other hand, if industries do not invest early enough, making use of the time window provided by the allowance allocation, they could face even harder times toward 2025-2030.

Other policies, nevertheless, will likely be needed to encourage and enable industries to make these investments, as an alternative to cutting production or moving their operations to low-cost, low-regulation locations.

Production Costs

Energy price increases in the Mid-CO_2 Price Policy would drive up total production costs in the energy-intensive industries. Table ES-B shows, though, that these impacts would vary considerably across the industries. The iron and steel industry would see the largest real production cost increases of all the industries analyzed, growing from 4 percent above BAU by 2012 to over 11 percent by 2030, while secondary aluminum and petrochemicals would experience the most modest cost impacts, rising only to a little under 2 percent by 2030.

Operating Surplus

The II-CPM projections of the impacts on industries' *operating surpluses*—a proxy for their profits—incorporated the market dynamics associated with international

CLIMATE POLICIES THAT IMPOSE A MODEST TO HIGH COST ON CARBON-BASED ENERGY SOURCES WOULD INCREASE MOST OF THE ENERGY-INTENSIVE INDUSTRIES' PRODUCTION COSTS, REDUCE THEIR OPERATING SURPLUSES AND MARGINS, AND SHRINK THEIR DOMESTIC MARKET SHARES.

Real Unit Production Costs Above BAU, Mid-CO$_2$ Price Policy

Industry Sector (Unit)	2012		2020		2030	
	$2000	Percent	$2000	Percent	$2000	Percent
Primary Aluminum (mt)	38	2.2	40	2.6	64	4.6
Secondary Aluminum (mt)	7	0.5	10	0.8	19	1.7
Iron & Steel & Ferroalloys (ton)	29	4.0	50	6.7	90	11.4
Paper & Paperboard (ton)	11	2.1	17	4.0	31	8.7
Petrochemicals (ton)	3	0.6	5	1.0	9	1.5
Chlor-Alkali (mt)	4	3.6	6	5.5	10	9.9

mt=metric ton

competition. These results show what might happen if manufacturers make no adjustments to their outputs or invest in new energy-saving technologies to offset cost increases.

As Figure ES-1 shows, every industry in the study would see an operating surplus decline relative to BAU under the Mid-CO$_2$ Price Policy, although in absolute terms the operating surplus would still be positive for all industries. As noted above, these scenarios assumed no major new investments are undertaken to improve efficiency, and that no complimentary policies are implemented to mitigate increased energy costs.

Not surprisingly, the industries with the greatest production cost increases associated with higher energy costs, also would suffer the largest operating surplus and operating margin declines. These include iron and steel, paper and paperboard, and chlor-alkali, followed by primary aluminum.

> **Manufacturers have several options when confronted with higher production costs, including investments in energy-saving technologies.**

Investment Options

Manufacturers have several options when confronted with higher production costs, including investments in energy-saving technologies. A review of near-, mid-, and long-term energy efficiency opportunities available to the industries suggests that a number of such technology options exist for each industry. The II-CPM enabled estimations of the energy efficiency gains that would be needed in each industry to offset the energy cost impacts from climate policies. These calculations, summarized in Figure ES-2, include the gains that would be required in the use of energy fuels, electricity and energy feedstocks. The estimates first involved calculating the energy equivalent for the incremental cost increases arising from a climate policy. For any given year after the policy went into effect, this amount was divided by the total energy consumption through that year, to give the energy efficiency gains needed to

offset the cost increases.

Over the short run, these options might be limited, as many of the industries already have invested over the years in substantial energy-efficiency gains. On the other hand, we found that relatively low-cost incremental improvements in energy efficiency and savings are possible over the near-to-mid term, such as more combined-heat and power (CHP) generation; relined boilers; enhanced heat recovery; improved sensors and process controls; more efficient electric motors, pumping systems and compressed air systems; and improved recycling technologies, among other measures. These improvements could result in small, steady energy-efficiency gains, offsetting some of the added costs from a climate policy. However, the energy-efficiency analysis indicates that

much larger gains, requiring substantial investments in advanced low- or no-carbon production processes would be necessary over time.

To varying degrees, the industries have been supporting research and development on advanced production and process technologies that could result in significant energy savings (Table ES-C). However, several barriers to commercialization and deployment of these and other important technologies remain. First, it may be many years before most of these technologies are proven to be technically and commercially feasible, and cost effective from manufacturers' point of view, even with higher energy costs. Second, these technologies mostly involve installing large, expensive pieces of equipment, requiring fairly substantial infusions of new capital

RELATIVELY LOW-COST INCREMENTAL IMPROVEMENTS IN ENERGY EFFICIENCY AND SAVINGS ARE POSSIBLE OVER THE NEAR-TO-MID TERM, SUCH AS MORE COMBINED-HEAT AND POWER (CHP) GENERATION.

FIGURE ES-1
MID-CO$_2$ PRICE CASE REAL OPERATIONG SURPLUS RELATIVE TO BAU COMPARING ALL INDUSTRIES [NCPA]
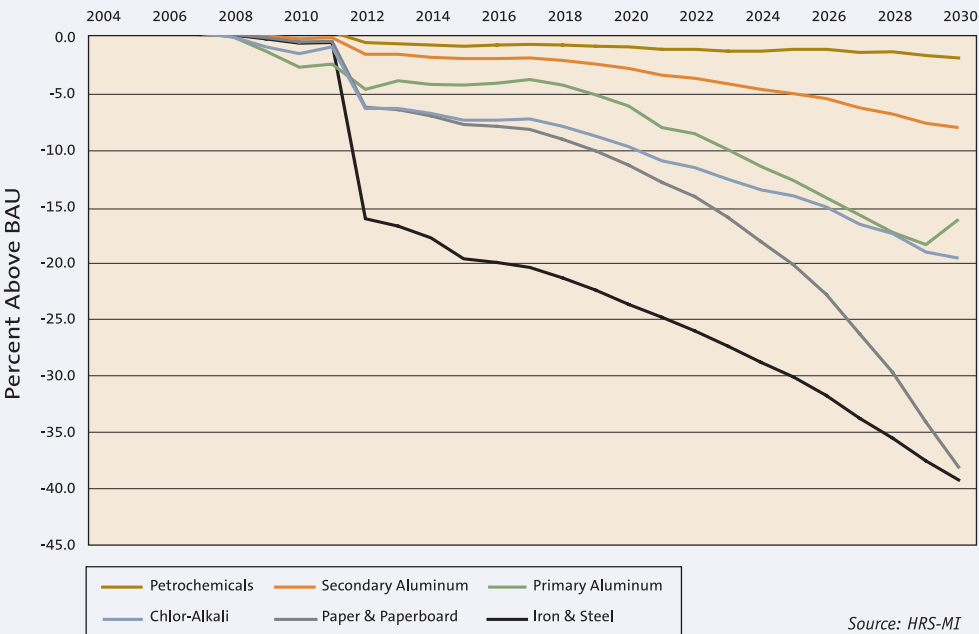
Source: HRS-MI

Figure ES-2

Energy Efficiency Gains Required by 2020 (Cumulative) Mid-CO₂ Price Policy Case [Percent of BAU]

		Percent
Iron & Steel	Fuel	34.2
	Electricity	6.6
	Feedstock	42.1
Primary Aluminum	Fuel	13.4
	Electricity	6.6
Secondary Aluminum	Fuel	14.7
	Electricity	6.6
Paper & Paperboard	Fuel	22.9
	Electricity	6.6
Petro-chemicals	Fuel	12.9
	Electricity	6.6
	Feedstock	1.3
Chlor-Alkali	Fuel	14.2
	Electricity	6.6
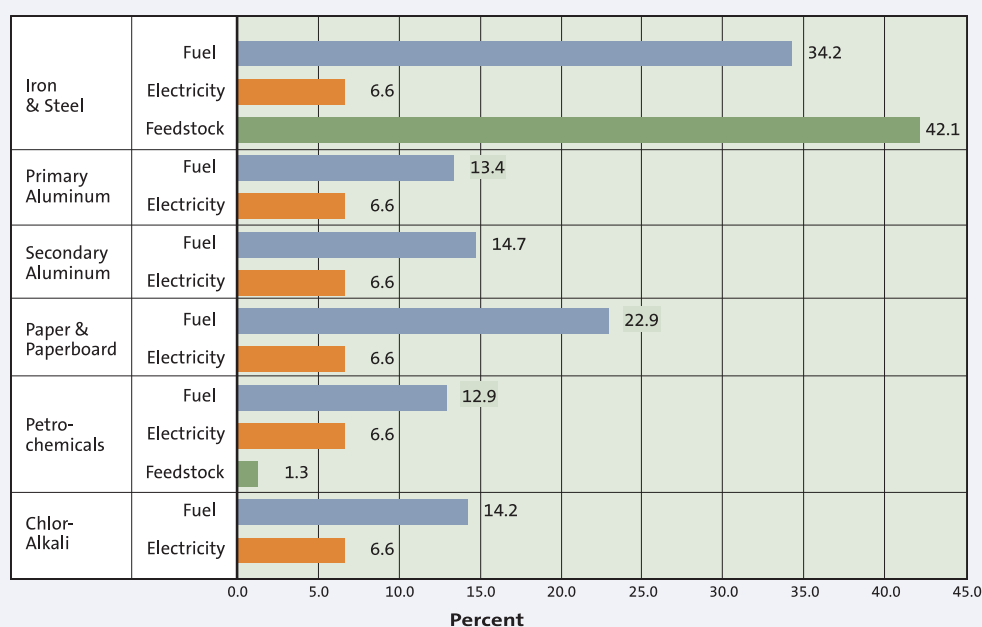
HRS-MI

ADDITIONAL POLICIES WOULD LIKELY BE NEEDED TO SUPPORT TIMELY INVESTMENT IN ENERGY EFFICIENCY AND RETROFITTING OF LESS ADVANCED PRODUCTION FACILITIES.

investments, by industries that chronically complain about a lack of capital. Finally, the vintage of existing equipment, machinery and facilities in these industries will dictate when manufacturers will be willing to replace aging production capacity with new, more energy-efficient technologies.

Additional policies would likely be needed to support timely investment in energy efficiency and retrofitting of less advanced production facilities. Also, more research is needed to assess the industries' potential to adopt new energy-savings technologies and whether or not this would be sufficient to offset the impact of higher energy prices for different climate policies. Finally, we need a better understanding of the financial and market conditions—that is, the "business case"—that would motivate and justify

manufacturers' investments in advanced low-carbon production technologies.

Allowance Allocation Option

We also conducted a preliminary examination of policies for mitigating the impacts of CO₂-pricing policies on energy-intensive manufacturers. Specifically, we used the II-CPM models to evaluate a policy that would allocate free emission allowances equal to 90 percent of the increase in energy costs. Companies could then sell these allowances to offset their increased energy costs. The number of

Technology Options for Reducing Energy Use and CO$_2$ Emissions

Technology Option	Description	Time-frame
Iron & Steel		
Pulverized coal and plaste waste injection	Pulverized coal is already used by more than 50% of U.S. BOFs	ST-MT
New reactor designs	Uses coal and ore fines (COREX, FINEX)	MT
Paired straight hearth furnace	Substitutes coal for coke in blast furnaces, lower costs, uses 2/3 energy	MT-LT
Molten oxide electrolysis	Produces iron and oxygen, no CO$_2$	LT
Hydrogen flash melting	Uses hydrogen in shaft furnaces, no CO$_2$	MT
Geological sequestration + steelmaking		MT-LT
Paper and Paperboard		
Black liquor gasification	In demonstration, R&D; commercially available 2030; 15%-23% gain	MT-LT
Efficient drying technology	R&D now; commercial demo, 2015-2030; commercial 2030-->	MT-LT
Primary Aluminum		
Wetted, drained cathode technology		MT
Alternative cell concepts	Combines inert anode, drained cathodes	LT
Carbothermic and kaolinite reduction process on commercial scale	Alternatives to the Hall-Héroult process	LT
Petrochemicals		
High-temperature furnaces	Able to withstand more than 1,100°C	MT-LT
Gas-turbine integration	Higher-temperature CHP for cracking furnace	MT-LT
Advanced distillation columns		MT-LT
Combined refrigeration plants		MT-LT
Biomass-based system options	Feedstock substitution	LT
Chlor-Alkali Manufacturing		
Convert mecury-process and diaphragm-process plants to membrane technology	Combined electrolytic cell with a fuel cell, using hydrogen by-product	MT-LT

ST=Short Term (Current Year-2015); MT=Medium Term (2015-2030); LT=Long Term (2030-2050)
Sources: IEA, DOE, AISI, Aluminum Assocation, Korean Energy Institute

Real Operating Surplus Above BAU (%)
90 Percent Allocation Policy vs. No
Allocation Case, Mid-CO$_2$ Price Case [NCPA]

Industry Sector	2020		2030	
	No Allocation	90% Allocation	No Allocation	90% Allocation
Primary Aluminum	-6.4	-1.7	-16.5	-7.6
Secondary Aluminum	-3.1	-0.8	-8.3	-3.8
Iron & Steel	-24.0	-6.2	-39.6	-18.2
Paper & Paperboard	-11.7	-3.0	-38.4	-17.7
Petrochemicals	-1.2	-0.3	-2.2	-1.0
Chlor-Alkali	-10.0	-2.6	-19.9	-9.2

PROVIDING FREE ALLOCATIONS, AT LEAST FOR THE NEAR-TO-MID TERM, WOULD GREATLY LESSEN THE COST PRESSURES ON THESE INDUSTRIES THAT MIGHT OTHERWISE LEAD TO PRODUCTION CUTBACKS DOMESTICALLY.

allowances that are distributed would decrease 2 percent annually. The results showed that, for each of the industries, the declines in operating surplus would be reduced by nearly three-quarters under the allocation scenario compared to the non-allocation case by 2020, and by roughly 50 percent by 2030. As Table ES-D shows, every industry would benefit from the same large gains if the allocation allowance measure were enacted. (Note: This scenario assumes no new investments in energy efficiency improvements).

Allocating allowances to firms also substantially decreases the efficiency improvements needed to offset increased energy costs, allowing more time to develop and deploy advanced technologies (see Figure ES-3). By 2020, these requirements for the different energy sources (fuel, electricity, feedstock) with the allocation would be diminished by from 70 to over 80 percent across the industries compared to the no allocation case. Nevertheless, for iron and steel at least, some requirements would still be significant though achievable. For example, by 2020, the required fuel and feedstock efficiency gains would be 9 percent and 12 percent in the 90 percent allocation scenario, compared to 34 percent and 42 percent, respectively, without an allocation. The implication of these findings is that providing free allocations, at least for the near-to-mid term, would greatly lessen the cost pressures on these industries that might otherwise lead to production cutbacks domestically.

Conclusions

Manufacturing remains a vital part of the American economy. Many business, labor, and political leaders are rightly concerned that climate policies may contribute to the erosion of U.S. manufacturing competitiveness. This challenge is especially acute for energy-intensive basic materials manufacturing industries, which form the cornerstone of the nation's manufacturing base. There is particular concern about climate policy impacts on this sector, which is especially vulnerable to both rising energy costs and global competition. A primary goal of climate policy, therefore, should be to help energy-intensive industries reduce their dependence on fossil-fuels while improving their productivity and competitiveness in global markets.

The findings presented in this report show that climate policies that price CO_2 could have significant impacts on the competitiveness of U.S. energy-intensive manufacturing sectors over the next two decades if climate regulations are applied only in the United States, and no action is taken to invest in advanced low- and no-carbon technologies or otherwise mitigate the cost impacts on these industries. The extent of these impacts would vary across industries, depending on their energy-intensities, the mix of energy sources they rely on (electricity, natural gas, coal), and how energy is used in production activities (heat and power, feedstock). An industry's

Many business, labor, and political leaders are rightly concerned that climate policies may contribute to the erosion of U.S. manufacturing competitiveness.

Figure ES-3
Energy Efficiency Gains Required by 2020 (Cumulative) Mid-CO₂ Price Policy Case, 90% Allocation [Percent of BAU]

Industry	Category	Percent
Iron & Steel	Fuel	9.1
	Electricity	1.3
	Feedstock	12.3
Primary Aluminum	Fuel	2.8
	Electricity	1.2
Secondary Aluminum	Fuel	3.2
	Electricity	1.3
Paper & Paperboard	Fuel	5.3
	Electricity	1.3
Petro-chemicals	Fuel	2.7
	Electricity	1.3
	Feedstock	.2
Chlor-Alkali	Fuel	3.0
	Electricity	1.3

Percent

HRS-MI

an allocation of a 90 percent allowance, reduced by 2 percent yearly, a substantial decrease in efficiency improvements would be needed to offset increased energy costs, allowing more time to develop and deploy advanced technologies. Furthermore, with such an allocation, declines in operating surplus for the Mid-CO_2 Price Policy, would be reduced by nearly three-quarters by 2020, and by roughly 50 percent by 2030.

In short, our findings strongly suggest that over the long-run, technologies are available to enable energy-intensive industries to achieve sufficient efficiency gains to offset and manage the additional energy costs arising from a climate policy. However, we also strongly believe that **the industries analyzed will need additional measures that both mitigate these cost impacts in the short-to-medium term, and policies that encourage and facilitate the transition of energy-reliant companies (and their employees) to a low-carbon future, while enhancing their competitiveness in global markets.**

sensitivity to foreign imports and its ability to pass through cost increases to its customers in the face of international market competition are also major factors.

Our results also show that the energy efficiency gains required to offset the energy cost impacts from climate policies for energy fuels used for heat an power would range from 14 percent to 34 percent, by 2020. Iron and steel and paper and paperboard, in particular, would require the largest energy fuel efficiency gains. We also estimated that the former would require as much as a 42 percent gain in feedstock consumption. While relatively low-cost incremental improvements in energy use are possible over the near-to-mid term, much larger gains, requiring substantial investments in advanced low- or no-carbon production processes, would be necessary over time.

Our findings further suggest that policy measures that mitigate the short- to mid-term cost impacts of climate policy would buy time for—and, if coupled with appropriate policies, encourage—energy-intensive manufacturers to make the transition to low-carbon production processes. In particular, we found that with

POLICY MEASURES THAT MITIGATE THE SHORT- TO MID-TERM COST IMPACTS OF CLIMATE POLICY WOULD BUY TIME FOR—AND, IF COUPLED WITH APPROPRIATE POLICIES, ENCOURAGE— ENERGY-INTENSIVE MANUFACTURERS TO MAKE THE TRANSITION TO LOW-CARBON PRODUCTION PROCESSES.

INTRODUCTION

Nestled in the heart of a Northern Wisconsin forest, the small town of Park Falls, with only 3,000 residents, was in trouble. In 2006, the town's major employer, a pulp and paper mill located along the Flambeau River, closed, costing 300 workers their jobs. The mill, originally built in 1896, had been having difficulties for several years. Its equipment was antiquated and it used an expensive and outmoded process to make pulp. Ultimately, higher energy prices combined with rising international competition and stagnant demand forced Smart Papers, owners of this mill, to declare bankruptcy.

Two years later, with the help of state loans and private investors, the mill reopened under new owners with a new name, Flambeau River Papers. The mill's restart was enabled by investments in new biomass-energy boilers, making it the first fossil-fuel free, energy independent, integrated pulp and paper mill in North America.

It has reemployed almost all of the workers laid-off by Smart Papers at the same previous pay and benefits. The new company also forged an agreement with Swedish-owned CellMark, the world's largest paper and pulp marketing company, to buy 100 percent of its production. Moreover, the Flambeau River mill is moving towards becoming the first modern U.S.-based pulp mill biorefinery to produce cellulosic ethanol. Not only would the new biorefinery have a positive carbon impact of about 140,000 tons per year, it would create an additional 100 new jobs in the Park Falls area.[1]

The Flambeau River Papers' story exemplifies the challenges facing many American industries—volatile energy prices, intense international competition, a lack of capital, and aging equipment. Nevertheless, the Flambeau River mill's success in turning itself into an energy-efficient, carbon-free competitive enterprise illustrates that new opportunities are being created as well. This suggests that policies requiring mandatory reductions in greenhouse gas (GHG) emissions, such as a cap-and-trade program, need not have devastating effects on American manufacturing. Indeed, a climate policy that puts on a price on carbon dioxide (CO_2) and other greenhouse gas emissions would promote energy efficiency gains throughout the economy, as well as spawn new industries and generate new jobs. However, making the transition to a low-carbon economy will not be without costs. Moreover, it would require the right kinds of supporting public policies and serious industry commitments to invest in such transformations.

The challenge confronting policymakers is how to design policies that maintain and enhance the competitiveness of America's manufacturing industries by promoting

improvements in energy efficiency, while also reducing greenhouse gas emissions. Meeting this challenge is especially important if the United States is going to preserve its capacity in critical energy-intensive industries—such as iron and steel, aluminum, paper, and chemicals—which form the cornerstone of the nation's industrial base. These basic industries supply the materials used in almost every sector of the economy, from construction and transportation to a myriad of industrial and consumer products. They are also among the most sensitive industries to rising energy costs and international competition.

To date, however, only a small number of studies have attempted to evaluate the impacts of climate policies on these industries, much less examining policies that would mitigate these costs while enhancing competitiveness. Most studies of climate policy impacts have employed traditional economic models and analytical approaches, primarily aimed at measuring the macroeconomic consequences of climate policies. With some exceptions, they have only been capable of assessing industrial sectors at a high level of aggregation. Few studies have attempted to examine—and even less have tried to quantify—the impacts on costs, markets, production, and investments associated with climate policies

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[1] Glenn Ostle, "Reopened Flambeau River Papers targets energy independence," *Paper360°*, December 1, 2006, 12-16; "Flambeau River BioFuels Gets OK for Biorefinery Project," *PaperAge*, July 15, 2008, http://www.paperage.com/2008news/07_15_2008flambeau_river.html.

at individual industry levels, especially for energy-intensive manufacturing industries. Yet such analyses are needed to provide policymakers a fuller understanding of the implications of climate policies for the nation's industrial base, and to craft measures for mitigating these impacts.

The study presented in this report, conducted by High Road Strategies, LLC in collaboration with the Millennium Institute[2] (referred to as the "HRS-MI study"), was undertaken to help address this gap. Specifically, our objective was to examine the impacts of energy price changes resulting from CO_2-pricing policies on the competitiveness of five energy-intensive industries—iron and steel, aluminum, paper and paperboard, chlor-alkali, and petrochemicals—that are among the largest industrial consumers of fossil fuels in the American economy. In the study, we also do a preliminary evaluation of potential options to reduce the adverse effects of these impacts, including energy-saving and low-carbon technology investments and cost-mitigating policy measures. Our hope is that the results presented here will shed light on the impacts of climate policies on energy-intensive manufacturing, in general, as well

as other industries in this sector, such as cement and ceramics.

Employing the *Integrated Industry-Climate Policy Model* (II-CPM), a computer-based system dynamics model developed by the HRS-MI team—supplemented by econometric and qualitative analyses—we investigated three questions:

• How will climate policy-driven energy price increases affect the production costs of manufacturers in energy-intensive manufacturing sectors?

• In the face of energy-driven cost increases, and constraints on manufacturers' ability to pass these costs along to consumers, how will international competition affect the industry's competitiveness (i.e., profitability and market share)?

• How will manufacturers respond to the energy price increases and possible threats to their competitiveness? For example, would firms adopt new energy-saving practices and technologies, expand or reduce production capacity, or move operations or plants offshore?

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[2] In addition, University of Maryland environmental economics professor Matthias Ruth served as a consultant for the project.

This report is divided into two parts and a set of appendices. The first part is devoted to providing an overview and summary of our research approach (Chapter Two), followed by a summary of its principal findings and conclusions (Chapter Three). The second part (Chapters Four through Eight) presents in-depth profiles of the five industries examined in the study—iron and steel, aluminum, paper and paperboard, petrochemicals, and chlor-alkali—with a summary of the findings for each. The appendices at the end include a literature review and elaborate on the method of analysis and assumptions used in the study, with a comparison to other approaches and studies. They also include the findings of alternative scenarios conducted using the II-CPM to examine how a few important, alternative assumptions, such as changing material costs and higher energy efficiency, might affect the study's results.

STUDY OVERVIEW AND APPROACH

The primary objective of the HRS-MI study was to investigate how energy price increases resulting from a mandatory program to reduce GHG emissions through a cap-and-trade program could affect the competitiveness of major U.S. energy-intensive manufacturing industries. We also sought to evaluate the affected industries' capabilities and opportunities for responding to the potentially adverse economic impacts of a climate policy, and examine alternative measures that could mitigate these costs. This chapter provides an overview of the principal policy issues the study addressed along with a summary of the research approach and methodology employed. (See Appendix B for a more detailed treatment including a technical description of the II-CPM). The research findings are summarized in the chapter that follows.

CLIMATE CHANGE AND COMPETITIVENESS

A number of proposals aimed at reducing GHG emissions in the U.S. have been introduced and debated in Congress over the past few years, and momentum is building towards enacting major legislation. Under these proposals, a mandatory cap would be placed on the total amount of greenhouse gases that could be emitted, generally tightening over time to meet long-term emission reduction goals. The resulting increase in fossil fuels prices would prompt a shift towards the use of lower-carbon fuels, especially in electricity generation and in industrial processes, as well as encourage gains in energy-efficiency in all sectors of the economy, thereby lowering GHG emissions.

But these gains would not come without transitional costs, especially in the sectors most heavily reliant on carbon-based fuels. Of particular concern are the impacts these policies would have on the U.S. manufacturing base, which has undergone significant capacity and job losses for well over a decade, accompanied by a growing trade deficit. Since 1998, the manufacturing sector has shed well over 4 million jobs, or one-quarter of its workforce—the most precipitous decline in its employment levels in nearly 7 decades. Correspondingly, a *net* of nearly 33,000 American manufacturing establishments shut down between 1998 and 2005, including 3,400 with 500 or more employees.[3]

There has been a great deal of debate about the causes of these trends. Some economists point to productivity gains, driven in particular by information technology advances, as a key driver in the decline of manufacturing employment. There is also substantial and compelling evidence that foreign competition has been a major factor in the shrinking and restructuring of U.S. manufacturing over the past few decades, especially since 1998. American firms across the spectrum of manufacturing industries have lost significant market shares to cheap foreign imports. As a result, the United States has experienced a substantial and growing trade deficit for many years, rising to more than $700 billion in 2007, in part fueled by the considerable increase in oil prices between 2005 and 2008.

Although Canada, Mexico, Japan and European Union countries continue to be major trading partners, China by far has been the largest net exporter to the United States—the U.S. trade deficit with China in 2007 was over $256 billion. Other fast growing nations, such as Brazil, India, Russia, and Indonesia, also have made inroads into American markets in a large variety of industries. American producers also have been moving their plants and jobs offshore in droves, drawn in particular to large developing nations with large pools of cheap energy and labor, little or no environmental regulations, and other inducements. China, again, has been the largest beneficiary of this off-shoring movement and associated investment.

Industry groups and labor unions have expressed strong concerns about the competitive disadvantages a climate policy might impose on U.S. manufacturing—especially energy intensive sectors. As a National Association of Manufacturers (NAM) report observes, "how energy policy is managed has a direct and immediate

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[3] U.S. Census Bureau, Company Statistics Division, *Statistics of U.S. Businesses* (SUSB), http://www.census.gov/csd/susb/susb.htm.

impact on the outlook for the future of U.S. manufacturing."[4] The American Chemistry Council laments the "severe damage historically high natural gas prices have had on the U.S. chemical industry and how it has promoted a shift in production overseas. With a mature market and the movement of customer industries overseas, companies are shifting investments towards regions offering lower feedstock costs (and the cost of production) as well as in markets experiencing a higher degree of dynamism."[5] For example, Dow Chemical, whose energy costs rose from 29 percent to 50 percent of its overall costs between 2002 and 2005, closed 20 plants in recent years, and not one of the more than 80 new, large-scale chemical plants on its drawing board is

planned for the United States.[6]

Similarly, iron and steel industry groups have argued that American manufacturing is at "a distinct disadvantage in global competition... due to dramatically rising costs associated with energy."[7]

They warn that a mandatory cap-and-trade program would consequently hurt the competitiveness and viability of the domestic steel industry. The American Iron and Steel Institute (AISI) also worries that the steel industry is approaching the physical limits of energy efficiency for the processes it operates today. To adjust to rising energy prices, it would need to adopt costly "new and transformational

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[4] National Association of Manufacturers, The Manufacturing Institute and the American Council for Capital Formation, *The Impact of Energy and Environmental Policy Choices on U.S. Manufacturing*, U.S. Economic Growth and Energy Markets. Prepared by Global Energy Services (Lexington, MA: Global Insight, June 2005).

[5] American Chemistry Council, "Testimony on the Impact of High Energy Costs on Consumers and Public," *Presented to Energy and Mineral Resources Subcommittee, U.S. House of Representatives,* May 19, 2005. See also Tony Friscia and Kevin O'Marah, *The Hidden Backbone of U.S. Manufacturing, Weakening Under Chemical Cost and Supply Pressures* (AMR Research, Inc., National Association of Manufacturers, and The Manufacturing Institute, 2007).

[6] Friscia and O'Marah, *Hidden Backbone.*

[7] The American Iron and Steel Institute (AISI), the Steel Manufacturers Association (SMA) and the Specialty Steel Industry of North America (SSINA), "Submission On behalf of Our U.S. Member Companies, To The U.S. Department of Commerce (DOC), In Connection with The DOC's Review of U.S. Manufacturing and The Need to Develop and Implement A Pro-Manufacturing Policy Agenda," Washington, D.C., August 15, 2003.

[8] American Iron and Steel Institute (AISI), "Climate Change Priorities" *2007 Public Policy Agenda,* Washington, DC, February 22, 2007, 8-10.

steelmaking technologies to achieve major additional reductions."[8]

Labor unions have had comparable fears about climate change impacts on trade vulnerable industries, dating back to the Kyoto debate. For example, International Emeritus President Charles W. Jones of the International Brotherhood of, Iron Ship Builders, Blacksmiths, Forgers & Helpers (IBB) warned that "many Boilermakers companies, faced with spending hundreds of millions of dollars to refit their factories, will instead move them to third-world countries, where they can take advantage of lower wages as well as less restrictive air standards." Citing a study conducted by the Argonne National Laboratory, he predicted significant losses under Kyoto in the aluminum, paper, steel, cement, and petroleum refining industries.[9]

Today, although most labor unions favor enacting a comprehensive climate policy, industry impacts and international competition remain under scrutiny. Abraham Breehey, IBB's Assistant Director of Government Affairs articulates a more current labor perspective: "Our union and others in the labor movement have longstanding concerns about the impact of policies designed to reduce our nation's greenhouse gas emissions on the competitiveness of our economy and workers, particularly those whose work relates to the manufacturing of energy-intensive products."[10] Breehey and other labor leaders maintain that climate policies should not encourage off-shoring of manufacturing or the sale of assets. They also warn against "carbon leakage", which results when companies move their

production to regions of the world without comparable GHG emissions reduction commitments.

As Robert Baugh, executive director of the American Federation of Labor-Congress of Industrial Organizations (AFL-CIO) Industrial Union Council (IUC) and co-chair of the AFL-CIO Energy Task Force, testified before the U.S. Senate Environment and Public Works Committee in 2007, "it is not in our national interest to see our efforts to reduce carbon emissions become yet another advantage that a developing nation uses to attract business. However, it is in our interest and the world's interest to have developing nations become part of the solution because the problem cannot be solved without them."[11]

In recent years the attention devoted to climate change and its impacts, as well as the consequences of the financial and economic crisis currently underway, have contributed to change the way labor unions, industry groups, and policymakers approach climate policies. They are all concerned about reviving the U.S. manufacturing sector and keeping domestic jobs. But they now see an opportunity to modernize and make U.S. industries more energy efficient. With the U.S. and the rest of the world investing in renewable energy and energy efficiency, and in light of the upcoming climate negotiation at the Conference of the Parties (COP15) that will take place in Copenhagen in December 2009, there are reasonable expectations for comprehensive and fair domestic and international climate policies.

IN RECENT YEARS, THE ATTENTION DEVOTED TO CLIMATE CHANGE, AS WELL AS . . . THE FINANCIAL AND ECONOMIC CRISIS . . ., HAVE CONTRIBUTED TO THE WAY LABOR UNIONS, INDUSTRY GROUPS, AND POLICYMAKERS APPROACH CLIMATE POLICIES.

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[9] Charles W. Jones, "The Kyoto Pact Is a Lot of Smoke, It Will Weaken Our Economy But Not Reduce Pollution," *The Boilermaker Reporter 37*, no. 4 (July-August):16, http://www.boilermakers.org/6-reporter/commN4.html.

[10] "Testimony of Abraham E. Breehey, Assistant Director of Government Affairs, International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers and Helpers (AFL-CIO) Before the United States Senate Committee on Finance," February 14, 2008.

[11] Robert C. Baugh, "A 21st Century Energy Policy for Environmental and Economic Progress, Testimony Before the Environment and Public Works Committee for the U.S. Senate," July 25, 2007.

Previous Studies

In response to the concerns about manufacturing competitiveness, legislators have attempted to incorporate a number of different measures in cap-and-trade bills that attempt to address the goals of reducing GHG emissions while mitigating economic impacts on vulnerable industries.[12] In addition to estimating the economic impacts of climate policies on energy-intensive manufacturing, an objective of the HRS-MI project was to develop economic modeling tools that enable evaluation of such measures.

Unfortunately, few such tools are currently available, much less being applied to evaluate how CO_2-pricing policies might affect energy-intensive manufacturing industries, and the efficacy of different policy measures to mitigate those impacts. As Resources for the Future (RFF) economist Richard Morgenstern observes, "information concerning industry-level impacts associated with new carbon mitigation policies is quite limited."[13] This information not only is important for crafting measures that minimize economic losses for affected sectors, we also need tools for evaluating measures that encourage and enable manufacturers to invest in technologies, equipment, and processes that reduce their CO_2-intensity.

Only a small number of studies have attempted to examine climate policies and their implications for manufacturing industries in any depth.[14] One set of studies are largely qualitative—they do not quantify policy impacts on industry sectors, but include in-depth industry profiles, and evaluated different energy and climate policy options in light of industry analyses, in some cases supplemented by

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[12] The most important of these are cost containment measures ("safety valve" prices, offsets, banking), economic mitigation measures (allowance allocations; countervailing trade duties), and international compliance provisions.

[13] Richard D. Morgenstern, Joseph E. Aldy, Evan M. Herrnstadt, Mun Ho, and William A. Pizer, *Competitiveness Impacts on Carbon Dioxide Pricing Policies on Manufacturing* (Washington, DC: Resources for the Future, 2007).

[14] See Appendix A for a fuller discussion of these studies and their findings.

[15] Trevor Houser et al, *Leveling the Playing Field, International Competition and US Climate Policy Design* (Washington, DC: World Resources Institute and Peterson Institute for International Economics, 2008). See also, U.S. Environmental Protection Agency (EPA), *Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes, Final Report.* Prepared by ICF International [EPA 100-R-07-003] (March 2007); Interlaboratory Working Group, *Scenarios for a Clean Energy Future* [ORNL/CON-476 and LBNL-44029] (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; Lawrence Berkeley National Laboratory, November 2000); McKinsey Global Institute (MGI), *Curbing Global Energy Demand Growth: The Energy Productivity Opportunity* (San Francisco, CA: McKinsey&Company, May 2007).

[16] Houser et al, *Leveling the Playing Field.*

economic modeling.[15] For example, a report by the Peterson Institute for International Economics and the World Resources Institute, *Leveling the Carbon Playing Field*, summarizes the challenges policymakers face in crafting climate legislation that addresses the international competitiveness problem for U.S. manufacturing, and evaluates different policy options for limiting the economic impacts of climate proposals.[16]

Another set of studies have applied traditional economic modeling tools in attempts to quantify these impacts. These include RFF studies aimed at understanding how CO_2 charges affect industrial competitiveness, measured as impacts on operating costs, profits, and production output.[17] In addition, there have been three detailed studies of the impacts of the European Union Emissions Trading Scheme (EU-ETS) on the competitiveness of European manufacturing industries, with a focus on narrower, more energy-intensive industrial sectors than traditional macroeconomic studies are capable of evaluating.[18]

A 2004 RFF study estimated the near-term impacts of a price on CO_2 emissions on a relatively disaggregated (four-digit NAICS)[19] set of domestic manufacturing industries. It also compared these results to a downstream policy focused exclusively on the electric power industry.[20] A more recent RFF study employed a simulation model of the U.S. economy, incorporating trade flows and an international sector, to estimate the industry-level impacts of pricing CO_2 emissions. The study evaluated broader industry categories (2-3 digit NAICS) primarily at a higher level of aggregation than the earlier RFF study, estimating cost impacts over the short, medium, and then long-term.[21]

A 2006 study by McKinsey & Company and Ecofys measured the bottom-line impact of CO_2 charges under the EU-ETS for several industries, including electric power, steel (integrated and electric-arc furnace mills), pulp and paper (several grades), cement, refining, and aluminum, which account for over 90 percent of all emissions from the trading sectors in the EU. Unlike the U.S. or other EU studies, the McKinsey/Ecofys analysis factored in the varied capabilities of each industry to pass through cost increases based on the researchers' own industry expertise and the published literature. A second study, by the International Energy Agency (IEA)[22] assessed the short- to medium-term impacts of the EU-ETS on measures of international competitiveness of several EU industries (steel, pulp and paper, aluminum, cement), such as loss in production output for each industry and the possibility of emissions leakage. Another, more recent IEA report examined the EU-

A SECOND STUDY, BY THE INTERNATIONAL ENERGY AGENCY (IEA) ASSESSED THE SHORT- TO MEDIUM-TERM IMPACTS OF THE EU-ETS ON MEASURES OF INTERNATIONAL COMPETITIVENESS OF SEVERAL EU INDUSTRIES.

[17] Richard D. Morgenstern, Mun Ho, Jhih-Shyang Shih, and Xuehua Zhang, "The near-term impacts of carbon mitigation policies on manufacturing industries," *Energy Policy 32* (2004): 1825-1841; Morgenstern et al, *Competitiveness Impacts*; Mun S. Ho, Richard Morgenstern, and Jhih-Shyang Shih, "Impacts of Carbon Price Policies on U.S. Industry," *Discussion Paper* [RFF DP 08-37] (Washington,DC: Resources for the Future, November 2008).

[18] McKinsey & Company and Ecofys, *EU ETS Review, Report on International Competitiveness* (European Commission, Directorate for Environment, December 2006); Julia Reinaud, *Industrial Competitiveness Under the European Union Emissions Trade Scheme*. IEA Information Paper (International Energy Agency (IEA), February 2005) ; –, *Carbon Policy and Carbon Leakage, Impacts of the European Emissions Trading Scheme on Aluminum,* IEA Information Paper (International Energy Agency, October 2008). See also Morgenstern et al, *Competitive Impacts*.

[19] NAICS is the North American Industry Classification System, used by business and government to classify and measure economic activity in Canada, Mexico and the United States. It has replaced the older Standard Industrial Classification (SIC) system. NAICS uses a six-digit code to classify industries; lower numbers of digits designate higher levels of industrial aggregation; four through six-digit codes refer to industry groups and particular industries within the higher level sectors.

[20] Morgenstern et al "Near-term impacts;" See also Morgenstern et al, *Competitive Impacts*.

[21] Morgenstern et al, *Competitiveness Impacts*; Ho et al, "Impacts of Carbon Price Policies."

[22] Reinaud, *Industrial Competitiveness*. See also Morgenstern et al, *Competitiveness Impacts*.

of specific energy-intensive industries. In particular, we attempted to quantify the increased production costs and subsequent impacts on industries' profitability resulting from a climate policy, while also investigating technology and policy options for mitigating these impacts.

Energy-Intensive Manufacturing

In this inquiry, we selected five energy-intensive manufacturing industries—iron and steel and ferroalloy products, aluminum (primary and secondary aluminum), paper and paperboard mills, petrochemicals, and alkalies and chlorine (chlor-alkali) manufacturing (see industry definitions in Box 1). These are major industries within three of the largest energy consuming manufacturing sectors (chemicals, primary metals, and paper) in the American economy.

Table 2-A shows the energy intensity for manufacturing as a whole, as well as the energy intensity of the major industries and sub-sectors examined in the study. The selected industries have some of the highest levels of energy intensity in the manufacturing sector, measured as total energy expenditures (fuels and electricity) as a share of total operating expenditures.[25]

ETS impacts on the competitiveness of the European aluminum industry.[23]

A few studies over the past decade have attempted to evaluate climate policies and their impact on energy-intensive industries using system dynamics modeling tools, which identify and represent the causal relations underlying the systems analyzed. These include research studies that evaluated climate policy impacts on the steel, paper, and ethylene manufacturing industries, led by University of Maryland environment economics professor Matthias Ruth in the late 1990s and early 2000s with Environmental Protection Agency support.[24]

The HRS-MI study is a new addition to this small group. Like the research conducted by Ruth and his colleagues, it differs from past economic studies in its use of the system dynamics approach to evaluate a CO_2-pricing scenario and its longer term impacts (through 2030) on the competitiveness

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[23] Reinaud, *Impacts on Aluminum.*

[24] Ruth and his colleague generated several published articles on their work. A representative sample includes: B. Davidsdottir and M. Ruth, "Pulp Non-Fiction: Dynamic Modeling of Industrial Systems," *Journal of Industrial Ecology* 9, no. 3 (2005): 191-211; Matthias Ruth, Brynhildur Davidsdottir, and Anthony Amato, "Climate change policies and capital vintage effects: the cases of US pulp and paper, iron and steel, and ethylene," *Journal of Environmental Management 70* (2004) 235-252; and, M. Ruth, B. Davidsdottir, and S. Laitner, "Impacts of Energy and Carbon Taxes on the US Pulp and Paper Industry," *Energy Policy* 28 (2000): 259 – 270.

[25] Operating expenditures are roughly equal to the sum of materials, labor compensation and capital expenditures in the Census Bureau's *Annual Survey of Manufactures* tables, in 2006. See U.S. Census Bureau, Statistics for Industry Groups and Industries (Annual Survey of Manufactures), [M05(AS1)] (Washington, DC: November 2006) ("Census Bureau, ASM"). The table indicates that the chosen manufacturing industries are among the most energy-intensive in the economy. The measure of energy-intensiveness used here is approximately equivalent to the measure of energy cost as share of total production cost calculations used in the models, as shown below.

Industry Definitions

Aluminum Production (NAICS 331312,4) includes establishments that turn alumina (refined bauxite) and recovered aluminum into aluminum. It is has two major subsectors:

• *Primary aluminum production* (NAICS 331312) that includes establishments primarily engaged in making aluminum and/or aluminum-based alloys from alumina, and may also engage in rolling, drawing, extruding, or casting the aluminum they make into primary form (e.g., bar, billet, ingot, plate, rod, sheet, and strip).

• *Secondary smelting and alloying of aluminum* (NAICS 331314) that includes establishments engaged in recovering aluminum and aluminum alloys from scrap and/or dross (i.e., secondary smelting) and making billet or ingot (except by rolling) and/or alloys, powder, paste, or flake from purchased aluminum.

Iron and Steel Mills and Ferroalloy Products (NAICS 3311) includes establishments that manufacture raw steel and semi-finished and finished steel products. It's primary divisions include:

• *Iron and steel mills* (NAICS 331111) that engage in the direct reduction of iron ore, produce pig iron in molten or solid form, convert pig iron into steel, make steel and shapes (e.g., bar, plate, sheet, strip, wire) and may form steel into tubes and pipe; and,

• *Electrometallurgical ferroalloy products* (NAICS 33112) producers which add critical elements, such as silicon and manganese for carbon steel, and chromium, vanadium, tungsten, titanium, and molybdenum for low- and high-alloy metals.

Paper and Paperboard Mills (NAICS 32212,3) includes establishments primarily engaged in manufacturing paper and paperboard from pulp, including:

• *Paper mills* (NAICS 322121) that manufacture paper (except newsprint and uncoated groundwood paper),

• *Newsprint mills* (NAICS 322122) that manufacture newsprint and uncoated groundwood paper, and:

• *Paperboard mills* (NAICS 32213) that manufacture paperboard from pulp.

These establishments may manufacture or purchase pulp and some also may convert the paper or paperboard they make into paper and paperboard products.

Petrochemical Manufacturing (NAICS 32511) includes establishments primarily engaged in manufacturing acyclic (i.e., aliphatic) hydrocarbons such as ethylene, propylene, and butylene made from refined petroleum or liquid hydrocarbon and/or cyclic aromatic hydrocarbons such as benzene, toluene, styrene, xylene, ethyl benzene, and cumene made from refined petroleum or liquid hydrocarbons.

Alkalies and Chlorine (Chlor-Alkali) Manufacturing (NAICS 325181) includes establishments primarily engaged in manufacturing chlorine, sodium hydroxide (i.e., caustic soda), and other alkalies often using an electrolysis process.

Source: U.S. Census Bureau, Statistics for Industry Groups and Industries, 2006 (Annual Survey of Manufactures), M05(AS1) (Washington, DC: November 2006)

In fact, these numbers are understated for some of the industries (e.g., petrochemicals and iron & steel), which consume large quantities of energy fuels as feedstock, and therefore are substantially more energy-intensive than reported in the table.

At the same time, aluminum and paper have sub-segments or divisions that are somewhat less energy intensive than other segments within their grouping. Secondary aluminum's energy intensity, while greater than manufacturing as a whole, is less than one-quarter than that of primary aluminum. The paper mill industry's energy intensity is about one-third less than that of the paperboard mill industry. The paper manufacturing sector (NAICS 322) also includes converted paper product manufacturing, which uses the products of paper and paperboard manufacturing and is less energy intensive. Petrochemicals and chlor-alkali were deemed representative of the basic chemicals sector, although there are other important energy-intensive industries within that category, such as nitrogenous fertilizers (NAICS 325311), carbon black (325182), and other basic organic chemicals (325199), and others that are not as energy intensive.

TABLE 2-A
ENERGY INTENSITY*†
FOR SELECTED INDUSTRY SECTORS, 2006

[Industries in bold are examined in the study]

NAICS Code	Industry Sector	Energy Intensity* [Percent]
31-33	Manufacturing	2.9
322	Paper Manufacturing	7.3
32212,3	**Paper and Paperboard Mills**	**14.5**
32212	**Paper Mills**	*13.0*
32213	**Paperboard Mills**	*18.0*
325	Chemicals Manufacturing	5.6
3251	Basic Chemicals	10.2
32511	**Petrochemicals**	**8.0**
325181	**Alkalies and Chlorine**	**38.9**
331	Primary Metals	6.4
3311	**Iron & Steel & Ferroalloy Products**	**8.8**
3313	Alumina and Aluminum Production and Processing	7.5
331312,4	Primary and Secondary Aluminum Production	14.8
331312	**Primary Aluminum Production**	*26.5*
331314	**Secondary Aluminum Production**	*6.2*

*Energy intensity is calculated as the share of total energy expenditures (fuel and electricity) as a share of total operating expenditures (roughly equal to sum of materials costs, labor compensation and new capital expenditures in the Census Bureau's *Annual Survey of Manufactures*, for 2006)

†Does not include expenditures on energy fuels used as manufacturing feedstock (e.g., natural gas used in petrochemical production; coke used in steel production).

Aside from their high energy-intensities, the selected industries are similar in some characteristics, but differ in others, that need to be considered in assessing the scale and scope of climate policy impacts and their responses to these impacts:

Energy Mix.

The industries consume different mixes of energy for supplying heat, power and feedstock. If a climate policy drives up the prices of some energy sources more than others, industries reliant on the former would suffer greater cost impacts than those that are large consumers of the latter.

Import Vulnerability.

All the industries in the study compete in global markets, but some are more vulnerable to foreign competition than others. Trade-sensitive industries would be less able to pass along the additional costs of energy to their customers than those less concerned about losing market share to foreign competitors.

Energy Savings.

The selected industries are very capital-intensive, and most have made substantial gains in reducing their energy-intensity by investing in energy efficiency and new technologies. The industries differ, however, in the extent to which further energy savings are possible without substantial new investments, the nature of energy-saving investment opportunities, and the incentives that might be needed to induce these investments.

Recycling.

Recycling or recovery of scrap or waste materials is a critical characteristic of several industries. Scrap steel, recovered aluminum, and wastepaper account for substantial shares of the outputs of the steel, aluminum, and paper and paperboard industries, respectively. Policy-driven energy

cost increases could further shift the relative share of domestic production to the recycled end of these industries, which are somewhat less energy-intensive than segments that process raw materials.

Internal Energy Generation.

The industries also vary in the degree they internally generate heat and power as by-products of their production processes. Increasing the relative share of internal energy sources in some industries (paper and paperboard, iron and steel) would reduce the need for external energy sources, offsetting the impacts of higher energy prices associated with climate policies.

Research Approach

To carry out the HRS-MI study, we developed detailed energy and economic profiles of these manufacturing industries, entailing the collection and processing of historical economic data. We then constructed substantial, system dynamics industry sector models supported by stakeholder group model-building sessions. These steps are briefly described below. (See Appendix B for a fuller description of our research approach and assumptions.)

Profile Development and Data Gathering.

This involved extensive gathering and analysis of statistical data and information from multiple sources, including the professional literature, U.S. government databases and studies, domestic and international industry sources, and academic research. Drawing on this large body of information, we developed economic and energy profiles of each industry sector being examined. This included descriptive, historical and statistical information on fundamental production processes and

Recycling or recovery of scrap or waste materials is a critical characteristic of several industries.

technologies, industrial organization and structures, markets and trade flows, economic and financial trends (production outputs, shipments, and materials, capital, labor and energy expenditures) and energy use and flows.[26]

Model Development.

The HRS-MI study employed a powerful, flexible, transparent, and interactive modeling tool based on the Vensim® modeling platform.[27] This modeling approach enables examination of complex, dynamic economic interrelationships at the industrial sector level that few traditional economic models are capable of carrying out.[28] In particular, we developed the *Integrated Industry-Climate Policy Model* (II-CPM), which enabled construction of detailed models of each industry sector, allowing simulations of the impacts of alternative climate policies on the industry's cost structure and market dynamics.

Group Modeling Sessions.

The HRS-MI team held numerous "group modeling" sessions involving industry stakeholders. These meetings enabled the collection of primary industrial data, provided perspectives and information about industry behavior and trends, and elicited invaluable feedback about industry model structures, assumptions, and data. The meetings frequently involved computer-based demonstrations of the models to help guide discussion and enable participants to view and respond to changes in model parameters and assumptions in real time.

Model Description

Employing II-CPM, the HRS-MI study followed a three-phased approach schematically represented in Figure 2-1 and described below. We first constructed basic production cost models for each of the chosen industries. These models were then extended and broadened to enable modeling of market dynamic features that accounted for international trade flows. The integrated models were used to measure the impacts of a GHG-price policy, on a series of indicators, such as production costs and operating surplus, compared to a "business as usual" (BAU) scenario for different market assumptions.

Finally, the modeling results were used to inform preliminary analyses of investment and policy options for the different industries. Although investment options were not directly modeled, we calculated

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[26] The primary data source used in modeling industry production costs was the U.S. Census Bureau's *Annual Survey of Manufactures*. Detailed industry import and export data used in modeling market impacts came from United States International Trade Commission (USITC) databases. Production and a wide-range of other statistical data for specific industries were made available by several major industrial trade associations.

[27] A product of Ventana Systems, available on http://www.vensim.com

[28] The studies of Dr. Ruth and his colleagues were an exception. Like the HRS-MI study, they employed a system dynamics modeling platform (called STELLA), and their work is considered a precursor to the current HRS-MI study.

Figure 2-1

Measuring Climate Policy Impacts on Manufacturing
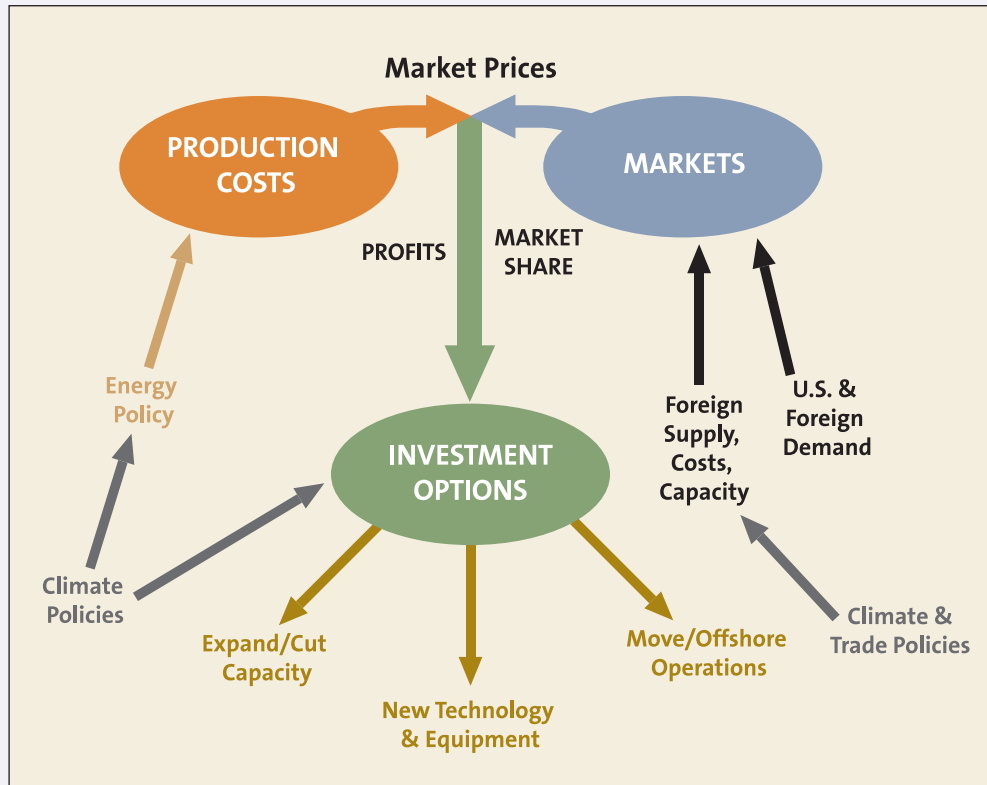
Market Prices

PRODUCTION COSTS

MARKETS

PROFITS

MARKET SHARE

Energy Policy

Foreign Supply, Costs, Capacity

U.S. & Foreign Demand

INVESTMENT OPTIONS

Climate Policies

Expand/Cut Capacity

New Technology & Equipment

Move/Offshore Operations

Climate & Trade Policies

energy-efficiency improvements needed to offset the increasing energy costs from a climate policy. We also modeled an allowance allocation scenario, wherein allowances are distributed to energy-intensive industries to mitigate a portion of the increased energy prices. In addition, we modeled several alternative scenarios to test the sensitivity of the findings to changes in various assumptions, including materials costs, domestic and world prices, energy efficiency, and elasticities of demand

I. Modeling Production Costs

In the first phase of our work, we constructed a model of the production cost structure for each of the selected industries. Productions cost calculations were based on a cost component model that summed the operating (or variable) costs associated with production outputs for the selected industries—materials and capital expenditures, labor expenditures (full compensation including wages, salaries and benefits), and energy expenditures (fuel, electricity and non-fuel energy (i.e., feedstock)).[29] Historical data on the key cost components (materials, capital, labor, purchased fuels and electricity data) and other important industry financial data

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[29] Energy fuels and electricity are used for heat and power consumed in the operation of facilities and in production processes. Non-fuel energy or "feedstock" energy is consumed as a raw material in the production of an industry's products.

(value of shipments, value added), back to 1992, were obtained from the Census Bureau's *Annual Survey of Manufactures* (ASM).

Our calculations of the industries' energy costs and intensities relied on industrial energy use data from the Department of Energy's *Manufacturing Energy Consumption Survey* (MECS).[30] The BAU and climate policy scenarios were characterized by energy prices projections for different energy sources generated by the Energy Information Administration's (EIA) National Energy Modeling System (NEMS). Industry associations provided primary data on production output quantities and other important production-related statistics.[31]

The models were dynamically calibrated to track costs starting from 1992, and set up to project them out to 2030 for the policy and BAU cases. These projections included assumptions about future material, investment and labor costs based on historical trends, as well as input from industry experts. The commodity price projections we used for each of the commodities were derived from data provided by Global Insight.[32] Material cost projections for each industry sector were correlated with these market price projections and calibrated to the historical data from the ASM.[33] We took care to include costs associated with carbon-based energy feedstock (coke in steelmaking, natural gas in petrochemicals) in the energy cost calculations, while subtracting them from the materials costs.

II. Modeling Market Dynamics and Profit Impacts

We then constructed models of the market dynamics, incorporating import and export trends, and were then integrated with the production cost models. We also estimated the elasticities of demand of the products produced domestically by the sectors, taking into consideration the historical differences between domestic and foreign-import prices. Industry import and export data (quantities and prices) were supplied by the U.S. International Trade Commission (USITC).[34] As noted above, the domestic market price projections for each industry were based on data supplied by Global Insight and the ASM.

Because of data limitations, we defined new variables, the *operating surplus*, to serve as a proxy for an industry's profits, and the *operating margin*, as a proxy for its profit margin, and therefore are indicators of an industry's profitability (see Box 2). The magnitudes of these results—absolute and relative to BAU—are contingent on assumptions about the extent to which companies in a given industry would be able pass additional energy costs through to their customers. Whether producers are able to pass the costs along to the market depends on a number of factors, including their financial strength (e.g. production capacity utilization, operating surplus and profitability), market demand and prices, and international competition. This is especially problematic for many

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[30] See U.S. Department of Energy, Energy Information Administration (EIA), *Manufacturing Energy Consumption Survey* (2002) http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html. ("EIA, MECS 2002")

[31] In particular, a substantial amount of statistical data was generously provided by the American Iron and Steel Institute, American Forest and Paper Association, Aluminum Association, and American Chemistry Council. [32] For details, see the Numerical and Modeling Assumptions section of Appendix B.

[33] Historically, materials costs show a strong statistical correlation with market prices for each industry. It was assumed that they would continue to show a correlation with market prices into the future, which were derived using Global Insight data, as indicated. This is reasonable, as the industries in the study are the largest if not the only consumers of the primary raw materials that account for the bulk of their materials costs. Thus, the demand for these materials, and consequently their prices, will rise and fall more or less in tandem with the demand and market prices for the products of the industry sectors.

[34] U.S. International Trade Commission (USITC), *Interactive Tariff and Trade DataWeb, available at http://dataweb.usitc.gov/.*

energy-intensive industries, whose ability to pass through such costs is typically constrained by market conditions and low-cost foreign imports. These industries sell their products in highly competitive global markets, and largely focus on keeping their costs sufficiently low to maintain their profitability.

Drawing on discussions with industry experts and the literature, we concluded that a no, or low, cost pass-along assumption is probably closer to their industries' real market situation than a total cost pass-along assumption, especially under current market conditions. In some cases, specialty products in niche markets under certain circumstances might be better positioned to pass these additional costs through to higher prices. The McKinsey/Ecofys study of EU manufacturing industries suggests that some industries or industry segments (electric arc furnace mills in the iron & steel industry) could pass along some of these costs, while others (primary aluminum or integrated steel mills) have little or no ability to do so. In any case, our

study models the two poles of cost pass-along: a no cost-pass along (NCPA) scenario and 100 percent cost pass-along (CPA) scenario.

Box 2

Operating Surplus and Operating Margin Defined

At the unit of production level, the ***operating surplus*** is defined as the difference between an industry's aggregate market price and its unit production cost. For each industry, the II-CPM generated operating surplus and margin projections for the climate policy case and the BAU scenario. At the industry output level, the total operating surplus was calculated by subtracting total production costs from total industry revenues for a given year.[35] The ***operating margin*** is defined as the ratio of an industry's total operating surplus and total revenues.

The operating surplus includes several overhead-related costs (such as sales, general and administrative (SG&A) costs), depreciation, interest on capital, and other expenses that could be considered part of the industry's fixed production costs, and profits and taxes not yet paid out. When a firm's operating surplus and margin is reduced as a result of increased production costs, this generally leads to lower profits, at least over the short-run unless administrative costs are reduced as well.

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[35] Total production costs equals total production output multiplied by unit production costs. Total industry revenues equals production output multiplied by market price.

III. Assessing Investment Options and Policy Alternatives

In the final phase of the study, we identified potential investment options in energy-saving technologies available to each sector. In addition, we employed the II-CPM to evaluate policy alternatives for mitigating costs and encouraging energy-saving investments.

This work included the following assessments:

1. **Energy-efficiency requirements**—for each industry, estimates of the energy efficiency gains required to offset increased energy costs under a climate policy.

2. **Technology investment options**—review of the principal near-, mid- and long-term technology options available to reduce energy use, improve efficiency, and offset higher production costs arising from a climate policy.

3. **Ninety percent allocation policy option**—simulations of a policy option that would allocate to each of the industries allowances mitigating 90 percent of the additional costs incurred as a result of a climate policy.

Climate Policy Case

Our study analyzed *the Lieberman-Warner America's Climate Security Act of 2008* (S. 2191), and compared it to BAU case that assumes no climate policies are enacted into law throughout the study period. The

Lieberman-Warner proposal is referred to as the "Mid-CO_2 Price Policy" throughout the report because the projected emission allowance prices and the associated reduction in emissions for the core Lieberman-Warner bill fall between those of other climate policy proposals that Congress has considered in recent years. The EIA's analysis of the Lieberman-Warner bill projects the inflation-adjusted (USD 2006) allowance price to be $30 per metric ton of CO_2-equivalent by 2020 and $61 by 2030.[36] The policy case was assumed not to go into effect until 2012. The energy price projections used in this study—for electricity and five fuel types, (metallurgical coal, natural gas, liquefied petroleum gas, residual fuel and distillate fuel)—correspond to the EIA's Lieberman-Warner analysis. Table 2-B summarizes key provisions of the policy and BAU or scenarios.

It should be expected that cost impact projections for an industry would reflect price trends of the energy sources on which they rely most. Indeed, this is a very important factor that could influence the relative impacts of emissions reduction policies on different industries. As Table 2-C shows, the prices of some energy sources would vary greatly over time, absolutely and

relative to BAU, while others would vary much less, depending on the associated policies and their CO_2 content.

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[36] U.S Department of Energy, Energy Information Administration (EIA), *Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007* [SR/OIAF/2008-01] (Washington, DC, April 2008), xii, table ES3.

Table 2-B

Climate Change Policy Cases

SCENARIO	DESCRIPTION
Business As Usual (BAU) or Reference Case	▸ Non-policy case: assumes that current policies affecting the energy sector remain unchanged throughout the projection period. ▸ *Annual Energy Outlook 2008* (AEO2008) Reference Case, including provisions of H.R. 6, the *Energy Independence and Security Act of 2007*, and assumes a continuation of other current laws and regulation ▸ Non-CO_2 emissions growth based on Environmental Protection Agency "with measures" and "voluntary technology adoption" cases
Mid-CO_2 Price Case [**Lieberman-Warner** America's Climate Security Act of 2007 **(S.2191)**]	▸ Evaluated under AEO2008 Reference Case assumptions ▸ Economy-wide cap and trade policy, upstream for petroleum, NG, non-CO_2 GHGS, downstream for coal-using facilities ▸ Allowances auctioned gradually to 69%; 33% free to industry (10% to carbon-intensive manufacturing) with phase out ▸ Bonus credit incentives for CCS; Key low-emissions technologies, including nuclear and coal with carbon capture and sequestration (CCS), developed and deployed in a timeframe consistent with emissions reduction requirements ▸ Domestic and international offsets ("international emissions allowances"); up to 15% compliance obligation for each type ▸ Incentives, countervailing trade measures ("international reserve allowance") conditioned on comparable international climate actions ▸ Title X cap-and-trade for other Group II GHGs (hydrofluorocarbons) not represented

References:

Energy Information Administration, U.S Department of Energy, *Energy Market and Economic Impacts of S.2191*, the Lieberman-Warner *Climate Security Act of 2007*, SR/OIAF/2008-01, (Washington, DC, April 2008). [EIA 2008]

Energy Information Administration, *Annual Energy Outlook 2008*, DOE/EIA-0383(2008) (Washington, DC, April 2008), [EIA, 2008a]

For example, metallurgical coal and coke prices would rise by nearly 180 percent for the Mid-CO_2 Price Policy over BAU by 2030. However, electricity prices would climb by only 13 percent above BAU. Similarly, natural gas prices would experience a 39 percent rise by 2030, compared to a small decrease for liquefied petroleum gas (LPG), assumed to be a feedstock in petrochemicals manufacturing. Residual fuel oil and distillate fuel oil, whose prices would increase to 43 percent and 24 percent above BAU by 2030, are important sources of heat and power in the industries examined, and these increases would be reflected in energy cost increases observed in these sectors.

The accuracy of the overall results of the study for the policy case is contingent on the price trends for the BAU case, as estimated by EIA in its projections for its *Annual Energy Outlook* (AEO). AEO 2008 includes recent price spikes and the declines that followed, which are reflected in the energy price projections used in our study. Hence, we see a large bump in all the energy prices between 2004 and 2007, after which the EIA model predicts declines for some fuels (e.g., metallurgical coal), eventually followed by modest growth in future years.

For example, metallurgical coal and coke prices would rise by nearly 180 percent for the Mid-CO2 Price Policy over BAU by 2030.

Table 2-C
Carbon-Based Fuels and Electricity Price Scenarios Mid-CO$_2$ Price Policy and BAU Cases

($2000/MBtu and % above BAU)

Energy Source	Real Energy Prices ($2000)		
		Mid-CO$_2$ Price	
	2006	2020	2030
Electricity	15.42	16.09	17.11
Percent above BAU	—	*8.6*	*13.1*
Natural Gas	6.57	6.51	8.69
Percent above BAU	—	*22.2*	*39.0*
Metallurgical Coal	3.04	6.01	8.65
Percent above BAU	—	*104.7*	*180.0*
Liquefied Petroleum Gas	16.91	14.48	15.25
Percent above BAU	—	*0.5*	*-0.1*
Coal Coke	9.11	18.02	25.94
Percent above BAU	—	*104.7*	*180.0*
Residual Fuel	7.77	9.01	11.81
Percent above BAU	—	*26.7*	*43.1*
Distillate Fuel	13.15	*14.31*	17.30
Percent above BAU	—	*14.1*	*24.0*

Source: EIA, HRS-MI

We simulated a wide variety of scenarios for each industry, and conducted sensitivity analyses to examine variations on the key assumptions used in the II-CPM models.

II-CPM Scenarios

We simulated a wide variety of scenarios for each industry, and conducted sensitivity analyses to examine variations on the key assumptions used in the II-CPM models, concerning material costs, market prices, and market sensitivity to price changes. These scenarios are summarized below:

Core Scenarios. Simulations estimating the impacts of the Mid-CO$_2$ Price Policy relative to BAU on the six industries (primary and secondary aluminum, iron and steel and ferroalloy products, paper and paperboard, petrochemicals, and chlor-alkali), assuming no cost pass-along by the industries to their customers (NCPA). The outputs measured in the simulations included energy costs, production costs, and operating surpluses and margins.

Cost Pass-Along Scenarios. Simulations of the Mid-CO$_2$ Price Policy relative to BAU assuming that the 100 percent of the additional energy costs are passed along by industries (CPA). Two alternative CPA scenarios were simulated: *cost-basis CPA,* assuming that manufacturers increase their prices by the exact amount of their increased costs; and *margin-basis CPA,*

assuming manufacturers raise prices in proportion to the increase in costs, to maintain original operating and profit margins. The model outputs included production costs, operating surpluses and margins, and domestic and import market shares and production outputs.

Required Energy Efficiency Gains. Examination of the potential for mitigating energy cost increases if energy efficiency improvements were made, comparing the Mid-CO_2 Price Policy and BAU. This entailed calculations of the energy efficiency gains required to offset the increased energy costs associated with the climate policy case relative to BAU.

Allowance Allocation (With Energy Efficiency Analysis). Simulations of the impact on industries of a policy measure designed to mitigate the increased energy costs associated with the climate policy—specifically, allowance allocations equal to 90 percent (diminishing by 2 percent per year) of the increased prices for energy consumed by each industry resulting from the Mid-CO_2 Price Policy. Energy efficiency gains required to offset the climate policy-driven energy cost increases, with the allocation measure in effect, were also estimated.

Additional Scenarios

Finally, we simulated several additional scenarios to examine changes in the II-CPM outputs resulting from variations in key assumptions, under different economic conditions and scenarios. Some of the results from these analyses are referred to in other parts of the report. A presentation and discussion of these additional scenarios can be found in Appendix C.

Rising Material Costs. Assumed a 1.15 percent average real yearly rate of increase in the cost of materials starting 2009, approximating how unexpected costs of production factors other than energy would affect the II-CPM results.

Energy Efficiency Growth. The study compared the Mid-CO_2 Price Policy and BAU assuming that industries annually increase energy efficiency by 5 percent, and potential cost savings if these efficiency gains are achieved. The energy efficiency rate simulated assumes a yearly increase in energy efficiency for each fuel consumed by an industry and for electricity, but not for energy feedstocks, starting from 2009, including the baseline increase of 0.25 percent simulated for all industries and scenarios.

Declining World Price Relative to US Prices. Assumed a 1.15 percent average real decline in world prices, starting in 2009, approximating a situation in which low-cost foreign competitors push down world market prices, reducing U.S. operating margins.

Changing Market Elasticity Values. A comparison of the original industry simulations, using the II-CPM derived elasticities of demand, with simulations using higher and lower elasticity of demand values.

THE MODEL OUTPUTS INCLUDED PRODUCTION COSTS, OPERATING SURPLUSES AND MARGINS, AND DOMESTIC AND IMPORT MARKET SHARES AND PRODUCTION OUTPUTS.

SUMMARY OF FINDINGS

Our findings show that climate change policies that put a price on CO_2 and other greenhouse gas emissions in the economy, when applied only in the United States and with no relevant energy efficiency investments, could have substantial impacts on the competitiveness of U.S. energy-intensive manufacturing industries over the next two decades. On the other hand, we also found that technology investment and policy options exist that could mitigate the industries' policy-related cost increases, improve their energy-efficiency, and ultimately enhance their economic performance. More research, however, is needed to further explore and analyze these options, as well as other policies that could preserve and strengthen this vital part of the nation's manufacturing base while reducing the threat of global warming.

The extent of these impacts, challenges and opportunities will vary across industries, depending on their energy-intensities, the mix of energy sources they rely on (electricity, natural gas, coal), and how energy is used in production activities (heat and power, feedstock). Other factors include the industries' vulnerabilities to foreign imports and their ability to pass through cost increases to their customers in the face of international market competition.

In general, the industries we examined in the study typically would be limited in their ability to pass through additional costs from a U.S. climate policy,

THE INDUSTRIES WE EXAMINED IN THE STUDY TYPICALLY WOULD BE LIMITED IN THEIR ABILITY TO PASS THROUGH ADDITIONAL COSTS FROM A U.S. CLIMATE POLICY

especially in the face of strong competition from lower-cost foreign manufacturers who may not have to bear the burden of higher energy costs. Moreover, deterioration in market conditions, such as the current recession and financial industry crisis, could lower projections for product demand and prices in these industries, as well as the costs and availability of critical non-energy factor (i.e., raw materials) costs. These consequences in turn could both ease the pressure on the industries (e.g. reducing energy and materials prices) and aggravate their problems (e.g. by reducing demand).

These variations, contingencies, and caveats notwithstanding, our findings support the

following general conclusions:

Climate policies that impose a modest to high cost on carbon-based energy sources would increase most of the energy-intensive industries' production costs, reduce their operating surpluses and margins, and shrink their domestic market shares. This assumes that no investments or actions are made to mitigate or offset the additional cost impacts. These results also are contingent on each industry's future energy mix and reliance on fossil fuels.

Since these industries typically are constrained in their ability to pass along domestic policy-driven energy costs (because of international competition, market conditions, the nature of their markets, and other factors), **they likely would feel increasing pressure by 2030—if not 2020 or earlier in some instances—to take actions to reduce their costs and prevent their profitability from decreasing to undesired levels.**

The adoption of both readily available and more cutting-edge technology and the achievement of high energy efficiencies on a large scale could offset costs and generate additional profits. All the industries investigated are exploring a range of energy-saving technologies that could help mitigate these impacts, but face financial, technological, and other limitations (such as the age and sunk costs of their existing equipment) on their ability to successfully invest and adopt these alternatives over the short-to-mid-term.

An allowance allocation policy that substantially offsets energy cost impacts, at least through 2025, could buy time for these industries to make the adjustments and energy-saving technology investments required for maintaining their domestic production capacity and competitiveness. On the other hand, if industries do not

Figure 3-1

Mid-CO₂ Price Case Real Production Costs Relative to BAU, Comparing all Industries

Source: HRS-MI

invest early enough, making use of the time window provided by the allowance allocation, they could face even harder times toward 2025-2030.

Other policies, nevertheless, will likely be needed to encourage and enable industries to make these investments, as an alternative to cutting production or moving their operations to low-cost, low-regulation locations.

Production Costs

Energy price increases in the Mid-CO$_2$ Price Policy would drive up total production costs

in the energy-intensive industries. Figure 3-1 and Table 3-A show, however, that these impacts would vary considerably across the industries.

The iron and steel industry would see the largest real production cost increases of all the industries analyzed, growing from 4 percent above BAU by 2012 to over 11 percent by 2030.

Chlor-alkali production cost increases would grow at a rate comparable to iron and steel, from a little below 4 percent to 10 percent between 2012 and 2030. Paper and paperboard production costs would rise at a similar but more modest rate.

Primary aluminum costs would increase modestly, rising roughly 4 percent over BAU by 2030. However, higher energy prices could increase the cost of two key inputs in primary aluminum production—alumina and carbon anodes. These costs were not included in the II-CPM but were nevertheless estimated using the results of the simulations. We estimated that projected cost increases for primary aluminum production could be as much as twice that originally calculated when increases in alumina and carbon anode cost increases are included. [37]

Secondary aluminum, which consumes only about 5 percent of the energy used in primary aluminum smelting to produce a unit of aluminum, not surprisingly would experience very modest cost impacts, rising only to a little under 2 percent by 2030.

Although petrochemicals is a highly energy intensive industry—energy costs accounted for 30 percent of total production costs in 2006—its policy-induced cost increases would be as modest as those in secondary aluminum.

Energy-mix variations. Figures 3-2 and 3-3 compare the energy cost components for the iron and steel and petrochemicals industries, respectively, for the Mid-CO$_2$ Price Policy and BAU. Figure 3-2 shows that iron and steel energy costs would grow mostly because of increases in feedstock energy costs,[38] as higher CO$_2$ charges are applied to metallurgical coal and coke (feedstock) relative to natural gas and fuel oils (fuel).

Figure 3-3 shows, in contrast to iron and

steel, that petrochemicals would experience only very modest cost increases under the Mid-CO$_2$ Price Policy, even though like iron and steel it uses a substantial amount of energy feedstock. According to the DOE's Manufacturing Energy Consumption Survey (MECS), the petrochemicals industry has relied most heavily on liquefied petroleum gas (LPG) since early in this decade, and secondarily on natural gas for feedstock in its production processes (to make ethylene, propylene, benzene, and related bulk petrochemicals). Although the EIA/NEMS analysis projected LPG to remain relatively expensive, it barely changes in the policy case compared to BAU (see Table 2-C). In contrast, natural gas increase by 39 percent by 2030 compared to BAU.

If instead—as some industry experts claim—natural gas liquids (NGL) accounts for some, most or all feedstock use in the U.S. industry, climate policy cost impacts could be somewhat greater than generated in the II-CPM simulation.[39] This possibility is supported by findings in the materials cost sensitivity analysis (see Appendix C), which indicates that additional materials cost increases, such as greater use of natural gas

> **Petrochemicals would experience only very modest cost increases under the Mid-CO$_2$ Price Policy, even though like iron and steel it uses a substantial amount of energy feedstock.**

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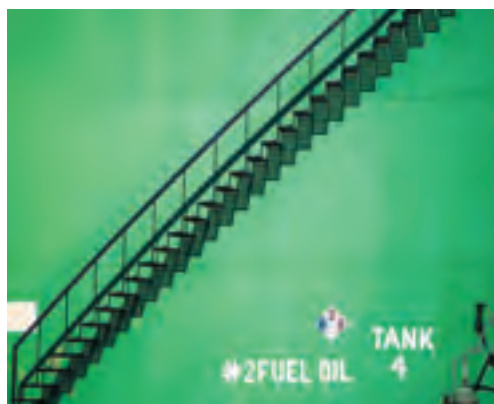
[37] Alumina refining is a highly energy-intensive process that turns bauxite (aluminum oxide) into alumina, the raw material used in primary aluminum smelting. Carbon anodes are major components used in the electrolysis process that transforms alumina into aluminum. See Chapter Six and Appendix B for detailed explanations of both products and estimations of the additional carbon-related energy costs associated with in their production and use

[38] In iron and steel making, according to EIA, *MECS 2002*, coal and coke are the primary feedstock—raw materials used in the production of a product—consumed. Fuel (for heat and power) energy consists primarily of natural gas and fuel oils, as well coal and coke.

[39] For discussion on the use of NGL versus LPG as feedstock in estimating energy cost impacts see Chapter Eight and in Appendix B.

TABLE 3-A
REAL UNIT PRODUCTION COSTS ABOVE BAU, MID-CO$_2$ PRICE POLICY

Industry Sector (unit)	2012		2020		2030	
	$2000	Percent	**$2000**	Percent	**$2000**	Percent
Primary Aluminum (mt)	38	*2.2*	40	*2.6*	64	*4.6*
Secondary Aluminum (mt)	7	*0.5*	10	*0.8*	19	*1.7*
Iron & Steel & Ferroalloys (ton)	29	*4.0*	50	*6.7*	90	*11.4*
Paper & Paperboard (ton)	11	*2.1*	17	*4.0*	31	*8.7*
Petrochemicals (ton)	3	*0.6*	5	*1.0*	9	*1.5*
Chlor-Alkali (mt)	4	*3.6*	6	*5.5*	10	*9.9*

mt=metric ton

PRODUCTION COST INCREASES IN THE PRIMARY ALUMINUM INDUSTRY ALSO WOULD NOT BE SUBSTANTIAL IN THE CLIMATE POLICY CASE BECAUSE OF PRIMARY ALUMINUM SMELTERS' RELIANCE ON ELECTRICITY AS ITS MOST IMPORTANT ENERGY SOURCE.

as a petrochemicals feedstock, would result in somewhat higher production costs than projected in the II-CPM simulations.

In either case, however, the CO$_2$ sequestered in the production of chemical products would be compensated with a credit to the petrochemical sector, offsetting the cost impacts.[40]

Production cost increases in the primary aluminum industry also would not be substantial in the climate policy case because of primary aluminum smelters' reliance on electricity as its most important energy source (see Table 2-C). In addition, because about 50 percent of U.S. smelters rely on hydroelectric generated power (non-carbon electricity sources) the II-CPM results could be overstating electricity cost increases.[41] On the other hand, as noted above, if the energy costs associated with alumina refining (a materials cost) and carbon anodes (a feedstock and additional materials cost), are factored in, primary aluminum production costs increases could

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[40] That is, whether LPG or NGL are used as feedstock consumed in the production of petrochemicals, the carbon content of those fuels would be "sequestered" in petrochemical products and downstream derivatives, rather than emitted as CO$_2$, say if the fuels were used for heat and power.

[41] Chapter Six discusses an important caveat regarding assumptions made by the EIA NEMS in generating electricity prices. The EIA NEMS assumes that the bulk of fossil-fuel (coal) generation would switch to nuclear generation. If this scenario proved to be unrealistic, fossil-fuel generation would have a greater role in the economy in the climate scenario, and electricity prices would rise more than the EIA's projections—and the subsequent costs for those smelters still reliant on fossil-fuel generated power could be somewhat higher than those projected in the II-CPM simulations. In the higher carbon-based electricity generation scenarios, other energy-reliant industries, such as chlor-alkali would also likely experience higher overall cost increases, than under the Mid-CO$_2$ Price Policy.

Figure 3-2
Steel Real Unit Energy Cost Components

US Dollars (2000) per Metric Ton

	2005	2020		2030	
	2005	BAU	Mid-CO$_2$ Price	BAU	Mid-CO$_2$ Price
Fuel	15.5	15.5	30.5	16.5	43.7
Electricity	19.7	19.8	21.5	20.2	22.8
Feedstock	56.9	48.9	82.3	52.6	112.6

Fuel   Electricity   Feedstock
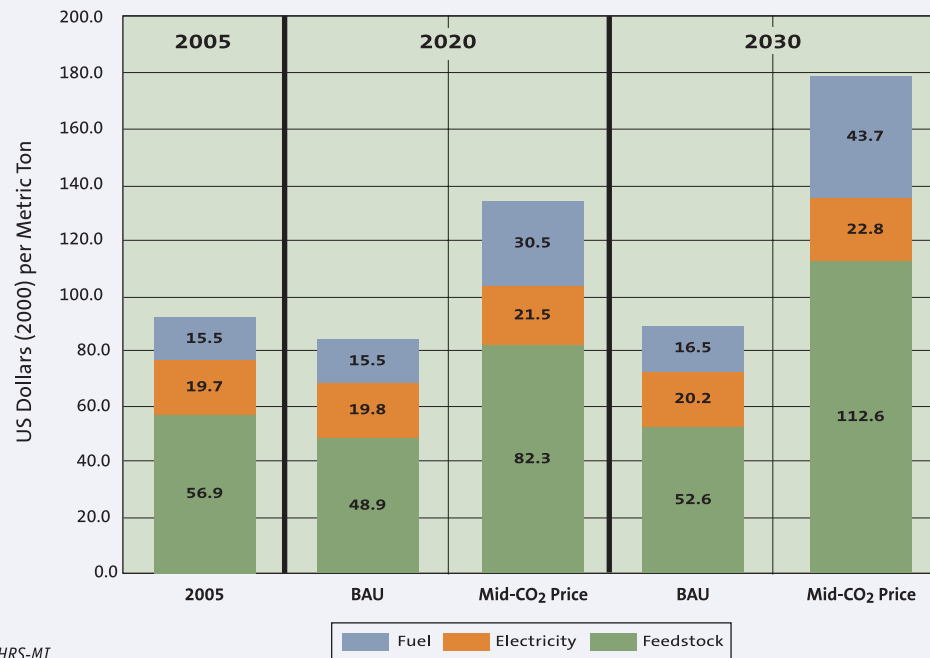
HRS-MI

The somewhat larger increases for fuel, coal and coke feedstock . . . would generate large cost increases in the basic oxygen furnace (BOF) segment of the iron and steel industry than in the electric-arc furnace segment.

Figure 3-3
Petrochemicals Real Unit Energy Cost Components
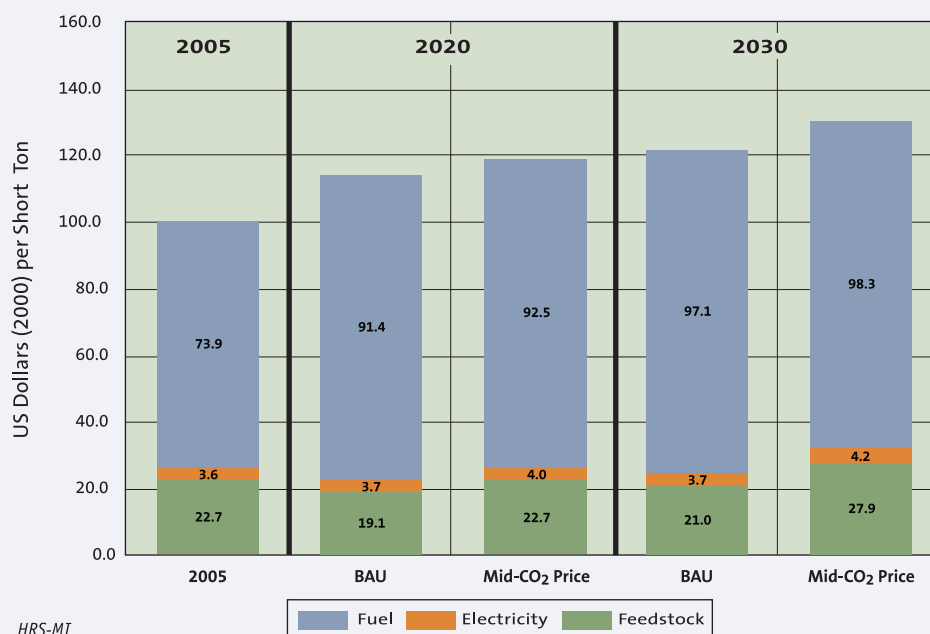
US Dollars (2000) per Short Ton

	2005	2020		2030	
	2005	BAU	Mid-CO$_2$ Price	BAU	Mid-CO$_2$ Price
Fuel	73.9	91.4	92.5	97.1	98.3
Electricity	3.6	3.7	4.0	3.7	4.2
Feedstock	22.7	19.1	22.7	21.0	27.9

Fuel   Electricity   Feedstock

HRS-MI

be quite a bit higher than projected by the II-CPM for the Mid-CO_2 Price Policy (see Chapter Six).

Similarly, the somewhat larger increases for fuel, coal, and coke feedstock, compared to the low electricity price increases under the Mid-CO_2 Price Policy, would generate larger cost impacts in the basic oxygen furnace (BOF) segment of the iron and steel industry than in the electric-arc furnace segment (see Chapter Five). These results also highlight the substantially lower carbon-footprint of the recycled end of the iron and steel industry, which is comparable to the far lower energy-intensity of secondary aluminum, the recycled end of the aluminum industry.

Operating Surplus

The extent to which policy-driven production cost increases translate into profit declines in the industries under study would depend on the degree to which manufacturers can pass along these costs to their customers. This ability is contingent on too many uncertain market factors—demand, market prices, international competition—for the II-CPM to realistically simulate. To frame the full range of industry options in the face of higher energy costs due to a climate policy, therefore, we employed the II-CPM to simulate the opposite ends of the cost pass-along spectrum: scenarios assuming zero or no cost pass-along (NCPA) and scenarios assuming total cost pass-along (CPA). (See Chapter Two and Appendix B for a more detailed discussion of the CPA and NCPA scenarios).

Most of the industry experts and literature we consulted suggested that, though cost pass-along could be possible for some industry segments, under certain favorable market conditions (strong demand, high market prices), the industries are typically constrained in their ability to pass through their costs, especially if the cost increases apply only to the United States.[42] These industries tend to measure their competitiveness (and preserve their profit margins) by their ability to keep their costs low relative to prevailing global market prices. Thus, the II-CPM simulations that assume that manufacturers will not be able to pass through cost increases would likely be closer to reality in most instances for the energy-intensive industries studied, assuming climate policies are implemented only in the United States.

Operating surplus and operating margin. The II-CPM projections of the impacts on industries' *operating surpluses*—a proxy for their profits—incorporated the market dynamics associated with international competition. These results show what might happen if manufacturers make no adjustments to their outputs or do not invest in new energy-saving technologies to offset cost increases. The analysis was conducted for the two different assumptions about the industries' abilities to pass along the additional costs: no costs would be passed along (NCPA) and all costs would be passed along (CPA).

Figure 3-4 illustrates the impacts on operating surplus—the difference between market price and production costs—as a result of the climate policy for the iron and steel industry, for the NCPA scenario. As operating surplus declines, manufacturers would start to consider different options

THE EXTENT TO WHICH POLICY-DRIVEN PRODUCTION COST INCREASES TRANSLATE INTO PROFIT DECLINES IN THE INDUSTRIES UNDER STUDY WOULD DEPEND ON THE DEGREE TO WHICH MANUFACTURERS CAN PASS ALONG THESE COSTS TO THEIR CUSTOMERS.

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[42] Cost increases for, say, raw materials, that affect manufacturers in an industry on a global basis, on the other hand, are much more likely to be passed through in higher market prices by most if not all producers around the world.

to reduce their costs and improve their profitability, including investments in new energy-saving technologies, or alternatively, cut back production, or in the worst case, move their operations to low-cost foreign locations.

NCPA findings. As Figure 3-5 and Table 3-B show, every industry in the study would see an operating surplus decline relative to BAU under the Mid-CO$_2$ Price Policy, although in absolute terms the operating surplus would still be positive for all industries. As noted above, these scenarios assumed no major new investments are undertaken to improve efficiency, and that no complementary policies are implemented to mitigate increased energy costs.

Not surprisingly, the industries with the greatest production cost increases associated with higher energy costs, also would suffer the largest operating surplus and operating margin declines, in particular, iron and steel, paper and paperboard, and chlor-alkali, followed by primary aluminum.

- The iron and steel industry would experience very high operating surplus declines, rising to 24 percent by 2020 and to 40 percent by 2030 relative to BAU, and operating margin declines of 5 percent and 9 percent, respectively.

- The paper and paperboard industry would see comparable declines in its operating surplus—12 percent by 2020 and 38 percent by 2030—and operating margin—3 percent and 7 percent, respectively—relative to BAU.

- Operating surplus and operating margin declines in the primary aluminum industry would be less acute, rising from 6 percent and 2 percent, respectively, in 2020, to over 16 percent and 4 percent, respectively in 2030, relative to BAU. If, however,

alumina and carbon anode costs rise as well, the decline in operating surplus could nearly double by 2030.

- Secondary aluminum, in contrast, would experience very modest operating surplus declines over most of the policy period.

- Chlor-alkali and petrochemicals represent opposite ends of the spectrum in the chemicals industry in terms of climate policy impacts on operating surpluses and operating margins. Chlor-alkali's operating surplus declines would be somewhere in between those of paper and paperboard and primary aluminum, rising to 20 percent by 2030.

- In contrast, operating surplus declines in the petrochemical industry are only slightly above 2 percent by 2030. However, if the industry uses NGL on a larger scale for feedstock compared to LPG than the study originally assumed, the cost increases and operating surplus declines could be greater than estimated by the II-CPM. On the other hand, as noted above, many of these costs—in particular those associated with feedstock price increases—most likely would be offset by a credit (issued by the government) for the CO$_2$ not emitted in petrochemicals production.

Not surprisingly, the industries with the greatest production cost increases associated with higher energy costs, also would suffer the largest operating surplus and operating margin declines.

FIGURE 3-4

IRON & STEEL REAL UNIT PRODUCTION COSTS, COMPARED TO DOMESTIC MARKET PRICE [NCPA]*

DOMESTIC MARKET PRICE

Real Unit OS
[Mid-CO₂ Price Case]

Real Unit OS
[BAU Case]

PRODUCTION COSTS

Mid-CO₂ Price Case   BAU Case   HRS-MI   * NCPA=No Cost Pass-Along
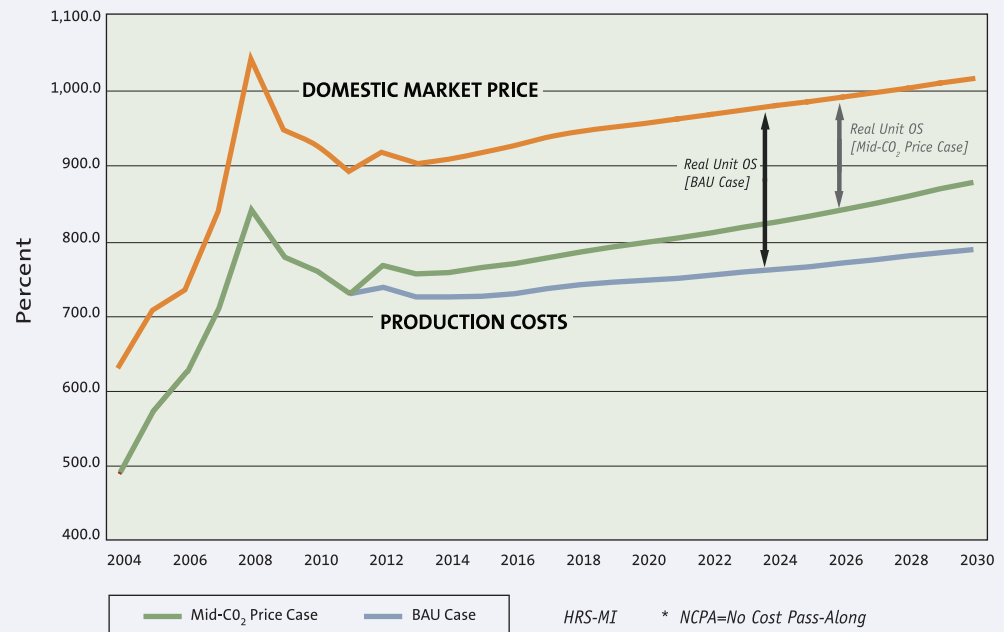
FIGURE 3-5

MID-CO₂ PRICE CASE REAL OPERATIONG SURPLUS RELATIVE TO BAU COMPARING ALL INDUSTRIES [NCPA]

Petrochemicals   Secondary Aluminum   Primary Aluminum
Chlor-Alkali   Paper & Paperboard   Iron & Steel

Source: HRS-MI
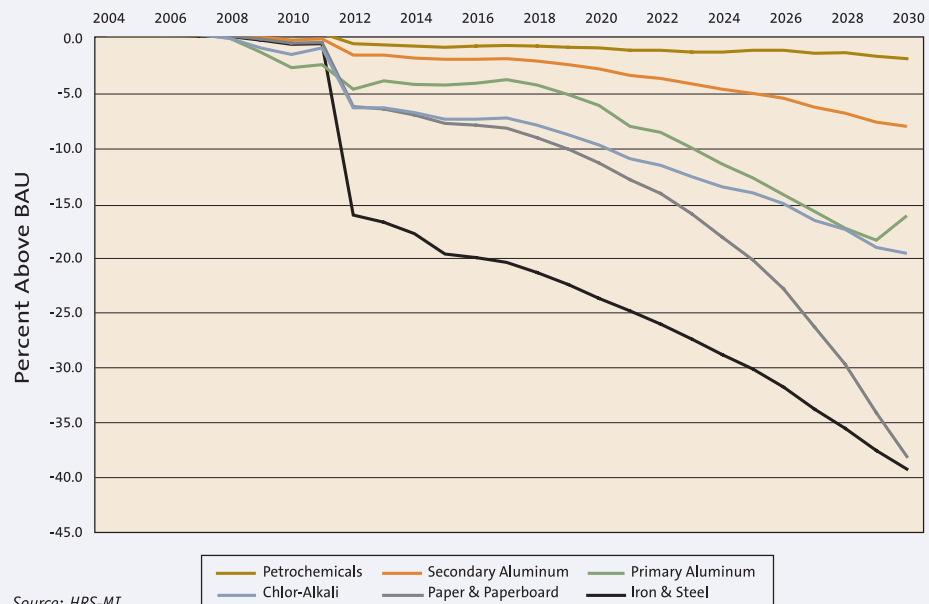
TABLE 3-B

OPERATING SURPLUSES, MID-CO$_2$ PRICE POLICY PERCENT ABOVE BAU [NCPA]

Industry Sector	2012	2020	2030
Primary Aluminum	-5.0	-6.4	-16.5
Secondary Aluminum	-1.9	-3.1	-8.3
Iron & Steel & Ferroalloys	-16.4	-24.0	-39.6
Paper & Paperboard	-6.6	-11.7	-38.4
Petrochemicals	-0.8	-1.2	-2.2
Chlor-Alkali	-6.7	-10.0	-19.9

COST PASS-ALONG ANALYSIS

It might be possible for energy-intensive manufacturers to pass along some or all the added energy costs associated with the Mid-CO$_2$ Price Policy, in the form of higher prices to their customers. To help frame the analysis of this possibility, we ran II-CPM simulations assuming that the industries would pass along *all* their new energy-related costs (CPA). As expected, the results showed that the industries would retain or even experience a gain in their operating surpluses *per unit* of production.[43] At the same time, they would lose a small part of their domestic market shares (domestic production as a share of total domestic supply) to foreign imports, reflecting the higher domestic prices relative to foreign competitors. These reductions would range from very small for the relatively import-insensitive chemicals industries to modest declines (up to 2 to 4 percent) for the aluminum and paper and paperboard industries, to more significant reductions (6 percent) for the iron and steel industry.

But according to economic studies and industry experts, the cost pass-along potential for these industries is generally constrained, especially in the short-to-medium run, depending on economic conditions and the strength of market

As expected, the results showed that the industries would retain or even experience a gain in their operating surpluses per unit of production.

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[43] This depends on the mode of how costs are assumed to pass through to domestic market prices by the industries. If an industry's new costs are simply added to market prices (cost-basis CPA) to offset the cost increases in their revenues, unit operating surplus would remain equal to BAU level. If the industry raises its market prices to maintain their operating (profit) margins (margin-basis CPA), then they would see a gain in their operating surplus. See Appendix B for further explanation of the two CPA modes of calculation.

demand.[44] Manufacturers typically would pass along new costs, say from higher-priced raw materials, if most or all their principal competitors face similar cost increases on a worldwide basis. However, if these increases are geographically confined, such as would be the case with climate policy-induced energy price increases tied to a CO_2 charge, then cost pass-along would be somewhat more difficult for domestic producers, especially if confronted with strong low-cost international competitors. Hence, we believe that the no, or little, cost pass along scenarios would more realistically represent the energy-intensive industries' market situation under a climate policy.

For example, it is widely agreed that in the primary aluminum industry, whose products are mostly sold on international commodity exchanges[45] and subject to world prices set in these markets, there would be nearly zero cost pass-along possibilities (see Chapter Six). In iron and steel, product sales in international markets are more bilateral in nature, and in principle there could be greater cost pass-along possibilities, especially in periods of strong market demand.[46] On the other hand, the domestic steel industry, more typically—at least over the past few decades—has had to struggle with weakening market demand, global overcapacity, and intensifying low-cost foreign competition, which would make cost pass-along a much less likely option (see Chapter Five). Other energy-intensive industries, such as paper and paperboard (see Chapter Seven), have historically faced similar market conditions. The basic chemicals industries also are constrained, largely by the impact cost pass-along would have on their much more trade-sensitive downstream products[47] (see Chapter Eight).

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[44] See the industry profiles, Chapters Four through Eight for a detailed treatment of this point for each industry.CO_2 Price Policy.

[45] Primarily, the London Metal Exchange and Shanghai Futures Exchange.

[46] This characterized the 2004 to mid-2008 period, a time of rising prices and high demand, and lower cost foreign producers from emerging economies were more preoccupied supplying the needs of their own nations (e.g., China, India, Brazil).

[47] That is, downstream producers tend to be vertically integrated with the upstream bulk chemicals manufacturers (such as petrochemicals and chlor-alkali)

Investment Options

Manufacturers have several options when confronted with higher production costs. As noted above, the industries in the study are generally limited in their ability to pass along increased costs to their customers. In the less import-sensitive industries, producers facing rising production costs that threaten their ability to stay competitive might opt to pass through increased costs, accepting a potential loss of market share in order to maintain their operating (profit) margins. Manufacturers in more globalized industries, such as aluminum and iron and steel, may not have this option. They instead may choose to reduce output or move their operations to lower-cost offshore locations, if their production costs grow to levels that seriously cut into their operating revenues.

Alternatively, manufacturers could attempt to preserve their domestic production capacity by making investments in energy-saving technologies. A review of near-, mid-, and long-term energy-efficiency and energy-reducing technologies available to the industries, suggests that a number of such technology options exist for each industry.

Energy efficiency gains needed. The II-CPM enabled estimations of the energy efficiency gains that would be needed in each industry to offset the energy cost impacts from climate policies. These calculations, summarized in Figure 3-6, include the gains that would be required in the use of energy fuels, electricity and energy feedstocks. The estimates first involved calculating the energy equivalent for the incremental cost increases arising from a climate policy. For any given year after the policy went into effect, this amount was divided by the total energy consumption through that year, to give the energy efficiency gains needed to offset the cost increases (see Appendix B for a fuller description of this calculation).

According to the energy efficiency estimates:

- The iron and steel industry would need to increase its energy efficiency in the use of fuels by 34 percent, the use of electricity by 7 percent, and the use of feedstock (coal, coke) by 42 percent, by 2020, to offset the rise in the costs of these energy supplies under the Mid-CO_2 Price Policy. These numbers would rise to 42 percent, 10 percent, and 50 percent, respectively, by 2030, if no investments to reduce energy use in iron and steel production were made by then.

- Primary aluminum would need to make efficiency improvements of 13 percent in fuel use and 7 percent in electricity by 2020. If we incorporate the additional costs of carbon-based consumption in alumina refining and carbon anode production and use in primary production, the required gains, especially for fuel energy and feedstock, would likely be higher. Similarly, paper and paperboard would need to improve its fuel-use by 23 percent.

ALTERNATIVELY, MANUFACTURERS COULD ATTEMPT TO PRESERVE THEIR DOMESTIC PRODUCTION CAPACITY BY MAKING INVESTMENTS IN ENERGY-SAVING TECHNOLOGIES.

Figure 3-6

Figure 3-6

Energy Efficiency Gains Required by 2020 (Cumulative) Mid-CO$_2$ Price Policy Case [Percent of BAU]

Industry	Type	Percent
Iron & Steel	Fuel	34.2
	Electricity	6.6
	Feedstock	42.1
Primary Aluminum	Fuel	13.4
	Electricity	6.6
Secondary Aluminum	Fuel	14.7
	Electricity	6.6
Paper & Paperboard	Fuel	22.9
	Electricity	6.6
Petro-chemicals	Fuel	12.9
	Electricity	6.6
	Feedstock	1.3
Chlor-Alkali	Fuel	14.2
	Electricity	6.6

HRS-MI

• Chlor-alkali and petrochemicals would need to make efficiency improvements in fuel use of 14 percent and 13 percent, respectively, by 2020, to offset higher energy costs. However, only a little more than a one percent increase in energy efficiency in feedstock consumption would be required in petrochemicals production, to offset the associated climate policy costs. If the NGL feedstock scenario (see operating surplus discussion above) is realistic, then the energy-efficient gain requirements for feedstock energy most likely would be greater, but still modest, indicating that a relatively small credit would be needed for the CO$_2$ sequestered (i.e. embedded or stored in the product).

Technology options. A major concern of our study was whether the industries have access to technologies capable of achieving these efficiencies. We found that over the short run, these options might be limited, as many of the industries already have invested over the years in substantial energy-efficiency gains (see Box 3). On the other hand, we found that relatively low-cost incremental improvements in energy efficiency and savings are possible over the near-to-mid term, such as more combined-heat and power (CHP) generation; relined boilers; enhanced heat recovery; improved sensors and process controls; more efficient electric motors, pumping systems and compressed air systems; and improved recycling technologies, among

other measures. These improvements could result in small, steady energy-efficiency gains, offsetting some of the added costs from a climate policy. However, the energy-efficiency analysis indicates that much larger gains, requiring substantial investments in advanced low- or no-carbon production processes would be necessary over time.

To varying degrees, the industries have been supporting research and development on advanced production and process technologies that could result in significant energy savings (Table 3-C). Some of the most promising of these technologies include low-carbon ironmaking processes in the iron and steel industry, inert anodes and wetted drained cathodes in primary aluminum smelting, black liquor gasification and advanced paper drying machines in paper and paperboard production, and membrane cells in chlor-alkali.[48]

However, several barriers to commercialization and deployment of these and other important technologies remain. First, it may be many years before most of these technologies are proven to be technically and commercially viable, and cost effective from manufacturers' point of view, even with higher energy costs. Second, these technologies mostly involve installing large, expensive pieces of equipment, requiring fairly substantial infusions of new capital investments, by industries that chronically complain about a lack of capital. Finally, the vintage of existing equipment, machinery and facilities in these industries will dictate when manufacturers will be willing to replace aging production capacity with new, more energy-efficient technologies.

For these reasons we believe that additional policies would be needed to support

timely investment in energy efficiency and retrofitting of less advanced production facilities. Also, more research is needed to assess the industries' potential to adopt new energy-savings technologies (costs, ROI, timing), and whether or not this would be sufficient to offset the impact of higher energy prices for different climate policies. Finally, we need a better understanding of the financial and market conditions—that is, the "business case"—that would motivate and justify manufacturers' investments in advanced low-carbon production technologies, as opposed to closing down capacity or moving operations to low-cost offshore locations.

WE BELIEVE THAT ADDITIONAL POLICIES WOULD BE NEEDED TO SUPPORT TIMELY INVESTMENT IN ENERGY EFFICIENCY AND RETROFITTING OF LESS ADVANCED PRODUCTION FACILITIES.

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[48] See part II, the industry profiles, Chapters Four through Eight, for a more detailed discussion of these and other energy-saving technology options for the industries.

Box 3
Savings Potential for Energy-Intensive Industries*

Graph labels: Energy Savings (y-axis); Time (x-axis); Production Frontier; Remaining energy savings possible at current technology levels; New Production Frontier; Current energy intensity level; New potential energy savings
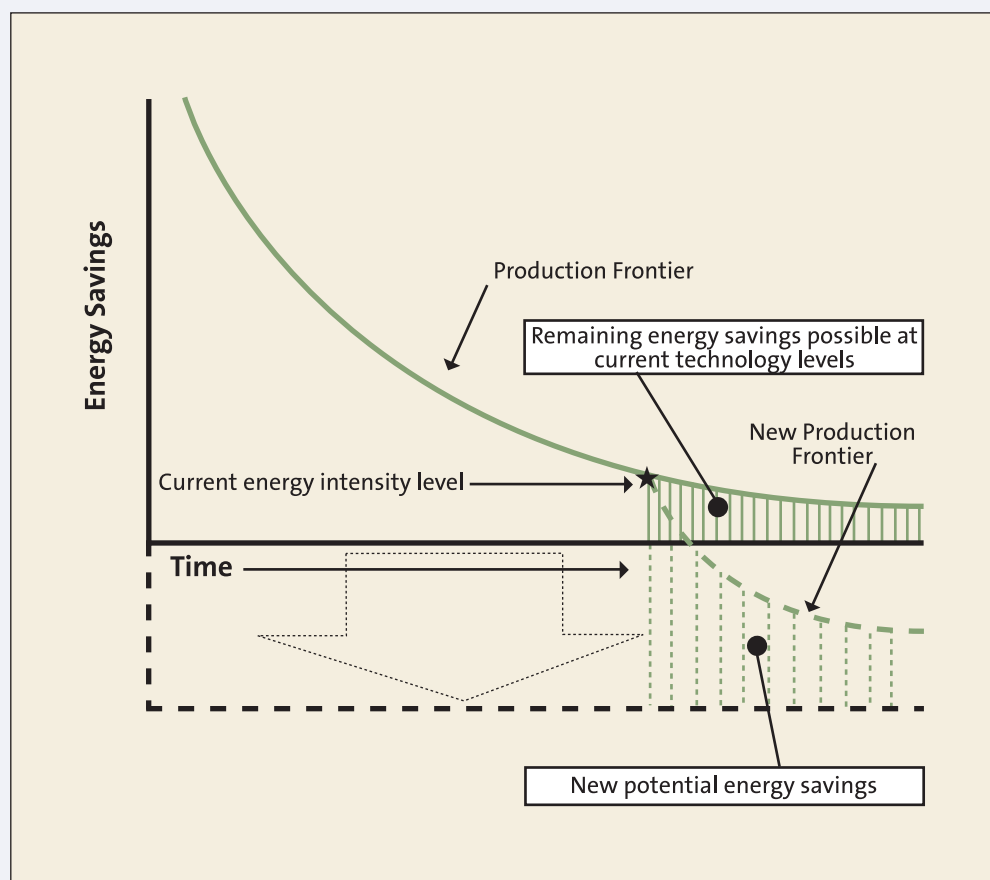
Adopted from the American Iron & Steel Insitute

As illustrated in the figure above, most of the industries the study analyzed may have steadily invested over the years in "low-hanging" fruit technology. That is, they have gone far down the energy savings curve, and additional incremental gains in energy-efficiency would be relatively small for the high marginal costs required to achieve them, given current levels of technology. While some of these improvements may become cost effective as energy costs increase in response to CO_2-pricing policies, substantial investments—a major "step jump"—in advanced low-carbon, energy-efficient production technologies most likely would be needed to offset the rising additional energy costs from climate policies over the next few decades.

TABLE 3-C

TECHNOLOGY OPTIONS FOR REDUCING ENERGY USE AND CO$_2$ EMISSIONS

Technology Option	Description	Time-frame
Iron & Steel		
Pulverized coal and plaste waste injection	Pulverized coal is already used by more than 50% of U.S. BOFs.	ST-MT
New reactor designs	Uses coal and ore fines (COREX, FINEX)	MT
Paired straight hearth furnace	Substitutes coal for coke in blast furnaces, lower costs, uses 2/3 energy	MT-LT
Molten oxide electrolysis	Produces iron and oxygen, no CO$_2$	LT
Hydrogen flash melting	Uses hydrogen in shaft furnaces, no CO$_2$	MT
Geological sequestration + steelmaking		MT-LT
Paper and Paperboard		
Black liquor gasification	In demonstration, R&D; commercially available 2030; 15%-23% gain	MT-LT
Efficient drying technology	R&D now; commercial demo, 2015-2030; commercial 2030-->	MT-LT
Primary Aluminum		
Wetted, drained cathode technology		MT
Alternative cell concepts	Combines inert anode, drained cathodes	LT
Carbothermic and kaolinite reduction process on commercial scale	Alternatives to the Hall-Héroult process	LT
Petrochemicals		
High-temperature furnaces	Able to withstand more than 1,100°C	MT-LT
Gas-turbine integration	Higher-temperature CHP for cracking furnace	MT-LT
Advanced distillation columns		MT-LT
Combined refrigeration plants		MT-LT
Biomass-based system options	Feedstock substitution	LT
Chlor-Alkali Manufacturing		
Convert mecury-process and diaphragm-process plants to membrane technology	Combined electrolytic cell with a fuel cell, using hydrogen by-product	MT-LT

ST=Short Term (Current Year-2015); MT=Medium Term (2015-2030); LT=Long Term (2030-2050)
Sources: IEA, DOE, AISI, Aluminum Assocation, Korean Energy Institute

Figure 3-7
Iron & Steel Real Operating Surplus
Mid-CO$_2$ Price Case (Percent Above BAU)
No Allocation and 90 Percent Allocation [NCPA]
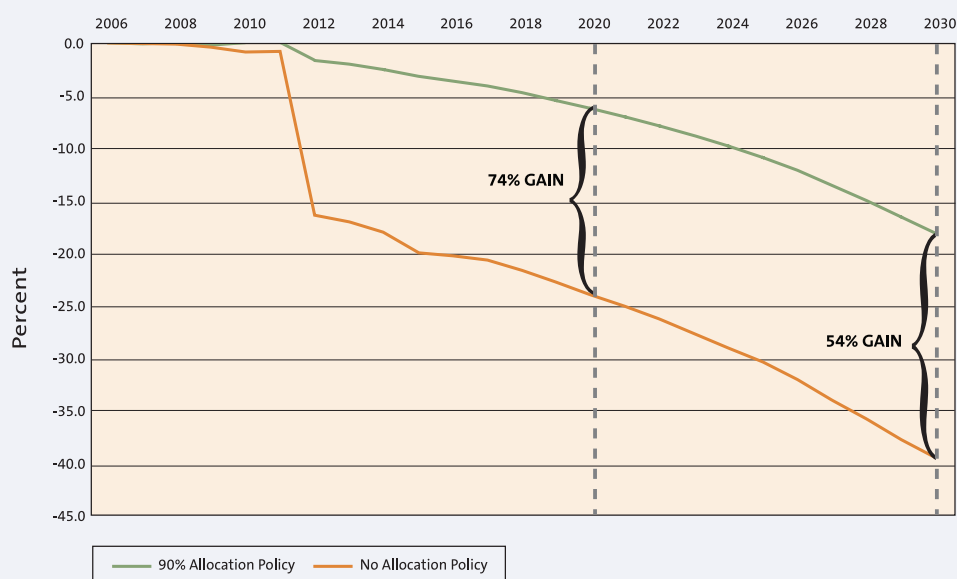
74% GAIN

54% GAIN

90% Allocation Policy   No Allocation Policy

Source: HRS-MI

Allowance Allocation Option

We also conducted a preliminary examination of policies for mitigating the impacts of CO$_2$-pricing policies on energy-intensive manufacturers. Specifically, we used II-CPM models used to evaluate a policy that would allocate free emission allowances equal to 90 percent of the increase in energy costs. These allowances could then be sold by companies to offset their increased energy costs. The number of allowances that are distributed would decrease 2 percent annually. The results showed that, for each of the industries,

the decline in operating surplus would be reduced by nearly three-quarters under the allocation scenario compared to the non-allocation case by 2020, and by roughly 50 percent by 2030 (Figure 3-7). As Table 3-D shows, every industry would benefit from the same large gains if the allocation allowance measure were enacted. (Note: This scenario assumed no new investments in energy efficiency improvements would be made.)

Allocating allowances to firms also substantially decreases the efficiency improvements needed to offset increased energy costs, allowing more time to develop and deploy advanced technologies (see Figure 3-8). By 2020, these requirements for the different energy sources (fuel, electricity,

feedstock) with the allocation would be diminished by from 70 to over 80 percent across the industries compared to the no allocation case. Nevertheless, for iron and steel at least, some requirements would still be significant, though still achievable. For example, by 2020, the required fuel and feedstock efficiency gains would be 9 percent and 12 percent in the 90 percent allocation scenario, compared to 34 percent and 42 percent, respectively, without an allocation. The implication of these findings is that providing free allocations, at least for the near-to-mid term, would greatly lessen the cost pressures on these industries that might otherwise lead to production cutbacks domestically.

ALLOCATING ALLOWANCES TO FIRMS ALSO SUBSTANTIALLY DECREASES THE EFFICIENCY IMPROVEMENTS NEEDED TO OFFSET INCREASED ENERGY COSTS

TABLE 3-D
Real Operating Surplus Above BAU (%) 90 Percent Allocation Policy vs. No Allocation Policy, Mid-CO$_2$ Price Policy [NCPA]

Industry Sector	2020		2030	
	No Allocation	90% Allocation	No Allocation	90% Allocation
Primary Aluminum	-6.4	-1.7	-16.5	-7.6
Secondary Aluminum	-3.1	-0.8	-8.3	-3.8
Iron & Steel	-24.0	-6.2	-39.6	-18.2
Paper & Paperboard	-11.7	-3.0	-38.4	-17.7
Petrochemicals	-1.2	-0.3	-2.2	-1.0
Chlor-Alkali	-10.0	-2.6	-19.9	-9.2

Figure 3-8

Energy Efficiency Gains Required by 2020 (Cumulative) Mid-CO₂ Price Policy Case, 90% Allocation [Percent of BAU]

		Value
Iron & Steel	Fuel	9.1
	Electricity	1.3
	Feedstock	12.3
Primary Aluminum	Fuel	2.8
	Electricity	1.2
Secondary Aluminum	Fuel	3.2
	Electricity	1.3
Paper & Paperboard	Fuel	5.3
	Electricity	1.3
Petro-chemicals	Fuel	2.7
	Electricity	1.3
	Feedstock	.2
Chlor-Alkali	Fuel	3.0
	Electricity	1.3

Percent: 0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0

HRS-MI

Conclusions

Manufacturing remains a vital part of the American economy. Many business, labor, and political leaders are rightly concerned that climate policies may contribute to the erosion of U.S. manufacturing competitiveness. This challenge is especially acute for energy-intensive basic materials manufacturing industries, which form the cornerstone of the nation's manufacturing base. There is particular concern about climate policy impacts on this sector, which is especially vulnerable to both rising energy costs and global competition. A primary goal of climate policy, therefore, should be to help energy-intensive industries reduce their dependence on fossil-fuels while improving their productivity and competitiveness in global markets.

The findings presented in this report show that climate policies that price CO_2 could have significant impacts on the competitiveness of U.S. energy-intensive manufacturing sectors over the next two decades if climate regulations are applied only in the United States, and no action is taken to invest in advanced low- and no-carbon technologies or otherwise mitigate the cost impacts on these industries. The extent of these impacts would vary across industries, depending on their energy-intensities, the mix of energy sources they rely on (electricity, natural gas, coal), and

how energy is used in production activities (heat and power, feedstock). An industry's sensitivity to foreign imports and its ability to pass through cost increases to its customers in the face of international market competition are also major factors.

Our results also show that the energy efficiency gains required to offset the energy cost impacts from climate policies for energy fuels used for heat and power would range from 14 percent to 34 percent, by 2020. Iron and steel and paper and paperboard, in particular, would require the largest energy fuel efficiency gains. We also estimated that the former would require as much as a 42 percent gain in feedstock consumption. While relatively low-cost incremental improvements in energy efficiency are possible over the near-to-mid term, much larger gains, requiring substantial investments in advanced low- or no-carbon production processes, would be necessary over time.

Our findings further suggest that policy measures that mitigate the near-to-mid-term cost impacts of climate policy would buy time for—and, if coupled with appropriate policies, encourage—energy-intensive manufacturers to make the transition to low-carbon production processes. In particular, we found that with an allocation of a 90 percent allowance, reduced by 2 percent yearly, a substantial decrease in efficiency improvements would be needed to offset increased energy costs, allowing more time to develop and deploy

advanced technologies. Furthermore, with such an allocation, declines in operating surplus for the Mid-CO_2 Price Policy, would be reduced by nearly three-quarters by 2020, and by roughly 50 percent by 2030.

In short, our findings strongly suggest that over the long-run, technologies are available to enable energy-intensive industries to achieve sufficient efficiency gains to offset and manage the additional energy costs arising from a climate policy. However, we also strongly believe that **the industries analyzed will need additional measures that both mitigate these cost impacts in the short-to-medium term, and policies that encourage and facilitate the transition of energy-reliant companies (and their employees) to a low-carbon future, while enhancing their competitiveness in global markets.**

POLICY MEASURES THAT MITIGATE THE SHORT-TO-MID-TERM COST IMPACTS OF CLIMATE POLICY WOULD BUY TIME FOR—AND, IF COUPLED WITH APPROPRIATE POLICIES, ENCOURAGE—ENERGY-INTENSIVE MANUFACTURERS TO MAKE THE TRANSITION TO LOW-CARBON PRODUCTION PROCESSES.

INDUSTRY OVERVIEW

I

In Chapters Four to Eight, we examine in-depth the potential impacts of climate policies on several important energy-intensive manufacturing industries, based on results of the II-CPM simulations and analysis. Until recently, most economic analyses of climate policies focused on the *industrial sector* as a primary unit of analysis, defined by the Department of Energy's Energy Information Administration (EIA) as all materials processing and goods producing industries, inclusive of manufacturing, but also agriculture, forestry, fishing and hunting, mining (including oil and gas extraction), and construction. According to the EIA, the industrial sector consumed 25.1 quadrillion Btu of delivered energy in 2005, or 35 percent of total delivered energy consumed in the U.S. economy. It also produced 1,651.8 million metric tons of carbon-dioxide emissions, or 28.0 percent of the U.S. total in 2006.[49]

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[49] U.S. Department of Energy, Energy Information Administration (EIA), *AEO2008 Overview* (Washington, DC, n.d.).

Manufacturing (NAICS 31-33) accounts for an estimated 90 percent of the energy consumed and 80 percent of emissions generated in the industrial sector.[50] Yet, despite manufacturing's role as a major consumer of energy and emitter of greenhouse emissions, the conventional economic wisdom is that climate policies that put a price on carbon dioxide emissions would only have very modest impacts on manufacturing costs, profits and outputs. This reflects the sector's low energy intensity on aggregate, which is only about 3 percent when calculated as total energy expenditures as a share of total operating expenditures (see Table 2-A, Chapter Two).

There is growing concern that highly energy-dependent manufacturing industries could... suffer large economic losses if carbon-pricing policies are enacted.

However, there is growing concern that highly energy-dependent manufacturing industries could disproportionately suffer large economic losses if carbon-pricing policies are enacted in the United States.

That is, in economic assessments of climate policies, we need to distinguish between *energy-intensive manufacturing* industries that consume large quantities of fossil-fuel energy (including fossil-fuel generated electricity) in their production and *non-energy-intensive* manufacturing industries that do not.

This is not to say that the latter industries are not concerned about energy costs. Although transportation equipment manufacturing is a relatively small consumer of energy, its primary products—autos, aircraft—are large consumers of fossil fuels, and therefore vulnerable to volatile energy prices, as well as policies that drive energy costs higher or require greater fuel efficiency. Even relatively non-energy intensive manufacturing sectors, such as metal-based durables, have been projected by the EIA to account for a 50 percent growth in industrial natural gas consumption from 2004 to 2030.[51] Nevertheless, energy-intensive manufacturing industries are much more vulnerable to rising energy costs, whether the result of market forces or climate policies, and therefore have attracted special attention in the climate policy debate.

Energy-Intensive Industries

We can calculate the energy-intensity of industries in different ways—for example, energy costs (dollars) or consumption (Btus) as a share of operating costs, or as a value

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[50] These estimates were based on other sources, as the AEO projections do not break out the manufacturing quantities from the industrial sector consumption of energy and generation of emissions. For example, energy consumption (22.666 quadrillion Btu) figures from the EIA's Manufacturing Energy Consumption Survey data for 2002 were matched with AEO industrial sector energy consumption for 2002. See EIA, *MECS 2002*. See also Houser et al, *Leveling the Playing Field*, 11, table 1.2, which reported manufacturing emissions as 1,369 mmt in 2005, compared to AEO industrial sector emissions in 2005 of 1,682.252 mmt, or 81 percent.

[51] U.S. Department of Energy, Energy Information Administration (EIA), *Annual Energy Outlook for 2007, With Projections to 2030* [DOE/EIA 0383 (2007)] (Washington, DC, February 2007), 47.

of shipments, or per employee.[52] Table 4-A shows energy consumption and energy intensity—measured as the total fuel consumption per dollar of value added—for most of the major manufacturing sectors and selected energy-intensive industries within these sectors. Fuel consumption includes all energy purchased off-site and on-site for heat and power and non-fuel use (feedstock) minus energy (heat and electricity) shipments to external establishments. Value added is widely considered to be the best economic measure for comparing the relative economic importance of manufacturing among industries and geographic areas.[53]

Regardless of the indicator used, five manufacturing sectors (3-digit NAICS)—petroleum and coal products, chemicals, paper, primary metals, nonmetallic mineral products—out of a total of twenty-one sectors, stand out as containing the most energy-intensive industries. Most of these sectors, include both energy-intensive industries and non-energy-intensive industries. For example, chemicals manufacturing (NAICS 325) is a very large, diverse sector, which includes many of the most energy-intensive industries in the economy and others that are not. Food manufacturing, which by the measure used in the table is not a very energy-intensive sector, is a large consumer of energy and includes industries such as wet corn milling and sugar refining that are highly energy-intensive, though most other food manufacturing industries are not especially energy-reliant.

Similarly, primary metals (NAICS 331) include iron and steel mills and ferroalloy products and primary aluminum industries with very high energy-intensity values (66.5 and 112.3 respectively), and iron and nonferrous foundries and nonferrous metals (except aluminum) that are somewhat less energy-intensive (10.3 and 12.0, respectively). In some instances, industries have segments or closely related industries serving the same markets, with very different levels of energy-intensity. For example, the integrated steel mills and primary aluminum production plants are substantially more energy-intensive than their counter-part industrial segments, electric-arc furnace mini-mills and secondary aluminum smelting and recovery, respectively.

In addition, major energy consuming sectors often include non-energy-intensive downstream producers of fabricated goods, supplied with materials and intermediate goods by upstream energy-intensive producers. For example, in the paper sector (NAICS 322) the converted paper product manufacturing industry is supplied by the far more energy-intensive pulp, paper and paperboard industries. The energy-intensive primary metals industries are primary suppliers to foundries, steel products and aluminum products manufacturers, and as well as fabricated metal and transportation manufacturers. The products of the chemicals sector's upstream bulk chemicals industries are used in the production of thousands of downstream products. Indeed, the energy-intensive basic materials industries are at the beginning of the supply chains for all other manufacturing sectors in the economy.

Regardless of the indicator used, five manufacturing sectors (3-digit NAICS) out of a total of twenty-one sectors stand out as containing the most energy-intensive industries.

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[52] See Houser et al, *Level the Playing Field*, 7, table 1.1, and EIA, MECS *2002*, table 6.1.

[53] Fuel consumption definition and data are from MECS *2002*, table 6.1. The value added definition is from Census Bureau, *ASM*. The value added of an industry is calculated by subtracting from the total value of shipments all expenditures on materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments.

Table 4-A
Manufacturing Energy Consumption and Intensity

Subsector and Industry	Total Energy Consumed (trillion Btu)	Energy Consumed Percent of Manufac-turing	Fuel Consumed Per Value Added (thousand Btu/$)
Food, Beverage and Tobacco Products	1,228	5.42	4.9
Textiles	267	1.18	8.5
Apparel, Leather and Allied Products	37	0.16	1.9
Wood Products	377	1.66	10.6
Paper	2,363	10.43	31.1
Pulp Mills	224	0.99	116.6
Paper and Paperboard Mills, (inc. Newsprint)	*2,004*	*8.84*	*55.2*
Printing and Related Support	98	0.43	1.8
Petroleum and Coal Products	6,799	30.00	91.3
Petroleum Refineries	6,391	28.20	116.3
Chemicals	6,465	28.52	15.3
Petrochemicals	*889*	*3.92*	*77.4*
Industrial Gases	204	0.90	44.1
Alkalies and Chlorine	*191*	*0.84*	*143.3*
Carbon Black	88	0.39	77.3
Other Basic Inorganic Chemistry	218	0.96	21.4
Other Basic Organic Chemicals	1,833	8.09	66.8
Plastics Materials and Resins	1,821	8.03	41.4
Nitrogenous Fertilizers	497	2.19	202.5
Plastics and Rubber Products	351	1.55	3.9
Nonmetallic Mineral Products	1,059	4.67	20.7
Glass and Glass Products	201	0.89	16.7
Cements	409	1.80	95.5
Primary Metals	2,120	9.35	34.6
Iron and Steel Mills & Ferroalloys	*1,335*	*5.89*	*70.9*
Alumina and Aluminum	473	2.09	34.3
Primary Aluminum	*325*	*1.43*	*112.3*
Fabricated Metal Products	388	1.71	3.0
Machinery	177	0.78	1.4
Computer and Electronic Products	201	0.89	0.9
Electrical Equipment, Appliances & Components	172	0.76	1.9
Transportation Equipment	429	1.89	1.8
Furniture and Related Products	64	0.28	1.6
Manufacturing	**22,666**	**100.00**	**8.9**

Source: EIA, MECS 2002, table 6.1

Selected Industry Characteristics

In the HRS-MI study, we focused on five industries (indicated in bold in Table 4-A)—*iron and steel and ferroalloy products* (NAICS 3311), *primary aluminum production* (NAICS 331312), *paper and paperboard mills* (NAICS 32212,3), *petrochemical manufacturing* (NAICS 32511) *and alkalies and chlorine (chlor-alkali) manufacturing* (NAICS 325181) that are among the most energy-intensive in the economy. We also examined the much less-energy intensive *secondary smelting and alloying of aluminum* (NAICS 331314) industry, mainly because it is an integral part of the aluminum industry, and its products—made from recycled aluminum— are mostly traded in the same markets as primary aluminum products.

The selected industries represent a cross-section of the energy-intensive manufacturing sector, though they are not the only important energy-reliant industries—others include cement, nitrogeneous fertilizers (including ammonia) and petroleum refineries. They also are key industries within three of the largest energy consuming (3-digit NAICS) manufacturing sectors, chemicals, primary metals, and paper manufacturing, which ranked first, third and fifth, respectively among all major sectors in energy spending. These three sectors alone accounted for 41 percent of all energy expenditures for energy fuels and electricity in manufacturing in 2006.

Economic characteristics.

Table 4-B places the selected industries in a broader economic context. The iron and steel industry is the largest in the group, with total shipments of $93.3 billion, in 2006, and primary aluminum and chlor-alkali are the smallest, with total shipments of $6.2 billion and $6.4 billion, respectively, in 2006. Iron and steel mills (inclusive of ferroalloys) and aluminum producers accounted for 40 percent and 18 percent, respectively, of the total value of shipments of the primary metals sector, 63 percent and 22 percent, respectively, of the sector's total energy consumed (in million Btus), and 40 percent and 39 percent, respectively, of its electricity use in 2006. Pulp, paper and paperboard mills accounted for 47 percent of the total value of shipments of the paper manufacturing sector, yet consumed 94 percent of the energy[54] and 79 percent of net electricity.

Basic chemicals, itself a very diverse mix of industries, in 2006 accounted for 29 percent of the total value of shipments, and 61 percent of both energy expenditures (non-feedstock) and electricity use (kWh) in the chemicals manufacturing sector. Petrochemicals (NAICS 325110) and alkalies and chlorine (NAICS 325181) are two of the most energy-intensive industries within the basic chemicals category. However, they are of very different sizes: the former represents about one-third of total value of shipments for the basic chemicals group, the latter for only about 3 percent. However, petrochemicals accounted for 22 percent of energy fuel expenditures and 8 percent of electricity use of the basic chemical group, while alkalies and chlorine accounted for 12 percent and 14 percent, respectively.

Consolidation and restructuring.

Over the past several decades, all the industries have experienced shrinkage in their overall capacity and employment, largely to reduce costs and remain

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[54] See EIA, *MECS 2002.* This is total "first use" energy, which includes energy consumed for heat and power and for feedstock. Energy use is in Btus and electricity use in kWh.

Table 4-B

Industry Sector Financial Characteristics, 2006

NAICS Code	Industry Sector	Total VS	Total EC	PF & E	PE	PE (billion kWh)
		Billions of US Dollars				
31-33	Manufacturing	5,020.0	758.5	103.7	49.7	892.2
32212,3	Paper and paperboard mills	75.7	10.2	7.1	2.7	55.9
32511	Petrochemicals	60.8	1.0	2.8	0.4	7.5
325181	Chlor-alkali manufacturing	6.4	0.7	1.6	0.6	12.9
3311	Iron & steel mills & ferroalloys	93.3	9.4	6.2	2.6	57.1
331312	Primary aluminum	6.2	0.7	1.2	1.1	28.4
331314	Secondary aluminum	7.0	0.5	0.4	0.1	3.3

VS=Value of Shipments; EC=Employee Compensation; PF&E=Purchased Fuel & Electricity; PE=Purchased Energy
Source: Census Bureau, Annual Survey of Manufactures, 2006

competitive in the face of increasing globalization and rising energy costs. These pressures have been critical factors in manufacturers' decisions to consolidate, invest in new technologies, and shutdown facilities, or even to move operations offshore, to be closer to cheap sources of energy and labor and avoid environmental regulations.

Energy use. The industries rely on different mixes of energy sources. Paper and paperboard's largest fuel source is biomass, but uses natural gas and other fuels, and electricity in pulping and drying. Primary aluminum, chlor-alkali and electric arc furnace steel mills rely heavily on electricity. Integrated (basic oxygen furnace) steelmaking requires coal and

coke (a coal derivative), and petrochemical manufacturing is a major consumer of natural gas and liquefied petroleum gas (LPG).

Internal energy generation. Several of the industries generate internal heat and power as by-products of their production processes. For example, basic oxygen furnace steelmaking generates coke oven and blast furnace gas, which in turn, modern facilities recycle to generate electricity in combined heat and power generation or use as process heat. Papermaking also generates much of its energy internally, and the more efficient recovery of black liquor could be an important source of energy that greatly reduces reliance on external energy sources

All the industries have experienced shrinkage in their overall capacity and employment, largely to reduce costs and remain competitive in the face of increasing globalization and rising energy costs.

RECYCLED OR
RECOVERED SCRAP OR
WASTE MATERIALS
PLAY AN INCREASINGLY
IMPORTANT ROLE IN
STEEL, ALUMINUM
AND PAPER AND
PAPERBOARD
PRODUCTION.

in paper and paperboard mills.

RECYCLING. Recycled or recovered scrap or waste materials play an increasingly important role in steel, aluminum and paper and paperboard production. Over 70 percent of steel is recycled, and 60 percent of all domestic steel production comes from the processing of scrap steel. Secondary smelting of recovered aluminum account for over 60 percent of U.S. aluminum production. Nearly 40 percent of U.S. paper and paperboard production is made from recovered wastepaper. The recycled/recovery segments of these industries are somewhat less energy intensive than the parts that process virgin materials.

INTERNATIONAL MARKETS

The energy-intensive industries' sensitivity to volatile energy prices is influenced by their exposure to foreign competition. Most

energy-intensive industries, and especially the industries we examined in the study, are highly globalized, and becoming more so over time. Foreign companies now own many major domestic production facilities, and U.S. companies have acquired large international holdings in these industries. The products of these industries are internationally traded on a growing scale—increasingly sold on commodity exchanges, and their prices set in world markets. Raw materials, energy and other critical inputs (including scrap metals) for energy-intensive manufacturing are also traded internationally, and producers worldwide are vulnerable to volatility in these goods' prices set in global markets.

America's NAFTA partners, Canada and Mexico, account for the largest U.S. trade flows in energy-intensive manufacturing goods. Indeed, it has been suggested that aluminum, paper, and steel should be treated as North American industries, rather than distinct national industries. Certain countries show up frequently on

the lists of major U.S. importers for most of the selected industries, including Japan, China, Korea, Brazil, Germany, the United Kingdom, other EU countries, and Russia, among others. Finland, Sweden and Norway are large importers of paper, and Russia and Venezuela are major importers of aluminum, to the United States. The U.S. steel industry has multiple large trade competitors, including Brazil, Canada, Japan, China, Russia, Germany, Korea and Mexico. Countries such as the Ukraine, Turkey and South Africa, though smaller, also are important net steel importers into the United States.

China's expanding economic clout, in particular, has become a major concern for U.S. manufacturers—not to mention policymakers—in these industries. In 2007, China was the world's largest producer of steel and aluminum, second largest of chemicals, and the third largest of pulp and paper. It also was the world's largest consumer of steel and aluminum, and third in paper consumption, and its appetite for chemicals, including petrochemicals and chlorine has rapidly expanded. Yet, despite China's massive development of capacity in energy-intensive manufacturing, mostly to supply its own rapid economic development, it historically had not been a major trade partner of the United States in most of the sectors examined in the study. The exception is steel, but even here China— until recently, at least—was far from the largest net importer of steel in the domestic steel market.

However, over the past four years, China increased the size and share of its imports, and before the recent economic crisis it was likely to become one the leading trade competitors in all these sectors, as it has in many other industries. Some industry analysts have expressed concern that if China's buildup of new capacity were to outstrip its internal demand, it could dump large quantities of relatively inexpensive products into the world markets. Because of the sheer scale of its development, even a small share of China's basic manufacturing capacity diverted to exports could dramatically increase its import penetration into the U.S. and other nations' domestic markets.

Prices and the Cost Pass-Along Dilemma

Although China's relative ranking in the group of major U.S. importers has little direct bearing on construction of the II-CPM models, there are potential implications for interpreting the models' results, especially regarding how manufacturers might respond to higher domestic energy prices driven by a climate policy. Because of its sheer scale, Chinese production has had an outsized influence on world prices—which, in turn dictates what U.S. manufacturers must adjust to in the face of higher costs. The greater the competition from major low-cost producers, U.S. manufacturers would find it harder to pass along additional costs to their customers, in higher domestic

Over the past four years, China increased the size and share of its imports, and before the recent economic crisis, was likely to become one of the leading trade competitors in all these sectors.

prices. Foreign producers not subject to the same policy-driven energy price hikes, and with other cost advantages (access to cheaper inputs, government subsidies, low-cost labor, lax environmental regulations), therefore, could improve their competitive position relative to U.S. manufacturers, cutting into U.S. manufacturers' market shares and profits.

Cost pass-along options. The determination of whether or not producers decide to pass-through their input costs depends on an array of factors. These include the nature of the markets manufacturers operate within (e.g., how commoditized and globalized the markets are), market conditions and market price levels and movements (e.g., demand growth or shrinkage), how widely the input cost increases are shared by competitors, and the elasticity of the demand for manufacturers' products (i.e., what impact changing market prices will have on customer demand). The extent large low-cost producers, such as China influence product market prices, and the degree of foreign import penetration, are other factors that could affect manufacturers' choices.

In general, energy-intensive manufacturers will tend to pass along part or all their additional costs arising from an increase in their input prices (e.g., raw materials or energy), if these price hikes also widely affect their competitors on a global basis—and everybody raises their product prices accordingly. Problems arise, though, if the input price increases are localized—that is, only felt by domestic producers—and foreign competitors (or domestic firms owning foreign facilities) have access to energy or other inputs that are now relatively cheaper. The problems could be exacerbated if an industry experiences a downturn because of weakening economic conditions, which would push market prices down, as domestic costs are driven upwards because of higher input costs.

Some companies may nevertheless decide to pass their costs along to customers. For example, Kemira Chemicals, Inc. in 2008 increased prices by 5 percent to 20 percent for products it supplies to the paper industry in North America, to offset increased raw material, energy and freight costs.[55] In contrast, others may not pass their costs along by choice, or may not be able to in their markets. One consequence could be a decision to reduce capacity if their costs rise sufficiently high in the face of unfavorable market conditions. For example, International Paper, in response to continued higher input costs and economic conditions, decided in October 2008 to shut down, at least for several months, a major paper machine at an Oregon paperboard mill,

> In general, energy-intensive manufacturers will tend to pass along part or all their additional costs arising from an increase in input proces, if these price hikes widely affect their competitors on a global basis.

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[55] "Kemira to Increase Prices for Products in North America," *PaperAge,* October 3, 2008.

which produces 250,000 tons annually of containerboard, laying off forty workers.[56]

Cost pass-along assumptions. Because of the complex analytical difficulties in ascertaining the degree to which, and under what conditions, industries might pass along domestically increased energy prices resulting from climate policy, we ran industry simulations using the II-CPM, assuming the two poles of zero or no cost pass-along (NCPA) and 100 percent cost pass-along (CPA) (see Chapter Two). This enabled us to frame the range of possible impacts the industries would experience, and their options for responding to these impacts. On the one hand, in the NCPA scenarios, the II-CPM simulations showed that the industries would suffer from reduced operating surpluses and profits, but because their market prices were not affected, the industries maintained their market shares. On the other hand, in the CPA scenarios, if the magnitudes of the additional costs are simply added to the domestic market prices, the industries would lose market shares and their total operating surpluses (profits) would only marginally shrink.

As discussed in Chapter Two (see also Appendix A), the literature and feedback from the industry groups strongly suggest that the NCPA scenarios more closely approximate reality than the CPA scenarios for the study's selected industries. That is, the industries would likely have difficulty passing along additional energy costs, resulting from climate policies that only affect domestic producers. A study by the McKinsey Global Institute and Ecofys lends support to this conclusion. It is one of the only climate policy impact studies to assign a value to cost pass-along behavior of energy-intensive industries.[57] The authors assumed zero pass-through for the

The literature and feedback from the industry groups strongly suggest that the NCPA scenarios more closely approximate reality than the CPA scenarios for the study's selected industries.

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[56] "International Paper to Idle No. 2 PM at Albany, OR Mill," *PaperAge,* October 2, 2008.
[57] McKinsey/Ecofys, *EU ETS Review;* See also, Morgenstern et al, *Competitiveness Impacts.*

aluminum industry (in Europe), reflecting that primary aluminum is a commodity whose prices typically are represented by transactions quoted on the London Metals Exchange (LME).

Some steel commodity futures also are being traded on the LME. McKinsey/Ecofys estimated that the basic oxygen furnace segment of the steel industry would typically only be able to pass-through 6 percent of its costs. On the other hand, it assumed that the electric arc furnace segment would be able to pass along 66 percent of its costs, primarily because its products tend to be much more domestically traded and less subject to foreign competition, at least in Europe. At the same time, it assigned a 0 to 20 percent cost pass-through rate for pulp, paper and paperboard industry, depending on the grade of product. Paper industry experts confirmed to the HRS-MI team that cost pass-through might be difficult in most

instances, though it may occur in high-end specialty paper markets.

McKinsey/Ecofys did not examine the chemicals industry, though it appears likely that petrochemicals and chlor-alkali manufacturers also would be reluctant to pass along domestically increased energy costs to their customers in worldwide markets. The market conditions in these basic bulk chemicals industries however are a little different from the other energy-intensive industries. Their products often are internal inputs used in the production of downstream products made by the same manufacturer in the same plant. Although this happens in other industries, the market dynamics for the downstream chemical products may be more important for understanding the implications for the impacts of higher energy prices on the upstream petrochemical or chlor-alkali products.[58] That is, if a downstream product loses market share it translates back up the value chain within the industry to a loss in demand for the upstream chemicals.

Technology Investment and Policy Options

Faced with likely declines in their profits or their market shares or both, especially if they are constrained in their ability to pass along added costs, energy-intensive manufacturers must consider different options for reducing these costs, perhaps gaining back lost sales and revenues, such as by investing in energy efficiency processes

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[58] For example, the NAICS category for primary aluminum includes some transformation of aluminum ingot into extruded, drawn, rolled, or wire products at the site of the aluminum smelter by the same company. Similarly, iron and steel and ferroalloy product facilities transform some raw steel into shapes and products usually produced by independent steel fabricators. Paper and paperboard mills also engage in converting some paper and paperboard into downstream products. The blurring of the lines between basic materials manufacturing and fabrication or converting of these materials into downstream products (which themselves may be intermediate inputs) underlies some complaints from industry experts the we talked with, that the NAICS categories do not accurately capture the actual activities of their industries.

and technologies, cutting back capacity, or moving operations to low-cost offshore locations. The problems confronting U.S. manufacturers in these industries under a GHG-emissions trading regime that would increase their energy costs, could be greatly amplified by sharp economic downturns. In the worst case scenario, modest energy cost increases that might be absorbed by manufacturers with relative ease under conditions of strong economic growth (increased demand for basic materials and rising product prices), could turn into a tipping point under declining economic conditions (reduced demand and lower product prices) leading to cuts in production and jobs—or even worse, shifts of operations overseas.

One of the main objectives in our study, therefore, was to evaluate the possible options available to energy-intensive industries to mitigate, offset, or prevent the potentially adverse impacts of climate policy that were measured in the first phases of the study. To help frame this evaluation, we first estimated the energy efficiency gains that each industry would need to achieve over the next twenty or more years, to offset the steadily increasing costs resulting from a climate policy. We then conducted

a preliminary review and analysis of technology options the industries might be able to invest in to reduce their energy costs and their carbon footprints. Finally, we did an initial assessment, using the II-CPM, of a policy that would provide a free allowance allocation to each industry that would offset 90 percent (reduced by 2 percent annually) of the climate policy-driven energy price increases.

In the following chapters, we provide detailed profiles of the iron and steel and ferroalloys, aluminum, paper, and chemicals industries (in particular, petrochemicals and chlor-alkali manufacturing), which examine in-depth the findings of the model simulations for each industry. Each profile includes an overview of an industry's business structure and history, the nature of its markets and international competition, and the key elements of its production processes and energy use. We then summarize and analyze the findings of the II-CPM simulations of climate policy impacts on the industry's production costs, operating surpluses and margins, and market shares, and review the industry's investment and policy options for addressing these impacts.

One of the main objectives of our study, therefore, was to evaluate the possible options available to energy-intensive industries to mitigate, offset, or prevent the potentially adverse impacts of climate policy.

THE IRON AND STEEL INDUSTRY

The iron and steel mills and ferroalloy products manufacturing industry (NAICS 3311; referred to as the iron and steel industry, below) is among the most important U.S. manufacturing industries, supplying basic materials and products vital to the nation's economic growth and national security. It includes establishments that manufacture raw and semi-finished steel and over 3,500 finished steel products used throughout the economy—in the construction of bridges, buildings and houses; construction equipment; electric powerline towers; farm implements; highways; household appliances; machine tools; military weapons; natural-gas pipelines; subways; trains and other vehicles; cans and containers; and many other applications.[59]

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[59] Michael D. Fenton, "Mineral Commodity Profiles—Iron and Steel," *Open-File Report 2005-1254* (Reston, VA: U.S. Department of Interior, U.S. Geological Survey (USGS), 2005), 5.

Iron and steel is the largest and most energy-intensive industry in the primary metals sector (NAICS 331).[60] It also is one of the largest industrial consumers of energy in the economy—accounting for about 5 percent of total manufacturing consumption and 2 to 3 percent of total U.S. consumption.[61] As examined here, the iron and steel industry includes *iron and steel mills* (NAICS 331111), that engage in the direct reduction of iron ore, produce pig iron, convert pig iron or scrap steel into steel, and then turn steel into shapes (bar, plate, strip, wire) and sometimes tubes and pipes. It also includes the *electrometallurgical ferroalloy products industry* (NAICS 331112), which produces alloyed ferrous metals.

Below is a synopsis of the industry's principal characteristics and statistics:

STRUCTURE AND LOCATION. In 2006, the iron and steel industry consisted of 57 companies that produced raw steel at about 116 plants, with a combined production capacity of 124.6 million short tons, and employed over 100,000 workers.[62] Steelmaking activities are located throughout the nation, though four states— Indiana, Ohio, Pennsylvania, and Michigan— account for half of all U.S. steel production.

PRODUCTION. Steel is produced in two types of facilities—*integrated mills*, which make steel from molten pig iron—produced in blast furnaces, mostly from iron ore—and some scrap steel in basic oxygen furnaces (BOFs), and *mini-mills* which make steel by smelting scrap steel and other iron sources in electric arc-furnaces (EAFs). In 2006, eight companies operating integrated steel mills at 18 locations produced all pig iron in the United States.[63] Total U.S. raw steel production in 2006 was 108.5 million tons— of which carbon steel accounted for 91.2 percent, stainless steel for 2.5 percent, and other alloyed steel products for 6.5 percent. In 2007, EAFs accounted for 58.1 percent of U.S. raw steel production and BOFs for 41.9 percent.[64]

SCRAP AND RECYCLING. The United States leads the world in recycling of steel products, with a 76 percent rate in 2005. In 2006, EAF mills accounted for 83 percent and BOF for 16 percent of the steel scrap consumed in the United States. Scrap provided nearly 90 percent of the raw iron-based materials processed in EAF mills and one-quarter in BOF mills. According to the American Iron and Steel Institute (AISI), nearly two-thirds of all raw steel produced in the NAFTA countries (United States, Canada, Mexico) included recycled content, more than any other region of the world.[65]

SHIPMENTS. The industry shipped 109.5 million tons of finished steel products, worth $93.3 billion, in 2006. The largest shares of steel shipments went to steel service centers (28 percent), construction (19 percent), and the automotive industry (14 percent). Between 1 to 3 percent of shipments went to the rail transportation, oil and gas, machinery and electrical equipment, appliance, and containers and

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[60] The primary metals sector also includes non-ferrous production (aluminum, copper and other metals) and downstream, fabricated products from purchased steel (NAICS 3312) and purchased non-ferrous metals, and ferrous and non-ferrous metal foundries.

[61] Only the petroleum refineries, pulp, paper and paperboard, other basic organic chemicals and plastics and resins consume more energy than iron and steel, according to EIA, MECS *2002*.

[62] Fenton, *Mineral Commodity Profiles—Iron and Steel* (2005).

[63] U.S. Department of Interior, U.S. Geological Survey, "Iron and Steel," *Mineral Commodity Summaries* (January 2007), 83-84.

[64] American Iron and Steel Institute (AISI), *2006 Annual Statistical Report* (Washington, DC, 2007) ("AISI, ASR 2007"). See also, World Steel Association (WSA), *World Steel in Figures 2008, 2nd Edition* (Brussels, Belgium, 2008), http://worldsteel.org/. This is compared to 66 percent BOF versus 31 percent EAF and 2.5 percent open hearth steel production worldwide.

[65] See AISI, *ASR 2007* for detailed statistics on recycled steel.

shipping materials industries, each.[66]

INTERNATIONAL TRADE. The United States, in 2007, was the third largest producer of crude steel in the world, behind China (489 million metric tons) and Japan (120 million metric tons). It was the world's largest net importer of steel (32.6 million metric tons), in 2006.[67] Finished steel imports accounted for 26.5 percent of the apparent steel supply in the United States.[68] The largest importers of steel include the other NAFTA countries (Canada, Mexico), major Asian nations (China, Korea, Japan), the European Union, and other European countries, such as Turkey and Ukraine, and Brazil.[69]

INDUSTRY STRUCTURE AND HISTORY

The American steel industry today looks very different from what it was during the 1950s and 1960s. Increasingly buffeted by global economic forces and the rise of competition from Europe and Japan as they rebuilt their industrial bases, and more recently from China, the domestic steel industry has undergone steady, and at times dramatic structural changes over the past three decades. The industry's attempts to improve its productivity, competitiveness, and profitability have been accompanied

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[66] Ibid. Steel shipments in 2006 consisted of sheet (53 percent), bar (17 percent), plate (10 percent), structural (8 percent) and pipe and tube (5 percent) products. The remainder included rail, wire, semi-finished, and tin mill products.

[67] WSA, *World Steel 2008*. This includes imports of 42.2 Mmt and exports of 9.6 Mmt of steel.

[68] AISI, *ASR 2007*, 3, table 1A. The "apparent supply of steel" is calculated as total U.S. steel shipments plus total imports less semi-finished steel imports less exports.

[69] AISI, *ASR 2007*.

by bankruptcies, consolidations, numerous plants closures and hundreds of thousands of lost jobs.

According to the 1997 Census of Manufacturers, the number of U.S. blast furnace and steel mill establishments fell from 504 in 1977 to 193 in 1997.[70] It then grew between 1998 and 2001, before declining again, by 40 percent, from 2001 to 2005. The number of *firms* with establishments of over 500 shrunk by one-fifth, reflecting the consolidation wave in the industry over that period.[71] The number of blast furnaces alone fell from 125 in the mid-1970s to approximately 40 by 1999-2000.

Domestic raw steel production capability also shrank, by approximately 30 percent between 1980 and 2000. In the early 1980s, U.S. steelmaking capability was more than 150 million tons per year. By 1994, the industry's capability had dropped to 108 million tons. Between 1994 and 1998 the industry's capability grew to 125 million tons in 1998.[72] U.S. steel's capability today has since more or less remained steady—it was 123.5 million tons in 2006.[73]

Total steel industry employment (for steel mills and steel products manufacturing) fell from 500,000 in 1970 to 160,000 in 2007, due to lost capacity and productivity improvements. Investments in new technologies, facilities, employee training, and product development reduced the

number of man-hours needed to produce a ton of steel by 60 percent from the mid-1980s to 1998.[74] Between 1990 and 2004, iron and steel mill employment fell another 50 percent, from 187,000 to 95,400, rebounding to a little less than 100,000 workers in 2008.[75]

The pace of industry consolidation reached new heights after 2000, following the near collapse of the North American industry, with nearly three-dozen bankruptcies after 1998. About one-third of the leading U.S. and Canadian steel mill operators in 2002-2003 either went out of business or merged

into other companies.[76] The two dominant players among integrated steel companies in the United States—ArcelorMittal and U.S. Steel—and the two among mini-mill

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[70] U.S. Department of Energy, Office of Industrial Technologies (DOE/OIT), *Energy and Environmental Profile of the U.S. Iron and Steel Industry*. Prepared by Energetics, Inc [DOE/EE-0229] (August 2000), 2.

[71] Census Bureau, *SUSB* 2005.

[72] DOE/OIT, *U.S. Iron and Steel Industry,* 3.

[73] AISI, *ASR 2007,* 3, table 1B.

[74] DOE/OIT, *U.S. Iron and Steel Industry,* 1. New process technologies also improved yield from around 70 percent in early 1970s to more than 90 percent in 1999-2000.

[75] Source: U.S. Department of Labor, Bureau of Labor Statistics (BLS), *Current Employment Statistics* (CES), http://www.bls.gov/ces/.

[76] Steve Cooney. "Steel: Price and Policy Issues," *CRS Report for Congress* (Order Code RL32333) (Washington, DC: Congressional Research Service, The Library of Congress, August 31, 2006).

companies—Nucor and Gerdau Amersteel—are products of consolidations and mergers involving U.S. and international steel companies. Nucor and U.S. Steel ranked number one and two in 2007, in terms of U.S. production volume.[77] Among the top four, these two are also the only companies headquartered in the United States.[78]

Russian steel companies have been making inroads in the U.S. industry, as well. OA Severstal, Russia's second largest steelmaker and eleventh ranked global steel producer, has acquired Rouge Steel, an integrated mill built by Henry Ford to supply his Detroit auto manufacturing operation. It also has an 80 percent controlling share of SeverCorr, a new $800 million mini-mill being built in Columbus, Mississippi, to supply steel to automotive assembly plants in the Deep South. Once its plants are operational, Severstal would become one of the six largest steel producers in the United States.[79]

INTERNATIONAL MARKETS

The U.S. iron and steel industry's restructuring and consolidation trends result from the increasing globalization of steel production and markets. Foreign corporations (Arcelor-Mittal, Gerdau-Amersteel) own the largest steel facilities in the United States, and several other large iron and steel facilities (e.g. Severstal), and

large U.S.-based steelmakers, such as U.S. Steel, have significant international holdings outside of North America. Steel production occurs in over 67 countries around the world, but is highly concentrated. Five nations—China, Japan, the United States, Russia, and India—accounted for nearly two-thirds of total world production in 2007 and ten countries accounted for over three-quarters.[80] China, the United States, Japan, South Korea, and India were also the top five users of finished steel, accounting for 58 percent of total world consumption in 2007.[81]

Although both production and demand has grown in every region of the world over the last decade, developing countries have accounted for most of the sharp growth in demand for steel in recent years. The current

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[77] "Top 10 steelmakers in the United States," *American Metal Market* (May 2008), 56-57. Nucor produced, 22.1 million tons and U.S. Steel, 16.8 million tons of steel in 2007.

[78] Cooney, "Steel: Price and Policy Issues," CRS-5/7.

[79] The new operations will double Serverstal's U.S. production, to 5.8 million tons annually. Other Russian steelmakers have also been investing in U.S. steel. In November 2006, Evraz Holding, Russia's largest steelmaker, acquired U.S. rail and plate producer Oregon Steel for $2.3 billion. And, Magnitogorsk Iron & Steelworks (MMK) is in talks to build a $1 billion steel mill in Southern Ohio. Jason Bush, "Russia's Steel Wheels Roll Into America," *BusinessWeek,* October 1, 2007, 44. Also Cooney, "Steel:Price and Policy Issues," CRS-9/10; ———"Steel: Price and Policy Issues," *CRS Report for Congress* (Order Code RL32333) (Washington, DC: Congressional Research Service, The Library of Congress, Updated October 31, 2007), CRS-14-15.

[80] *WSA, World Steel 2008.* South Korea, Germany, Ukraine, Brazil and Italy round out the top ten.

[81] Ibid. Others in the top ten include Russia, Germany, Italy, Spain, and Turkey.

worldwide economic crisis notwithstanding, these nations are expected to drive demand well into the future, as they attempt to build up their own industrial capabilities.[82] The world volume of trade in steel products has grown accordingly. In 1975, total world exports accounted for 22.6 percent of total world production; in 2007 it was 36.3 percent. The world's largest net exporters include China, Japan, Ukraine, Russia and Brazil.[83] The United States has been the largest importer and net importer of steel in the world, but was only the fourteenth largest exporter, in 2006.

U.S. trade deficit in steel.

Figure 5-1 illustrates the rising U.S. trade deficit in steel products since the mid-1970s, as imports grew much faster than exports. Figure 5-2 shows the top net importers of steel to the United States since 1997. The U.S. steel industry has been confronting threats from international competition since the 1960s, especially from Japan and Europe. The growing competition coupled with other factors led to the crisis of the U.S. steel industry during the late 1970s through the mid-1980s, resulting in a dramatic loss of markets, capacity, and jobs. The integrated steel industry was forced to restructure itself including rapid adoption of new production technologies, such as BOFs and continuous casting.

During the mid-1990s, the industry benefited from a relatively weak U.S. dollar and strong demand for its products from the auto, appliance and construction markets. During the late 1990s, the Asian financial crisis triggered an unprecedented increase in the level of steel imports into the U.S. market from 1998 to 2001. In 1998, world steel overcapacity was estimated at 275 million metric tons, or one third of total worldwide production.[84] This led to "dumping" of imports by nations with subsidized overcapacity, whose own domestic demand had dried up. In 2002, President Bush imposed steel "safeguard" tariffs, after which steel prices rose, in part driven by increases in the cost of raw materials and other steelmaking inputs. Surprisingly, even after the tariffs were removed in 2003, steel prices accelerated, the result of a surge in global demand tied to economic growth in China and other Asian nations, and an accompanying rise of raw material and other steelmaking input costs.[85]

Aside from helping to drive all domestically sold steel prices higher—benefiting domestic steel makers but not steel-consuming industries—the tariffs achieved the desired effect of reducing steel imports in 2003 (reflected in the sharp dip in Figure 5-1 and 5-2). After the tariffs were removed, though, net imports once again increased—by almost 50 percent in 2004—driven by domestic demand, and have been fluctuating since.

The China challenge. The
emergence of large emerging economies (Brazil, Russia, India, and China, i.e., the BRIC nations) as major producers, consumers and exporters of steel, presents new challenges for the U.S. steel industry. Import penetration from countries that have significant cost advantages over the U.S.

Although both production and demand has grown in every region of the world over the last decade, developing countries have accounted for most of the sharp growth in demand for steel in recent years.

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[82] Ibid. At least until the world economic slowdown, WSA estimated that the industry would need continue to grow by 3-5 percent worldwide and by 8-10 percent in China, India and Russia to meet projected demand for steel, which was expected to double by 2050. Steel use projections suggest a global growth rate of 6.3 percent, with Brazil, Russia, India, and China the leaders.

[83] Ibid.

[84] Gary Hufbauer and Ben Goodrich, "Steel: Big Problems, Better Solutions," Policy Brief (Washington, DC: Peterson Institute for International Economics, July 2001), 2.

[85] Cooney, "Steel: Price and Policy Issues" (Updated), CRS-1.

Figure 5-1

U.S. Iron & Steel Imports, Exports and Trade Balance, 1975-2006

Source: AISI Statistical Yearbooks 2006

Trade Balance · Exports · Imports
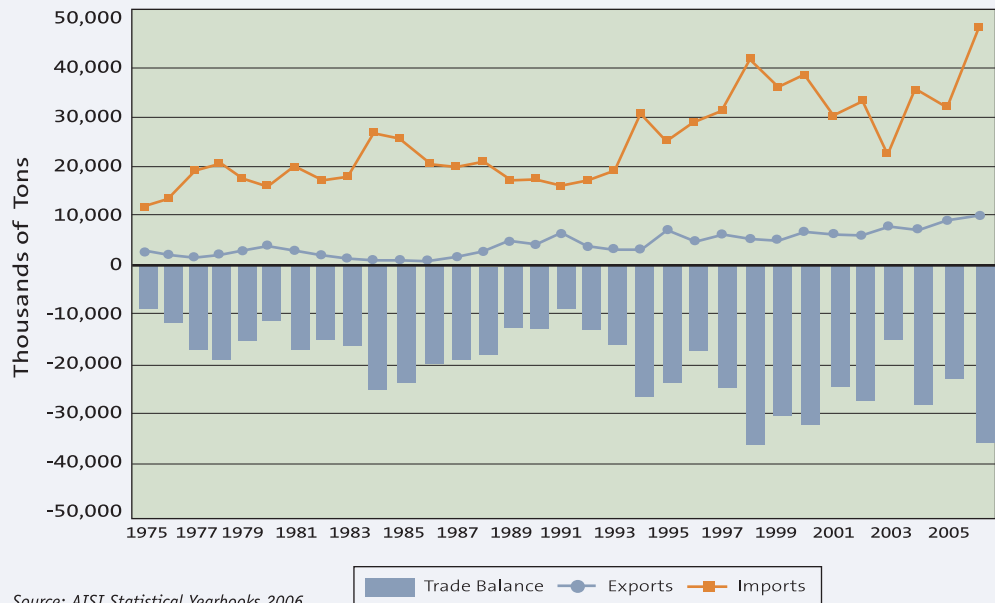
Figure 5-2

Top Net Importers of Steel to the United States, By Quantity 1997-2007

Data Source: USITC

Brazil · Japan · China · Russia · Korea · Germany
Mexico · Ukraine · South Africa · Turkey · Canada · France
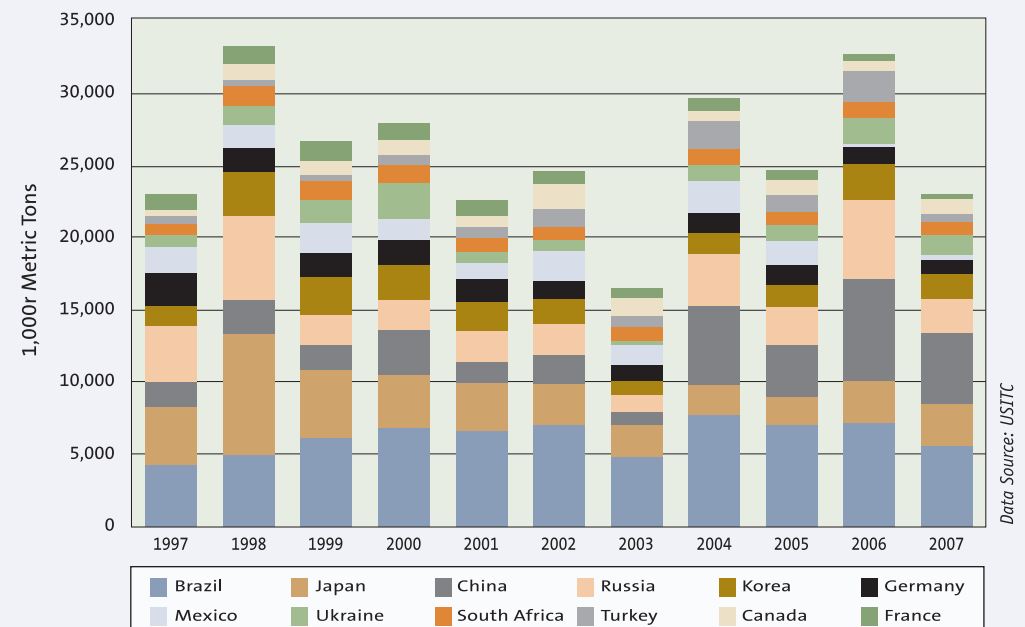
steelmakers is a particular concern. Industry groups have long complained that U.S. manufacturers have not been operating on a level playing field in international markets, and have warned about illegal dumping of cheap steel goods and government subsidies, especially by China.[86]

U.S. steelmakers are also vulnerable to fluctuations in global supply and demand for steel, and are joined by foreign steel-producers in their concerns about the potential for Chinese production to contribute to a glut in global steel supply. In 2005, China went from a net importer to a next exporter of steel products for the first time, helped by subsidies and industrial restructuring, according to some observers. A year after that, China rose to the world's largest exporter of finished goods.[87] China was only a small importer to the U.S. steel market until 2004, but from 2004 on, it has ranked second in total net imports to the United States after Brazil.

The concern with China is not just about imports. Chinese demand has driven up the costs of key material inputs, such as iron ore[88] and scrap metals, and energy. On the other hand, soaring marine transport costs from high energy prices have cut into some of China's advantage in the steel industry. One analyst has predicted that because products such as steel and heavy machinery have relatively low labor content and are expensive to ship, "Canada and the U.S. may see real gains in market share and jobs." For example, China's reported a 20 percent drop in steel shipments to the U.S. since 2007, its

worst performance in a decade, while U.S. domestic steel production rose 10 percent.[89]

RECOVERY AND CRISIS. After decades of restructuring, the shedding of less efficient operations, adopting more advanced technologies and implementing efficiency improvements, U.S. steelmakers by the third quarter of 2008 had become more financially viable than they had been in many years.[90] However, although worldwide and U.S. steelmakers enjoyed a very strong first three-quarters in 2008, and in some cases, had record third-quarter profits, signs of economic deterioration and the weakening of steel demand appeared in August, and especially in September. World crude steel production grew by 4.6 percent in the first nine months in 2008 over same period in 2007, but was lower by 3.2 percent in September 2008 than the same month a year before. Chinese, Commonwealth of Independent States (CIS), and U.S. crude steel production, in particular, dropped, 9.1 percent, 6.4 percent, and 1.3 percent, respectively, in September 2008 over the same month a year before.[91]

The financial crisis in October 2008, plunged the industry, along with almost all other sectors of the economy, into great uncertainty, with significant impacts on steel demand, prices, production, and steelmakers' bottom-lines across the globe. Although, world steel prices began to weaken in August, they plummeted in the months that followed. London Metal Exchange-reported prices for Asian steel billet (15-month contracts)—a semi-finished

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[86] See Usha C. V. Haley, *Shedding Light on the Energy Subsidies in China, An Analysis of China's Steel Industry from 2000-2007*. Prepared for the Alliance for American Manufacturing (January 8, 2006).

[87] Bill Lambrecht, "Chinese steel an issue in Pennsylvania primary," *Post-Dispatch*, April 20, 2008.

[88] Javier Bias and Rebecca Bream, "Chinese agree 96% jump in ore prices," *Financial Times (FT.com)*, June 23, 2008, http://www.FT.com/.

[89] Julian Beltrame, "Fuel costs cutting trade," *Winnipeg Free Press,* May 28, 2008.

[90] T. Considine, *The Transformation of the North American Steel Industry: Drivers, Prospects, and Vulnerabilities.* White paper prepared for the American Iron and Steel Institute (April 2005). Cited in EPA, *Energy Trends in Manufacturing,* 3-54.

[91] World Steel Association (WSA), "September 2008 Crude Steel Production," October 22, 2008, http://www.worldsteel.org/.

The financial crisis in October 2008, plunged the industry, along with almost all other sectors of the economy, into great uncertainty.

form of steel used for long products (bars, structural steel and wire rod), accounting for an annual average of 48 percent of world semi-finished steel output—plunged from a high of nearly $1,200 per metric ton of steel late July 2008 to under $300 per metric ton by late October 2008.[92]

Major international and U.S. steel corporations began making large cuts in production and jobs in response to shrinking demand and profits in October and November 2008. ArcelorMittal announced output cuts of 35 percent in November, despite posting third-quarter profits 29 percent higher than a year before.[93] U.S. Steel Corp.'s, whose 2008 third-quarter and fourth quarter surged, forecasted in early 2009 likely operating losses due to the global economic slowdown, as demand and prices

soften for flat-rolled products in North America and Europe, in response to losses in the auto, appliance and construction industries. In late 2008, it announced it was laying off of 675 workers in North America and temporary idling of three plants, affecting 3,500 workers.[94]

Steel demand and prices—offset only by declines in input prices—are likely to continue their collapse in the wake of the financial crisis in October 2008, and the economic downturn that followed.[95] As of this writing, the future of all manufacturing markets has become highly uncertain. Manufacturing purchasing managers' indexes (PMI) from around the world sank during October 2008, the Chicago PMI having its biggest decline in the index's 40-year history.[96] Consequently, market

[92] London Metal Exchange, *The Ringsider, Steel 2008,* London:Newsdeck Communications, Ltd., n.d., 57, http://www.lme.com/.

[93] Peter Marsh, "ArcelorMittal to cut output by 35%," *Financial Times* , November 5, 2008, http://www.ft.com; Aoife White, "ArcelorMittal plans steeper output cuts," *Forbes,* November 5, 2008, http://www.forbes.com/feeds /ap/2008/11/05/ap5649618. html.

[94] Daniel Lovering, "US Steel reports surge in 4Q profit," *The Boston Globe* (boston.com), January 27, 2009, http://www.boston. com/business/.

[95] "Global Steel Prices in Free Fall—Further Reductions Anticipated, *MEPS Steel News 29,* October 29, 2008, http://www.meps.co.uk/ viewpoint10-08.htm.

conditions for steel manufacturers are becoming increasingly problematic across the globe. Even China's largest steelmakers reportedly were expected to cut their output by 20 percent in October 2008, in response to falling steel prices at a time of weakening demand.[97]

Steel Production and Energy Use

Steel is an alloy of iron containing varying amounts of carbon, and in some forms, other elements. Over 90 percent of U.S. steel production is carbon steel, where the main alloying element is carbon (commonly from 0.06 percent to 1 percent). The remainder is steel alloyed with elements such as manganese, nickel, chromium and vanadium, usually introduced while steel is in the molten stage before cast into intermediate or final shapes. This includes stainless steel, made with a minimum of 10.2 percent chromium, and some forms include nickel and molybdenum.

In the United States, steel is produced in two types of facilities, characterized by different equipment, technologies, raw materials and energy use. In integrated steel mills, iron ore is reduced or smelted in blast furnaces, producing molten iron, which is either cast as pig iron or sent to a *basic oxygen furnace,* where it is carried to a second stage known as steelmaking. In mini-mills, *electric arc furnaces* produce carbon and alloy steels mostly from scrap metal, which is melted and refined using electricity.

Steelmaking. In either type of mill, steelmaking entails removing impurities such as sulfur, phosphorus, and excess carbon from the molten iron or scrap metal to produce molten steel, which then undergoes a casting process that produces semi-finished steel products such as slabs, blooms and billets.[98] Continuous casting—a process for solidifying steel in the form of a continuous strand, rather than individual ingots that used to characterize traditional steelmaking—is used in almost all U.S. steelmaking today.[99] After casting, the semi-finished steel products are subjected to several other shaping and finishing processes such as hot rolling, cold rolling, pickling, annealing, electrolytic and hot-tip coating, and other processes, depending on the desired finished product. All flat rolled products, such as sheet (which are often put into the form of coils) come from steel slabs. Blooms are usually shaped into girders, beams and other structural shapes, and billets are typically turned into bars, tubes, and rods.

The production and energy flows of steelmaking are illustrated in Figure 5-3. Integrated mills melt iron ore (taconite, mostly in the form of pellets) in blast furnaces. The molten iron is then charged into BOFs, usually with some scrap steel (about 20-25 percent),[100] other metallic iron sources, and fluxes (such as limestone),

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[96] "Global Manufacturing Takes A Hit," *Manufacturing and Technology News 15,* no. 19 (October 31, 2008): 4-5.

[97] "China 2008 Steel productions may drop to 480 million tonnes," *SteelGuru,* November 5, 2008, http://www.steelguru.com/news/index/2008/11/04/.

[98] ArcelorMittal, *Fact Book 2006* (Luxembourg, July 2007). A slab is a wide, flat semi-finished steel product, blooms are large and mostly square in cross-section, and billets are nearly square pieces of iron or steel, longer than blooms.

[99] DOE/OIT, *U.S. Iron and Steel Industry.* According to a DOE-sponsored report, in 1998 approximately 96% of all steel produced in the United States was continuously cast, and only 4 percent was ingot cast. However, just 20 years before, continuous casting accounted for less than 10 percent of cast production.

[100] AISI, *ASR 2007,* 84, table 34. In 2005, steel scrap accounted for 26 percent of iron-containing materials consumed by BOFs in the United States, and DRI inputs accounted for 3 percent.

Figure 5-3
Iron & Steel Mills Production and Energy Flows

Iron & Steel & Ferroalloy Manufacturing [NAICS 3311]
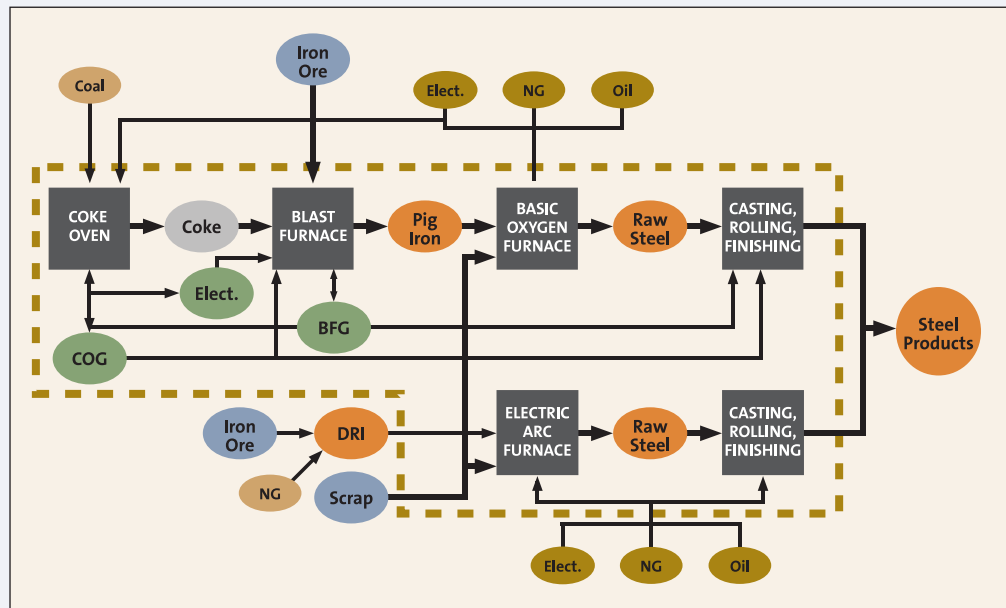
Coke (and the coal used to produce coke) is a feedstock and the majority form of energy used in blast furnaces.

to produce steel. Coke (and the coal used to produce coke) is a feedstock and the majority form of energy used in blast furnaces. The combustion of coke produces reducing gas (including carbon monoxide) converting the iron oxide (FeO) in iron ore to iron (Fe). It also generates enough heat to melt the iron, which collects as the bottom of the furnace.

Coke is the residue produced from heating coking coal (generally bituminous) in coke ovens to very high temperatures. It is either produced on-site in facilities owned or affiliated with iron and steelmaking companies, or purchased from merchant plants that produce coke for sale on the open market. On-site coke production also produces coke oven gas (COG), which along with blast furnace gas (BFG), a byproduct of ironmaking in blast furnaces, are used as heating and process fuels throughout the

mill, and for generating onsite electricity.

When hot metal from the blast furnace and scrap are charged into the BOF, oxygen is injected and fluxes added (including calcinated limestone), to oxidize carbon in the iron releasing CO and CO_2. The BOF steelmaking process is autogenous (no external heat source is needed) and does not require fuel for melting and refining. Natural gas and electricity are used for auxiliary processes. The resulting molten steel is then tapped into a ladle where it is deoxidized and alloying elements added as desired.

In the EAF process, the steel scrap and iron charge is melted in cylindrical, refractory-lined electrical arc furnaces with carbon electrodes lowered through the furnace roof. Modern EAFs increasingly supplement the process with chemical energy derived
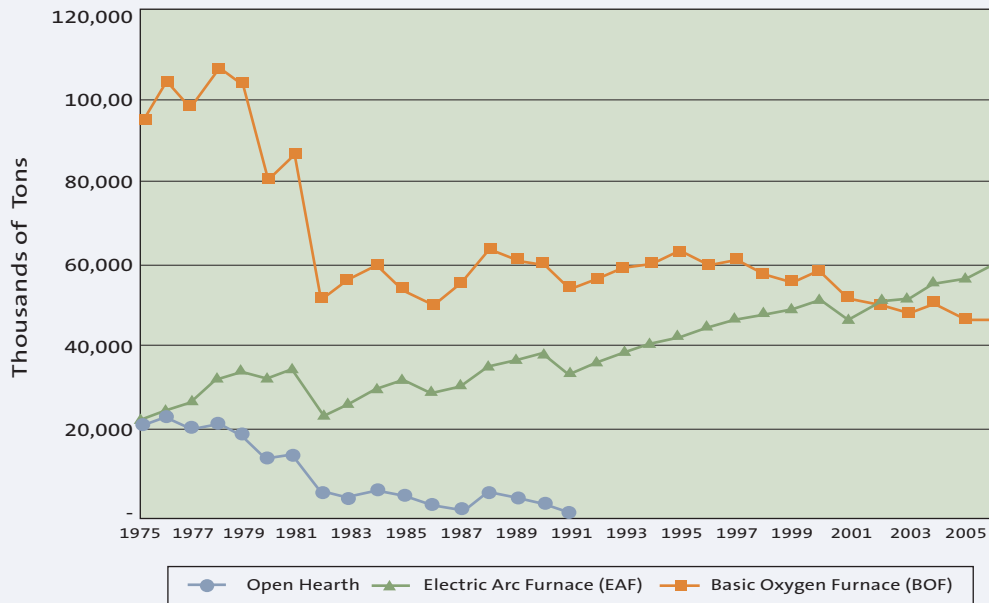
Source: AISI Statistical Yearbooks

from sources such as oxy-fuel burners that introduce combinations of natural gas, oil, or coal into the furnace to displace electricity use.

BOF vs. EAF. Figure 5-4 shows the relative share of BOF and EAF production of raw steel in the United States since 1975. It also shows the steady decline of basic open hearth (BOH) steel production. The basic open hearth process dominated steelmaking from the last half of the 19th century up until the 1960s. The BOF process was introduced in North America in 1954 and eventually replaced the less economical open hearth. By 1969, the BOH and BOF annual outputs were both equal at 60

million tons. International competition and other economic pressures drove a major restructuring of the industry in the late 1970s and early 1980s leading to the closure of the remaining BOH facilities, and none has operated in the United States since 1992. Mini-mills were introduced in 1970s, and have claimed a progressively greater share of total U.S. production, surpassing integrated mills in 2002.

Historically, BOF and EAF mills produced for different steel markets. Both produce carbon steel, but the EAFs also make low-tonnage alloy and specialty steel (such as stainless).[101] EAFs typically have had lower capacity than integrated mills with narrower product

IN THE EAF PROCESS, THE STEEL SCRAP AND IRON CHARGE IS MELTED IN CYLINDRICAL, REFRACTORY-LINED ELECTRICAL ARC FURNACES WITH CARBON ELECTRODES LOWERED THROUGH THE FURNACE ROOF.

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[101] Early mini-mills were a combination of an electric arc furnace, a billet continuous caster, and a rolling mill. They made long products (e.g., bars, rods, sections) exclusively and were more focused on productivity than on quality. They also were low-cost, low-manpower, and usually non-union operations that used (then) inexpensive raw material (scrap), were willing to invest in new technologies and tended to remain profitable even during hard times.

EAF and BOF Production and Consumption Inputs, 2007

Production and Inputs	EAF	BOF	EAF	BOF
Total Production (thousand tons)	62,835	45,303	58%	42%
Primary Energy Sources				
Electricity (million kWH)	42,665	13,636	76%	24%
Natural Gas (million cubic feet)	121,586	201,825	38%	62%
Coal (thousand equivalent tons)	1,257	25,823	5%	95%
Feedstock Consumption				
Scrap	58,060	11,892	83%	17%
Pig Iron (incl. DRI, etc.)	7,540	40,093	16%	84%

Source: AISI

In 2007, steel scrap accounted for nearly 89 percent of the iron-bearing materials consumed in U.S. EAF mills, and 23 percent in U.S. BOF mills.

lines. A typical integrated mill produces an average of 3 million tons of steel annually, compared to a typical EAF, which produces about one million tons per year,[102] though several have 2 million tons of output.[103] EAFs are now the only domestic source of "long products" such as concrete reinforcing bars, steel wire rod, and construction beams.[104] In 1989, thin slab casting was introduced, opening the door to further EAF penetration of the U.S. steelmaking process.[105] Newer EAF mills produce commercial-quality flat-rolled products, which historically was a mainstay of integrated mills.[106]

The BOF and EAF steelmaking processes employ different mixes of materials feedstock and energy sources, as shown in Table 5-A. A mini-mill typically employs electric furnaces and continuous casting to produce steel products mostly from scrap, with some pig iron and direct-reduced iron (DRI).[107] In 2007, steel scrap accounted for nearly 89 percent of the iron-bearing materials consumed in U.S. EAF mills, and 23 percent in U.S. BOF mills. Pig iron accounted for 11 percent of iron-bearing feedstock in EAF production, and 77 percent of BOF steelmaking.

[102] DOE/OIT, *U.S. Iron and Steel Industry, 4.*
[103] AISI email communication, February 2009.
[104] Cooney, "Steel: Price and Policy Issues," CRS-3.
[105] Thin slab casting produces automotive quality as well as hot rolled gauges in the cold-rolled gauge spectrum of steelmaking.
[106] See DOE/OIT, *U.S. Iron and Steel Industry, 4,* which notes, "By upgrading furnaces and casters and installing intermediate ladle furnaces, mini-mills quickly penetrated long product quality markets and displaced integrated mills in that market segment."
[107] In DRI steelmaking, iron ore is the primary input (sometimes mixed with scrap), producing higher quality steel than all-scrap-based EAF-made steel. DRI represents about 1 percent of EAF feedstock and other iron-bearing materials. Currently there are no DRI mills in the United States. Source is AISI email transmission, 2008.

Aside from iron-bearing feedstock, EAF production differs from the BOF process in the mix of energy inputs consumed. EAFs consumed more than three-quarters of the electricity consumed in the iron and steel industry, and nearly 40 percent of the natural gas in 2007. BOF mills, however, consumed 95 percent of all coal used in the industry.

In 2007, EAFs accounted for 58 percent of all raw steel produced, and their share is like to grow in the future. Some industry sources have raised doubts about the construction of any new BOF plants in the United States in the future, though the recent acquisitions and investments by Russian steelmakers may belie that prediction.[108] As a result, as domestic and world demand grows, U.S. EAF mills might meet more of this increased demand than domestic integrated mills.

At the same time, an industry source has noted that the crucial production bottleneck for either industry segment is ironmaking based on processing virgin materials (iron ore), especially since scrap is in limited supply. Both BOF and EAF companies are planning new ironmmaking capacity, and EAFs are using more virgin materials. Ironmaking processes account for the most carbon-intensive consumption of energy

(they can be based on the consumption of coke, coal, or natural gas) in the steelmaking process, and climate policy could influence whether new ironmaking facilities to supply U.S. steelmakers are built domestically, or overseas.[109]

Climate Policy Impacts on Iron and Steel

According to the II-CPM simulations, the iron and steel industry would experience the largest economic impacts associated with the climate policy case compared to the other industries in the HRS-MI study. It was projected to have the highest production cost increases throughout most of the 2012-2030 period, relative to BAU, and the highest decline in operating surplus (see Figure 3-1), and a comparable reduction in its operating margin, assuming no costs are passed along and no major investments in energy efficiency are made. It also would suffer the largest losses in domestic market shares in scenarios where costs are passed along. These impacts reflect the industry's heavy reliance on coke and coal energy sources, compared to the other industries. These fuels would have the greatest price increases of any fuel type under the Mid-CO_2 Price Policy.

The industry also is one of the most highly sensitive to international competition, as evidenced by the high degree of import penetration in the domestic steel market, second only to the aluminum industry (see Table 3-C). The II-CPM results suggest that, in response to policy-driven hikes in energy prices, at least some iron and steel industry companies would be under pressure to reduce their costs perhaps even shortly after

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[108] Bush, "Russia's Steel Wheels."
[109] AISI email communication, February 2009.

a climate policy is enacted, and at the latest by 2020.

Production cost structure (BAU). Figure 5-5 illustrates the production components cost trends for the BAU reference case. These constitute the baseline for assessing the II-CPM simulations of the Mid-CO$_2$ Policy impacts on the iron and steel industry.

Material costs. Materials costs account for the largest share of production costs, and are expected to become an increasingly important cost factor. As a share of total costs, materials rose from about 60 percent in 1992 to nearly three-quarters in 2006, and were projected to rise to another 11 percent by the 2020s. In real dollars, unit material costs declined steadily from 1992 through 2003, by almost one-third, and then it climbed to 90 percent above the

1992 level, in 2008. This recent sharp rise reflected growing global demand for iron ore, scrap steel, and other non-energy inputs (limestone, other flux materials) over this period. Unit material costs were then projected to fall by nearly 30 percentage points by 2011, relative to 1992, reflecting the recent economic downturn and Global Insights price projections. These costs were projected to again steadily grow through 2030, to about 43 percent above 2006 levels.

Labor costs. Unit labor costs have fallen for many years in the steel industry, a result of productivity gains, industry consolidation, and perhaps the steady shift in production, from the BOF steel mills to EAF mills. Real unit labor costs in 2006 were about half those in 1992. In the industry simulation, it was assumed that unit labor costs would decline at a very modest rate through

FIGURE 5-5

Iron & Steel Real Unit Production Cost Components, Business As Usual, 1992-2030
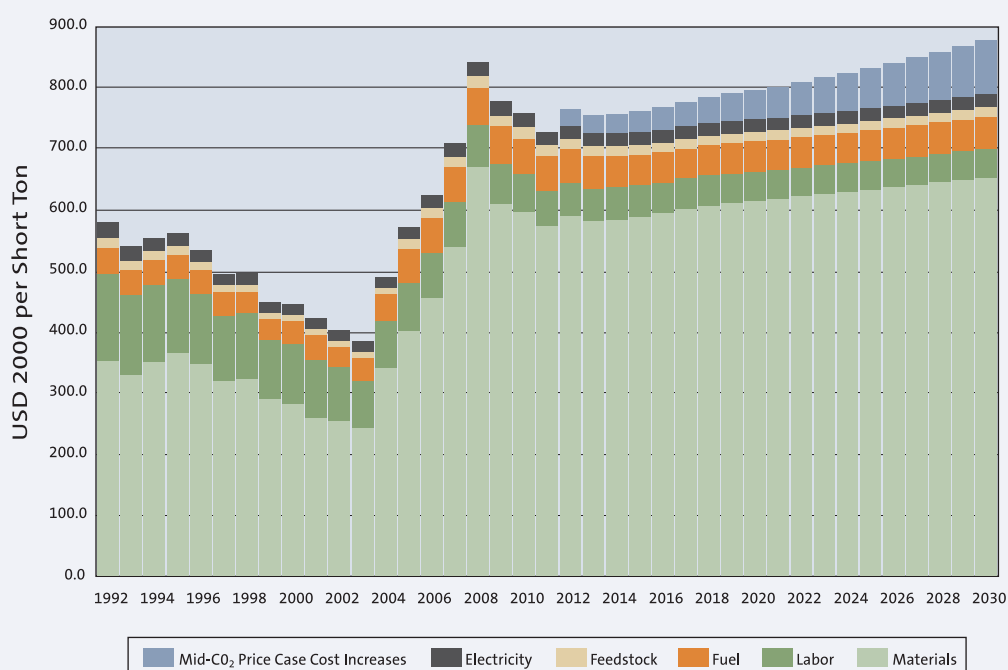
Source: HRS-MI

Table 5-B

**Production Costs, Energy Share
and Energy Cost Components,
Iron and Steel Industry**

Item	2006	2020		2030	
	Value	**Value**	**% above BAU**	**Value**	**% above BAU**
Production Costs (USD 2000/ton)					
BAU	621	746	—	787	—
Mid-CO$_2$ Price Case Above BAU	—	50	*6.7*	90	*11.4*
Energy Share of Production Costs (Percent)					
Mid-CO$_2$ Price Case	*15.1*	*16.9*	*5.6*	*20.4*	*9.1*
Energy Cost Components (USD 2000 per ton)					
Mid-CO$_2$ Price Case:					
Total Energy Costs	94	134	*59.4*	179	*100.4*
Fuel Costs	57	*82*	*68.2*	113	*113.9*
Electricity Costs	21	*21*	*8.6*	23	*13.1*
Feedstock Costs	16	*30*	*96.3*	44	*164.1*

Source: HRS-MI

around 2020, leveling off to two-thirds the 2006 level after 2025. Labor costs as a share of total production costs also fell dramatically in the 1992-2006 period, from one-quarter to only 12 percent, and was projected to fall to half that, 6 percent, by 2030 in the simulations.

Energy costs. Energy costs in the BAU scenario relative to their 1992 level, fell by about 20 to 30 percent from 1992 to the early 2000s. It was then projected to rise to a peak of over 20 percent above the 1992 level by 2009, before falling back to between 0 and 6 percent above from 2015 on. Energy's share of total production costs for BAU fluctuated between 13 to 15 percent over the historical period, and was projected to settle down at around 11 percent after 2015.

Energy share of costs. Under the Mid-CO$_2$ Price Policy, the II-CPM projected that energy costs as a share of total production costs in iron and steel would grow considerably relative to other production factor costs, and relative to BAU. Share values are contingent on how the other cost factors vary over time. The ratio of energy costs relative to labor costs in the BAU case was only 60 percent in 1992—much more was spent on labor compensation per unit of production than on energy—but by 2006, this ratio flipped; energy costs were about 30 percent greater than labor costs per ton of steel produced. Even under BAU, this ratio would continue to increase—by 2030, energy costs would be nearly double those of labor. However, under the Mid-CO$_2$ Price Policy, energy costs were projected to soar to almost *four* times labor costs.

Under the Mid-CO$_2$ Price policy, the II-CPM projected that energy costs as a share of total production costs in iron and steel would grow considerably relative to other... costs, and relative to BAU.

Similarly, although in the climate policy case, materials costs themselves would grow over time and be somewhat greater than energy costs in magnitude, the energy/materials costs ratio would *rise* from about one-fifth in 2006 to almost 30 percent by 2030. By contrast, for BAU, energy costs would *fall* to 17 percent by 2030. Correspondingly, energy's share of total production costs would jump from 15 percent in 2006 to 20 percent in 2030, under the Mid-CO_2 Price Policy, 9 percentage points greater than BAU (see Table 5-B).

Energy and production cost impacts. Figure 5-5 illustrates the total additional cost increments that would be added to the BAU production costs resulting from higher energy prices under the Mid-CO_2 Price Policy. As Table 5-B shows (see also Figure 3-1), the II-CPM simulations projected significant real dollar (USD 2000) increases in the industry's production costs if the Mid-CO_2 Price Policy was enacted and no investments in energy efficiency were made. Under the policy case, production costs would increase by $50 (USD 2000) per ton of steel, or 6.7 percent above BAU in 2020, rising to $90 or 11.4 percent above BAU by 2030.

The table and Figure 5-6 (see also Figure 3-2) illustrate the roles of different fuel types

and their price variations under the policy case in raising the industry's production costs. The costs of fuels (coal, natural gas, residual oils) used in iron and steelmaking for heat and power account for two-thirds of the additional production costs the industry would bear in the policy case, in 2020 and in 2030.

Feedstock costs (coke and coal) would account for 30 percent of the increased production costs, while electricity would account for only about 3 percent over the same period. These results indicate that the cost of steelmaking processes using coal and coke (as feedstock) and non-electric heating and power applications would grow substantially faster and higher than those processes and applications that rely on electricity; the formers' prices were estimated to be far more volatile and rise to a much greater extent than that of electric power under a policy that imposes a CO_2 charge.

This is evident in Table 5B, which shows that electricity costs were somewhat greater than energy feedstock costs in 2006, but would grow only about 13 percent above BAU by 2030. In contrast, feedstock costs would increase to nearly double the electricity costs by 2030, a huge 164 percent above their BAU levels for that year. Fuel costs (including coal) would grow even faster; in 2006 they were somewhat less than three times greater than electricity costs; by 2030 they would rise to over 5 times these costs.

Operating surplus and margins (NCPA). The II-CPM calculated the proxy variable, *operating surplus*, by subtracting variable production costs from the domestic revenues for the industries' products. This remainder includes the fixed production costs, non-production-related variable costs, such as SG&A (sales, general and administration) costs, depreciation

IRON & STEEL PRODUCTION COSTS, MID-CO₂ PRICE CASE ABOVE BAU ENERGY COST COMPONENTS, 2012-2030
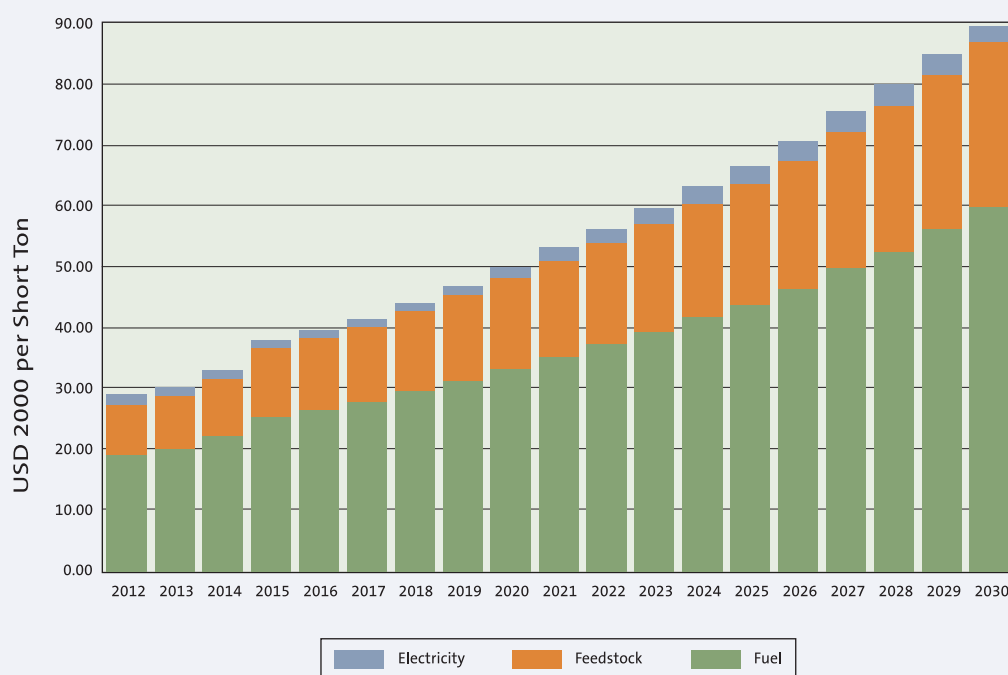
Source: HRS-MI

expenditures, taxes and profits. The per-ton operating surplus calculation (market price less unit production cost) for the iron and steel industry is schematically shown in Figure 5-7. Assuming that the additional energy costs are not passed along (NCPA), the figure shows a large real unit operating surplus throughout the policy period of 2012-2030 for BAU, which, however, would be steadily diminished under the Mid-CO$_2$ Price Policy.

The NCPA scenario is the worst-case situation for the industry. It assumes that steelmakers would be required to absorb *all* the additional costs resulting from a steadily increasing carbon charge imposed by a climate policy. By 2020, the industry's total operating surplus (total production

times the unit operating surplus) would fall by $7.5 billion in real terms (USD 2000) or 24 percent below the BAU level of nearly $31.1 billion (see Table 5-C), if no action to offset increasing energy costs is taken. By 2030, the operating surplus was projected to descend even further, by $16.6 billion, a 40 percent drop below the BAU level of $42.0 billion.

The *operating margin,* the ratio of operating surplus to total revenues, would suffer accordingly, falling to almost 17 percent in 2020, compared to nearly 22 percent in the BAU case—a 5 percent decline—and to under 14 percent in 2030, nearly 9 percent less than BAU. However, because the NCPA scenario assumes that domestic prices relative to foreign competitors would not

FEEDSTOCK COSTS (COKE AND COAL) WOULD ACCOUNT FOR 30 PERCENT OF THE INCREASED PRODUCTION COSTS, WHILE ELECTRICITY WOULD ACCOUNT FOR ONLY ABOUT 3 PERCENT OVER THE SAME PERIOD.

Table 5-C
Operating Surplus, Operating Margin and Market Shares, Iron and Steel Industry

Item	2006	2020		2030	
		Value	% above BAU	Value	% above BAU
Operating Surplus (Million USD 2000)					
BAU	12.8	31.1	—	42.0	—
Mid-CO$_2$ Price Case Above BAU:					
NCPA	—	-7.5	-24.0	-16.6	-39.6
CPA [Cost Basis]	—	-1.4	-4.5	-3.1	-7.4
Operating Margin (Percent)					
BAU	15.0	21.8	—	22.4	—
Mid-CO$_2$ Price Case:					
NCPA	—	16.6	-5.2	13.5	-8.9
CPA [Cost Basis]	—	20.7	-1.1	20.5	-1.8
Domestic Market Share (Percent)					
BAU	77.6	76.5	—	76.5	—
Mid-CO$_2$ Price Case:					
CPA [Cost Basis]	—	73.0	-3.4	70.8	-5.7

NCPA=No Cost Pass-Along; CPA=Cost Pass-Along

change, the U.S. industry's market shares would not be affected.

The declines in the industry's operating surplus and margins in the NCPA scenario do not bode well over the mid-to-long-term for the domestic iron and steel industry under the climate policy scenario examined in the HRS-MI study. As the industry's operating surplus and margins declines, especially as the former is reduced by more than 20 percent by 2020, and the latter by 5 percent by 2020, the industry's profitability would suffer accordingly, perhaps significantly, especially as the reductions grow in scale through 2030.

At some point in time, the operating surplus and operating margin trends would pressure

steelmakers to consider options for reducing their costs—i.e., by investing in energy efficient technologies, reducing output, or relocating offshore, depending on their financial and market conditions at the time. In the study, however, we did not attempt to calculate exactly where this point might be—or what actions firms might actually take.

Operating surplus and market shares (CPA).
Steelmakers might opt, though, to pass along some or all their costs, to avoid such losses, depending on market conditions. However, we only calculated the operating surplus and market share impacts from the climate policy case for a 100 percent cost pass-along scenario (CPA), rather than estimate

intermediate cost pass-through values.

Table 5-C shows the operating surplus and market share results, comparing the BAU and Mid-CO_2 Price Policy for the cost basis CPA scenario, which assumed that costs are passed through by adding the new energy costs to the domestic market price. In this scenario, because U.S. steelmakers would increase their market prices relative to foreign competitors in the domestic steel market, they would suffer a steady decline in their domestic market share, in magnitude and relative to BAU. The II-CPM projected that the BAU market share would drop slightly from 78 percent in 2006 to a little over three-quarters by 2020—and remain constant through 2030. In the policy case, assuming CPA, domestic market share would fall by 3 percent below BAU by 2020, and 6 percent by 2030.

Although the iron and steel's unit operating surplus in the CPA scenario would not be reduced (see Figure 5-7), the industry's *total* operating surplus (and hence profit) would decline, as the loss of market share translates into smaller total revenues. These reductions would not be as great as in the NCPA scenario, but by 2030, they also would not be insignificant (over 7 percent below BAU).

Under certain favorable market conditions, such as strong demand and high global prices, or for some specialty products in high-end niche markets, steelmakers could decide not only to pass-through the additional costs to their prices but also add

FIGURE 5-7

IRON & STEEL REAL UNIT PRODUCTION COSTS, COMPARED TO DOMESTIC MARKET PRICE

Source: HRS-MI

a premium to maintain their operating margins (margin basis CPA). Under this scenario, the new domestic market prices would be somewhat higher than the cost basis CPA prices, yielding a net additional revenue gain for each ton of steel produced. Consequently, the operating surplus for steel could be as high as a little over 7 percent above BAU by 2020 and 14 percent above BAU by 2030. On the other hand, market share losses become even more significant, because of the relatively higher domestic prices in the margin basis CPA case—over 5 percent and 9 percent below BAU market share levels in 2020 and 2030, respectively.

Steel markets, prices and CPA.

Increases in the global costs of raw materials (iron ore, scrap steel) and other inputs (limestone), even with regional differences, would drive up the world price of steel. Domestic producers will usually pass through such costs, as long as their foreign competitors also face similar cost hikes. Steelmakers have opportunities to pass along costs, as steel prices are mainly set on

Weakening markets, global overcapacity, and low-cost foreign competitors would create conditions unfavorable to U.S. manufacturers for passing along localized, policy-driven energy costs that could put them at a disadvantage.

a bilateral basis over a region, though steel production and markets are global in scale. Although there is no worldwide common price indicator or central market place for steel products, the industry increasingly has been referring to a benchmark price for long products on a regional basis, and steel futures exchanges have been developing on the London Metals Exchange, the New York Metals Exchange and the Dubai Gold and Commodities Exchange.[110]

In any event, whether or not U.S. steelmakers would pass through the additional energy costs resulting from a U.S. climate policy that foreign steelmakers would not incur, depends on a number of uncertain factors. For example, the extent and intensity of international market competition, the demand for steel products, the cost structures of international competitors, the availability and prices of key manufacturing inputs, and the subsequent impact on market prices, can all influence these decisions.

Uncertain market conditions. Weakening markets (slowing demand and declining steel prices), global overcapacity, and low-cost foreign competitors (perhaps aided by government subsidies) would create conditions unfavorable to U.S. manufacturers for passing along localized, policy-driven energy costs that could put them at a disadvantage. Conversely, tightening markets resulting from rising demand outstripping production growth, leading to higher steel prices, would create conditions more favorable for manufacturers to pass along additional costs, especially in high-end markets.

The steel industry has cycled through both kinds of market situations. In times of rapid economic growth and international

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[110] Reinaud, *Impacts on Aluminum*, Box 1, page 14.

demand for steel, such as the period from 2004 to mid-2008, some cost-pass along, even with a premium (margin basis) for some niche products, might have been possible. However, slowing demand, global overcapacity, volatile input prices, growing foreign competition and import penetration have been persistent problems for the U.S. industry over the past three decades.

Import sensitivity. Such conditions have opened the door for cheap imports to flood domestic markets, forcing domestic steelmakers to slash their own prices to remain competitive. For example, in 1998, Nucor cut its prices for hot-rolled, cold-rolled, and galvanized steel by $20 per ton to fend off a record surge of steel imports from Russia, Japan, Brazil and others, which were priced at about 20 percent below the U.S. market.[111] This was a time when major structural economic failures in Asia, the CIS, and elsewhere—and accompanying drops in steel demand—exacerbated global steel overcapacity. Owners of more than 300 million tons of capacity—one-third of total world steel capacity—were reportedly in distress and desperately seeking markets.[112]

The current global economic slowdown creates new challenges to U.S. domestic steel industry, but not only because of a loss of domestic and international demand for its products. Our findings in the study suggest that CO_2-pricing climate policy is likely to exacerbate the impacts of these negative consequences on the industry under these conditions, *if no action is taken to mitigate increasing energy costs*. There could be a significant new threat from low-cost foreign competitors—such as from China and Ukraine—anxious for new places to sell their inventories and maintain their capacity, as their own domestic demand recedes.

China's Challenge. In recent months, low-cost Chinese imports have begun to penetrate deeper into international markets, as China's domestic demand for steel products fell due to its own economic slowdown in the wake of the worldwide financial crisis. They even have begun to create problems for the steel industries of other major emerging developing nations, such as India. Several leading Indian steel producers slashed their prices to ward off the threat of cheaper imports from China and Ukraine and other countries, in the face of shrinking demand.[113] For example, in October and November 2008, India-based JSW Steel scaled back its prices by a total of 25-30 percent to compete against cheaper imported Chinese steel. This is on top a 50 percent drop in international steel prices in response to the global fall in steel demand.[114]

Under these conditions, the uniqueness and extreme nature of the current economic crisis notwithstanding, in assessing climate policy impacts on the competitiveness of the steel industry, it seems reasonable to conclude that the NCPA scenario rather than the CPA scenario would prevail. It would be harder for steelmakers to pass through their costs when faced with low cost foreign competitors, shrinking demand for steel, and falling world steel prices. Indeed, in a time of declining global demand and prices—especially if there is a lag in associated reductions in key input prices (say, due to long-term contracts for coal and other

[111] Chris Adams, "Nucor cuts steel prices amid rush of imports," *The Wall Street Journal Western Edition,* 1998, http://www.faqs.org/abstracts/Business-general/Nucor-cuts-steel-prices-amid-rush-of-imports-Big-Pennsylvania-health-system-to-file-Chapter-11.html.

[112] DOE/OIT, *U.S. Iron and Steel Industry,* 5.

[113] "Steel cost cut prices by up to Rs6,000 per ton to keep afloat," *Livemen.com,* November 3, 2008, http://www.livement.com/Articles/.

[114] Shobhana Subramanian and Varun Sharma, "JSW Steel: Hard times," *Business Standard,* 4 November 2008, http://www.business-standard.com/India.

Figure 5-8
Total BOF & EAF Steel Production
Mid-CO_2 Price Cases and BAU, 1992-2030

Legend:
- Eaf Share of Total Production
- BAU, Mid-Price CO_2-NCPA
- BAU, Mid-Price CO_2-NCPA
- Mid-CO_2 Price CPA*
- Mid-CO_2 Price CPA*

EAF STEEL PRODUCTION

BOF STEEL PRODUCTION

* CPA=Cost Pass Along (Margin Basis); NCPA=No Cost Pass Along

HRS-MI

inputs)—the impact of higher domestic energy price hikes could be worse than projected in the II-CPM simulations of NCPA scenarios. It also is possible that the ability to preserve existing domestic steelmaking capacity could be in jeopardy, even without the added burden of higher climate policy-driven energy costs.

BOF/EAF comparisons. Because of insufficient data, we could make only a cursory effort to distinguish between the BOF and EAF segments of the iron and steel industry, and did not attempt to evaluate either cost pass-along scenarios for the two parts of the industry. The resultant production cost and operating surplus

impact assessments, therefore, applied only to the aggregated industry. However, the two industry segments, which are based on different production processes and rely on different mixes of energy, have somewhat different energy footprints. This is significant, as it suggests that climate policy impacts are likely to vary for each segment, with implications for the future structure and health of the industry.

First, the ability to pass-through energy cost increases could differ depending on the industry segments and the markets it serves. As noted above (Chapter Three; also Appendix A), the McKinsey/Ecofys study[115] assumed that the BOF steel sector would

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[115] McKinsey/Ecofys, *EU ETS Review.*

pass-through 6 percent of its costs, and the EAF sector would pass-through as much as 66 percent of additional costs. The latter assumed that the European EAF market primarily serves only domestic markets and apparently would not be as vulnerable to international competition as the EU's BOF sector. On the other hand, as suggested by the above example of Nucor cutting prices to fend off cheap foreign imports in the late 1990s, the U.S. EAF segment could be subject to global competition every bit as intense as the U.S. BOF sector faces.

Second, the historical trends suggest that the majority of the new major steelmaking capacity needed to meet any projected demand growth for steel, might have to be met by EAF mills, as shown in Figure 5-8. At group modeling sessions, industry experts expressed skepticism about whether even under the best of circumstances major new BOF capacity would be built in the United States over the next 10 to 20 years, news stories about Russian investment in new domestic integrated mills notwithstanding.[116] EAF production accounts for nearly 60 percent of total U.S. production. Under the II-CPM assumptions, it could rise to as high as 70 percent by 2020 and 80 percent by 2030.[117]

The cost and availability of scrap steel, however, could be a limiting factor for this scenario. China in particular has soaked up huge quantities of scrap steel—it is the largest recipient of U.S. scrap exports—driving up the costs of scrap metal, even though most Chinese steel production still uses BOF technology. Because of the constraints on scrap metal availability, U.S. steelmakers—both BOF and EAF—have been planning to build new U.S. ironmaking capacity, based on DRI technology. Although this new capacity is being planned to meet future demand for steel, produced by both types of steelmaking mills, it also reflects EAF mills greater use of virgin iron materials, in order to compete in high-quality steel markets with BOF products.

BOF/EAF energy footprints.

The evidence suggests that the impacts of climate policy on EAF steelmakers are likely to be smaller than on BOF mills. Drawing on industry and government data, it is possible to estimate that BOF energy consumption per ton of steel produced is roughly from 4 to 5 times EAF[118] energy use, though an industry source suggests that the ratio may be only 2 to 1, and even closer in some instances.[119] EAF production uses more than double the amount of electricity, per ton of steel, but only about 40 percent of natural gas, and a tiny fraction of the amount of coal as BOF steelmaking. In addition, it consumes no coke or breeze, while BOF production relies on large quantities of both coal and coke as sources of heat, power, and feedstock, which accounts for its large energy and emissions footprints.

Because of constraints on scrap metal availability, U.S. steelmakers—both BOF and EAF—have been planning to build new U.S. ironmaking capacity, based on DRI technology.

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[116] For example, Bush, "Russia's Steel Wheels."

[117] Based on assumptions used in the study, drawn from historical trends and industry estimates, the II-CPM model was applied to make projections comparing potential production trends for the EAF and BOF segments. The results appear in Figure 5-8. Another key assumption was that the growth in global and domestic demand for steel would continue to grow as it had since 2004, driven by the rapid economic expansion of the BRIC and other emerging nations.

[118] The AISI provided detailed data for total production output, and the quantities of electricity, natural gas, coal consumed in 2006 by EAF and BOF mills. Energy data from EIA, *MECS 2002* enabled estimates of the energy (MBtu) consumed per unit of energy source (ton of coal, cubic feet of natural gas, kilowatthours of electricity). For each energy source, the energy consumed per ton of steel produced by both the EAF and BOF segments could then be estimated, by multiplying the energy consumed per unit of energy souce by the quantity of energy source consumed per ton of steel. Finally, the total energy consumed per unit of steel produced by each segment could be estimated by summing the respective contributions of each energy source.

[119] For example, many flat rolled EAFs with finishing complexes (galvanizing, etc.) use comparable finishing energy and they use more pig iron/DRI to make these products. Counting electricity generation losses, EAF energy use may be even closer to BOF. AISI email communication, February 10, 2009.

The II-CPM simulations assumed that the energy and production cost profiles for the EAF and BOF are identical—reflecting the profiles of the aggregated industry examined in the study. They calculated that, assuming NCPA, a Mid-CO_2 Price Policy would result in energy cost increases of 60 percent higher than BAU in 2020 and 100 percent higher in 2030. Rough estimates of energy costs indicate that the comparable energy costs for the EAF and BOF industry segments would fall on either side of the aggregate numbers. According to these estimates, in the policy case, EAF energy costs could rise only by about 14 percent above BAU by 2020 and 24 percent by 2030. By contrast, BOF energy costs could rise by 77 percent by 2020 and 131 percent by 2030.[120]

The subsequent impacts of these cost increases on the overall production costs and operating surpluses for the two segments could not be calculated with the data available.[121] However, it is reasonable to conclude that the BOF segment of the iron and steel industry would be more economically vulnerable than the EAF sector to the impacts of a carbon-pricing climate policy, especially in the face strong foreign competition, and even more so during periods of economic downturn.

These conclusions need to be qualified by two points. First, the greater use of DRI by both EAF and BOF mills would change the overall and relative carbon- foot prints within the industry, especially if large-scale domestic DRI capacity is constructed. DRI ironmaking uses natural gas or coal, and is perhaps around 20 to 25 percent more energy-efficient than blast furnace ironmaking based on coke and coal consumption.

Second, a different, perhaps more important issue concerns the assumption that electric power cost increases would be much

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[120] For each industry segment (BOF, EAF), these estimates entailed multiplying the calculated energy consumed per ton of steel for each energy source (coal, coke, electricity, natural gas)—see note 70 above—by the (real USD 2000) prices of each source, for the BAU and policy cases, and the given years (2020, 2030), provided by the EIA NEMS for the II-CPM simulations. For each industry segment, for each policy case (BAU, Mid-CO_2 Price Policy) and year, total energy costs per unit of production equaled the sum of the respective calculated costs for each energy source. The resultant total energy cost increases relative to BAU (in percent), shown in the text, were then calculated for each segment.

[121] This would require historical time series of consumption and cost data for the energy sources examined in this estimate and for other energy sources and the raw materials and other key inputs used by the different segments, as well for labor costs. A full comparative analysis would need data on market prices and trade (exports and imports) for the respective segments.

smaller than for coal and coke, under the climate policy. The estimation that BOF mills would suffer from greater energy cost impacts than EAF mills, is predicated on EIA NEMS energy price projections for the Lieberman-Warner climate bill (see Chapter Two). Electricity price variations under the climate bill relative to BAU were projected to be much lower than those for coal, coke, and natural gas. As discussed in Chapter Eight, with respect to aluminum energy cost impacts, the underlying assumption in the EIA projections that there would be a large-scale shift in energy generation from coal to nuclear power by 2030 is problematic. If instead, there is a slower move away from coal-based (and natural gas-based) electricity generation, the costs of electricity-intensive EAF steelmaking could be greater than the estimates based on the II-CPM simulations.

Technology Investment and Policy Options

In the study, we conducted a preliminary examination of technology investment and public policy options that could help the steel industry mitigate the economic costs of a climate policy. We first found that the industry would need to achieve fairly substantial energy-efficiency gains to offset these costs. At the same time, although we were able to identify both incremental and advanced heat, power and process technologies that could greatly reduce the industry's energy costs, there remain barriers to their successful implementation. Nevertheless, we found that a 90 percent allowance allocation policy would alleviate some of the short-to-mid-term cost pressures on U.S. steel manufacturers, which would buy time, if not encourage them to invest in new energy-saving technologies and processes.

Energy efficiency requirements.

Figure 5-9 illustrates estimates—drawing on II-CPM results for the iron and steel industry—of the energy-efficiency gains required to offset the increased costs of energy resulting under a Mid-CO_2 Price Policy (assuming NCPA), comparing the normal (no allocation) scenario with an alternative policy scenario (90 percent allocation) discussed below. Specifically it shows the annual cumulative energy efficiency gains required to offset costs for an energy source (fuel, electricity, energy feedstock) in the policy case up through a specified year. These were calculated by taking the ratio of the cumulative energy gains (Btus for fuel and feedstock, kilowatthours (kWh) for electricity) up to the specified year, and the total cumulative energy consumed for the BAU reference case up to that year. If no earlier action were taken, the industry would suffer a decline in operating surplus associated with the rise in energy costs every year up to that point in time.

If the climate policy were to take effect in 2012, offsetting the increase in energy costs above BAU that first year in the iron

We first found that the industry would need to achieve fairly substantial energy-efficiency gains to offset these costs.

Figure 5-9
Iron & Steel Industry – Cumulative Yearly Energy Efficiency Gains Required to Offset Climate Policy Costs

Feedstock	2030	50.4	
	2020	42.1	
	2012	32.7	
Fuel	2030	41.9	
	2020	34.2	
	2012	25.9	
Electricity	2030	10.1	No Allocation
	2020	6.6	
	2012	7.7	
Feedstock	2030	24.1	
	2020	12.3	
	2012	4.7	
Fuel	2030	18.5	
	2020	9.1	
	2012	3.4	
Electricity	2030	3.6	90% Allocation
	2020	1.3	
	2012	0.8	

Percent (0.0 – 60.0)

HRS-MI

Margin note:
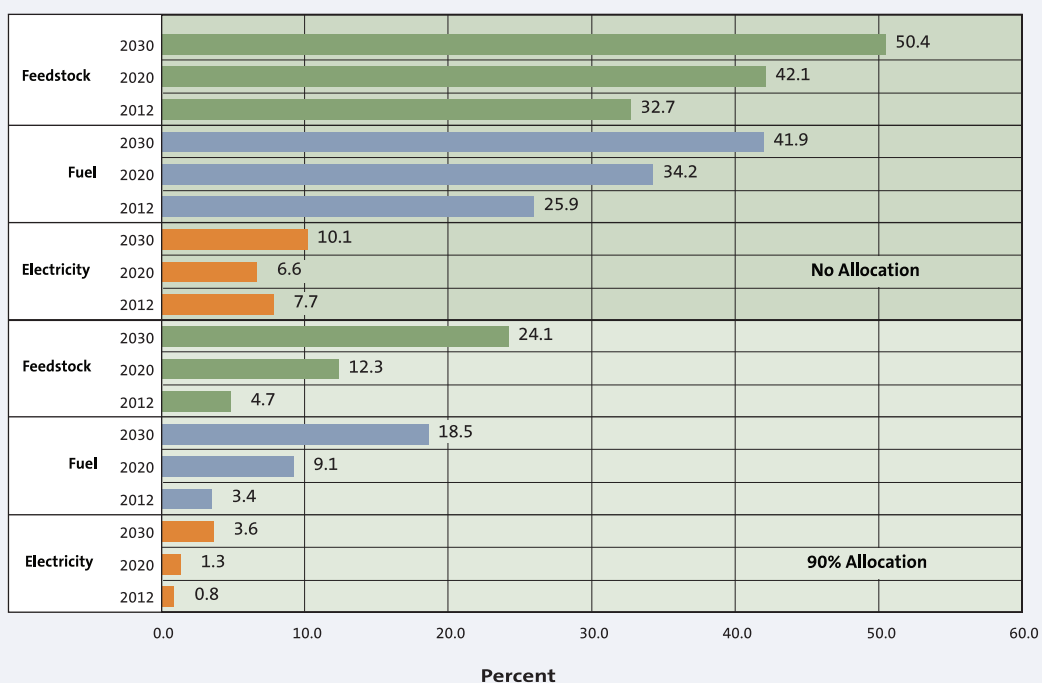
Although some gains might be made through incremental energy efficiency improvements, a large step increase in energy savings would be required in the iron and steel industry.

and steel industry would require an energy efficiency gain of 33 percent for feedstock energy, 26 percent for fuel energy, and approximately 8 percent for electricity, assuming that no earlier action is taken to reduce energy consumption. By 2020, energy consumption would need to be cut back by 42 percent, 34 percent, and 7 percent, respectively. If nothing were done to address the rising energy costs, by 2030, the energy efficiency gains required would grow another 6 percent, 8 percent and 3 percent, respectively.

This is equivalent to a 4.4 percent annual increase in energy efficiency from 2012 through 2030 for fuel energy, a 5.3 percent annual improvement in energy savings for feedstock, but only about a 0.7 annual increase for electricity over the 18-year period. However, Figure 5-9 suggests that although some gains might be made through incremental annual energy efficiency improvements, a large step increase in energy savings might be required in the iron and steel industry to achieve desired offsetting gains early in the policy timeframe.

In any case, a substantial reduction clearly would be required in the fuel energy used for heating and power in steel production, and in the feedstock consumed in the steelmaking process, to the enable the industry to maintain its energy costs close to or at BAU levels. This reflects the high cost of that the coal and coke that the integrated BOF part of the industry especially relies upon, and the relatively low cost and low variability of electricity prices under the

Mid-CO_2 Price Policy. The energy efficiency gains required for BOF steel plants therefore will likely be higher than for the aggregated industry. The gains needed for EAF side of the industry, would be somewhat smaller.

Technology options.

A critical question is, to what extent would the steel industry, especially BOF steelmakers, be capable of introducing technologies and practices that could make the necessary, cost-effective improvements in energy efficiency to offset the added costs of a climate policy? How much room for improvement does the industry in reality have for achieving such large gains? The American Iron and Steel Institute argues that the U.S. steel industry is the most energy efficient in the world,[122] a result of steady investments in its energy efficiency over the past two decades. Since 2002, the U.S. steel industry reduced its energy intensity per ton of steel shipped by approximately 12 percent and a total of 27 percent between 1990 and 2005.[123]

An industry expert has argued that there is little room left for any additional significant energy savings gains in the iron and steel industry, over the short-to-mid term. Even incremental gains will be difficult. Referring back to Box Three, in Chapter Three, while modest energy savings remains possible at current technology levels, the incremental gains would be relatively small for the high marginal costs incurred in achieving them. That is, companies already have done most of what can be done, such as recycling blast furnace and coke oven gases, and further improvements are not cost-effective at this time. At best, the industry expert

has estimated that only a few percent of efficiency gains—perhaps one-quarter percent to one-half percent per year—may be possible over the next decade. [124]

Nevertheless, driven by the rising costs of energy and the possibility of a U.S. climate policy being enacted in coming months, the iron and steel industry, both domestically and internationally—with some help from federal programs[125]—has been exploring a wide range of short, medium, and long-term energy saving technologies.

Over the short and medium-term, there are a number of incremental measures and technologies the industry itself has identified that might be able to improve energy management (sensors, post-combustion), increase yields (i.e., more output for the same or less energy), reduce refractory consumption (e.g., used in boiler linings), and reduce flux consumption (used in metal smelting). Most of these energy savings opportunities generally are applicable to both ore-based and scrap-based steelmaking processes, though BOF steelmaking is likely to enjoy the greatest improvements, given its large energy footprint. Nevertheless, there also are best practice opportunities for energy savings in EAF production, primarily through improvements in furnace design, process control, scrap reheating and charging practices, and post combustion practices.[126]

Heat recovery and energy substitution are areas where energy improvements are possible, and have been flagged by both industry and the federal government for

A CRITICAL QUESTION IS, TO WHAT EXTENT WOULD THE STEEL INDUSTRY BE CAPABLE OF INTRODUCING TECHNOLOGIES AND PRACTICES THAT COULD MAKE THE NECESSARY, COST-EFFECTIVE IMPROVEMENTS IN ENERGY EFFICIENCY TO OFFSET THE ADDED COSTS OF A CLIMATE POLICY?

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[122] Andrew G. Sharkey III, *Prepared Statement, Legislative Hearing of America's Climate Security Act of 2007, S. 2191, The Senate Committee on Environment and Public Works* (Washington, D.C.: American Iron & Steel Institute, November 12, 2007).

[123] AISI, *ASR 2007*

[124] Phone conversation with AISI official, April 30, 2008.

[125] This includes, for example, the U.S. Department of Energy's Industrial Technology Program.

[126] American Iron and Steel Institute (AISI), *Saving One Barrel of Oil per Ton (SOBOT), A New Roadmap for Transformation of Steelmaking Process* (Washington, DC, October 2005).

further R&D. These include energy recovery technologies, which enable recovery of energy contained in the by-products of the steelmaking process—slags, fumes, off-gases, coke-oven and blast furnace gases—and reallocate otherwise wasted energy for use elsewhere in the production process.

Some measures along these lines are already being successfully applied in current steelmaking processes. For example, ArcelorMittal in East Chicago, IN partnered with Recycled Energy Development to develop an on-site energy plant to capture waste heat and gases. AcelorMittal was able to cut its purchases of coal-fired power by one-half at its integrated BOF mill, also reducing carbon emissions by 1.3 million tons a year, and saving $100 million annually. The company has since gone on to use waste heat recovery at three more of their steel facilities.[127]

Energy substitution entails the maximum use of alternative fuels—using coke oven gas, blast furnace gas, BOF gas, and EAF gas, produced in steelmaking process—to substitute for purchased fuels (especially natural gas) currently used in steelmaking. Longer term, research is being pursued to develop other alternative fuels for substitution for currently used fuels. This includes, for example, charcoal from biomass sources, such as trees, silage, and sawmill wastes as a replacement for coke. Other work is exploring coal gasification technologies, which would enable manufacturing of syngas from coal onsite at steel plants.[128]

Long-term technology options.

In the long-run, the industry will need to introduce process improvements and even new steelmaking processes that use substantially less carbon-based energy to counter rising energy costs—whether market or policy driven. Some important process improvements have been made, such as advances in casting—e.g., near-net shape casting, (thin slab casting is its most significant form), which lessens energy use in the rolling process by reducing the number of forming steps required to produce a final product. Additional improvements in rolling and finishing could generate savings through the elimination and minimization of reheating steps.

The most promising and important long-term, large-scale improvements, however, lie in the introduction of new, low energy-intensive iron-making processes, which could generate energy savings as great as 30 percent in the most advanced technologies, by the elimination of coke and other fossil-fuel energy sources. A steel industry source has observed that alternative coal-based ironmaking technology is in use today. The injection of pulverized coal into blast furnaces is already a widely applied technology, which reduces the need for coke and coke ovens.[129] According to the International Energy Agency (IEA), coal injection has been shown to replace up to half the coke now used in blast furnaces.[130] Plastic waste can also be injected into blast furnaces as a substitute for coal and coke. This technology already has been applied in Germany and Japan, but important barriers to the increased use of plastic as injection fuel remains.

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[127] Jackie Roberts and Isabel Grantham, *Managing for Success: Steel in a Carbon Constrained Economy*. PowerPoint presentation, Environmental Defense Fund, July 2008.

[128] AISI, *SOBOT*.

[129] Phone conversation with an AISI official, April 30, 2008.

[130] International Energy Agency (IEA), *Energy Technology Perspectives 2006, Scenarios & Strategies to 2050* (Paris, France:OECD/IEA, 2006), 401.

A "family of technologies," also in use today in different locations around the world, can replace blast furnaces and coke ovens at a fraction of operating and capital costs, substituting coal for coke as the energy source and reduction agent.[131] For example, COREX is a direct iron-ore smelting reduction process that uses coal fines and agglomerated ore to produce pig iron without processing coking coal. FINEX, an advanced version of COREX, is based on the direct use of non-coking coal, and uses iron-ore fines instead of agglomerated ore, reducing production costs. Both processes produce fine DRI at substantially reduced pollution emissions and costs compared to conventional blast furnaces.

The IEA states, though, that the COREX process is only marginally economic at this time, and mostly suitable for medium-scale integrated plants.[132] There are no DRI plants in the United States, but there are COREX facilities in India, South Africa, Korea and China. Recently, Baosteel, China's largest steelmaker doubled its pig-iron capacity of its low-emissions COREX plant to 3 million tons.[132]

The Paired Straight Hearth (PSH) Furnace is a technologically advanced member of this "family," but it is in demonstration, and may not be available for at least a decade or more. According to an industry expert, the PSH furnace development occurs in two steps. In the first phase, it makes coal-based DRI. When it is proven (in an estimated 3 years), it would be coupled to a smelter. In that configuration, it would use only two-thirds the energy, and result in 20 to 25 percent less CO_2 per ton, at a fraction of the operating and capital cost, as conventional blast furnaces. It would be applicable to both integrated and EAF steelmaking.[133] Other breakthrough technologies, such as ironmaking by molten oxide electrolysis and hydrogen flash melting are much longer-term (see Table 3-D).[134] The AISI also identifies the development of carbon capture and sequestration technology (CCS), as a solution for offsetting emissions and carbon costs for blast furnaces in integrated mills. AISI reports that it has been investigating CCS for blast furnaces in the United States.[135]

In the long-run, the industry will need to introduce process improvements and even new steelmaking processes that use substantially less carbon-based energy to counter rising energy costs.

[131] Phone conversation with AISI staff member, April 30, 2008.

[132] IEA, *Energy Technology Perspectives*, 403

[133] "Baosteel to expand low-emissions Corex iron plant," *Reuters,* November 24, 2007.

[134] AISI email communication, February 10, 2009.

[135] AISI, *SOBOT*.

[136] AISI email communication, February 10, 2009.

Investment costs and barriers.
In short, there several technologies being considered that might be able to achieve significant energy savings in the steel industry. At the same time, it is likely that the industry would continue to make incremental improvements, especially if there is an added incentive of climate policy-driven energy cost increases. However, a major step-jump in iron-making processes, which would yield the largest energy use reductions, would require substantial new infusions of investment capital by the industry.

We would need further research to evaluate the cost-effectiveness of investing in new technologies, especially large-scale new low-energy iron-making technologies. It is likely that these investments could be in the vicinity of several hundred millions of dollars at a single steel facility. An examination would be needed of possible trade-offs with the costs of alternative choices domestic steelmakers may have.

We also would need to consider the potential costs to the industry of *not* investing in energy-saving technologies. Every year the industry does not find a way to offset the added energy costs due to climate policy, results in increasing declines to its operating revenues and profits. For example, based on II-CPM results we estimated that by 2015 the total cumulative operating surplus reductions due to added energy costs (in real 2000 dollars) in the steel industry would be $16.7 billion. This would rise to $48.3 billion by 2020 and $165.7 billion by 2030—or an average of $8.7 billion per year through 2030.[136] This can be interpreted as an opportunity, or an upper limit investment, that can reasonably be made to offset increasing energy costs.

However, the timing for when the industry would be able to effectively introduce new iron and steelmaking technologies would need to be considered, as well. The relevant new technologies may not become commercially viable for at least a decade or more, and time would be needed before manufacturers would be willing to retire and replace older vintage capital with new equipment and processes.[137] Even though alternative coal-based iron-making technologies are available now, the evidence suggests that it is unlikely that they soon would be able to be introduced on any significant scale in the United States.

This may especially be true for integrated steel plants that have recently relined their boilers, which yields incremental improvements in productivity. Blast furnaces will continue to operate as long as demand growth is maintained, and steelmakers may not be willing to make substantial investments in new substitute

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[137] These estimates entailed summing the additional costs above BAU for each year under the policy case up to a given year. It assumes NCPA and no efforts were made by the industry to offset the added costs or reduce costs by reducing output before the given year.

[138] See Ruth et al, "Climate Change and Capital Vintage Effects," for an earlier work on evaluating vintage impacts of climate policy on the steel, paper and ethylene industries.

equipment until the next cycle of refractory replacements. In addition, any new domestic iron-making capacity to meet rising steel demand is more likely to be added to existing integrated mills, or EAF mills if scrap becomes too costly, rather than replacing older, energy-intensive capacity. [138]

Investments in the newer technologies to replace existing blast furnaces, therefore, may have to wait. Relining is done every 15 to 20 years, locking in the blast furnace technology and investments. As an International Energy Agency (IEA) study notes, the longevity of blast furnaces "severely limits the opportunities for timely adoption of new technology." In addition, the integrated, complex and interlinked infrastructure including coke ovens, sintering and blast furnaces, constitutes another barrier to the introduction of the new technology.[139]

Policy options to mitigate impacts.

Given the obstacles to early adoption of energy-saving technologies in the iron and steel industry, policies that mitigate the climate policy economic impacts, and/or enable the industry to develop and introduce such technologies, need to be considered. Towards this end, we ran II-CPM simulations evaluating one such measure, which would offset the increased energy costs from the Mid-CO_2 Price Policy by 90 percent starting in 2012, reduced by 2 percent annually. All the model runs are assumed NCPA.

As reported in Chapter Three, regardless of the policy case or industry, the II-CPM simulations found that the declines in total operating surplus as a percent above BAU would be reduced by nearly three-quarters in the allocation scenario, compared to the non-allocation case by 2020, and over 50 percent less by 2030 (see Figure 3-9). The implications of this shift are illustrated in Figure 5-10, which compares the steel industry real (USD 2000) unit production costs for the Mid-CO_2 Price Policy with no allocation and the 90 percent allocation policy, relative to the domestic steel market price.

THE II-CPM SIMULATIONS FOUND THAT THE DECLINES IN TOTAL OPERATING SURPLUS AS A PERCENT ABOVE BAU WOULD BE REDUCED BY NEARLY THREE-QUARTERS IN THE ALLOCATION SCENARIO, COMPARED TO THE NON-ALLOCATION CASE BY 2020.

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[139] Phone conversation with AISI staff member, April 30, 2008.
[140] IEA, *Energy Technology Perspectives*, 403.

FIGURE 5-10
IRON & STEEL REAL UNIT COSTS & MARKET PRICE
90% ALLOCATION VS. NO ALLOCATION CASES

Source: HRS-MI

— Domestic Market Price-NCPA   — Mid-CO$_2$ Price No Allocation   - - Mid-CO$_2$ Price 90% Allocation   — BAU Production Cost

Predictably, the allocation curve is well below the original no allocation curve. Mid-CO$_2$ Price Policy unit production costs were projected to be 2 percent above BAU for the allocation scenario, compared to 7 percent, for the no allocation scenario, in 2020, and 5 percent above BAU, compared to 11 percent above, respectively, in 2030. Similarly, the operating surplus reduction for the industry would be much smaller, only 6 percent below BAU for the allocation scenario, compared to 24 percent for the no allocation case in 2020, and 18 percent below, compared to 40 percent below, respectively, in 2030 (see Table 3-E).

In the allocation scenario, the economic impacts of the climate policy therefore would be dramatically reduced through 2020, though they would grow again as the offset is reduced, if action is taken to increase energy efficiency. Accordingly, with the allocation, the industry would not be under the same intense pressures to reduce costs, as it would be with no allocation

offset, though by 2025-2030 these pressures would begin to grow significant again.

By 2020, we can reasonably anticipate that the industry would have begun to make steps towards greater energy savings, by adopting new technologies. This would be made easier by the allocation, which in theory would buy time for the industry to make the necessary investments without a substantial loss of operating revenues associated with the climate policy.

The opportunities are evident from an analysis of the energy efficiency gains required to offset cost increases in the allocation scenario, compared to the gains calculated for the no allocation scenario. As Figure 5-9 illustrates, cumulative yearly efficiency gains required in the former would be far less than in the latter, though by 2030, the requirements for feedstock and fuel energy will once again have grown to sizable levels. In 2012, there would be an initial jump of only 5 percent, 3 percent and

a little less than 1 percent, in feedstock, fuel, and electricity gains required, respectively. But by 2030, the required gains would grow to 24 percent for feedstock, 19 percent for fuel energy, and a little over 4 percent for electricity.

Conclusion

Even under the best global economic conditions, enactment of a climate policy that imposes a cost on carbon dioxide and other greenhouse gases would create challenges to the competitiveness of the American iron and steel industry if no mitigating actions are taken and if no climate regulation is enacted by major U.S. trade partners. By driving up the cost of fossil-fuel energy used for heat and power and consumed as feedstock in iron and steel production, climate policy would result in increased costs and reduced operating surpluses and margins in the industry. Because iron and steelmaking is a global industry, and subject to intense international competition from both developed nations (Japan, EU) and large emerging economies (China, Russia, CIS, India, Brazil), U.S. steelmakers may find it difficult to pass along these additional costs, especially during times of declining world demand and market prices.

As a result, our analysis indicates that domestic steelmakers increasingly would feel strong pressures to cut their costs. The question remains, however, is whether they would attempt to do so by investing in economical energy-saving technologies and practices, or by cutting production—and jobs—or, worse, moving their facilities to low-cost, less regulated offshore locations. Although the industry has made great strides in improving its energy-efficiency, there remains room for incremental improvements to make further energy savings, for which there would new be

incentives, as energy costs increase due to climate policy. However, these known potential gains would not be adequate for achieving the levels of energy efficiency needed to offset these rising costs. Only major new investments in advanced, low-carbon iron-making technologies—replacing older, carbon-intensive processes—would enable the U.S. iron and steel industry to maintain its competitiveness in an increasingly carbon constrained economy. Aside from being expensive, however, it will be at least a decade before such technologies are commercially available, and perhaps longer before manufacturers would be find it cost-effective to retire and replace existing capacity.

At the same time, we found that an allowance allocation policy associated with the climate policy, that would offset the short-to-medium cost impacts on the industry—but phased out over time—could be effective in buying time for the industry to make both the incremental improvements and, eventually, longer-term large scale investments in more energy-efficient, modernized steelmaking capacity. This would be a necessary, if not sufficient, move in the right direction that not only could preserve domestic capacity, but also make U.S. steel producers more globally competitive.

It is likely that other public policies also would be needed to encourage U.S. steelmakers to make these investments, in the face of rising costs, rather than cutting production or moving offshore, even with an allocation policy. These might include various investment incentives (e.g., production tax credits) and beefed-up support for research, development and demonstration programs in advanced low-carbon or zero-carbon steelmaking processes, and other breakthrough technologies.

It is likely that other public policies would be needed to encourage U.S steelmakers to make these investments, in the face of rising costs, rather than cutting production or moving offshore, even with a n allocation policy.

THE ALUMINUM INDUSTRY

Although the aluminum industry is much smaller than the iron and steel industry, its products are used throughout the economy—in autos and light trucks, aircraft, rail cars, beverage containers, food containers, household and institutional foil, and building construction, electrical components, consumer durables, and numerous other applications. In 2006, aluminum surpassed iron to become the second most used material in new cars and trucks worldwide, as automakers make efforts to improve fuel efficiency, reduce emissions and enhance vehicle performance.[140]

The alumina and aluminum production processing industry (NAICS 3313) includes alumina production, aluminum production (primary and secondary) and aluminum semi-fabricated manufacturing.

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[141] Aluminum Association website "Industry Overview," http://www.aluminum.org. For the first time, in 2006, more than one-half of all engine blocks manufactured in North America were made from aluminum. E. Lee Bray, "Aluminum," *2006 Minerals Yearbook* (U.S. Department of Interior, U.S. Geological Survey, November 2007)..

In the study, we focused primarily on the primary and secondary aluminum industries (NAICS 331312 and 331314). Although alumina manufacturing (NAICS 331311) is itself energy-intensive, the II-CPM treats it as a material input supplier to the primary industry. *Primary aluminum* is produced globally by mining bauxite ore, refining the ore to alumina, and combining the alumina and carbon in an electrolytic cell to produce aluminum metal. *Secondary aluminum* is produced from recycled aluminum scrap. Both primary and secondary aluminum are cast into large ingots, billets, T-bar, slabs or strips and then rolled, extruded, shape-cast, or formed into components and other useful products.[141]

In 2006, aluminum surpassed iron to become the second most used material in new cars and trucks worldwide.

Below is a synopsis of some of the industry's principal characteristics and statistics:

Structure and location. In 2007, six companies operated fourteen primary aluminum smelters in eleven states, though five smelters were temporarily idled. Because they are electricity-intensive,

primary smelters prefer to locate where hydropower is abundant and electricity rates are lower. As a result, the majority of U.S. primary aluminum producers are in the Pacific Northwest and the Ohio River Valley. Secondary smelters typically locate near major industrial and consumer centers to be close to large amounts of scrap. Well over 300 secondary aluminum smelters in the United States are spread throughout 37 states, with the largest concentrations in the Great Lakes Region (Ohio, Indiana, Illinois, Michigan, Wisconsin) and Southern California.[142] There also are about 4 alumina refining plants in the Gulf region. Aluminum industry (NAICS 3313) employment was 71,800 in 2007—8,500 employed in primary production and 6,800 in secondary aluminum production.[143]

Production. Total primary aluminum production was an estimated 2.6 million metric tons, a total value of $7.1 billion, in 2007,[144] accounting for under 40 percent of total U.S. aluminum production. Secondary recovery (from old and new scrap) totaled 3.51 million metric tons in 2006, an estimated total value of $9.4 billion at published market prices,[145] accounting for about 60 percent of domestic aluminum production.

Scrap and recycling. Recycling saves almost 95 percent of the energy needed to produce aluminum from its original source, bauxite ore. Of the 3.5 million metric tons of aluminum produced from

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[142] Aluminum mill products include semi-fabricated products such as sheet, plate, foil, extruded products, drawing stock, bare wire, ACSR and bare cable, insulated/covered wire and cable, pigments and powder, forgings, and impacts.

[143] Sources: U.S. Department of Energy, Office of Industrial Technology (DOE/OIT), *Energy and Environmental Profile of the U.S. Aluminum Industry*. Prepared by Energetics, Inc. (July 1997), 3; "Secondary Aluminum Smelters of the World," *Light Metal Age*, 19 June 2008, http://www.lightmetalage.com/producers.php.

[144] Aluminum industry data is from the Bureau of Labor Statistics. The primary and secondary aluminum employment data for 2006 is from the Census Bureau, *ASM* (2007).

[145] U.S. Geological Survey (USGS), "Aluminum," *Mineral Commodity Summaries* (January 2008), 22-23. The dollar value was based on published market prices. Total primary production was up from 2.48 million metric tons, in 2006. Primary production data was from both USGS and Aluminum Association statistical sources.

[146] Ibid. Published prices for an ingot of aluminum, on average, in the U.S. spot market in 2006 was 121.4 cents per pound. In 2007, the price rose to 125.2 cents per pound.

secondary recovery for $7.0 billion.[147] The largest share of aluminum end-use shipments are for transportation products (mostly passenger automobiles, one-third in 2006), followed by containers and packaging (20 percent), and building and construction (14 percent). Others large users include electrical goods, consumer durables, and machinery and equipment.

International trade. Total net imports of aluminum ingots in 2007 equaled 2.58 million metric tons,[148] down from 3.09 million metric tons of ingot in 2006.[149] The largest importers of aluminum to the United States in 2006 were Canada (55 percent) and Russia (18 percent). China (32 percent), Canada (27 percent), and Mexico (20 percent) together received nearly 80 percent of total U.S. exports of aluminum. The United States is a net exporter of scrap aluminum; it shipped a net of 2,079 million pounds of scrap overseas in 2006.[150]

scrap in the United States in 2006, two-thirds from new (manufacturing) scrap and one-third from old scrap (discarded aluminum productions). In 2006, 51.9 billion aluminum used beverage cans (UBCs) were recycled, 51.6 percent of total aluminum cans that were shipped in the United States. Aluminum UBCs accounted for 54 percent of reported old scrap consumed. Automotive aluminum is also a major source of scrap, almost 90 percent of which is reclaimed and recycled.[146]

Shipments. Aluminum shipments were 9.23 million metric tons in 2007, down from 9.87 million metric tons, valued at $13.2 billion (primary and secondary) in 2006—primary aluminum accounted for $6.2 billion and

Industry Structure and History

The aluminum industry has experienced restructuring, consolidation and globalization over the past decade, and significant reduction in capacity, especially since 2000. In 1997, there were 23 primary

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[147] Aluminum Association website "Industry Overview," http://www.aluminum.org; Aluminum Association, *Aluminum Statistical Review for 2006 ("ASR 2007")* (Arlington, VA, August 2007).

[148] Census Bureau, *ASM*; Also, Lloyd T. O'Carroll, "Aluminum Outlook," Presentation to Aluminum Association Spring Meeting. Davenport & Company, LLC, April 22, 2008. Aluminum shipments were projected to fall further in 2008, by 3.2 percent in 2008, but grow again in 2009, by 3.4 percent.

[149] Source: Aluminum Association, *ASR 2007*.

[150] Source: Ibid., and personal communications with Aluminum Association. Total net imports in 2006—including ingot and net imports of mill products of 450 thousand metric tons—equaled 3.54 thousand metric tons or 37.8 percent of apparent aluminum consumption in the United States. The Aluminum Association prefers a measure of the import share of total supply, with imports equal to ingots and mill products and supply equal to primary and secondary production plus total imports. In 2006, total imports equaled 5,057 thousand metric tons and accounted for 46.5 percent of total domestic aluminum supply of 10,874 thousand metric tons.

[151] Aluminum Association, *ASR 2007*, 13, table 14a. Other importers were China (4 percent), Brazil (3 percent), Germany (3 percent), Venezuela (3 percent) and Mexico (3 percent).

production facilities operated by 13 companies.[151] By 2005 there were only six companies operating 15 primary aluminum smelters at about two-thirds of rated or engineered capacity, with another four smelters idle. This shrank further in 2007, to 14 smelters and five idled smelters.[152] The largest primary aluminum companies (and share of U.S. capacity) include Alcoa (51.5 percent), Century Aluminum (14.4), Ormet (7.3), Golden Northwest Aluminum (6.8), Noranda (6.9), Rio Tinto Alcan (5.4), Columbia Falls Aluminum (4.6), and Evergreen Aluminum (3.2).[153]

Energy pricing pressures are largely responsible for the loss in U.S. primary aluminum production and capacity since 2000, particularly in the Pacific Northwest where the majority of aluminum smelters are located. The electricity crisis in 2000-2001, which affected most Western states, caused aluminum companies to shut down several Pacific Northwest smelters because of skyrocketing electricity prices. Some companies shut down smelters to capitalize on the newly high-valued long-term electric power contracts they had with power generators. Several of these smelters were never restarted. This is reflected in the capacity utilization rates for primary aluminum, which dropped precipitously from a high of 88.2 percent in 2000 to 62.5 percent in 2006.

International Markets

Aluminum is a global industry. The extraction of bauxite, its basic raw material, is located in many nations throughout the world, and aluminum products are fabricated in every nation on the planet. Primary aluminum was produced in 42 countries in 2006. The United States ranks fourth in the world in annual primary aluminum production—behind China, Russia, and Canada—and second in aluminum consumption, behind China. These four countries accounted for more 55 percent of total world production in 2006. World primary aluminum production was 33.7 million metric tons in 2006, and was estimated to grow to 38.0 million metric tons in 2007.[154]

China was the main driver of this increase, largely due to a 20 percent increase in the production between 2005 and 2006, and another estimated 28 percent between 2006 and 2007. China accounted for 28.0 percent of global output in 2006, producing an estimated 9.35 million metric tons. Russia

Recycling saves almost 95 percent of the energy needed to produce aluminum from its original source, bauxite ore.

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[152] DOE/OIT, *Profile of U.S. Aluminum Industry,* 3. This report also indicates, however, there are a much larger number of aluminum semi-fabricated and finished products facilities. In 1995, the number of plants included 48 sheet & plate, foil, 21 wire, bare, conductor, and nonconductor, 14 steel-reinforced aluminum stranded conductor (ACSR) and aluminum cable (bare), 37 wire & cable (insulated or covered), 190 extruded products, 16 powder and paste, 47 forgings, and 13 impacts manufacturing plants.
[153] USGS, *2008.*
[154] Aluminum Association, *ASR 2007,* 6.
[155] USGS, "Aluminum".

Source: Aluminum Association

Trade Balance — Imports — Exports
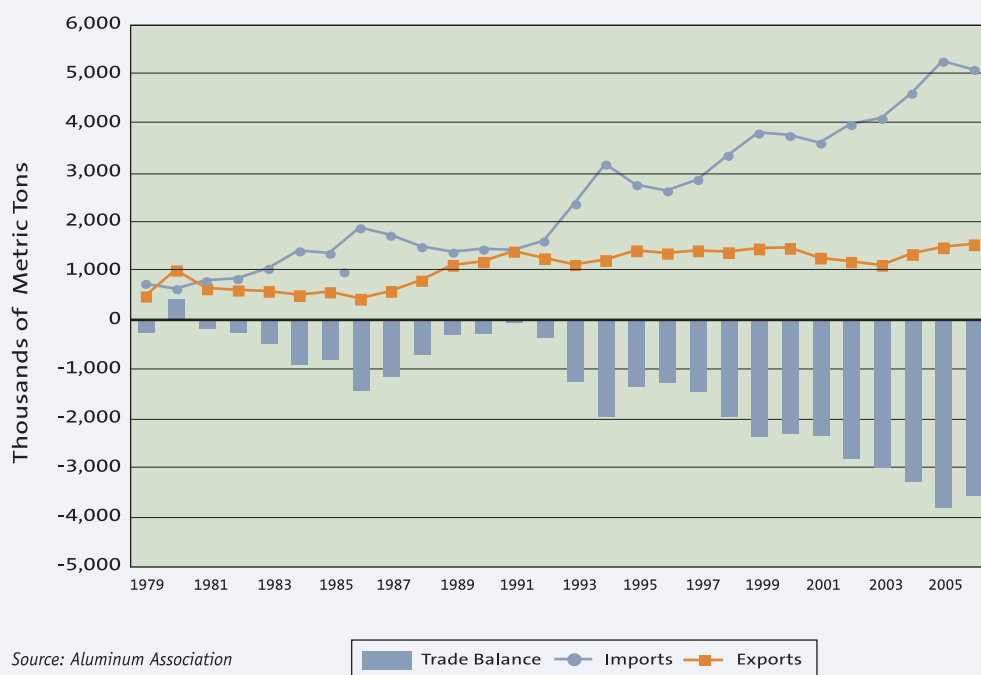
accounted for 11.0 percent of the world total, followed by Canada (9.1 percent), and the United States (6.8 percent). Other major world producers include Australia, Brazil, Norway and India.[155]

ALUMINUM TRADE. Primary aluminum is a commodity that trades in global markets. Primary smelters do not directly compete with each other. Instead, they sell into the same commodity market and compete by trying to keep their operating costs below the world market price for primary aluminum, which typically is represented by the price for financial transactions for aluminum as quoted by the London Metals Exchange (LME).[156]

Secondary aluminum ingot is metalurgically indistinguishable from primary aluminum ingot, and much of its also is traded in the same international markets and subject to the LME pricing, as well.

Figure 6-1 illustrates the trade pattern for U.S. aluminum industry since 1979, showing a rising imports and trade deficit for this sector since 1991. From 1996 to 2006, U.S. net imports have grown at an annual rate of 6.3 percent, while exports have remained relatively flat, dipping temporarily in 2001 through 2003, reflecting the capacity use losses to the electricity crisis in that period.[157]

[156] Ibid. See also, Aluminum Association, *ASR 2007,*
[157] Golden Northwest Aluminum, "Market Factors Affecting Smelter Operations," *BPA's Straw Proposal,* March 2005, http://www.bluefish.org/smelter$.htm.
[158] Aluminum Association, *ASR 2007*, 13.

Figure 6-2 illustrates the declining importance of primary production compared to rising imports and secondary recovery of aluminum to meet U.S. domestic demand since 1976. Net imports as a share of total apparent aluminum consumption rose from nearly zero in 1991 to 23.5 percent in 2000 and then to 37.8 percent in 2006.[158] Secondary aluminum production growth accounted for much of the revival of exports since 2003 shown in Figure 6-1.

TRADING PARTNERS. Table 6-A shows the top trading partners with the United States for aluminum ingot produced by primary and secondary smelters, ranked according to cumulative trade flows—imports, exports and net imports—from 1995 through 2007. Canada and Russia, followed by Venezuela, Brazil and Australia ranked as the largest importers and net exporters of aluminum ingot to the United States. Canada also was the largest *recipient* of aluminum exports from the United States.[159]

The massive bilateral trade flow between the United States and Canada actually

FIGURE 6-2
PRIMARY AND SECONDARY ALUMINUM PRODUCTION AND NET IMPORT SHARES OF APPARENT CONSUMPTION, 1979-2006

HRS-MI
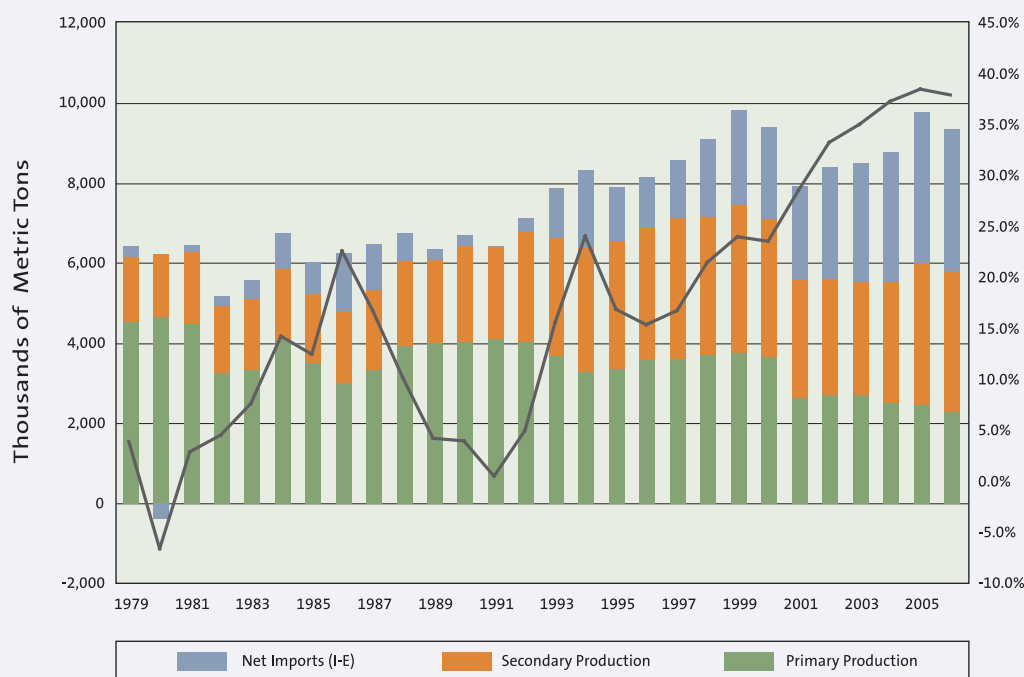
The massive bilateral trade flow between the United States and Canada actually reflects the extent their respective aluminum industries are integrated.

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[159] Net aluminum share of total aluminum supply is calculated by summing primary and secondary production and imports of ingot and mill products minus exports.
[160] Source: Aluminum Association, *ASR 2007*.

Table 6-A
Top U.S. Aluminum Trading Partners, Aluminum Ingot

TOP SOURCES OF IMPORTS			TOP RECIPIENTS OF EXPORTS			SOURCES OF NET IMPORTS		
Country	Cum. 1995-2007		Country	Cum. 1995-2007		Country	Cum. 1995-2007	
	% World	Rank		% World	Rank		% World	Rank
Canada	58.5	1	Canada	44.4	1	Canada	60.6	1
Russia	22.6	2	Mexico	32.0	2	Russia	26.1	2
Venezuela	4.9	3	Japan	15.6	3	Venezuela	5.6	3
Brazil	3.2	4	South Korea	1.8	4	Brazil	3.7	4
Australia	1.9	5	EU-15	1.1	5	Australia	2.2	5
EU-15	0.7	9	Hong Kong	1.0	6	EU-15	0.7	11
China	0.6	12	China	0.3	10	China	0.7	13
ROW	7.5		ROW	3.8		ROW	0.4	
World	36.00 mmt		World	4.77 mmt		World	31.23 mmt	

mmt=million metric tons; ROW=Rest of the World

Source: The Aluminum Association

CHINA IS NOW THE NUMBER ONE IMPORTER OF U.S. ALUMINUM, AND THE LARGEST NET IMPORTER OR SCRAP FROM THE UNITED STATES, RECEIVING A NET 917 THOUSAND METRIC TONS OF U.S. ALUMINUM SCRAP IN 2006.

reflects the extent their respective aluminum industries are integrated. Outside of Canada, the largest shares of aluminum exports from the United States flowed to Mexico and Japan. China, despite being the world's largest producer of aluminum, ranks far down the list of major trading partners, ranking only twelfth in aluminum ingot imports and thirteenth in net imports, and tenth as a recipient of aluminum ingot exports.

Nevertheless, China has played a

progressively larger role in U.S. aluminum trade. In 2003, U.S. net imports of aluminum ingot from China were only 499 metric tons; by 2006, this figure had grown 59.9 thousand metric tons. If we include the exports and imports of semi-fabricated aluminum products and scrap, with aluminum ingot, China rises to the third largest exporter of aluminum products to the United States, by 2006—an annual growth rate of 32 percent, though it remains far behind Canada and Russia.[160]

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[161] Aluminum Association supplied trade data; Aluminum Association, *ASR 2007*, Table 14.

U.S. exports to China of all aluminum products (ingot, mill products, scrap) have increased dramatically, at an annual rate of 23 percent between 2003 and 2006. China is now the number one importer of U.S. aluminum, and the largest net importer of scrap from the United States, receiving a net 917 thousand metric tons of U.S. aluminum scrap in 2006. Meanwhile, Canada and Mexico are the largest importers of scrap into the United States, accounting for 90 percent of total U.S. scrap imports.[161] Other major recipients of U.S. scrap exports include, Turkey, Taiwan, South Korea, Japan and Germany.[162]

Aluminum Production and Energy Use

A production and energy flow chart for the alumina and aluminum production sector
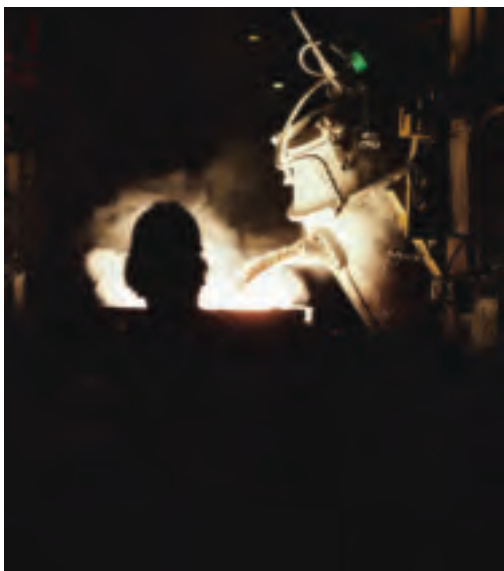
(NAICS 3313) is shown in Figure 6-3. The dashed line indicates the boundaries of the industry subsectors we examined in the HRS-MI study—primary and secondary aluminum production—plus the alumina refining stage, carried out in different facilities and a separate but very closely linked industry sector, which the II-CPM does not directly model. Semi-fabrication of aluminum also was not included. The principal alumina and production processes are described below:

Alumina production (NAICS 331311)—the production of alumina (aluminum oxide, Al_2O_3) by refining bauxite (the ore of aluminum) in the Bayer process. This entails chemically filtering out impurities and precipitating aluminum hydroxide, which, in turn, is heated to a very high temperature *(calcination)*, and then decomposes to alumina and water vapor. Nearly all bauxite consumed in the United States (9.78 million metric tons in 2007) is imported and more than 90 percent of that is converted to alumina at domestic refineries in Louisiana and Texas. Total alumina capacity in 2007 was 5.75 million metric tons. However, there were only three Bayer refineries operating throughout the year, and one that was temporarily idled,[163] producing 3.9 million of alumina, of which 84 percent was used for metal production. In 2007, 14 primary aluminum smelters consumed a total of 5.12 million metric tons of alumina, of which 1.28 million metric tons were supplied by net imports.[164]

Primary aluminum production (NAICS 331312)—the production of aluminum by reducing alumina through electrolysis,

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[162] Aluminum Association, *ASR 2007*.

[163] Paul Schaffer, "Value of US scrap exports, China's purchases set records in October," *American Metal Market*, December 12, 2006.

[164] These include plants owned by Alcoa Inc. (Point Comfort, TX), Gramercy Alumina (Gramercy, LA), jointly owned by Century Aluminum and Apollo Management, LP (a private equity firm), Ormet Corp. (Burnside, LA), and Sherwin Alumina Co. (Corpus Christi, TX), owned by Glencoe International, AG, a global commodities trader. E. Lee Bray, "Bauxite and Alumina [Advance Release]," *2007 Minerals Yearbook* (U.S. Department of the Interior, U.S. Geological Survey, November 2008), table 2, 10.8.

[165] Ibid. U.S. alumina exports totaled 1.16 million metric tons and imports were 2.44 million metric tons in 2007.

using the "Hall-Héroult" smelting process. A highly technical process, "smelting" involves dissolving alumina in an electrolytic bath of molten cryolite (sodium aluminum fluoride) in a large carbon or graphite lined steel container known as a "pot." An electric current is passed through the electrolyte at very high current, typically 200,000 to 350,000 amperes, flowing between a carbon anode (positive) and a cathode (negative). Once the aluminum ore is molten, ions from the aluminum oxide move around, and are reduced at the cathode. This causes the aluminum metal to sink to the bottom, where it periodically is siphoned off, taken to a holding furnace, and often blended to an alloy specification, cleaned, and then generally cast. A typical aluminum smelter consists of one or more potlines—each with around 300 pots, producing 300,000 metric tons per year and the largest makes as much as 1 million metric tons annually.

Anode production—the production of carbon anodes used in the electrolysis process. Different kinds of anodes are used in two types of aluminum smelting technologies: the Söderberg Cell and the Prebake Cell. Because carbon anodes are oxidized by the oxygen produced by the

electrolysis of alumina, they are consumed in the process and need to be regularly replaced. Söderberg cell anodes consist of petroleum-based binder pitch or anode paste baked in the pot by the heat from the electrolytic cell and are "continuously consumed." In prebake cells, multiple anodes are used in each cell. They are prebaked in a separate fabricating plant located on-site or nearby. The anodes are attached to rods suspended in the cells. The production of a typical anode requires 55 to 65 percent calcined petroleum coke, 15 to 30 percent recycled anode butts, and 15 per cent coal tar or petroleum pitch. About 80 percent of anodes produced are for prebake cells, the remainder is anode paste for Söderberg cells.

Secondary smelting and alloying of aluminum (NAICS 331314)—the production of aluminum from the treating, refining and remelting of scrap and recycled aluminum. Refiners and remelters transform aluminum scrap into standardized aluminum. Refiners and remelters, in turn, are supplied with scrap through a chain of collector, dismantlers, metal merchants and scrap processors. The refiners supply foundries with casting alloys and the remelters supply rolling mills and extruders with wrought alloys.

Semifabricated product manufacturing— includes the aluminum sheet, plate, and file manufacturing (NAICS 331314), aluminum extruded product manufacturing (NAICS 331316), and other aluminum rolling and drawing (NAICS 331319) sectors.

Energy use characteristics.
By any measure, primary aluminum is one of the most energy intensive materials to produce; it is the largest consumer of energy on a per-weight basis. Primary smelting requires 49 of the total energy consumed in

[166] William T. Choate and John A.S. Green, *U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits and New Opportunities.* Prepared under contract to BCS, Inc. (Washington, DC: U.S. DOE Energy Efficiency and Renewable Energy, February 2003), Diagram A

the U.S. manufacturing of aluminum, and is one of the largest electric energy consumers of all industries.[165] Electricity required for smelting accounts for over 98 of the energy used in the process, and accounts from about 20 percent to 40 percent of the cost of producing aluminum, depending on the location of the smelter.[166]

This is why the world's smelters are located in areas that have access to abundant power resources (hydro-electric, natural gas, coal or nuclear). Many locations are remote and the electricity is generated specifically for the aluminum plant.[167] The U.S. primary

aluminum industry has more than half of its capacity connected to hydroelectric facilities.

Process heating is the second largest energy consuming operation in aluminum production, accounting for 25 percent of the total energy consumed in U.S. manufacturing of aluminum. It is utilized in nearly all aluminum production operations, including for holding, melting, purifying, alloying and heat-treating.[168]

In contrast, recycled aluminum only requires about five percent of the energy required to

PRIMARY SMELTING REQUIRES 49 PERCENT OF THE TOTAL ENERGY CONSUMED IN THE U.S. MANUFACTURING OF ALUMINUM, AND IS ONE OF THE LARGEST ELECTRIC ENERGY CONSUMERS OF ALL INDUSTRIES.

FIGURE 6-3
Alumina & Aluminum Production and Energy Flows

Aluminum and Alumina Production [NAICS 3313]
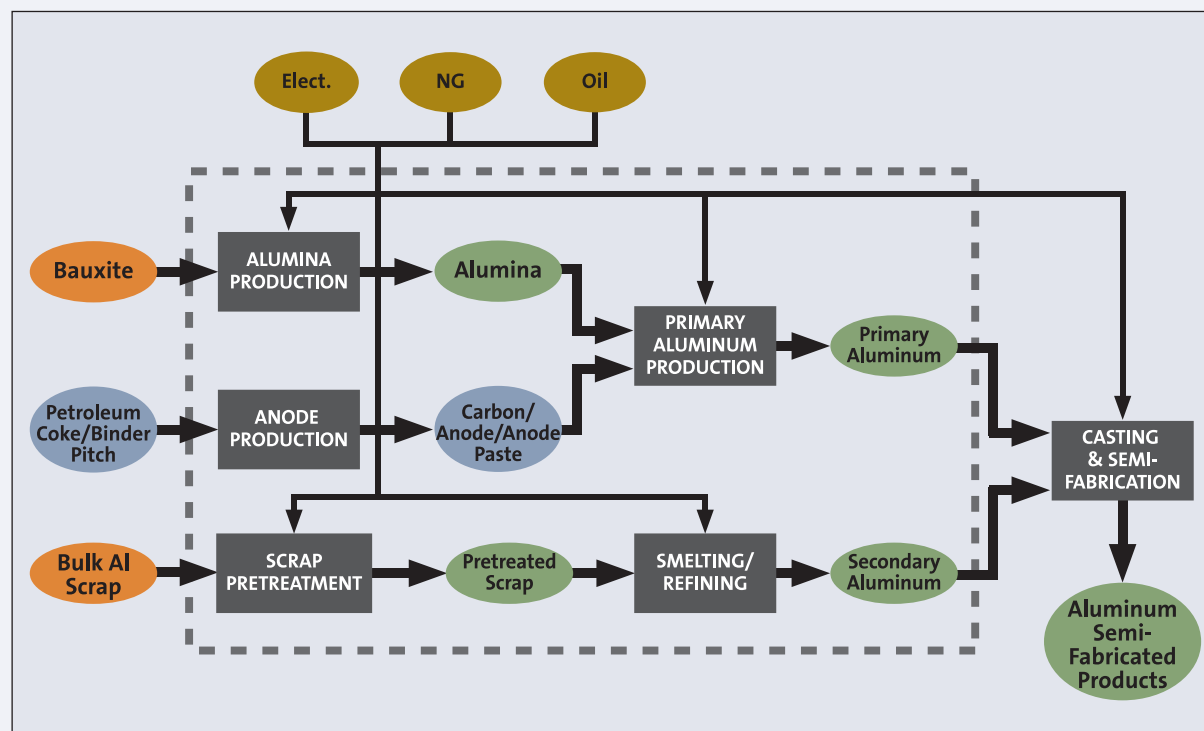
[167] Ibid.

[168] International Aluminum Institute (IAI) website (www.world-aluminium.org).

[169] Choate and Green, *U.S. Energy Requirements for Aluminum.*

make "new" aluminum. Blending recycled metal with new metal allows considerable energy savings, as well as the efficient use of process heat. There is no difference between primary and recycled aluminum in terms of quality or properties.[169] Aluminum in effect is an "energy bank": i.e., nearly all of the original energy stored in a metal product can be recovered again and again every time it is recycled. Small fractions of the recycled metal are lost to oxidation (melt loss) and entrapment in purifying fluxes (dross) during the recycling process. Yet, aluminum can be recycled indefinitely, allowing this saved energy to be collected again and again.[170]

The U.S. aluminum industry has made significant strides in reducing its energy use; over the past 40 years, it cut its energy intensity by 61 percent—22 percent as a result of technical progress and 39 percent from the growth of recycling.[171] As a result of design and process improvements, the amount of electricity required to produce one kilogram of aluminum from alumina has dropped, from about 21 kilowatt-hours, on average, in the 1950s to 15.7 kilowatt-hours today,[172] though state-of-the-art operating smelters (e.g., point feed pre-bake)

Aluminum in effect is an "energy bank"— nearly all of the original energy stored in a metal product can be recovered again and again every time it is recycled.

energy use was as low as 13 kilowatt-hours per kilogram of aluminum in 2000. The closure of older, more energy-intensive Söderberg smelters in the Pacific Northwest in the early part of the current decade also contributed to a gain in energy efficiency.[173]

Secondary Aluminum Production

In 2001, secondary smelting first surpassed primary production as a share of domestic aluminum production, accounting for 53 percent of the total, and growing to 61 percent in 2006 (see Figure 6-4).[174] It seems likely that secondary aluminum will continue to grow as a share of domestic U.S. aluminum production, limited however by the cost and availability of scrap aluminum.

The secondary industry relies on aluminum scrap as its raw material. The United States recycled an estimated 5.052 million metric tons of domestically generated aluminum scrap in 2006, an increase of 22 percent

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[170] IAI website.

[171] Choate and Green, *U.S. Energy Requirements for Aluminum*.

[172] U.S. Department of Energy, Industrial Technologies Program (ITP) website, http://www1.eere.energy.gov/industry/.

[173] IAI website.

[174] EPA, *Energy Trends in Manufacturing*.

[175] Aluminum Association, *ASR 2007*

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over the previous year. These figures include both manufacturing scrap and post-consumer scrap purchased by U.S. aluminum companies (less imports) as well as scrap exports. The aluminum industry purchased an estimated 4.109 million metric tons of aluminum scrap in 2006 from all sources, a jump of 16 percent over 2005. Meanwhile, U.S. exports of scrap, included as a component of recycled metal, jumped by almost 38 percent, to a total of 1.475 million metric tons in 2006.[175]

Recovery of aluminum from scrap (secondary recovery) equaled 3.51 million metric tons in 2006. New scrap from manufacturing accounted for 65 percent and old scrap (post-consumer) accounted for 35 percent of this total. A major source

of supply for the U.S. secondary industry is reclaimed used aluminum cans. In 2006, the aluminum industry melted an estimated 689 thousand metric tons of used beverage cans, an increase of four-tenths of a percent over 2005.[176]

Table 6-B compares the production, trade, financial and employment characteristics of the two aluminum segments in 2006. Imports accounted for over one-third of the total U.S. aluminum supply in 2006, while secondary aluminum production provided 38 percent, and primary production only one-quarter. The secondary industry's total shipments in 2006 was slightly greater than total shipments from the primary sector, though the domestic market price of secondary aluminum products averaged

It seems likely that recycled aluminum will continue to grow as a share of domestic U.S. aluminum production, limited however by the cost and availability of scrap aluminum.

Figure 6-4
Primary, Secondary and Total Domestic Production, 1979-2006
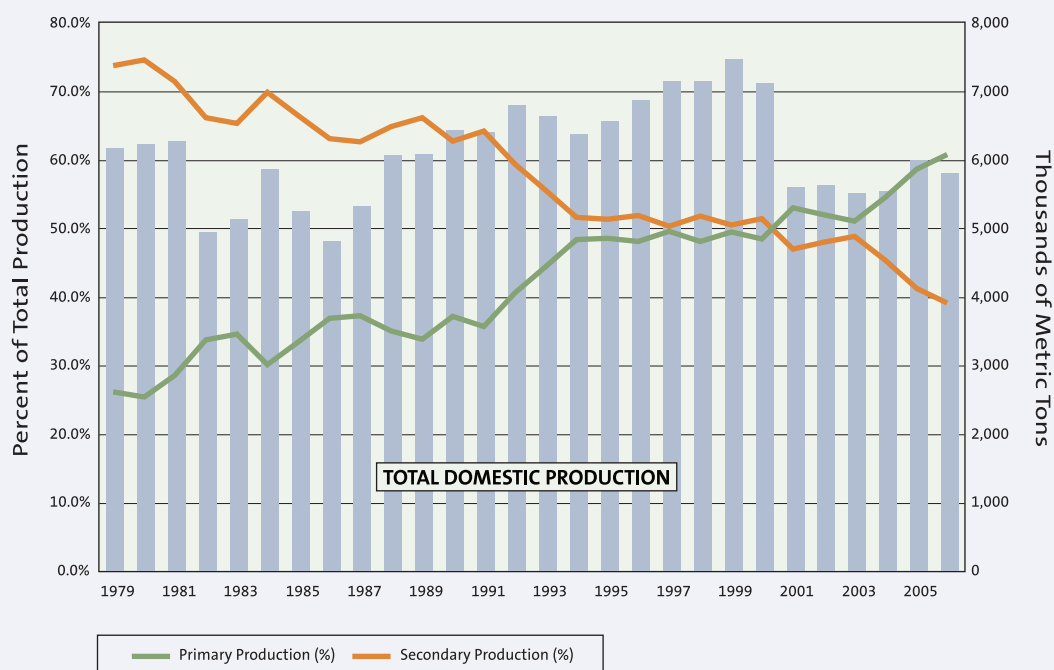
Aluminum Association

TABLE 6-B

COMPARISON OF PRIMARY AND SECONDARY ALUMINUM INDUSTRY CHARACTERISTICS, 2006

Production & Financial Category	Primary	Secondary	Import (Ingot)	Sec/Prim (Percent)
Production (thousand metric tons)	2,281	3,536	3,467	—
Share of Total Supply (percent)	24.6%	38.1%	37.3%	—
Share of Total Production (percent)	39.2%	60.8%	—	—
Value of Shipments ($million)	6,181.7	7,044.0	—	114%
Domestic Prices ($/metric ton)	2,710	1,992	—	74%
Materials ($/metric ton)	1,057	1,432	—	135%
Purchased Fuels + Electricity ($/metric ton)	519	106	—	20%
Purchased Fuels ($/metric ton)	40	76	—	190%
Purchased Electricity ($/metric ton)	479	31	—	6%
Quantity of Electricity (kWh/metric ton)	12,456	927	—	7%
Total Compensation ($/metric ton)	318	131	—	41%
Capital Expenditures ($/metric ton)	53	19	—	36%
Number of Employees (per metric ton)	4	2	—	51%

Source: Aluminum Association, ASM, USITC

about 70 percent of the cost of primary aluminum products.[177] By contrast, materials costs for the secondary industry are almost 50 percent greater than for the primary sector, reflecting the rising cost of recovered aluminum scrap.

The table further illustrates that the secondary industry's overall purchased energy costs were only one-fifth that of primary production, largely because of latter's huge consumption of electricity compared to the secondary sector (about 13 times more). However, secondary smelting spent nearly twice the amount as primary production did on purchased fuels for heat and power in 2006. Primary aluminum not only is more capital-intensive it employs more workers than the secondary industry. The latter spent only a little more than one-third on capital expenditures, only 41 percent on labor compensation and employed only half the number of employees as the former, per metric ton of production.

Climate Policy Impacts on Aluminum

Aluminum production, especially primary aluminum smelting, is very energy-intensive. Aluminum is also traded globally and highly vulnerable to import penetration. Primary aluminum would experience significant but relatively smaller economic impacts from the climate policy, compared to iron and steel, paper and paperboard, and chlor-alkali, examined in the II-CPM simulations. These impacts would be somewhat greater if the energy cost increases associated with carbon anodes and alumina were included. Because secondary aluminum smelting, is

actually not energy-intensive, it would have far lower cost impacts and consequently, smaller operating surplus declines compared to primary aluminum, and to the other industries, with the exception of petrochemicals (see Chapter Eight).

Consequently, by 2030, the Mid-CO_2 Price Policy is projected to impose strong cost pressures on the primary aluminum industry to promote actions to mitigate cost increases. Moreover, other market factors (such as regional and local availability and costs of electric power, declining demand and world prices) could lead some primary aluminum smelters to cut output or even shut down operations, a problem potentially exacerbated by additional domestic energy costs associated with a climate policy. Secondary aluminum would not begin to feel the same cost pressures over the policy period.

Production cost structure (BAU).

Although in both primary and secondary aluminum smelting, materials account for a large share of total variable production costs (see Figures 6-5a and 6-5b) per metric ton, the ratio is much larger in the latter than in the former industry. Labor expenditures make up a greater share of the total costs in primary aluminum production, though they still are large relative to energy costs in the secondary sector. In 2006, materials and labor costs accounted for 57 percent and 16 percent, respectively, of total primary production, but 87 percent and 8 percent respectively, of total secondary industry costs.

Materials costs. The magnitude of materials costs in primary production ($942 per metric ton)—primarily for bauxite and/or alumina—was about a quarter less than those in

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[178] This is an average price calculated by dividing total value of shipments from Census *ASM* by total production for the sector provided by the Aluminum Association.

Figure 6-5a

Primary Aluminum Real Unit Production Cost Components, Business As Usual, 1992-2030
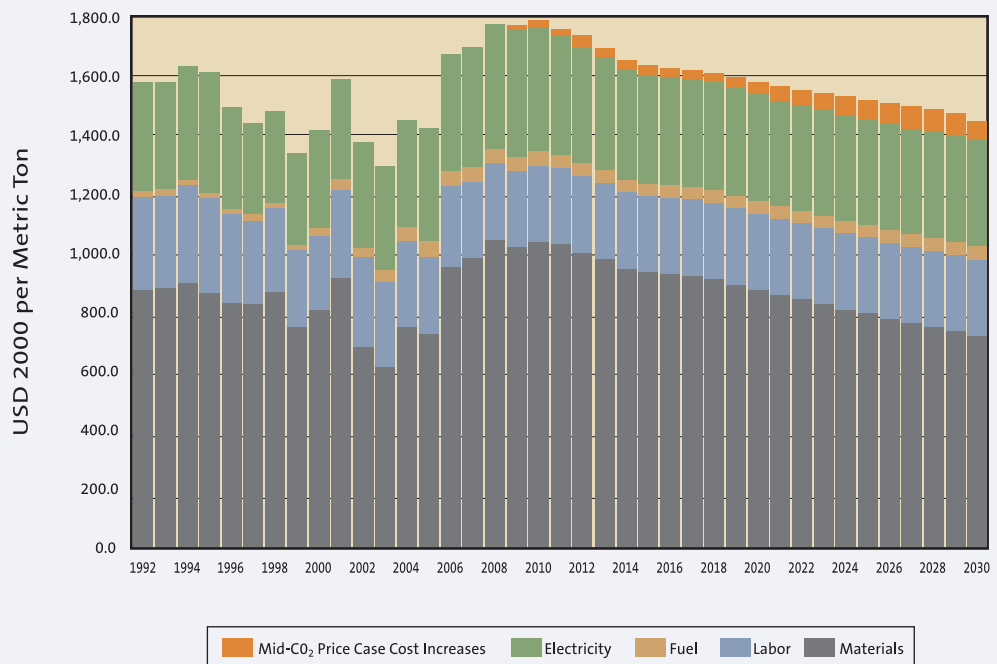
Source: HRS-MI

secondary aluminum ($1,243 per metric ton) production in 2006, mostly due to the high cost of recovered (scrap) aluminum used in that industry's production process. Real (USD 2000) unit (metric ton) materials expenditures in the primary aluminum industry fluctuated but headed downward between 1992 and 2003, before spiking back up between 2003 and 2006. They were then projected in the II-CPM simulation of the primary aluminum industry for the BAU case, to continue their rise until 2008 through 2011, before falling steadily through 2030.

Materials costs in secondary aluminum fell by 30 percent between 1995 and 1999, but then rebounded through 2005 before spiking in 2006. From 2007 on, the II-CPM simulation of this industry for the BAU case

projected that the industry's real materials costs would continue to grow to nearly 30 percent above their 1992 value, before falling by 8 percent below 1992.

In both industry segments, raw material costs (bauxite/alumina, scrap aluminum) are the primary drivers of total materials costs—and the dominant factor in shaping overall production cost trends. The spike upwards in materials costs in both industries between 2003 and 2008, in particular, reflected the impact of rapid demand growth driven by China and other emerging economies ramping up their own aluminum (primary and secondary) production outputs and consumption.

Labor costs. Real labor costs (total

In both industry segments, raw material costs (bauxite/alumina, scrap aluminum) are the primary drivers of total materials costs.

compensation, USD 2000) per metric ton of primary aluminum produced on the whole fell by 20 percent between 1992 and 2000—precipitously after 1994. They then rose rapidly to nearly the 1992 level by 2002, before steadily decreasing back to 20 percent below 1992, where they were projected to stay through 2030 in the II-CPM simulations. Secondary aluminum unit labor costs fell by 20 percent between 1992 and 1997, but then rose back to a little above the 1992 level by 2006, where they were assumed to stay through 2030 in the model. These fluctuations and trends reflect both the former industry's higher productivity rates and its lower employee compensation rates—between 20 to 30 percent less—compared to the latter, though employee compensation appears to have grown

significantly in both industries since 2001.

Overall, primary aluminum has suffered from a large, steady loss in output, employment and total compensation, despite gains in labor productivity, since the 1990s. The sharpest losses occurred over the 2000-2001 period, largely due to economic recession, compounded by the electricity crisis in California and the Western states which led to closing several smelters in the Pacific Northwest, from which the industry has never fully recovered.

Although labor productivity in the secondary industry fell between 1997 through 2001, it more or less improved after this period—indeed, it was roughly double that of the primary sector. At the same time,

Figure 6-5b
Secondary Aluminum Real Unit Production Cost Components, Business As Usual, 1992-2030

Source: HRS-MI

secondary industry labor costs per metric ton of aluminum produced have run from 30 percent to a little over 40 percent than those in primary production, between 1997 and 2006.[178]
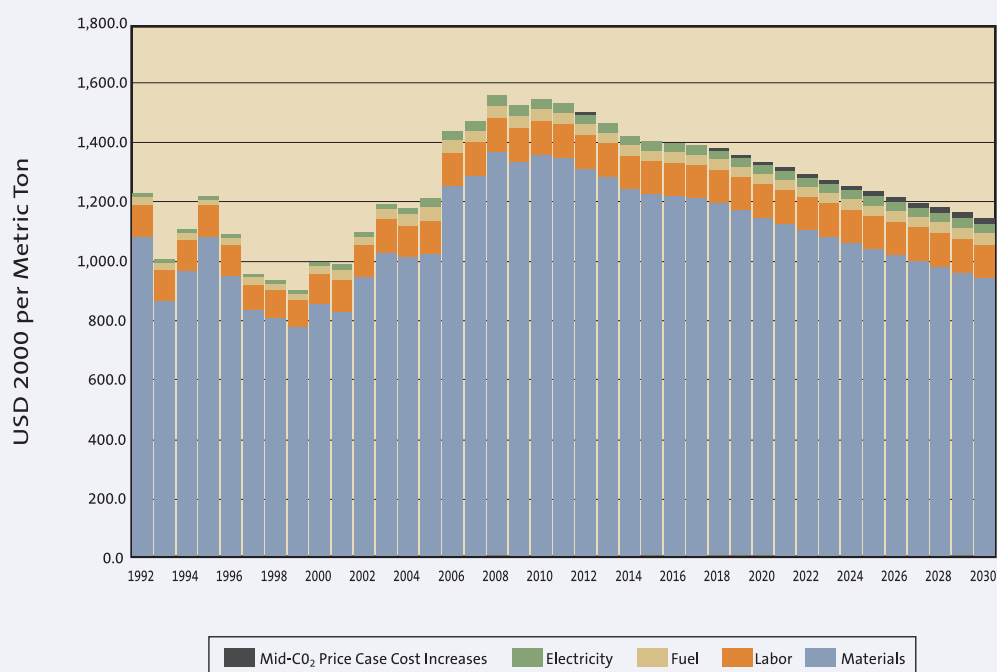
Energy costs. Energy cost trends and projections for each industry, under both the BAU and climate policy scenarios, need to be examined against this backdrop. Energy costs in both industries are dwarfed by

materials costs, though they play a larger role relative to both materials and labor costs in primary production. Historically, the energy costs cycled around half that of materials costs energy-materials through 2006. In the BAU case, the II-CPM projected the ratio of energy to materials costs to fall to under 50 percent between 2010 and 2018, and then steadily rise to 57 percent by 2030. In the Mid-CO_2 Price Policy, energy costs would fluctuate between 46 to 49

TABLE 6-C
PRODUCTION COSTS, ENERGY SHARE AND ENERGY COST COMPONENTS, PRIMARY AND SECONDARY ALUMINUM

Item	2006 Value	2020 Value	2020 % above BAU	2030 Value	2030 % above BAU
Production Costs (USD 2000/metric ton)					
Primary Aluminum:					
BAU	1,676	1,540	—	1,383	—
Mid-CO_2 Price Case Above BAU	—	40	2.6	64	4.6
Polcy Case inc. Alumina, Anode Costs (est.)	—	67	4.3	120	8.7
Secondary Aluminum:					
BAU	1,430	1,317	—	1,118	—
Mid-CO_2 Price Case Above BAU	—	10	0.8	19	1.7
Energy Share of Production Costs (Percent)					
Mid-CO_2 Price Case–Primary Aluminum	26.9	28.3	1.8	32.6	3.1
Mid-CO_2 Price Case–Secondary Aluminum	5.2	5.6	0.7	7.8	1.6
Energy Cost Components (USD 2000/metric ton)					
Mid-CO2 Price Case–Primary Aluminum:					
Total Energy Costs	451	448	9.7	472	15.6
Fuel Costs	52	49	20.2	63	35.5
Electricity Costs	400	398	8.6	409	13.1
Mid-CO2 Price Case–Secondary Aluminum:					
Total Energy Costs	74	74	15.6	88	27.2
Fuel Costs	42	40	22.2	52	39.0
Electricity Costs	32	34	8.6	36	13.1

mt=metric ton

[179] All figures are derived from Census Bureau, *ASM* data, covering the years of concern.

percent of materials costs through 2018, and then rise to 66 percent by 2030. In secondary aluminum, this ratio rose from only 3 percent in 1992 to 6 percent in 2006, and was projected to rise to 7 percent for BAU, and to 9 percent in the policy case, by 2030.

Energy costs greatly exceed labor costs in primary aluminum production, but are somewhat less than labor costs in secondary production. The energy costs in primary aluminum ranged from 20 percent more than labor costs in 1992 to 70 percent higher in 2006. The II-CPM projected that energy costs would then fall to 60 percent greater than labor costs by 2030, in the BAU case, but grow to between 80 to 90 percent higher by 2030, in the policy case. In contrast, secondary aluminum energy costs grew from a low of around 30 percent of labor costs in the early 1990s to between 60 to 70 percent by the mid-2000s. This ratio was projected to fall slightly after 2014 and then slowly grow to 61 percent, for BAU, and to about 75 percent, for the Mid-CO_2 Price Policy, by 2030.

Energy and production cost impacts. The estimated energy cost impacts associated with the Mid-CO_2 Price Policy are summarized in Table 6-C. As illustrated in Figures 6-5a and 6-5b, the additional energy costs due to the enactment of the policy would be small, but not insignificant relative to total unit costs, in primary aluminum production, and are nearly imperceptible for secondary aluminum. Total production costs in primary aluminum would rise to a little under 3 percent above BAU by 2020, and 5 percent above BAU by 2030—and closer to 6 percent from 2027 to 2029—, but to only a little under 2 percent above BAU in secondary aluminum. These projections assume that no major investment in energy efficiency is allocated throughout 2030.

Energy accounted for over one-quarter of total production costs in the primary aluminum industry in 2006. Under the Mid-CO_2 Price Policy, this proportion would grow by only about 2 percentage points above the BAU level in 2020 and 3 points above BAU in 2030. Secondary aluminum's energy share of total costs in 2006 was only about 5 percent, and in the policy case was projected to grow by less than 2 percent by 2030.

Electricity costs accounted for the overwhelming share—89 percent in 2006—of total energy costs in primary aluminum production, while fuel costs for energy used in heat and power accounted for most of the remainder. In contrast, fuel costs dominate in secondary aluminum—about 95 percent in 2006—and electricity is a tiny fraction—5 percent in 2006—of the industry's total energy costs (see Table 6-C). Correspondingly, as illustrated in Figures 6-6a and 6-6b, electricity cost *increases* in the climate policy case would account for most of the growth in primary aluminum production costs—the rate of increase accelerating after 2020—and fuel costs are responsible for most of the growth in secondary aluminum costs.

The relatively small projected total production cost impacts for primary aluminum are surprising, given that its energy cost share is even greater than that of the iron and steel industry. This is largely explained by the modest increases in electricity costs projected for the Mid-CO_2 Price Policy. Considerations about regional variations in the pricing of electric power generation suggest the possibility

THE ADDITIONAL COSTS DUE TO THE ENACTMENT OF THE POLICY WOULD BE SMALL, BUT NOT INSIGNIFICANT RELATIVE TO THE TOTAL UNIT COSTS, IN PRIMARY ALUMINUM PRODUCTION, AND ARE NEARLY IMPERCEPTIBLE FOR SECONDARY ALUMINUM.

Figure 6-6a

Primary Aluminum Production Costs, Mid-CO$_2$ Price Case Above BAU Energy Cost Components, 2012-2030

Source: HRS-MI

of even smaller impacts. On the other hand, fuel mix alternatives and pricing considerations other than those assumed in modeling the fuel prices used in the II-CPM simulations suggest potentially higher impacts. In addition, the primary aluminum production model's inability to fully account for important carbon-related cost factors (alumina, carbon anodes) also implies that the resultant impacts may be understated.

Regional price variations. The electricity prices used in the II-CPM simulations, derived using the EIA National Energy Modeling System (NEMS) model to analyze

Mid-CO$_2$ Price Policy,[179] were aggregated numbers for the nation, averaged across all the electricity regions in the NEMS, for which there are wide variations. About half of U.S. primary aluminum smelters obtain their electricity from hydroelectric sources—the remainder from coal-fired boilers. In addition, most are located in regions—the Northwest, Midwest and Southeast[180]—in which electricity prices are relatively lower than most of other major electricity regions, and lower than the average national electricity prices used in the study. Thus, the future primary aluminum cost increases under the Mid-CO$_2$ Price Policy from

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[180] That is, the EIA's analysis of the Lieberman-Warner Core legislation (S.2191). EIA, *Energy Market and Economic Impacts of S. 2191*.
[181] Ibid., 29, figures 17 and 18. Specifically, these include the East central Area Reliability Coordination Agreement (ECAR), the Northwest Power Pool (NWP), and Southeastern electric Reliability Council (SERC),

higher electricity prices may be less than the estimated costs found in the II-CPM simulation.

Electric generation fuel mix and prices. The BAU case in II-CPM, which was based on the EIA's Annual Energy Outlook 2008 Reference Case, projects that electric power generated by coal would account for over 51 percent of total generation in 2020—about the same share as in 2006—and 55 percent in 2030. Natural gas accounted for 20 percent in 2006, but would fall to an 18 percent share in 2020 and 14 percent in 2030. In total, though, fossil fuels would account for nearly 70 percent of U.S. electricity generation over this period. If in the unlikely event that the nation's electric generation fuel mix stayed the same after the climate policy was enacted, electricity prices would rise much higher, and the impact on primary aluminum and other electricity-intensive

industries (e.g., chlor-alkali) would be greater than projected in the current study.[181]

However, the EIA NEMS analysis assumed that rising carbon costs and allowance allocation provisions in the policy case would encourage the electric power sector to shift to a mix of low-carbon generation technologies, in particular, nuclear and renewable fuels, and later, to coal power plants with carbon capture and sequestration (CCS). The fuel mix shift would lead to higher electricity prices relative to BAU due the higher costs of cleaner, more efficient technologies and the costs of holding allowances. But, these increases probably would not be as great as those that would occur if fuel switching did not occur, and the original BAU fuel mix remained in place after a carbon-pricing policy was enacted. According to the EIA analysis, they would be mitigated by lower

THE EIA NEMS ANALYSIS ASSUMED THAT RISING CARBON COSTS AND ALLOWANCE ALLOCATION PROVISIONS WOULD ENCOURAGE THE ELECTRIC POWER SECTOR TO SHIFT TO A MIX OF LOW-CARBON GENERATION TECHNOLOGIES, IN PARTICULAR, NUCLEAR AND RENEWABLE FUELS.

FIGURE 6-6B

Secondary Aluminum Production Costs, Mid-CO$_2$ Price Case Above BAU Energy Cost Components, 2012-2030
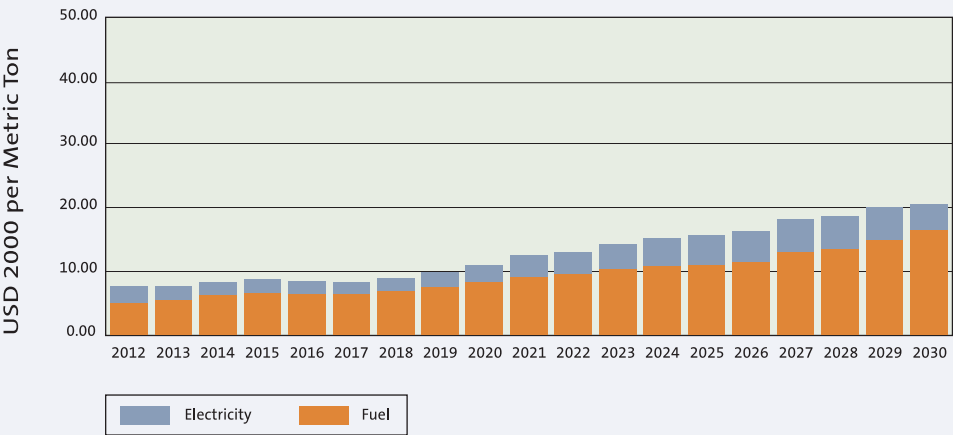
Source: HRS-MI

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[182] Ibid., 23-28, especially 26, figures 14 and 15.

fuel expenditures and lower CO_2 emissions for the electricity.[182]

Although the assumptions about renewables growth appear reasonable, the same might not be so easily said about the assumed huge growth in nuclear power—nearly four times 2006 levels—or the widespread availability of CCS technology in the timeframe considered. The still unresolved problem of nuclear waste disposal, notwithstanding, the economics of nuclear power—the costs of constructing nuclear plants that meet modern standards of safety and security in their operation and decommissioning—could limit how much new nuclear capacity might cost-effectively be built, even in the face of additional fossil-fuel costs from climate policy, which would make such investments more attractive.

In apparent recognition of these contingencies, the EIA analysis of the Mid-CO_2 Price Policy case estimated that electricity prices (and other energy prices) for an alternative scenario, which assumed

limited or no access to nuclear power or CCS technologies, and another that assumed that the costs of nuclear, CCS, and biomass fuels (an important renewable energy source), would be 50 percent greater than the core policy case. In both instances, electricity prices would grow substantially higher than in the core case, and higher still relative to BAU.[183] In those cases, therefore, aluminum energy costs would be higher—perhaps by as much as a third to forty percent—than projected in the II-CPM simulations, relative to BAU.

Alumina and carbon anode costs. Because of insufficient data and other analytical limitations, we were not able to fully incorporate the costs of alumina and carbon anodes—two important carbon-intensive materials that also emit GHGs in their production and use—directly in the II-CPM model of the primary aluminum industry. These costs were captured as part of the materials costs component of the primary aluminum production cost model in the BAU case. But we did not have access to

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[183] Ibid., 26. The EIA analysis assumes in the Lieberman-Warner Core case a substantial shift from coal and natural gas generation to nuclear and renewables, and a modest growth in coal with CCS. In 2006, the EIA reports that nuclear accounted for 19 percent of U.S. generation, renewables for 13 percent, and coal with CCS for zero generation. In the Mid-CO_2 Price case, by 2030, nuclear, renewables, and coal with CCS would account for 58 percent, 19 percent, and 10 percent, respectively, of total U.S. electricity generation. Meanwhile, coal and natural gas generation would dramatically shrink to 5 percent and 9 percent, respectively, by 2030.
[184] The EIA analysis was centered on the Lieberman Warner Core case. If the international offsets provision in the core case were also not available—which is a real possibility, if the core legislation was enacted—than the prices would rise even more—48 percent greater than the prices in the core policy case by 2030. See especially Ibid.,17 figure 16.

historically calibrated times series and could not calculate how the costs would change under a climate policy. Since materials costs in the policy case were assumed to be the same as in the BAU case in the future projections through 2030, potential variations in alumina and carbon anode costs associated with higher carbon-fuel prices in the climate policy case could not be observed in the II-CPM modeling results.

Nevertheless, drawing on existing technical literature, we were able to reasonably, if roughly, estimate the cost changes for these elements in the policy case relative to BAU. These estimates, more fully discussed below, found that under the Mid-CO$_2$ Price Policy, the combined increase in costs of alumina

and carbon anodes consumed in primary aluminum production could almost *double* the energy-related production cost increases for the industry (see Table 6-C).

Alumina production is an integral part of the primary aluminum industry, as illustrated in Figure 6-3, and is as highly energy-intensive. From a DOE-sponsored technical study we were able to obtain data on the quantities of different energy sources—in particular, fuel oil and natural gas—consumed in producing alumina.[184] Using the price projections for these energy sources in both the BAU and Mid-CO$_2$ Price Policy cases, we were able to estimate the total additional energy costs associated with producing a metric ton of alumina.[185] Using a conversion factor of 1.93 kilograms of alumina consumed to make a kilogram of primary aluminum, we then could calculate the total additional energy costs of producing the amount of alumina required to make a metric ton of aluminum.

However, because only 53 percent of the alumina consumed in U.S. primary aluminum production was domestic in origin in 2007,[186] it was necessary to reduce the estimated costs accordingly. In the end, these calculations showed that the additional costs associated with alumina consumed in producing a metric ton of aluminum in the United States would be $19 in 2020 and $37 in 2030. This is equivalent to an additional 1.2 percent and 2.7 percent, respectively, added onto the total cost increases of producing a metric ton of primary aluminum in the policy case relative to BAU.

We conducted a similar set of calculations for estimating the total additional energy costs associated with the production and consumption of carbon anodes in primary

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[185] Choate and Green, *U.S. Energy Requirements for Aluminum, Appendix F.* Total energy to produce alumina consumed in producing a metric ton of aluminum is 24.8 million Btus, including 4 million Btus of fuel oil and 8.2 million Btus. Smaller amounts of diesel fuel (59.5 thousand Btus), bituminous coal (210.4 thousand Btus), and electricity (371.9 thousand Btus), gasoline (779 Btus) and coke (45 Btus), also are consumed in producing a metric ton of alumina.

[186] EIA NEMS generated residual fuel prices for the HRS-MI study were used for calculating fuel oil costs, and distillate oil prices were used to calculate diesel costs in the estimates of total additional energy costs associated with alumina production.

[187] U.S. primary aluminum smelters obtain about half the alumina they consume from domestic alumina plants (53 percent in 2007) and half from imports. Only alumina produced by U.S. facilities and consumed domestically would have an energy footprint affected by a domestic climate policy, but the study did not have data for the different quantities for domestically produced and consumed alumina.

FIGURE 6-7

PRIMARY ALUMINUM MID-CO₂ PRICE COSTS AND OPERATING SURPLUS ABOVE BAU (%), WITH AND WITHOUT ANODE + ALUMINA COSTS (EST.)

Legend
— Mid CO₂ Price Case Costs inc. Anode + Alumina Costs (est.)
— Mid CO₂ Price Case Costs
--- Mid CO₂ Price Case OS
--- Mid CO₂ Price Case Costs inc. Anode + Alumina OS (est.)
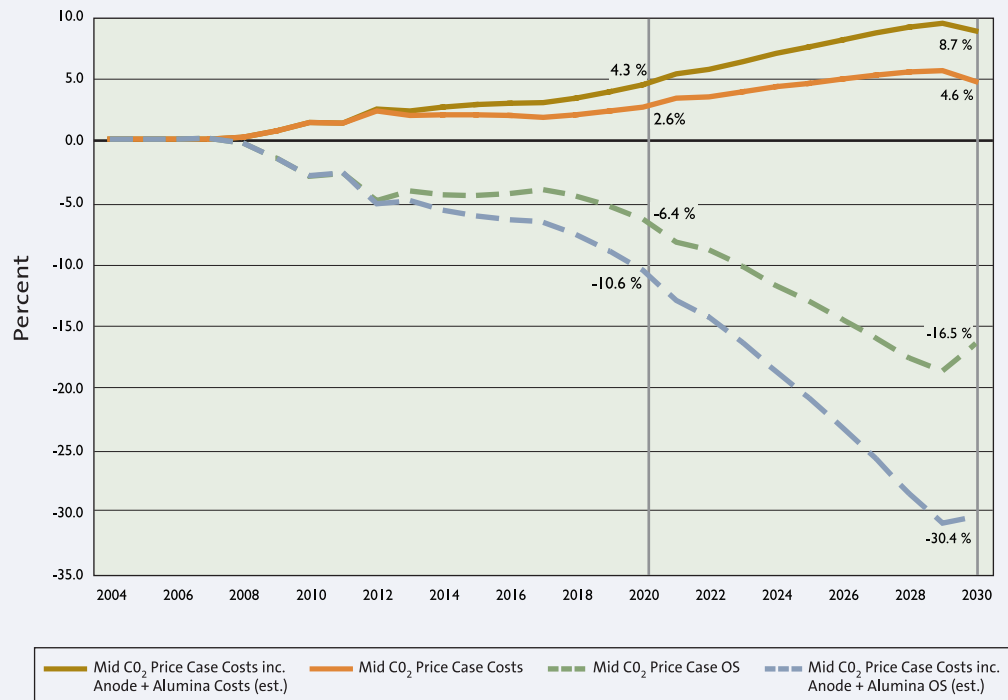
Source: HRS-MI

FOSSIL-FUEL ENERGY SOURCES ARE CONSUMED IN BOTH THE PRODUCTION OF A CARBON ANODE AND IN THE CONSUMPTION OF THE ANODE IN THE ALUMINUM PRODUCTION PROCESS.

aluminum production. According to the DOE study, the U.S. primary aluminum industry consumed 1.651 million metric tons of carbon anode in 2000, and approximately 0.45 kilogram of carbon anode was typically needed to produce a kilogram of aluminum.[187] Fossil-fuel energy sources are consumed in both the production of a carbon anode and in the consumption of the anode in the aluminum production

process (as feedstock in the aluminum smelter's electrolysis process). Natural gas is by far the largest energy input in carbon anode production followed by electricity. In addition, 17.4 million Btus of feedstock energy—petroleum coke and pitch—used in carbon anodes are consumed per metric ton of aluminum.[188]

Based on these inputs and using the energy

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[188] Choate and Green, *U.S. Energy Requirements for Aluminum,* 21. This conversion factor was used in the energy cost estimates for carbon anodes, though this ratio may have improved over the past eight years as a result of improved energy efficiencies in carbon anode production and use in the electrolysis process. The DOE reports that this anode consumption rate was 35 percent greater than the theoretical minimum requirement in 2000, implying that substantial energy efficiency improvements was theoretically possible in carbon anode use.

[189] Ibid., Appendix F. Energy inputs to produce 1,000 kg (one metric ton) of carbon include 164.4 thousand Btus of medium fuel oil, 38.1 thousand Btus of light fuel oil, 3.9 thousand Btus of diesel fuel, 3.3 thousand Btus of propane, and 1.5 thousand of gasoline.

source price projections used in the II-CPM models, and prices based on EIA AEO 2008 data for petroleum coke used in carbon anodes,[189] we were able to estimate that carbon anode production and consumption would add $8 (USD 2000), or 0.5 percent, per metric ton of primary aluminum in 2020, and $19, or 1.4 percent, in 2030 relative to BAU.

In sum, the total combined additional costs in the Mid-CO_2 Price Policy associated with the production and consumption of alumina and carbon anodes were estimated to be $27, or 1.8 percent above total primary aluminum costs in the BAU case, in 2020, and $56, or 4.1 percent, in 2030. Overall, therefore, if alumina and carbon anode costs are added to the costs estimated by the II-CPM simulations of primary aluminum production in the policy case (see Table 6-C), total production cost increases in the industry could grow to $67 per metric ton, or 4.3 percent above BAU, in 2020, and $120 per metric ton, or 8.7 percent—which are somewhat higher than the original II-CPM projections.[190] Figure 6-7 shows the production cost curves (and operating surplus curves, see below) comparing primary aluminum cost increases that account for alumina and carbon anode costs, with those that do not, for the Mid-CO_2 Price Policy, relative to BAU.

Operating surplus and margins (NCPA).

Table 6-D summarizes the cost impacts of climate policy translate into operating surplus and operating margin declines in the primary and secondary industries, for both the no cost pass-along (NCPA) and cost pass-along (CPA) scenarios. The underlying bases for calculating operating surplus for the primary aluminum sector are illustrated in Figure 6-8, which shows the difference between market prices and variable production costs for different assumptions and scenarios. The estimated impacts in the primary aluminum industry incorporating alumina and carbon anode costs are also shown, but they were not calculated for the CPA scenarios.

Primary aluminum operating surplus. Assuming NCPA, the growing operating surplus decline in primary aluminum from 2020 on would be larger and more significant for the Mid-CO_2 Price Policy when alumina and carbon anode costs are included than in the original policy simulations. Primary aluminum's operating surplus would shrink by over 6 percent in 2020 to over 16 percent by 2030, relative to BAU, if alumina and carbon anode costs were not incorporated. If these costs were included, the declines would be much

UNDER THE MID-CO_2 PRICE POLICY, THE COMBINED INCREASE IN COSTS OF ALUMINA AND CARBON ANODES CONSUMED IN PRIMARY ALUMINUM PRODUCTION COULD ALMOST DOUBLE THE ENERGY-RELATED PRODUCTION COST INCREASES FOR THE INDUSTRY.

[190] The petroleum coke prices were derived from data available from the EIA. The projections for petrocoke prices after 2006 were based on the assumption that they would follow the same trends as residual oil prices for both BAU and the Mid-CO_2 Price Policy, supplied by EIA NEMS for the HRS-MI study.

[191] These costs were projected to be even higher a littler earlier in the decade, 2026-2029, reflecting higher electricity-related costs. Electricity cost increases relative to BAU make a sudden dip in 2030, a result of a comparable drop in projected electricity prices generated by the EIA NEMS model for the HRS-MI study. The consequent estimated total cost increases, including alumina and carbon anodes, rise to as high as 9.3 percent in 2029 above BAU, before falling in 2030.

FIGURE 6-8

PRIMARY ALUMINUM REAL UNIT PRODUCTION COSTS COMPARED TO DOMESTIC MARKET PRICE

Source: HRS-MI

greater, rising to nearly 11 percent, in 2020, and over 30 percent, in 2030, relative to BAU, respectively. Both scenarios assume no major investment in energy-efficient technology.

If assumptions about fuel switching to non-carbon fuels or the international offset provision prove wrong and electricity prices are higher than projected in the case, the declines could be even greater. On the other hand, as noted above, these results would still be mitigated by the fact that about 50 percent of primary aluminum smelters rely on hydroelectric power. By how much, though, is not knowable without a more detailed and complete study of the industry

and its regional electric power arrangements (including long-term contracts with both hydro-electric and fossil-fuel generators).

These findings suggest that for either cost scenario, depending on market conditions and their financial situation (including long-term access to inexpensive electric power) primary aluminum smelters would start to consider options for reducing their costs to offset the climate policy impacts on their profitability. By 2030 they may already have responded by investing in energy efficiency or by containing production costs, especially since the industry is greatly limited in its ability to pass through additional costs (see below).

Secondary aluminum operating surplus reduction. As expected, the secondary aluminum industry's projected operating surplus and margin decline are smaller than those in the primary industry, though by 2030, its operating surplus reduction would increase to $138.1 million (USD 2000) or over 8 percent below BAU, and its dollar value magnitude would be higher than the primary aluminum decline (not counting alumina and carbon anode costs) for that year. (The smaller percentage share, compared to primary aluminum, is due to the larger total production cost levels for secondary aluminum manufacturing in the BAU case.) The small operating surplus and margin declines suggest that the secondary aluminum industry would not experience serious impacts on its profitability resulting from a climate policy.

Operating surplus and market shares (CPA).

If aluminum producers were able to pass through the additional energy costs (CPA) from the climate policy the resulting impacts on operating surpluses, operating margins and market shares would be small compared to the NCPA cases. As Figure 6-8 shows, the growth in the market price in the cost basis CPA scenario would parallel growth in production cost, and, there would be zero reductions in the *unit* operating surpluses for the primary and secondary aluminum industries. However, because domestic market prices would rise relative to foreign prices, the U.S. aluminum industry would lose a little market share as a result of the higher energy costs added to the market price. These would in turn result in domestic production cuts, and, therefore, a *total* operating surplus decline relative to BAU.

Because of the modest cost impacts found by the II-CPM simulations for the primary and secondary aluminum industries, the impacts on operating surpluses for both would be only a fraction of the declines in the NCPA cases (see Table 6-D). Since aluminum is largely a fungible commodity— primary and secondary aluminum products are not distinguishable—and primary aluminum imports and exports far exceed those of secondary aluminum trade flows[191]—market share impacts were calculated for the combined industries' output. However, because the interactions and relationships of the cost structures and markets for the two industries were not fully known and therefore modeled—this would take further research—we assumed that the market share impacts would affect both equally. That is, both would suffer from the same loss of market shares—nearly 1 percent in 2020 and close to 2 percent by 2030.[192]

Determining how much these impacts would change, if we took into account the additional costs of alumina and carbon anodes in the primary aluminum industry, would require further investigation. But it is reasonable to estimate that if the resultant higher additional energy costs added to domestic market prices in the CPA scenario for the primary industry are factored in, the market share losses for the aluminum industry as a whole undoubtedly would be slightly greater, and subsequently the operating surplus decline would be greater, though still somewhat less than in the NCPA case. The market share losses also would remain modest compared, say, to the iron and steel industry.

[192] Source: USITC, *DataWeb*. In addition, secondary aluminum exports (quantity) range from only about 1-4 percent of primary aluminum exports, and secondary aluminum imports are a very tiny fraction (less than 0.5 percent) of primary aluminum imports.
[193] As shown in Table 3-D, the resulting operating surplus losses as a percent of BAU for any given year also would be the same for each industry—a little over 1 percent in 2020 and nearly 4 percent in 2030, though the magnitudes of these losses would be different (e.g., $39.8 million (USD 2000) for primary aluminum and $78.5 million (USD 2000) for secondary aluminum).

Aluminum markets, prices and CPA.

However, the CPA findings may be moot, since aluminum is traded almost exclusively as a commodity and its prices set in global futures exchanges. There is wide agreement among industry experts and economic analysts that aluminum producers, especially in primary aluminum, would be unlikely to be able to pass through regionally limited, climate policy-driven, cost increases, to their customers. For example, the 2006 McKinsey/Ecofys study of EU-ETS impacts on energy-intensive manufacturing assumed that the aluminum industry would be able to pass-through zero costs from the ETS.[193]

Similarly, in a 2008 report on the EU ETS impact on the EU aluminum sector, IEA economist Julia Reinaud, explains that the industry "uses the London Metals Exchange (LME) and the Shanghai Futures Exchange (SFE) in almost all phases of the aluminium cycle. LME and SFE are a world price. Aluminium sales are determined by the market price and are only for a relatively small share driven by product and location premiums." As a result, a single company is not able to influence its levels. This pricing, she adds, extends from raw materials to semi-fabricated products such as sheets and extrusions, and finished products such as cans, foil, and even recycled material. Reinaud contrasts this with the iron and steel or cement sectors, as there are no world prices for their products, and therefore producers in these industries have greater cost pass-along opportunities.[194]

A company's cost structure, therefore, is especially key in determining its competitiveness in the aluminum industry. Since it can't pass along costs, it must try

to keep its costs low to remain competitive in global markets and maintain its profits. Energy and labor costs in particular can figure significantly in domestic aluminum producers' decisions regarding capacity and investments, even though materials costs represent the largest share of their costs. The latter are usually determined globally, as bauxite, alumina, and aluminum scrap are generally subject to prices set internationally at the global metals exchanges, and most producers are likely to pass along price increases on a worldwide basis. But, the prices of key energy sources (especially electricity) and labor costs tend to be regionally determined.

Rising energy cost impacts. U.S. primary aluminum companies have been particularly concerned about the impact of rising energy, especially electricity, costs on their economic viability. Even modest energy cost increases associated with climate policy could hurt aluminum producers' competitiveness, making them more vulnerable to foreign competition than they already are. Consequently, they usually have sought to limit the risk of high cost energy swings, by securing long-term, low-cost electricity contracts from regional electric power generators. Their success in securing long-term competitive electric power contracts can affect their ability to keep potlines operating at full capacity, or even stay in business. However, failure to obtain such contracts has resulted in curtailment, if not closure, of smelters, especially as energy costs have grown over the past decade.

For example, in December 2005, Alcoa idled its 195,000 metric ton per year, fossil-fuel powered Eastalco smelter near Frederick, MD, laying off over 700 workers, because it failed to secure a competitively priced

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[194] McKinsey/Ecofys, EU ETS Review.
[195] Reinaud, *Aluminum,* 13.

Table 6-D
Operating Surpluses, Operating Margins and Market Shares, Primary and Secondary Aluminum

Item	2006	2020		2030	
		Value	% above BAU	Value	% above BAU
Operating Surplus (Million USD 2000)					
Primary Aluminum:					
BAU	1,529.6	1,384.8	—	698.3	—
Mid-CO$_2$ Price Case Above BAU					
NCPA	—	-88.9	*-6.4*	-115.1	*-16.5*
NCPA inc. Alumina, Anodes (est.)		-146.3	*-10.6*	-212.3	*-30.4*
CPA [Cost Basis]	—	-19.0	*-1.4*	-25.5	*-3.7*
Secondary Aluminum:					
BAU	1,019.5	1,872.0	—	1,654.4	—
Mid-CO$_2$ Price Case Above BAU:					
NCPA	—	-58.3	*-3.1*	-138.0	*-8.3*
CPA [Cost Basis]	—	-25.7	*-1.4*	-60.5	*-3.7*
Operating Margin (Percent)					
Primary Aluminum:					
BAU	*27.9*	*28.7*	—	*21.9*	—
Mid-CO$_2$ Price:					
NCPA	—	*26.8*	*-1.8*	*18.3*	*-3.6*
NCPA inc. Alumina, Anodes (est.)		*25.6*	*-3.0*	*15.2*	*-6.7*
CPA [Cost Basis]	—	*28.1*	*-0.5*	*21.1*	*-0.8*
Secondary Aluminum:					
BAU	*16.3*	*19.6*	—	*16.8*	—
Mid-CO2 Price Case:					
NCPA	—	*19.0*	*-0.6*	*15.4*	*-1.4*
CPA [Cost Basis]	—	*19.5*	*-0.1*	*16.6*	*-0.2*
Domestic Market Share—Aluminum* (Percent)					
BAU	*55.4*	*59.8*	—	*59.8*	—
Mid-CO2 Price Case:					
CPA [Cost Basis]	—	*58.9*	*-0.8*	*57.6*	*-2.2*

*NCPA=No Cost Pass-Along; CPA=Cost Pass-Along   *Primary and Secondary Aluminum Combined*

long-term electric power arrangement.[195] In September 2008, Alcoa curtailed the remaining production at its 150,000 metric ton per year aluminum smelter in Rockdale, TX, because of uncompetitive local power arrangements and deteriorating market conditions.[196] In the Eastalco case, the company attributed the closure to electricity deregulation in Maryland and high costs of natural gas and coal used to fire Allegheny Energy's power plants, with which it had the power contract.[197]

Others observed that while Alcoa closed the Maryland smelter, it was expanding its aluminum capacity in Brazil and was planning new facilities in Iceland and Trinidad and Tobago, where electricity **costs were lower.[198] This supports the view** of some analysts, that failure to obtain inexpensive domestic electric power could induce some aluminum producers to shift production to foreign countries with low cost electricity. This is not solely a U.S. problem. European aluminum plants also have closed, shifting production to the Middle East, Russia, and China and other places where electric power is cheaper.[199]

On the other hand, the U.S. primary aluminum plants that continue to operate are largely reliant on power received from aluminum-company-owned electric plants[200] or from government-owned or other utilities with which they can arrange long-term, low-cost power arrangements. Most notable are the Bonneville Power Administration (BPA) and state authorities (e.g., the New York Power Authority) which typically have made long-term contracts with aluminum companies for electric power generated by hydroelectric plants, which would not be affected by rising fossil-fuel prices.

For example, Alcoa signed new agreements with the Bonneville Power Administration (BPA) for its Intalco Works smelter in Ferndale, WA, to provide financial benefits to reduce the cost impacts of market-based power purchases after its current contract expired in October 2006. After expressing concerns about expected significant energy cost increases in the Pacific Northwest, an Alcoa official noted, "Any viable long-term option for Intalco must include several key components—among them is the ability to secure long-term, globally competitive power. The long-term future of Intalco

Failure to obtain inexpensive domestic electric power could induce some aluminum producers to shift production to foreign countries with low cost electricity.

[196] Nelson Hernandez. "Rising Energy Costs May Put Eastalco Plant in Dark; In Frederick Area, Hundreds Could Lose Their Jobs," *The Washington Post, Washington Post Newsweek* Interactive Co., 2005. *HighBeam Research,* http://www.highbeam.com/ (accessed Dec. 19 2008). This includes 639 workers from Frederick County and Western Maryland, and over 100 from West Virginia.

[197] "Alcoa to Curtail Remainder of Rockdale, TX Smelter Due to Local Power Supply and Market Conditions," *Business Wire,* September 30, 2008. *HighBeam Research,* http://www.highbeam.com/ (accessed 19 Dec. 2008). The company already idled three of the Rockdale plant's six operating potlines representing approximately 120,000 metric tons per year of production because of ongoing local power supply issues.

[198] Justin Blum. "The Power of Rising Energy Prices; Soaring Costs Have Md. Aluminum Plant on the Brink," *The Washington Post, Washington Post Newsweek* Interactive Co, 2005. *HighBeam Research,* http://www.highbeam.com/ (accessed December 19, 2008). The situation was actually a little bit more complicated. As reported in the article, "If the market were still regulated, the company said, the price it pays would be more closely related to the price of coal, the dominant fuel for Allegheny's plants. But the company said that the PJM market establishes prices more heavily pegged to the price of natural gas. The most expensive unit of electrical generation, the company said, is used to determine the market rate. And that price is typically for power generated with natural gas, whose costs have increased much more rapidly than coal's."

[199] "Sen. Sarbanes, Mikulski seeking aid for displaced Eastalco Aluminum Workers," *US Fed News Service,* Including US State News, HT Media Ltd, 2006. *HighBeam Research,* http://www.highbeam.com/ (accessed December 19, 2008).

[200] Blum. "The Power of Rising Energy Prices."

[201] For example, Alcoa's Warrick Operations in Southwestern Indiana, one of the largest aluminum smelting and fabricating facilities in the world, is powered by electricity produced by Alcoa Generating Corp., a subsidiary of Alcoa. It includes 742-megawatt facility that produces enough electricity to supply a city of 200,000 people. See http://www.alcoa.com/locations/usa_warrick/en/about/history.asp.

hinges on obtaining a cost-based energy contract with BPA beginning in 2011."[201] In October 2008, the company obtained such an agreement, signing a power Memorandum of Understanding (MOU) with BPA to supply electricity to Intalco through 2028.[202]

Secondary aluminum cost pressures. The secondary aluminum industry, despite its much smaller energy profile, is not immune from cost pressures, especially if materials and energy costs increase enough to cut into their operating margins. In 2003 and 2004, U.S. secondary aluminum smelters' margins dwindled because of rising demand for old aluminum scrap, which escalated its prices and constricted its supplies. Industry officials decried the "phenomenal" volume of scrap going to China, which was driving up its price and eroding the profitability of secondary smelters. Scrap is this industry's most important cost factor, since 85 percent of the its sales revenues "is tied up in raw material costs," and "if you are not able to control those raw materials costs, not much else matters," according to an industry source. In addition, natural gas costs in 2004 rose 30 to 40 percent above what they were a few years before.[203]

Market condition contingencies. The energy and materials cost pressures that threaten the profits and competitiveness of primary and secondary aluminum manufacturers are contingent on market conditions that affect the global market prices for their goods. Stronger demand both domestically and internationally can alleviate cost pressures for at least for some aluminum smelters by driving up global market prices. The extent that market price increases follow materials or energy cost increases—assuming they are global and passed-through—manufacturers can maintain their profit margins, despite the higher costs.

The recession, other economic events, and the 9/11 disaster earlier in the decade contributed to low aluminum demand and prices. But by 2005, the market had recovered, and demand for both raw materials and aluminum products grew dramatically, largely fueled by China's and

THE ENERGY AND MATERIALS COST PRESSURES THAT THREATEN PRIMARY AND SECONDARY ALUMINUM MANUFACTURERS ARE CONTINGENT ON MARKET CONDITIONS THAT AFFECT THE GLOBAL MARKET PRICES FOR THEIR GOODS.

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[202] "Alcoa Takes Full Ownership of Intalco and Eastalco Smelters in Washington and Maryland; Signs Agreements for NW Power," June 29, 2006, http://www.alcoa.com/global/en/news; See also "High Energy Costs Impact Aluminum Production," *Engineering and Mining Journal,* Mining Media, Inc., 2005. *HighBeam Research,* http://www.highbeam.com (accessed December 16, 2008).

[203] "Alcoa Signs Power MOU with Bonneville Power Administration," *Business Wire,* October 10, 2008. HighBeam Research, http://www.highbeam.com (accessed December 19, 2008). See also, "Alcoa Reaches New Renewable Power Deal for Wenatchee, WA Smelter," *Business Wire,* July 18, 2008. *HighBeam Research,* http://www.highbeam.com (accessed 19 Dec. 2008). In a similar arrangement, Alcoa made an agreement in 2007 with the State of New York and the New York Power Authority for a 30-year power agreement after the current contract ends in 2013, for the company's Massena, NY operations. "Alcoa, State of New York Reach New Renewable Power Agreement for Massena Operations," December 21, 2007, http://www.alcoa.com/primary_na/en/news/releases/massena_agreement.asp.

[204] Deanne Toto, "Tight squeeze: secondary aluminum smelters struggle with tight scrap supply and higher pricing brought on by foreign competition.(related article on recycling industry in Lithuania)," *Recycling Today,* G.I.E. Media, Inc. January 1, 2004. *HighBeam Research,* http://www.highbeam.com (accessed December 22, 2008).

Figure 6-9: Primary and Secondary Aluminum Production Mid-CO₂ Price Cases and BAU, 1992-2030

* CPA=Cost Pass Along (Margin Basis); NCPA=No Cost Pass Along

Source: HRS-MI

other emerging nations' rapid economic growth. As a result, as materials costs (alumina and scrap) rose, aluminum prices grew as well.[204] LME prices both for high-grade primary aluminum and for aluminum alloys rose sharply in 2005, peaking in the period 2007 through mid-2008. However, in September, it started a precipitous fall as economic conditions in the United States and around the world deteriorated due to the global financial crisis. LME high grade primary aluminum prices, which were under $2,000 before 2005, rose to over $3,000 by mid-2008, but by December 2008 they had again dropped, to half or around $1,500.[205]

PRIMARY AND SECONDARY ALUMINUM SHIFTS.

A significant impact of a climate policy on the aluminum industry is that it likely would enhance the shift towards secondary aluminum as a share of total domestic aluminum production. Aluminum produced by secondary melting of aluminum scrap

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[205] See Dan Sandoval, "Pricing pressure: even though some U.S. manufacturing sectors are cooling, offshore activity may keep aluminum scrap markets aloft. (SCRAP METALS UPDATE)," *Construction & Demolition Recycling,* G.I.E. Media, Inc., 2007. *HighBeam Research,* http://www.highbeam.com (accessed December 16, 2008); "Elementary economics: slumping industrial production and demand from China is pinching aluminum scrap supply. (Commodity Focus)," *Recycling Today,* G.I.E. Media, Inc., February 1, 2004. *HighBeam Research,* http://www.highbeam.com (accessed December 23, 2008),

[206] These prices were for cash seller and settlement contracts on the LME. By the end of February 2009, they fell further, to around $1,250. Available at http://www.lme.co.uk/aluminium.asp.

surpassed aluminum produced from alumina in primary smelters for the first time in 2001. Underlying this shift are two important characteristics of aluminum. First, there is no difference in the chemical and physical properties of aluminum produced by primary or secondary processes. Second, producing a metric ton of aluminum ingot by secondary melting of scrap consumes only five percent of the energy required to produce a metric ton of primary aluminum from ore. Therefore, increasing energy costs would favor substitution of some primary aluminum by secondary production in aluminum markets, without a loss of quality.

Projections generated by the II-CPM model, illustrated in Figure 6-9, reflect this trend. The chart shows the estimated quantities of U.S. primary and secondary aluminum production, as well as secondary production's share of total domestic production, projected through 2030 for the BAU and Mid-CO_2 Price Policy. It also compares the trends for the no cost pass-along (NCPA) and cost pass-along (CPA) scenarios for both industries, which shows small declines in production associated with lost market shares if costs were passed-through to aluminum consumers.

It is important to note that the trends in Figure 6-9 were exogenously calculated, based on historical trends and assumptions about future aluminum capacity in the two industries, drawing from discussions with industry experts and the literature. They do not reflect assumptions about tradeoffs between primary and secondary production built into the model associated with differentials in energy consumption and costs. This would require further

investigation of the complex relationship between primary and secondary production and recycled aluminum markets.

However, the modeling results and evidence from the literature strongly indicate that the projected movement towards secondary aluminum accounting for larger and larger shares of total domestic aluminum production is generally correct and could even be understated. Most of the smelters idled as a result of the electricity crisis in 2000-2001 have never reopened. Industry representatives suggested to the HRS-MI team that they expect at least one primary smelter could close down in the future, depending on market conditions.

One study predicts the United States may only have three active primary smelters by 2020,[206] as multinational aluminum corporations find it more profitable to shift their primary operations to countries with lower electricity costs. Consequently, the burden of meeting any expanding U.S. aluminum demand in the future would increasingly rely on secondary remelting of recycled scrap. As an article in *JOM,* the magazine of the *Minerals, Metals & Materials Society,* contends, this shift "represents the greatest change in the structure of the industry and in the energy consumptions associated with aluminum manufacturing."[207]

A limiting factor in this shift is the availability and cost of recycled scrap aluminum, especially if and when the world economy starts to grow again. China might again be expected to play a leading role in driving up demand and prices for both aluminum products and the raw materials, especially scrap, used in the production

A LIMITING FACTOR IN THIS SHIFT IS THE AVAILABILITY AND COST OF RECYCLED SCRAP ALUMINUM, ESPECIALLY IF AND WHEN THE WORLD ECONOMY STARTS TO GROW AGAIN.

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[207] Study by Secat, a technical and business resource for the aluminum industry located in Lexington, Kentucky, cited in Subodh K. Das, W. Jerry Long III, H. Wayne Hayden, John A.S. Green, and Warren H. Hunt, Jr., "Energy Implications of the Changing World of Aluminum Metal Supply," JOM, Minerals, Metals & Materials Society, Aug. 2004. *HighBeam Research,* http://www.highbeam.com (accessed December 26, 2008).

[208] Das et al, "Energy Implications."

of aluminum, as it continues on its path of rapid economic expansion. Because materials costs account for over 85 percent of production costs in the secondary industry, the differential between primary and secondary aluminum prices could shrink as scrap becomes increasingly scarce and more expensive.[208]

Any gap in aluminum supplies available to meet expected rising domestic demand not met by U.S. secondary aluminum plants, may more likely be met by increased imports of aluminum produced in overseas primary smelters with lower energy costs—especially if not burdened by a climate policy. Hence, domestic market share would decline, even under an NCPA scenario.

Technology and Policy Options

Even without a climate policy, both the primary and secondary aluminum industries have strong incentives to find ways to reduce their energy costs, if they wish to remain competitive in the future. Under a climate policy that internalizes the cost of carbon in energy fuels, electricity, and feedstock consumed in the production of aluminum, aluminum firms would be further pressed to contain their costs.

U.S. primary aluminum companies would especially need to offset their rising energy costs associated with carbon-related energy costs within the next 10 to 15 years. This includes arranging long-term electric power contracts, especially with hydroelectric and other non-carbon-based electricity generation (nuclear, renewables), but also

investments in energy-saving technologies. Secondary aluminum production uses far less energy, and the magnitude of cost increases associated with climate policy would be small. But, because it will account for an increasingly greater proportion of aluminum supplied to manufacturers compared to primary aluminum, energy-efficient gains for secondary aluminum remelting will grow in importance for reducing energy consumption, environmental impacts, and imports in the aluminum industry.[209]

Energy efficiency requirements. The two aluminum sectors rely on different mixes of energy sources. Primary production heavily depends on electricity and on petroleum coke for feedstock in carbon anodes, while secondary aluminum mostly relies on natural gas for process heat. As the balance of production shifts to secondary metals, making efficiency gains in the consumption of natural gas would grow in relative importance.

Figure 6-10 shows that the cumulative energy efficiency required to offset the added costs of primary aluminum consumption (assuming NCPA) would be a jump step of 10 percent, in 2012, the year the Mid-CO_2 Price Policy would go into effect; for secondary aluminum fuel consumption, a 11 percent gain would be needed. These numbers would rise to 17 percent and nearly 20 percent, respectively by 2030. (The cumulative numbers represent the total energy efficiency gains that would be required to offset the total additional energy costs accumulated up to the given year.[210])

Even without a climate policy, both the primary and secondary aluminum industries have strong incentives to find ways to reduce their energy costs, if they wish to remain competitive in the future.

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[209] "Elementary economics: slumping industrial production and demand from China is pinching aluminum scrap supply.(Commodity Focus)," *Recycling Today,* G.I.E. Media, Inc., February 1, 2004. *HighBeam Research,* http://www.highbeam.com (accessed December 23, 2008).

[210] Das et al, "Energy Implications."

[211] See Appendix B for explanation of calculations.

The figures for the two aluminum sectors are comparable. In fact, the secondary industry's requirements for offsetting added fuel costs would actually exceed those for the primary industry. The small differences between the figures for the two industries reflect different fuel energy mixes, and different ranges of variation in energy prices in the policy case[211]—primary aluminum fuel consumption consists of multiple fuels, including natural gas, residual fuel oil, and liquefied petroleum gas (LPG), while secondary aluminum production uses mostly natural gas for process heat. Electricity savings requirements would be nearly the same because only electricity prices are considered; electricity savings requirements for a given year are directly proportional to the electricity price difference between the policy case and BAU (see Appendix B).

The comparability of energy efficiency requirements for the two industries however is misleading. Both sectors use a similar amount of fuel energy and the added costs therefore have a similar magnitude. However, primary production's massive consumption of electricity compared to secondary melting implies that a 6 to 10 percent reduction in electricity use in the former sector would require cutting the use of a much larger magnitude of electricity compared to the latter. These results also do not include the kinds of additional energy-saving requirements that would be needed to reduce the costs of carbon-based energy consumption in alumina refining and carbon anode production and use in primary production. It is reasonable to assume that incorporating the additional costs would drive up the efficiency requirements,

FIGURE 6-10
ALUMINUM INDUSTRY — CUMULATIVE YEARLY ENERGY EFFICIENCY GAINS REQUIRED TO OFFSET CLIMATE POLICY COSTS

PRIMARY

Fuel — 2030: 17.2; 2020: 13.4; 2012: 10.0
Electricity — 2030: 9.4; 2020: 6.6; 2012: 7.7 — No Allocation

Fuel — 2030: 5.9; 2020: 2.8; 2012: 1.1
Electricity — 2030: 3.1; 2020: 1.2; 2012: 0.8 — 90% Allocation

SECONDARY

Fuel — 2030: 19.7; 2020: 14.7; 2012: 10.8
Electricity — 2030: 10.2; 2020: 6.6; 2012: 7.7 — No Allocation

Fuel — 2030: 7.3; 2020: 3.2; 2012: 1.2
Electricity — 2030: 3.6; 2020: 1.3; 2012: 0.8 — 90% Allocation

Percent
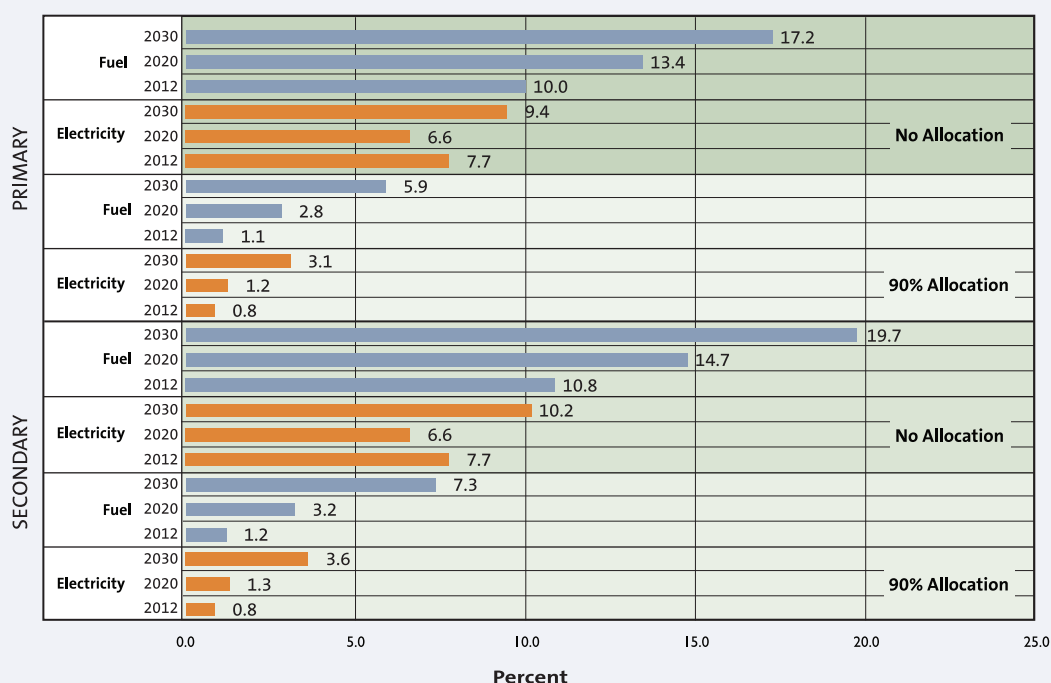
[212] See Chapter Two, Table 2-C.

especially for fuel energy and feedstock.[212]

In sum, primary aluminum plants would have a much steeper climb to achieve sufficient efficiency gains in energy use to counter the added costs of climate policy than secondary plants. The secondary industry, however, would not necessarily be off the hook in having to make significant energy savings over time, in order to stay competitive in both domestic and international markets, especially if aluminum scrap prices grow higher than would be expected, if and when the economy rebounds.

Technology options. The aluminum industry has for many years explored near, medium, and long-term energy saving technologies—often in partnership with or funded by the federal government[213]—in many instances, investing in them to increase energy efficiency and reduce energy costs in their production processes.

Primary aluminum options. The primary aluminum industry is considering energy technology improvements that include more efficient use of fossil fuel energy sources in alumina refining, gradual and mid-term efficiency improvements in the Hall-Héroult electrolysis process, and promising innovative technological changes in the Hall-Héroult process that could produce substantial energy savings. Finally, there are alternatives to the Hall-Héroult process currently being researched that could fundamentally transform how primary aluminum is produced, if they can be successfully commercialized and

implemented. These various options are summarized below:

- Major energy savings gains in the alumina refining process are possible—perhaps as much as a 25 percent energy reduction by 2020[214]—through better chemical process knowledge, and waste heat utilization and cogeneration. The alumina industry has recognized these as high-priority research and development needs. [215]

- Even though the Hall-Héroult process is a mature technology (it was invented in 1866) gradual efficiency improvements can still be made in cell designs, feeding systems, cryolite bath composition, and process control systems, and other technical advancements and practices. A DOE study observes that the adoption rates of new technologies and systems are to some degree governed by life of the cell, which typically ranges from seven to ten years. It estimates that this has resulted in a gradual decline in energy consumption ranging from 0.2 percent to 0.5 percent per year.[216]

- The wetted drained cathode and the inert anode are promising innovative Hall-Héroult technologies on the horizon for significantly improving energy efficiency. Wetted drained cathode technology would allow the anode-cathode distance in the aluminum reduction cell ("pot") to be greatly reduced, resulting in as much as an 18 percent reduction in the electrolysis energy needed to

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[213] The former would probably increase the efficiency gains needed in fuel energy use. The latter would require a calculation of a new feedstock energy gain requirements.

[214] For example, formerly, DOE's Office of Industrial Technologies, Industries of the Future program, and today, the DOE's Industrial Technologies Program (http://www1.eere.energy.gov/industry).

[215] Choate and Green, *U.S. Energy Requirements for Aluminum*, 20.

[216] Ibid.; U.S. Department of Energy, Office of Industrial Technologies (DOE/OIT), Alcan, Alcoa World Aluminum, et al, *Alumina Technology Roadmap*. Facilitated and prepared by Energetics, Inc. (circa 2002), http://www1.eere.energy.gov/industry/aluminum/pdfs/alumina.pdf.

[217] Choate and Green, *U.S. Energy Requirements for Aluminum;* DOE/OIT et al, *Alumina Technology Roadmap,* 38.

produce aluminum. Inert anodes would replace carbon anodes consumed by the electrolysis process. Inert anode systems could provide an estimated net 5 percent energy improvement, a 10 percent reduction in operating costs (from the elimination of carbon anode and plant costs associated with replacing anodes), and a 43 percent reduction in greenhouse gas emissions. Combining the wetted cathode and inert anode could result in a 22 percent reduction in energy consumption and eliminate cell CO_2 emissions.[217]

- The industry and others have been studying two alternative technologies to the Hall-Héroult process—carbothermic reduction and kaolinite reduction—which could replace Hall-Héroult cells in the future. Although they consume more carbon and have higher onsite emissions than the Hall-Héroult process, their electrical demands are lower, resulting in lower overall CO_2 emissions. A DOE study estimates that the carbothermic process could result in 20 percent in energy savings and be economical at a much smaller scale than Hall-Héroult plants.[218] The kaolinite process, could cut energy use by 11 percent.[219]

Achieving commercial viability for these new processes still requires overcoming many technical hurdles. Wetted cathodes and inert anodes are promising technologies that can be retrofitted into existing potlines once they are proven and when existing cells need rebuilding. Wetted cathode adoption

however will be gradual, as the typical cell life is seven to ten years. Inert anode could be adopted more quickly, since carbon anodes are replaced approximately every four weeks. There still is a need for more R&D and their superior performance must still be proven in industrial trials.[220]

Neither carbothermic technology nor kaolinite reduction is likely to be commercially viable until well after 2020, and perhaps not before 2030. Carbothermic reduction of alumina is a promising non-electrochemical process which industry has extensively researched for over forty years. But so far, the industry has not been able to develop an economical

ACHIEVING COMMERCIAL VIABILITY FOR NEW PROCESSES STILL REQUIRES OVERCOMING MANY TECHNICAL HURDLES.

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[218] Choate and Green, *U.S. Energy Requirements for Aluminum,* 44-48. As the name implies, *inert anodes* are made of inert materials that are highly conductive and thermally and mechanically stable, but do not react or dissolve to any great extent under the extreme conditions of a cell. Inert anodes would enable multipolar electrolytic cells, which would substantially increase reactor productivity by replacing multiple electrodes in a single reactor and also provide better control of heat losses.

[219] Ibid., 50. Carbothermic reduction involves a chemical reaction within a reactor to produce aluminum, and requires much less physical space than the Hall-Héroult process.

[220] Ibid., 38-39. The kaolinite process involves conversion of alumina to aluminum chloride and then reduction to aluminum using bipolar technology.

[221] Ibid., 41.

commercial system, though current R&D is examining new technology, modeling techniques and knowledge that could make the carbothermic process a more viable alternative to the Hall-Héroult cell.[221] If this technology were successful, some predict it would significantly transform the structure of the aluminum industry.[222]

Kaolinite reduction technology was demonstrated in the late 1970's. However, successful commercialization has eluded the industry because of problems with product purity and anticipated high capital and operating costs. The industry continues to research new construction materials, improved thermodynamic understanding, and the potential for using low-cost alumina containing clays, which have helped maintain interest in this alternative process for producing aluminum.[223]

Secondary aluminum options. The secondary aluminum industry can achieve substantial efficiency gains by improving

the recycling of scrap aluminum and the technology used in scrap handling and melting.[224]

- Each ingot of aluminum recovered by recycling saves nearly all the energy consumed in producing an ingot of primary aluminum from bauxite ore. Thus, improving the recovery of scrap aluminum can reduce the energy associated with aluminum production by an order of magnitude.[225] Key objectives for improving the recycling process include maximizing metal recovery, minimizing contamination, and lowering conversion costs. The DOE notes that non-technological and non-market factors can contribute significantly to increase recycling volume, such as consumer awareness through public education about the benefits of recycling and incentives for returning aluminum scrap.[226]

- To enhance recycling, the industry also

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[222] Ibid., 51. Specifically, the complex thermodynamic controls, sophisticated equipment, and construction materials required to make carbothermic technology economically viable. Recent industry R&D efforts include new, advanced high intensity electric arc technology, advanced thermodynamic and system modeling techniques, and improved understanding of process dynamics.

[223] Ibid., 52. The small footprint of the carbothermic technology would allow the industry to relocate away from regions of inexpensive power to centers of manufacturing. This would enable aluminum production "mini-mills" to be placed adjacent to or within aluminum casting facilities, generating additional energy, economic, and environmental benefits to the industry.

[224] Ibid., 54.

[225] Ibid., 59-64.

[226] Ibid., 59. Recycling in the United States saved more than 150 x 109 kilowatt-hours (0.51 quad) of energy in 2000, the equivalent of 17,200 Megawatts.

is looking at technologies that minimize oxidation and improve thermal inefficiencies in scrap processing and melting, improve collection systems and separation devices which can increase aluminum scrap recovery by 20 to 30 percent, and increase scrap recovery rates, especially with regard to aluminum in municipal solid waste.[227]

- Incremental improvements in existing furnaces—e.g., burner and furnace design modifications and by controlling furnace practice and operating conditions—can reduce recycling energy requirements, including recovery of stock gas energy for preheating combustion air and metal feedstock.[228] Secat, a technical and business resource for the aluminum industry, identifies major energy savings opportunities from improvements in furnace operation and components. This includes a potential 10 to 30 percent improvement in energy efficiency in process heating (e.g., better sensors and process controls and methods, advanced materials, and design models and tools). Other potential improvements include more efficient electric motor systems (5 to 20 percent savings in motor costs), pumping systems (10 to 20 percent cost savings), and compressed air systems (5 to 15 percent savings).[229]

Policy options to mitigate impacts.

As in all the other industries, enacting a policy measure that offsets 90 percent of the energy price increases (diminished by 2 percent per year) from the Mid-CO_2 Price Policy would result in savings in production costs and operating surplus reductions of

74 percent in 2020 and 54 percent, in 2030, relative to the policy case. These gains are reflected in Figure 6-11, which compares the operating surplus decline relative to BAU for the 90 percent allocation and no allocation scenarios for the Mid-CO_2 Price Policy. Figure 6-7 also illustrates the positive impacts of the allocation measure, showing that the energy-efficiency gains required to offset policy-induced costs would be substantially smaller, for both industries, than those needed if there was no allocation.

The data show that the primary aluminum operating surplus decline for the 90 percent allocation case would be reduced to 7.6 percent in 2030, compared to 16.5 percent for no allocation. Reductions in operating surplus in the allocation scenario for secondary aluminum would also be greatly diminished, to 3.8 percent. The primary aluminum results, however, do not incorporate the costs associated with carbon anode and alumina production. Rough estimates of these impacts in the allocation case, accounting for the additional alumina and carbon anode cost increases, shows that the operating surplus would fall to 14 percent below BAU, compared to 30 percent in the no allocation case, in 2030. This value would be 3 percent in 2030, compared to 11 percent in the no allocation case.

There is a potential issue regarding whether secondary aluminum should be eligible to receive the 90 percent allocation. Some question that it should not be classified as energy-intensive, and it may primarily serve domestic markets and therefore not as import sensitive as primary aluminum. However, under certain market conditions, such as rising materials costs (e.g., for

The data show that the primary aluminum operating surplus decline for the 90 percent allocation case would be reduced to 7.6 percent in 2030, compared to 16.5 percent for no allocation.

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[227] Ibid., 62-4.

[228] Ibid., 64.

[229] Ibid.

[230] Secat, *Energy Saving Opportunities in the Aluminum Industry,* PowerPoint presentation, 2003.

FIGURE 6-11

ALUMINUM OPERATING SURPLUS ABOVE BAU, MID-CO₂ PRICE POLICY, NO ALLOCATION AND 90 % ALLOCATION

Source: HRS-MI

aluminum scrap) and higher market-driven energy costs (e.g., for natural gas) that may be more local in nature, and/or weakening demand and declining market prices, the additional rising costs of energy due to a climate policy could cause secondary aluminum smelters to suffer lost operating revenues and profits that result in production cutbacks, perhaps even earlier than 2030.

Conclusion
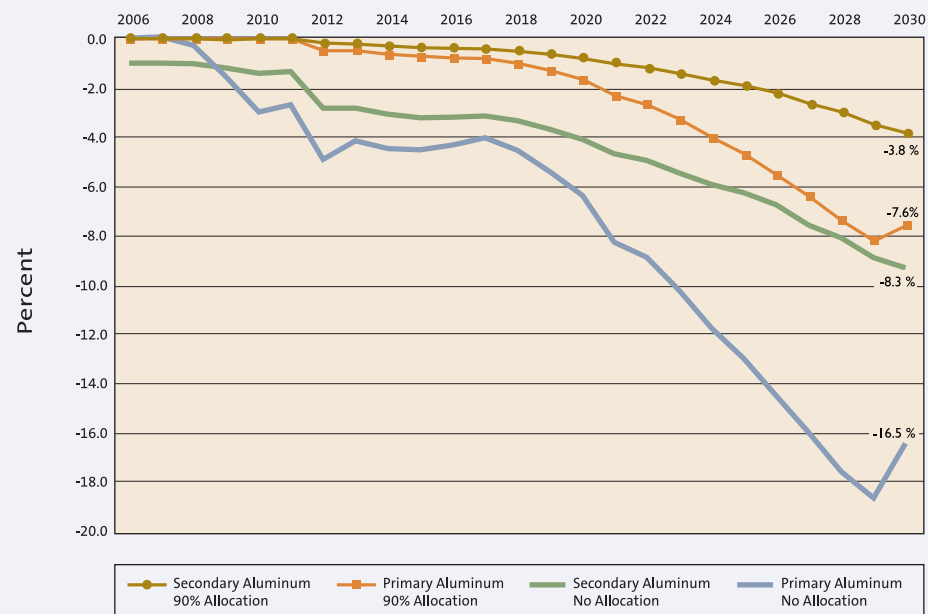
Although the impacts of the Mid-CO₂ Price Policy probably will not be as large as on other industries, such as iron and steel, they may create problems for the aluminum industry, if no actions are taken to mitigate costs as GHG emissions allowance prices grow over time. Primary aluminum in particular would experience cost increases and operating surplus and margin

reductions, especially if the carbon costs associated with alumina and carbon anodes are included in the analysis.

These impacts assume that the industry would be able to pass along little or none of the additional energy costs from a climate policy, that climate policies will be enacted only in the U.S. and that no investments in energy efficient technology will be allocated. The former assumption is widely accepted as applying to aluminum, whose prices are set by global commodity exchanges, more than any other sector. Primary aluminum smelters mainly are concerned about keeping their costs low in order to remain competitive and strengthen their economic performance.

Even without the impact of a climate policy, the primary aluminum industry has been stagnating, and studies indicate that it can lose at least another plant over the coming decade—depending on aluminum firms'

ability to obtain low-cost long-term electric power contracts—due to competition with other locations where electricity is cheaper. Under favorable market conditions, when there is growing demand for aluminum products—a situation that the industry enjoyed just prior to mid-2008—market prices can increase sufficiently that they might alleviate new energy cost pressures. However, when demand weakens and prices plummet, as in the current economic recession, climate policy-driven energy costs could amplify the pressures on domestic aluminum smelters to cut back their capacity, or move operations to less expensive locations.

Because of the primary sector's capacity limitations, and the unlikelihood of additional capacity being built, at least in the short run, the secondary aluminum industry, with its much lower energy-profile, would most likely expand to meet any new demand when the economy starts to grow again. However, if this capacity growth is restrained by higher materials costs (i.e. for aluminum scrap), which would accompany rising demand for them from China and other emerging economies, some additional domestic demand could be met by new imports.

In any case, our results show that by 2030, significant energy efficiency gains would be required to offset the costs of a climate policy. Hence, the aluminum industry would need to make energy-saving investments if it desires to maintain domestic smelting capacity over the long-term. Short-, medium-, and long-term advanced primary aluminum technologies exist, and some are already available to reduce energy use through incremental process improvements, such as more efficient recovery and use of internally generated energy. Larger, longer-term energy-efficiency gains will require more advanced Hall-Héroult processes. Even greater reductions in carbon-based

energy could be made with alternative primary aluminum process technologies that replace Hall-Héroult cells. There remain, however, unresolved questions regarding the costs and timing for introducing such technologies, that is, when they would be commercially available, and when it would be cost-effective to introduce them, and replace older existing technologies. For some of the new technologies, much more R&D would be required to illustrate their technical and commercial viability.

In addition, the study's results also show that the 90 percent allowance allocation measure would substantially mitigate cost impacts on the industry, at least through the latter half of the 2020 decade. However, its implementation would not preclude the need for the industry to start investing in incremental energy-saving technologies much earlier, Support also will be required for R&D and demonstration projects that could make more advanced low-carbon process technologies commercially available by the mid-2020s.

A reasonable question can be raised about the application of the allocation measure to secondary aluminum, but without it, even this relatively non-energy-intensive industry could begin to need some cost remediation under the policy by 2030, and most likely soon after. On the other hand, improvements in secondary aluminum energy use are readily available, and investments to strengthen this sector (including improvements in aluminum recycling technologies and methods) would improve not only its own energy-profile, but of the aluminum industry as a whole. Nevertheless, as in the case of the iron and steel industry, additional public policies (such as tax credits and targeted R&D programs) may be needed to encourage the aluminum industry to make the necessary investments in these technologies, even with the allocation measure.

IMPROVEMENTS IN SECONDARY ALUMINUM ENERGY USE ARE READILY AVAILABLE, AND INVESTMENTS TO STRENGTHEN THIS SECTOR (INCLUDING IMPROVEMENTS IN RECYCLING) WOULD IMPROVE NOT ONLY ITS OWN ENERGY-PROFILE, BUT OF THE ALUMINUM INDUSTRY.

THE PAPER INDUSTRY

T he paper industry is one of the oldest and most important industries in the U.S. economy. The United States leads the world in the production, consumption and exporting of pulp, paper, and paperboard products. It both produces and consumes about a quarter of the world's paper and paperboard, and is the highest per-capita user of paper worldwide.[230] It is also home to three of the world's five largest paper and forest companies.[231]

The paper industry is generally underappreciated for its contributions, largely because its products are so ubiquitous and taken for granted in modern society. "Paper is in almost every product that we use," notes the Center for Paper Business and Industry Studies (CPBIS).

[231] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program (DOE/ITP), *Energy and Environmental Profile of the U.S. Pulp and Paper Industry*. Prepared for Energetics, Inc. (Washington, DC, December 2005), 1. In 2003, per capita paper consumption was 714 lbs compared to 244 in Europe and 101 in Asia U.S.
[232] These include International Paper, Georgia Pacific, and Weyerhauser.

This includes "books and photocopies, tissue and sanitary products, newspapers and magazines, containers, catalogs, wallpaper, food packaging, gift wrap, and many other staples of every day life." Other applications are paper fibers used in computers, paper insulation in attics, car doors, and floors, cellulose-based derivative products in surgical gowns, gas mask filters, ice cream, clothing (Rayon), toothpaste, filmbase stock, and plastics, and other derivatives, such as tall oil, and turpentine.[232]

The paper and paper products industry (NAICS 322) includes pulp, paper and paperboard mills (NAICS 3221), and converted paper manufacturing (NAICS 3222). *Pulp mills* (NAICS 322111) produce the fibrous mass used in papermaking. *Paper mills* (NAICS 322112) produce printing-writing papers, newsprint, parchment, magazine, special packaging and industrial paper, and tissue and household papers. *Paperboard mills* (NAICS 322113) produce containerboard, boxboard, linerboard and other paperboard used in containers and packaging.

Below is a synopsis of some of the industry's principal characteristics and statistics:

Structure and location. The paper and paper products industry is one of the largest manufacturing industries in the U.S. economy, employing over 450,000 workers. According to a Department of Energy report, in 2004, there were more than 4,600 pulp and paper facilities in the United States (including converted paper manufactured products), typically located near wood sources to minimize transportation costs.[233] The paper and paperboard industries include 353 paper and paperboard establishments with 500 or more employees, owned by 84 firms (2005), with total employment of about 130,000.[234] Although all 50 states have forest product operations (including wood products), the largest producers are Wisconsin, California, and Georgia.[235]

Production and shipments. The North American pulp and paper industry had shipments worth $170 billion in 2006, including $52.5 billion in shipments by U.S. paper mills and $23.3 billion by U.S. paperboard mills.[236] U.S. paper and paperboard production in 2006 was 92.2 million tons, including 41.8 million tons of paper and 50.4 million tons of paperboard.[237]

Scrap and recycling. As in the iron and steel and aluminum industries, recycled or recovered materials have accounted for an increasing share of the production of paper and paperboard mills. Recovered paper (wastepaper) totaled 53.5 million tons in 2006, a recovery rate of 53 percent, compared to 22 percent in 1970.[238] This includes 34.5 million tons of recovered paper consumed by paper and paperboard mills for production and net exports of wastepaper of 17.0 million tons. The recovery utilization

The paper and paper products industry is one of the largest manufacturing industries in the U.S. economy, employing over 450,000 workers.

[233] Center for Paper Business and Industry Studies (CPBIS), "Paper Industry Facts, Paper—Its History and Role in Society" (Atlanta, GA, 2007), http://www.paperstudies.org/resources/industryfacts/history.htm.

[234] U.S. Department of Energy, *Forest Products Industry of the Future: Fiscal Year 2004 Annual Report* (February 2005). Cited in EPA, *Energy Trends in Manufacturing,* 3-39.

[235] Census Bureau, *SUSB* (2005); Employment data from BLS, *CES*. This includes about 2,000 pulp and paper mill establishments with over 500 employees, owned by 52 firms in 2005, and about 150 paperboard establishments. Paper mill employment in mid-2008 was about 93,000 and paperboard mills employed 33,000.

[236] EPA, *Energy Trends in Manufacturing,* 3-39.

[237] Census Bureau, *ASM* (2006).

[238] American Forest & Paper Association (AF&PA), *2007 Annual Statistics of Paper, Paperboard & Wood Pulp,* (Washington, DC, 2007).

[239] The recovery rate is calculated the ratio of recovered paper collected to new supply of paper and paperboard. New supply equals production plus imports less exports, excluding hard pressed board. AF&PA, *2007 Annual Statistics*, 50.

percent). Canada also was the top recipient of U.S. paper exports (28 percent), followed by Mexico & South America, Asia, and Europe.[241]

Industry Structure and History

Although the paper industry's output has steadily grown since the 1960s, it has gone through periods of both poor and strong economic performance. Along with business cycle swings, aging assets, high energy costs, limited investments, and international competition have been among the main factors underlying these fluctuations. Paper manufacturers expanded capacity during the economic upswing of the late 1980s, only to suffer a downturn during the recession of the early 1990s. However, the decline reversed in mid-1994, resulting in one of the industry's most profitable years in 1995. But industry sales then stagnated and fell again, forcing companies to reduce their capital spending by more than 14 percent in 1997. This also led to a spate of corporate restructuring, mergers, and acquisitions from late 1996 to 1998, as firms attempted to improve their profits. But as the U.S. economy grew again in the late 1990s, the demand for paper shipments increased, and the industry emerged from its most volatile business cycle in its history.

Since peaking in 1999, paper and paperboard production has grown in some years and declined in others, depending on the performance of the U.S. economy, but

rate—the ratio of recovered paper consumption to total production of paper and paperboard—also has grown, from 23 percent in 1970 to 37 percent in 2006.[239]

International trade. U.S. participation in international paper markets has steadily grown. U.S. paper exports as a share of total paper production was 9 percent in 1990, and nearly 15 percent in 2006. Paper imports also have grown, though not as fast as exports, from 14 percent of total apparent supply (production plus imports) in 1990 to 18 percent in 2006. The ratio of *net* imports (imports minus exports) and new paper supply (production plus imports minus exports) was little under 7 percent in 2006.[240] In dollar value, the top sources of U.S. paper imports in 2005 included Canada (61 percent), Europe (16 percent), Asia (14 percent), and Mexico and South America (8

Although the paper industry's output has steadily grown since the 1960s, it has gone through periods of both poor and strong economic performance.

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[240] AF&PA, *2007 Annual Statistics*.

[241] Total paper and paperboard imports in 2006 were 18.2 million tons with a total value of $13.1 billion, and exports were 10.6 millions valued at $7.8 billion, for a total net imports of 7.0 million tons valued at $5.3 billion. U.S. was a net importer of paper mill products (12.2 million tons), especially of printing-writing paper and newsprint, but a net exporter of paperboard mill products (4.7 million tons). AF&PA, *2007 Annual Statistics*.

[242] AF&PA, *2007 Annual Statistics*.

has generally trended lower. The industry especially suffered a sharp drop in its performance during the 2001 recession. However, the industry started to show signs of recovery after 2004, as it underwent further consolidation and companies sought to pay off the debts they incurred through asset sales.[242]

The restructuring, mergers and acquisition and consolidations between 1970 and 2000 resulted in a substantial concentration of production capacity among larger firms. The top ten companies had less than 35 percent of total paper, paperboard, and market pulp capacity in 1970. By 2000, the top ten accounted for nearly half the total capacity. At the same time, consolidation and elimination of older and smaller establishments more than doubled average

mill capacity over this period.[243] However the pulp and paper industry is still less consolidated than other manufacturing sectors. Analysts note that horizontal mergers, involving firms operating and competing in the same product market, were more representative of the consolidation wave that earlier occurred in the pulp and paper industry in the 1990s.[244]

Increased globalization has been an important driver of consolidation. In mergers and consolidations, domestic firms have shed inefficient capacity that is no longer competitive, to achieve cost efficiencies and counter foreign competition in the United States and the overseas markets, and to exploit new global opportunities.[245] This has led to a decline in U.S. paper manufacturing capacity[246] a trend continuing in 2006

The restructuring, mergers and acquisition and consolidations between 1970 and 2000 resulted in a substantial concentration of production capacity among larger firms.

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[243] DOE/ITP, *Profile of U.S. Pulp and Paper*, 1.

[244] Marilyn A. Brown and Nilgun Atamturk, "Potential Impacts of Energy and Climate Policies on the U.S. Pulp and Paper Industry," *Working Paper* (Atlanta, GA: The Center for Paper Business and Industry Studies and School of Public Policy, Georgia Institute of Technology, June 2008).

[245] Vivek Ghosal and Usha-Nair Reichert, "The Role and Value of Innovation in the Pulp and Paper Industry." Unpublished paper (Atlanta, GA: School of Economics, Georgia Institute of Technology, February 2007), 24.

[246] Ghosal and Reichert, " Innovation in the Pulp and Paper Industry," 27.

[247] DOE/ITP, *Profile of U.S. Pulp and Paper*. In 2000, 499 paper and/or paperboard mills and 176 pulp mills operated in the United States, including integrated pulp and paper mills. Today, about 160 pulp and paper mills operate in the United States, including 105 kraft, six sulfite, 23 semi-chemical, and 27 mechanical mills. See also A. John Rezaiyan, *Domestic Energy Parks–Filling the Transportation Void*. Final Report. Under Subcontract to Energy & Environmental Research Center, University of North Dakota [2007-EERC-08-01] (Washington, DC: National Commission on Energy Policy, August 2007), 2. About 70 percent of the operating kraft mills are located in the South, 11 percent in the Northeast, 15 in the West and 9 mills are in the Midwest.

with several mill closures.[247] Job numbers have also declined, reflecting both the concentration of production capacity and labor force productivity gains. Total U.S. paper industry employment fell from 625,000 in 1998 to 450,000 in 2008.[248]

Although no new virgin paper mills have been built in the United States for over a dozen years, some analysts have been guardedly optimistic about the industry's future. CPBIS notes a number of "drivers providing tailwinds for the U.S. industry," including Asia's huge and growing appetite for paper commodities and pulp and the rising costs of shipping, due to high energy prices and a weakening dollar which makes imports more expensive generally. As a result, it is now more expensive by 10-20 percent to import paper products from Europe and Asia than to manufacture

them domestically. CPBIS also notes several caveats, such as off-shoring and substitution by alternative mediums which have driven demand below peak levels, the industry's relatively higher cost structure, its history of "capital rationing" eroding its asset base, and declining capital spending.[249] CPBIS also has warned about the consequences of a recession on the industry, especially in light of the financial crisis, that the nation and the world has since fallen into, at the time of this writing.[250]

INTERNATIONAL MARKETS

The paper industry is highly internationalized—41 percent of its total production was traded across borders in

> **Although no new virgin paper mills have been built in the United States for over a dozen years, some analysts have been guardedly optimistic about the industry's future.**

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[248] "Paper and Paper Products: Overview," *Reuters,* October 27, 2007, http://www.reuters.com/business/industries,

[249] BLS, *CES*. Although jobs in all paper industry subsectors also steadily declined, the sharpest descent in the number of jobs occurred between 2001 and 2003-2004, due in part to the aftermath of 9/11 and the recession 2000-2001 recession. The pulp and paper sector suffered a 30 percent drop in employment between 1998 and 2003, falling another 17 percent by 2008, to 92,000. Paperboard employment similarly shrank by 31 percent over the past decade, to 33,000. Converted paper products, the most labor-intensive subsector in the paper manufacturing industry, lost a fifth of its workforce, falling to 329,000 in 2008.

[250] Colleen Walker and Dan Cenatempo, "State of the North American Pulp & Paper Industry, There Is Light on the Horizon." PowerPoint presentation (Atlanta, GA: Center for Paper Business and Industry Studies (CPBIS), Georgia Institute of Technology, April 2008). In the 1980s it was 250 percent of industry depreciation levels, 100 percent of depreciation in the early 1990s, and by 2003, it was below the 75 percent level needed to maintain facilities. Ghosal and Reichert, "Innovation in the Pulp and Paper Industry," 15.

[251] Walker and Cenatempo, "State of the North American Pulp & Paper Industry."

2005.[251] A number of large corporations, most of them with international holdings, and many headquartered overseas, operate U.S. pulp, paper and paperboard mills. For example, International Paper, the largest U.S. paper company, with revenues of $25.5 billion in 2004 operates 18 pulp, paper and packaging mills, 94 converting plants, and five wood products facilities in the United States. It owns about 11 percent of the nation's paper, paperboard, and pulp capacity and 4 percent of the global capacity.[252] It also has operations in Europe, Asia, and Latin America. Stora Enso is a global company with 44,000 employees in more than 40 countries on five continents. Before selling most of its operations to NewPage, it had 8 mills in the United States and Canada, with 4,500 employees, and was the leading producer of coated and super-calendared papers for the printing and publishing industries in North America. Domtar, also with operations in the United States and Canada, is the largest producer of uncoated freesheet paper in North America.[253]

Trade patterns and partners.

Although the United States is the largest producer of pulp and paper in the world, its competitive position has been increasingly challenged by foreign competition, fueled by rising costs of energy. Figure 7-1 illustrates the trade pattern for the paper and paperboard industry since 1965 through 2005. It shows a steady increase in both imports and exports, more or less at the same rate until 1997. Imports have dominated, however, and the industry has suffered from a steady increase in its trade deficit since the mid-1990s. Rising imports, along with high energy prices, and declining

newspaper demand are the three key issues the domestic industry has been concerned about. Segments such as coated paper, used for high quality printing applications have been particularly affected by competition from Chinese products.[254]

Canada is the American industry's largest trading partner (see Table 7-A). In 2007, 21.2 million short tons of pulp, paper, and paperboard flowed between the two countries. But the largest growth in trade is with the developing world. Emerging nations will continue to drive global demand in future years, though much of this will be to make products and packaging for export to developed world markets. At the same time, China has enjoyed the most impressive export growth. In 2000, Chinese paper imports were 7 million tons of paper but only exported 1.5 million tons. In 2006, China's imports fell to 5 million tons but its exports rose to 6.5 millions, leaving China with a paper trade surplus for the first time in decades.

At the same time, China's pulp and reclaimed paper imports have grown to 28 million tons, four times the amount of

Although the United States is the largest producer of pulp and paper in the world, its competitive position has been increasingly challenged by foreign competition, fueled by rising costs of energy.

[252] Trevor Houser. *Part 1: US Climate Policy and the Industrial Landscape.* Unpublished manuscript. Produced for Joint WRI/Peterson Institute Study Group, Washington, DC, September 13, 2007.
[253] Ghosal and Reichert, " Innovation in the Pulp and Paper Industry," 16.
[254] Other companies with major U.S. paper manufacturing facilities includes UPM-Kymmene Corp., Smurfit-Stone Container, Sappi Ltd., Potlatch Corp., Rock-Tenn, Abitibi-Consolidated, Wausau Paper and Neenah Paper.
[255] "Paper and Paper Products."

Figure 7-1

Paper & Paperboard Imports and Exports Trade Balance, 1965-2005

Source: AF&PA

the finished paper it exports. Most of the recovered paper comes from the United States. China's huge appetite for recovered paper has been fueled by a shortage of wood pulp and a burgeoning demand for boxes it needs to ship its exports. Mills in India, Indonesia, Japan and South Korea also are have been bidding for U.S. scrap paper. U.S. papermakers need the scrap themselves, consequently and have become concerned, as they have seen prices for their recycled products escalate as a result.[255] Meanwhile, the United States is the world's largest importer of virgin paper, accounting for 15 percent of the world total—two-thirds

comes from Canada, and Finland, Germany and China are also major suppliers.[256]

Paper Production and Energy Use

Paper manufacturing includes the processing of wood (virgin fiber), recovered paper and paperboard, and other cellulose fibers into thousands of end-use products. The overall process of converting wood resources into paper products includes six

[256] Knight Ridder Newspapers, "U.S. mills battle Chinese demand for scrap paper," *Sunday Gazette-Mail.* Charleston Newspapers, 2005. *HighBeam Research*, http://www.highbeam.com/doc/1P2-14751772.html (accessed February 2, 2009).

[257] Houser, *Climate Policy and the Industrial Landscape.*

process steps—wood preparation, pulping, chemical recovery, bleaching, papermaking and finishing[257]— illustrated in Figure 7-2 with their associated energy inputs and flows.

Wood preparation—The mechanical removal of bark from logs and breaking down the debarked logs into wood chips to prepare for pulping.

Pulping—The process of reducing wood (or other cellulosic fiber source) into a fibrous mass suitable for papermaking. It involves breaking the chemical bonds of the raw materials through mechanical, and/or chemical means in order to liberate the discrete fibers used to make paper. Once separated, the fibers are screened, washed, thickened and sent to pulp storage.[258] The pulping process can be classified as chemical, mechanical, semi-chemical, and

recycled, and they are selected based on the desired properties of the final product.[259] In 2006, chemical processes accounted for approximately 87 percent of wood pulp production (from virgin fiber), semi-chemical 6 percent and mechanical 7 percent.[260]

Chemical pulping—The dominant pulping process used, producing a strong pulp from a wide variety of tree species. Chemical pulp fibers have higher strength properties, greater resistance to aging, and are more easily bleached. The process cooks wood chips at high temperature and pressure with chemicals to dissolve the non-cellulose components (primarily lignin) and separate the fibers. There are two types of chemical processes—*kraft* (sulfate) and *sulfite*. The kraft process accounts for 98 percent of U.S. chemical pulp capacity and 86 percent of total pulping capacity. The remainder uses the sulfite process, which is in decline; no new U.S. sulfite mills have been built since the 1960s. The kraft process uses an efficient chemical recovery system and *black liquor* (spent cooking chemicals) combustion, and generates a large portion of energy required for pulping.[261]

Mechanical pulping—Conversion of wood in the form of small logs or chips into fibers by mechanical action. Because the lignin is not dissolved, the yield is very high (90-94 percent), but color permanency and strength are low. Therefore mechanical pulp is used to make non-permanent paper products such as newsprints, magazines, and catalogs.[262]

THE KRAFT PROCESS USES AN EFFICIENT CHEMICAL RECOVERY SYSTEM AND BLACK LIQUOR (SPENT COOKING CHEMICALS) COMBUSTION, AND GENERATES A LARGE PORTION OF ENERGY REQUIRED FOR PULPING.

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[258] DOE/ITP, *Profile of U.S. Pulp and Paper*.

[259] Ibid., 27. Three main types of raw materials are used for papermaking: pulpwood (trees), recovered paper or paperboard product, nonwood plant sources such as cotton, sugarcane bagasse, bamboo. Synthetic fibers made from thermoplastic materials such as nylon, polystyrene, and polyolefins aere also used in small amounts to make paper-like materials called "nonwovens."

[260] Ibid.

[261] AF&PA, *2007 Annual Statistics*.

[262] Ibid., 29-32.

[263] Ibid., 33-34. The primary types of mechanical pulping processes include stone groundwood (SGW)—the oldest, simplest form of pulping; refiner mechanical pulping (RMP), introduced in early 1960s, which allows use of residual wood and sawdust from lumber mills; thermo-mechanical pulping (TMP), in which wood feedstock is steamed under pressure for short period of time prior to and during refining; and, chemi-thermo-mechanical pulping (CTMP), which adds another step to the TMP process.

Semi-chemical pulping—Combines aspects of the chemical and mechanical pulping methods. Mild cooking partially delignifies the pulp, followed by mechanical defibering. It produces an intermediate range of yields between pure chemical and mechanical pulping.

Recycled paper pulping—A type of mechanical pulping, recovered paper is rehydrated and turned into a slurry, in preparation for being remade into paper and paperboard. It typically includes processes for re-pulping, contaminant removal, screening, and bleaching. Three major types of wastepaper are collected: post-consumer (old) corrugated containers (47 percent); old newspapers (20 percent) and mixed papers

TABLE 7-A
TOP U.S. PAPER AND PAPERBOARD TRADING PARTNERS

TOP SOURCES OF IMPORTS		TOP EXPORT RECIPIENTS		TOP SOURCES OF NET IMPORT	
Country	Cumulative 1997-2007 (mmt)	Country	Cumulative 1997-2007 (mmt)	Country	Cumulative 1997-2007 (mmt)
Canada	130.9	Canada	20.0	Canada	110.9
Finland	11.0	Mexico	13.2	Finland	11.0
Germany	4.2	Japan	7.7	Germany	2.4
Korea	4.1	China	6.0	Korea	2.2
Norway	2.0	Italy	2.8	Norway	2.0
Sweden	1.9	United Kingdom	2.3	Sweden	1.8
Japan	1.8	Netherlands	2.1	Austria	1.1
Mexico	1.8	Korea	1.9	Indonesia	0.3
China	1.5	Spain	1.8	France	0.2
France	1.1	Germany	1.8		
ROW	8.5	ROW	34.5	ROW	-57.3
WORLD	168.7	WORLD	94.2	WORLD	74.6

mmt=million metric tons; ROW=Rest of the World

Source: The Aluminum Association

(office paper, magazines, phone books) (20 percent); and other recovered sources.

Chemical recovery—Involves recovery and reuse of chemicals (e.g., black liquor) used in chemical and semi-chemical pulping. It is integral to the kraft pulping process and essential to the cost-effective operation of kraft pulp mills. Steam and electricity are generated from the organic material remaining in the slurry after the pulp has been separated out, helping to offset the large energy requirements of pulp and papermaking. The chemical recovery steps includes black liquor evaporation, which concentrates black liquor to increase its solids content; black liquor combustion (in the recovery boiler), which entails burning the organic portion of black liquor to generate steam and produce molten smelt from spent inorganic cooking chemicals; and byproduct recovery, such as the recovery of tall oil.

Bleaching—A chemical process used to whiten or brighten some pulp before it is used in papermaking. The bleaching method is determined by the pulping process, as each process removes variable amounts of lignin. [263]

Papermaking—Turns the pulp into paper, and prepares the paper for finishing (converting). This includes four stages: the preparation of a homogeneous pulp slurry (stock), dewatering which removes a portion of the water in the pulp, and pressure and drying that submits the pulp to pressure and heat, which removes more water, After preparation, the stock is sent to a papermaking machine, which are very expensive and extremely large in size. These machines can exceed 550 feet in length, and their installation can run as high as $550 million. As a result, the paper industry is among the most capital intensive in U.S. manufacturing. The capacity of these machines has grown significantly over time; today's new machines can average the production of 400,000 tons of paper per year.[264] This stage includes *wet-end operations*, which is the sheet formation stage, critical because it dictates the quality of the paper product, and the *dry-end operations*, which includes the drying section—a massive operation, and the most costly in papermaking in terms of capital and operating costs (due to high steam requirements).[265]

Finishing—Often called "converting operations," it takes place after paper is manufactured, and can include rewinding, trimming, sheeting, coating, printing, saturation, and boxmaking.

Paper and paperboard production.

The major paper industry production facilities include pulp mills, paper mills, paperboard mills, and plants that convert paper and paperboard products into end-use paper products (e.g., paper bags, cartons, corrugated boxes). Paper and paperboard mills are the most important types of paper manufacturing facilities, which may also

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[264] Ibid., 51-62. Mechanical and semi-chemical pulp, which contains a large portion of the original lignin, are whitened by decolorizing the lignin. For chemical pulp, bleaching removes a small amount of the remaining lignin, making a more permanent change in pulp brightness.

[265] Ibid., 65-66. Many paper companies continue to use older machinery, though modern machines are wider, faster, able to integrate off-line operations, and able to incorporate new technology to improve quality and productivity and reduce operating costs. They also have improved configurations, better drying capabilities from the roll press sections (reducing energy costs in drying), and higher design speeds. There are a variety of papermaking machines in use today. The first and most widely used machine is the Fourdrinier (865 in 2000).

[266] Ibid., 67-68. After pressing, the sheet passes through the dryer section, where additional water is removed via evaporation, accomplished by pressing the sheet against hot, steam-filled dryer drums. Three drying processes occur at the same time—a flow of heat from surface of cylinder to the paper (contact drying); cooling of paper as heat is used to evaporate water in it (flash); and a flow of heat from surrounding air to the paper (convection).

FIGURE 7-2

Pulp, Paper and Paperboard Mills Production and Energy Flows

Pulp, Paper and Paperboard Mills [NAICS 3221]
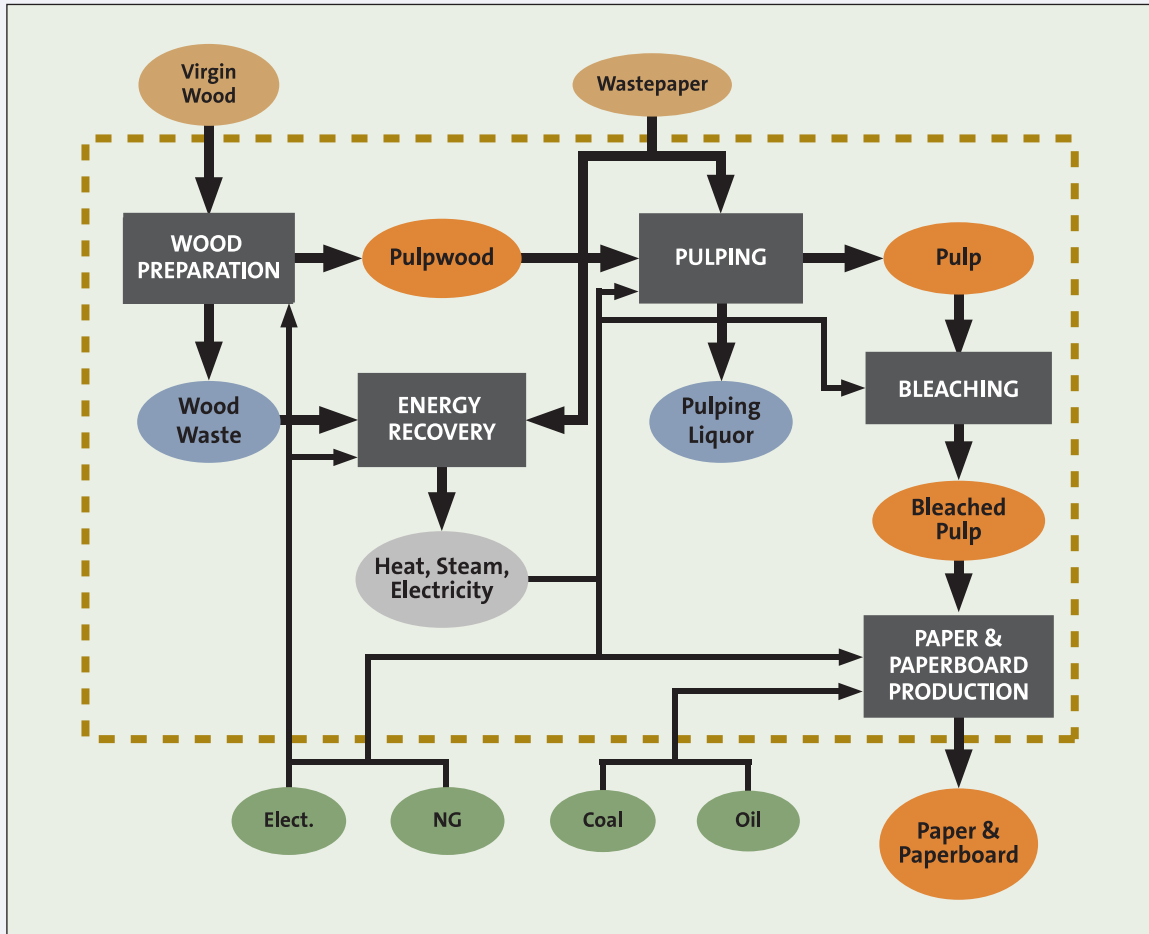
Pulp mills can stand alone or be part of integrated mills, which share common systems of generating energy and treating wastewater, eliminating the transportation costs for acquiring pulp.

produce converted paper products at the same locations. Pulp mills can stand alone or be part of integrated mills, which share common systems of generating energy and treating wastewater, eliminating the transportation costs for acquiring pulp. Early in the 1980s, 40 percent of the paper mills and 33 percent of paperboard mills were integrated with pulp mills. That number fell in the early 1990s, but more recently the industry has moved again towards integrated mills, perhaps due to the shut-

down of non-integrated mills.[266]

Figure 7-3 compares the production of the paper and paperboard segments. Production of both types of products grew steadily from 1965 to 1999, though paperboard production grew at a faster rate than paper. After peaking in 1999, production levels started a downtrend trend, accelerating in 2001 before rising again slightly from 2004 on. U.S. paper and paperboard production fell by 4.9 percent from 1999 to 2006, an

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[267] Ibid. 1.

average loss of about 0.7 percent per year. This contrasts with an average rate of production growth of 2.3 percent per year during the 1980s and 2.4 percent per year during the 1990s.[267]

Paperboard production has continued to fare better than paper production. Its share of total paper and paperboard production—55 percent in 2006—has grown modestly relative to the output of paper mills. Paper production has stayed more or less level around 40 to 42 million tons since 2001, though it remains 9 percent less than its peak in 1999. Production of certain grades of paper such as newsprint, Kraft papers (unbleached and bleached), uncoated free sheet papers, and bleached bristols has continued to descend after sharp losses in 1999.[268] Meanwhile, in 2006, paperboard production reached its highest level since 1999, and was 1.2 percent below the peak year's output.[269]

Increasing globalization and international competition have been a factor in the decline of production output for some paper and paperboard products. The growth of electronic communications (Internet) and alternative advertising media, also has had an impact on newsprint and printing-writing papers output. Reusable shipping containers and the offshoring of manufacturing could cut into containerboard production and flexible packaging and the movement of capacity offshore have hurt domestic packaging grade production.[270]

The chart also illustrates the growing importance of recovered paper (wastepaper) in the production of paper and paperboard. After slowly growing through the 1980s, wastepaper recovery and utilization in paper and paperboard production grew sharply during the 1990s. The recovered paper utilization rate—the amount of recovered paper consumption relative to the total production of paper and paperboard—rose from around a little under one-quarter in 1970 percent to 37 percent in 2006.

Climate Policy on Paper and Paperboard

Paper manufacturing is both one of the most capital- and energy-intensive industries in the economy, and paper and paperboard mills are the most energy-intensive and largest energy consumers of all the segments in this sector. The paper and paperboard industry ranks among the top three industries in the study with

Paper manufacturing is both one of the most capital- and energy-intensive industries in the economy, and paper and paperboard mills are the largest energy consumers in the sector.

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[268] AF&PA, *2007 Annual Statistics*, 1.

[269] Newsprint production, which accounts for 13 percent of total paper production/shipments, has been reduced by 28 percent between 2000 and 2006. Other grades, such as tissue papers and special industrial and packaging papers, however, have enjoyed gains in production. Source: AF&PA, *2007 Annual Statistics*.

[270] Source: AF&PA, *2007 Annual Statistics*.

[271] Walker and Cenatempo, "State of the North American Pulp & Paper Industry."

Figure 7-3

Paper & Paper and Paperboard Production* (NAICS 32212,3), 1965-2005
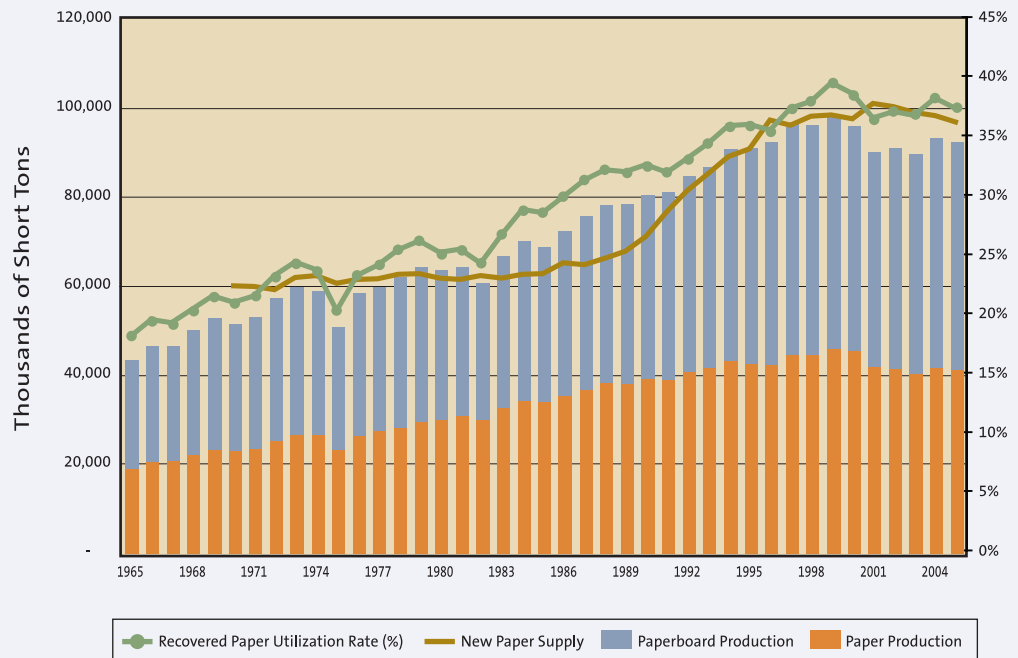
Source: AF&PA

* Includes Wet Machine Board and Construction Grade

Legend: Recovered Paper Utilization Rate (%) — New Paper Supply — Paperboard Production — Paper Production

THE INDUSTRY HAS
SEVERAL TECHNOLOGY
INVESTMENT OPTIONS
AVAILABLE FOR
REDUCING THEIR
ENERGY COSTS AND TO
MITIGATE OR OFFSET
THESE [CLIMATE
POLICY-INDUCED]
IMPACTS.

regard to potential climate policy impacts on its production costs, operating surplus and profits. It would see the third largest increases in production costs among the industry group analyzed, and the second largest reductions in operating surpluses (profits), under the Mid-CO_2 Price Policy. In the worst case, many plants could start to feel pressures to contain their costs. On the other hand, the industry has several technology investment options available for reducing their energy costs and to mitigate or offset these impacts, perhaps within the decade after a climate policy goes into affect, if the right supporting policies and incentives are in place.

PRODUCTION COST STRUCTURE (BAU).

Figure 7-4 illustrates the production components cost trends for the BAU reference case. These constitute the baseline for assessing the II-CPM simulations of the Mid-CO_2 Price Policy impacts on the industry.

Materials costs. Real unit materials costs account for the largest share of production costs, but was projected to fall steadily in absolute terms over the policy period (2008-2030), to a little over half their 1992 level by 2030. However, these costs remained roughly two-thirds of total production costs through 2006. According to projections, they would rise to around 70 through the mid-

2020s, and then fall back to two-thirds, by 2030.

Labor costs. Real unit labor costs fell steadily in the historical period (1992-2008); in 2006, they were only two-thirds what they were in 1992. Based on the historical trend and feedback from industry experts, the II-CPM model projected labor costs to continue to fall in absolute value to a little over one-third their 1992 levels, by 2024, where they would stay through 2030. Labor costs also would fall relative to total production costs. From 1992 through 2006, they would account from between one-fifth to one-quarter of total costs, but after 2006 they would fall to around 15 percent by mid-2020s through 2030, according to II-CPM projections.

Energy costs. Real unit energy costs in the BAU scenario fluctuated between 20 percent below to 10 percent above their 1992 levels, through 2004, rising to between 20-40 percent above, over the next six years. They then were projected to fall back to about 10 to 20 percent above 1992, through 2030. Energy would account for only 9 percent of total production costs through 2000. This number would rise to 14 percent by 2006, where it was projected to stay until the early 2020s. By 2030, however, this share was projected grow to one-fifth of total costs. These trends reflect expectations of increasingly expensive energy relative to other costs, even without a climate policy.

The rise in energy's importance as a cost

FIGURE 7-4

PAPER & PAPERBOARD REAL UNIT PRODUCTION COST COMPONENTS, BUSINESS AS USUAL, 1992-2030

Source: HRS-MI

factor is also shown when energy costs trends are compared to materials and labor costs. The energy to materials cost ratio rises from a little over one-tenth to one-fifth by 2006, and was projected to grow gradually to nearly 30 percent by 2030. The energy to labor cost ratio shows a much sharper shift between the two factors. Energy costs were only about 40 percent labor costs in 1992; by 2006, they would be three-quarters the cost of labor. Energy and labor costs would be roughly the same by 2015, but the former would rise to nearly one-fourth greater than the latter by 2030, according to the II-CPM simulations.

Energy share of costs.

Over half the energy employed in papermaking comes from steam and other energy used to produce heat and power, or used as feedstock/raw material inputs. Steam, mostly generated internally and as a byproduct of heating processes, primarily is used in paper drying, but it is also used for pulp digesting and other uses. Electricity, much of which also is internally generated, is used to run equipment such as pumps and pans, and to light and cool buildings.

If the Mid-CO_2 Price Policy was enacted, the II-CPM simulations show that energy costs as a share of total production costs in the paper and paperboard industry would grow substantially, in absolute terms, relative to other production cost factors, and relative to BAU. The energy share of total production costs would rise to 18 percent in 2020, and 26 percent in 2030 (see Table 7-B). The ratios of energy costs to labor costs and to materials costs would both jump by 27 percent above BAU in 2020, and 45 percent above BAU in 2030.

Energy and production cost impacts.

Table 7-B
Production Costs, Energy Share, and Energy Cost Components Paper and Paperboard Industry

Item	2006	2020		2030	
	Value	Value	% above BAU	Value	% above BAU
Production Costs (USD 2000/ton)					
BAU	521	422	—	353	—
Mid-CO_2 Price Case Above BAU	—	17	4.0	31	8.7
Energy Share of Production Costs (Percent)					
Mid-CO_2 Price Case	13.8	18.2	3.3	25.7	6.5
Energy Cost Components (USD 2000 per ton)					
Mid-CO_2 Price Case:					
Total Energy Costs	72	80	26.9	98	45.3
Fuel Costs	46	53	39.0	70	64.8
Electricity Costs	26	27	8.6	29	13.1

Paper & Paperboard Production Costs, Mid-CO$_2$ Price Case Above BAU Energy Cost Components, 2012-2030
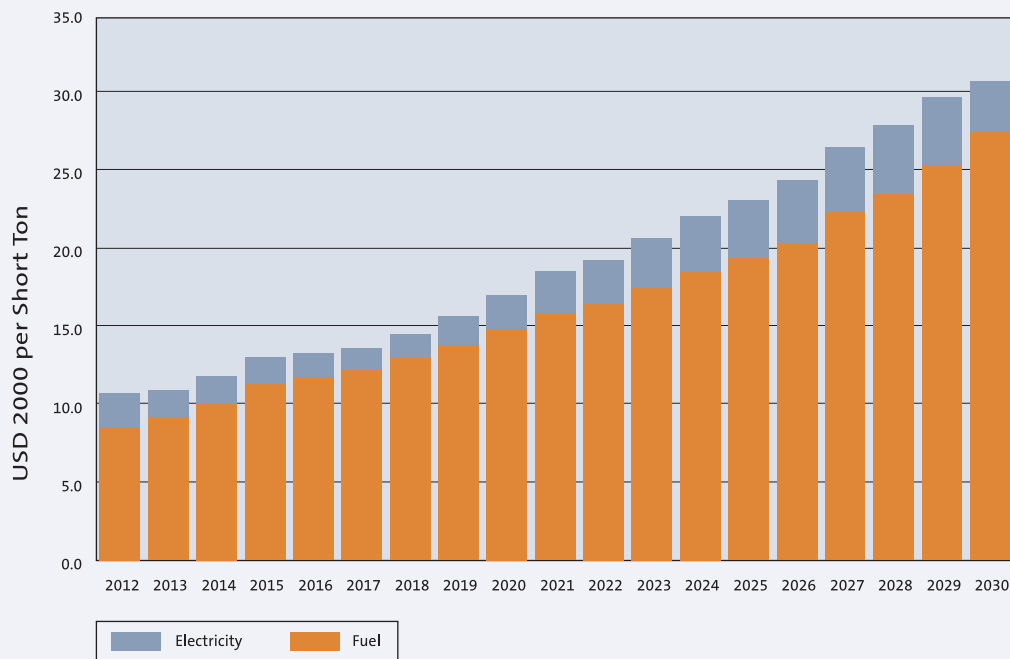
Source: HRS-MI

Figure 7-4 illustrates the total additional cost increments that would be added to the BAU production costs resulting from higher energy prices under the Mid-CO$_2$ Price Policy. As Table 7-B shows (see also Figure 3-1), the II-CPM simulations projected real dollar (USD 2000) increases in the paper and paperboard industry's production costs if the Mid-CO$_2$ Price Policy was enacted. Under the policy case, real unit production costs would increase by $17 per ton of paper and paperboard product or 4.0 percent above BAU in 2020, rising to $28 percent or 6.5 percent above BAU by 2030. The above assumes that the industry has made no investments in energy efficiency or other cost cutting measures.

Table 7-B and Figure 7-5 (see also Figure 3-2) show the role of different fuel types and their price variations under the policy case in raising the industry's production costs. Fuel (natural gas, fuel oils, coal) cost increases clearly account for most—about 90 percent—of the total energy cost increases in the policy case. The cost of fuels used in paper and papermaking for heat and power accounted for 64 percent of the cost of total energy consumption in paper and paperboard production in 2006. These costs would grow to 66 percent of total energy costs—39 percent above the BAU fuel costs—in 2020, and to 71 percent of total energy costs—65 percent above BAU— in 2030. Electricity costs, which would only rise 13 percent above BAU by 2030, would fall from 36 percent of total energy costs in

THE COST OF FUELS USED IN PAPER AND PAPERMAKING FOR HEAT AND POWER ACCOUNTED FOR 64 PERCENT OF THE COST OF TOTAL ENERGY CONSUMPTION IN PAPER AND PAPERBOARD PRODUCTION IN 2006.

Figure 7-6

Paper & Paperboard Real Unit Production Costs, Compared to Domestic Market Price

Source: HRS-MI
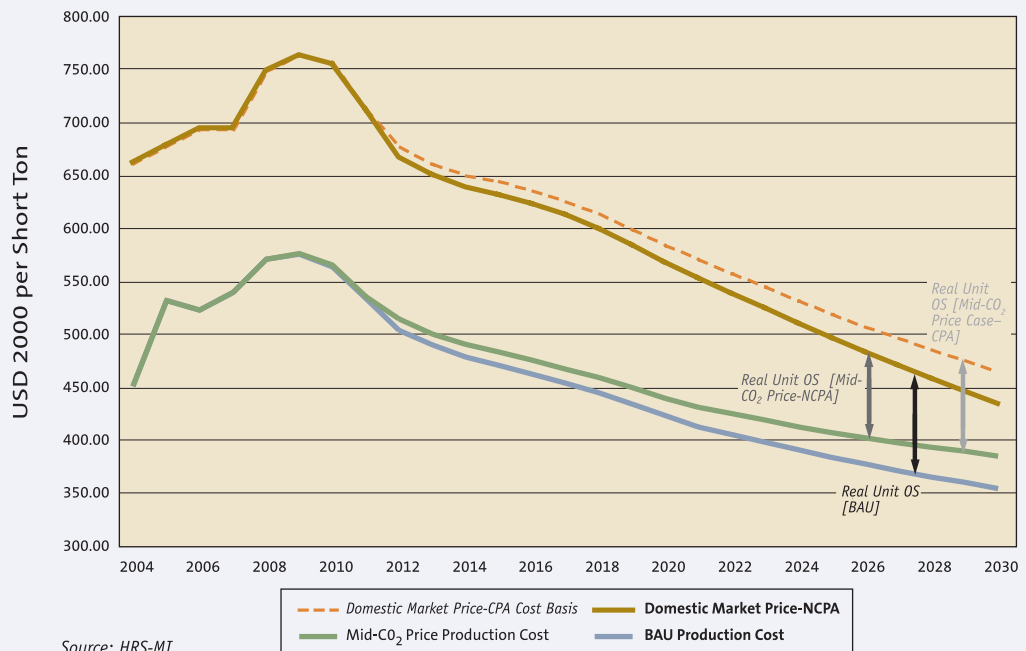
2006, to a projected 29 percent in 2030.

Operating surplus and margins (NCPA).

The II-CPM simulations of the paper and paperboard industry, assuming the industry cannot or will not pass costs along (NCPA) and will not invest in energy efficiency, predicts the operating surplus would decline, especially after 2020, under the Mid-CO_2 Price Policy. Figure 7-6 shows that by 2020, if not earlier, the cost curve for the policy case would begin to cut deeply into the operating surplus—the difference between the projected market price and projected production costs—in the BAU case. Based on data provided by Global Insights, the market prices are projected to fall substantially relative to earlier years, and especially from 2008-2009 on, in the BAU case. The BAU operating surplus and margin would shrink correspondingly.

These projections therefore portray a situation in which the industry's operating surplus and margins already would be increasingly squeezed under business as usual conditions. Additional costs under the Mid-CO_2 Price Policy would be somewhat harder to absorb than if market prices were more robust. Moreover, the extra costs would cut more deeply into the operating surplus, and the operating surplus decline would be greater relative to BAU. Consequently, the II-CPM projects that the relatively modest production cost increases for the paper and paperboard industry (see Table 7-B) would translate into a fairly substantial operating surplus decline relative to BAU of nearly 12 percent by 2020, and a large reduction of 38 percent by 2030 (see Table 7-C and also Figure 3-2), if no investments in energy efficiency are allocated and if a climate policy is enacted in the United States only.

The industry's operating margins also would shrink. The BAU operating surplus would decline from a little over one-quarter of total revenues in 2020, to less than one-fifth in 2030, reflecting declining market prices relative to production costs. The Mid-CO_2 Price Policy would reduce the operating margin even more, to 11 percent of revenues, or close to 7 percent less than BAU. This level of operating surplus and margin declines would translate into potential reductions in profitability, resulting in some paper and paperboard mills seriously contemplating their options to reduce costs.

Early actions to contain costs may be possible, as paper industry experts expressed their concerns to us that that the industry's profit margin (after taxes) historically has tended to be very slim, in the 2 to 4 percent range, though it was nearly 7 percent in 2006. In addition, since paper mills usually shut down paper machines if they aren't running at nearly fully capacity, production losses may be greater under deteriorating business conditions—i.e., declining market prices and demand—compounded by rising energy costs that affect only U.S. papermakers.[271]

Operating surplus and market shares (CPA). If paper and paperboard mills were able and willing to pass along all additional policy-driven energy costs to sales prices (CPA), Table 7-C shows that operating surplus reductions relative to BAU would be very much smaller in the NCPA case—i.e., less than 4 percent (cost basis) by 2030. Although unit cost operating surplus would not decline in the cost basis CPA case,

the industry's diminished market shares compared to BAU—1.5 percent less in 2020 and 3.6 percent less in 2030—and associated cuts in domestic sales, would translate into a modest decline in operating surplus. But as Table 7-C indicates, the paper and paperboard industry has enjoyed a domestic market share—about 80 percent—that is higher than that of the iron and steel and aluminum industries, but more vulnerable than the chemicals industries. The losses predicted by the II-CPM simulations would reduce market shares to a level within the industry's historical market share trends. Although the industry's imports exceed exports, this gap is smaller than in other U.S. industrial sectors, including iron and steel and aluminum.[272]

Paper markets, prices and CPA.
As in other industries, market driven materials or energy costs, especially if they are widely shared internationally, would likely be passed along in higher market prices. For example, surges in crude oil and

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[272] Matt Wickenheiser. "Modest recovery on the horizon for paper mills ; Foreign competition and fiber shortages loom, but market prices are rising and one company is rehiring workers," *Portland Press Herald* (Maine), February 1, 2004. *HighBeam Research,* http://www.highbeam.com (accessed February 8, 2009). Paper mills commonly shut down totally if their paper machines are not running at 90 percent capacity or greater, until market conditions improve. This is similar to the practices of capital-intensive industries such as steel.

[273] Matt Wickenheiser, "Modest recovery on the horizon."

natural gas prices were partly responsible for a sharp rise in paper prices in the spring and summer of 2004.[273] At the same time, price increases also were fueled by expanding paper demand associated with a business cycle-related expansion in manufacturing, which drove up demand for packaging paper, and advertising and marketing that revived printing paper demand. As demand grew, shrinking domestic production capacity—estimated at a 1 percent annual rate—and a weakening dollar, helped to further accelerate the growth in prices.[274] This trend continued through mid-2008, dampened only by the loss of demand for newsprint to digital (Internet) media. Under these strong market conditions, U.S. paper

manufacturers might more easily be capable of passing through added energy costs.

On the other hand, in a weakening market environment, the paper and paperboard companies may be constrained in their ability to pass through the additional policy-driven energy costs, especially if these costs only affect U.S. manufacturers, putting them at a disadvantage in global markets relative to lower-cost foreign producers. Industry experts told us that they believed that except possibly in high-end niche paper markets, most paper and paperboard mills would probably not pass along the additional costs. The McKinsey/Ecofys study of the European Union's Emission

On the other hand, in a weakening market environment, the paper and paperboard companies may be constrained in their ability to pass through the additional policy-driven energy costs.

Table 7-C

Operating Surplus, Operating Margin, and Market Shares Paper and Paperboard Industry

Item	2006	2020 Value	2020 % above BAU	2030 Value	2030 % above BAU
Operating Surplus (Million USD 2000)					
BAU	16.0	14.9	—	8.4	—
Mid-CO$_2$ Price Case Above BAU:					
NCPA	—	-1.7	-11.7	-3.2	-38.4
CPA [Cost Basis]	—	-0.2	-1.6	-0.3	-3.7
Operating Margin (Percent)					
BAU	24.8	25.6	—	18.5	—
Mid-CO$_2$ Price Case:					
NCPA	—	22.6	-3.0	11.4	-7.1
CPA [Cost Basis]	—	24.8	-0.7	17.2	-1.2
Domestic Market Share (Percent)					
BAU	79.8	84.4	—	84.4	—
Mid-CO$_2$ Price Case:					
CPA [Cost Basis]	—	82.9	-1.5	80.8	-3.6

NCPA=No Cost Pass-Along; CPA=Cost Pass-Along

[274] "Energy costs spurring paper price increases (Market Watch)(Brief Article)," *Graphic Arts Monthly*, Reed Business Information, Inc. (US), June 1, 2004. *HighBeam Research*, http://www.highbeam.com, (accessed February 8, 2009).
[275] "Mills planning to raise paper prices this year (Market Watch)," *Graphic Arts Monthly*, Reed Business Information, Inc. (US), June 1, 2004. *HighBeam Research*, http://www.highbeam.com, (accessed February 8, 2009).

Trading System's impact on manufacturing industries (see Chapter Two and Appendix A), estimated that the industry would pass along in the range of zero to 20 percent of additional costs depending on the grade of paper.[275]

Ultimately, the domestic paper and paperboard industry has been squeezed by global competition in a market characterized by growing overcapacity, which would keep prices low. For example, in 2008, NewPage Corporation closed its Kimberly Mill plant in Wisconsin, which produced wood-free printing paper, in response to a surge of non-Canadian imports into the United States.[276] The global paper industry increasingly is characterized by the commoditization of paper and paperboard products, resulting in more standardized products at a cheaper cost. Competition also is increasingly based on price,[277] rather than quality, which advantages low-cost foreign producers.

The financial crisis and rapidly worsening economic recession since mid-2008 have since created very poor market conditions for the pulp, paper and paperboard industry resulting in a growing number of slowdowns and curtailed production.[278] Both paper and paperboard prices have fallen in response, though they have lagged the decline in input costs (resins, coatings, pulping chemicals, wood fiber (chips) energy, and wastepaper), which provided a little relief for profits that nevertheless have suffered because of sharply declining demand and shipments.[279] However, even if and when the

global economy starts to recover, domestic paper and paperboard manufacturers may still face declining demand and prices as emerging economies, such as Indonesia, Brazil, and China continue to build up their paper and paperboard manufacturing capacity.[280]

This tracks well with the declining market price scenario projected by the II-CPM simulations. Real market prices per ton of paper and paperboard have fluctuated since 1992, and they were projected by the model, drawing on Global Insight data, to rise to a peak of $763 in 2010. Nevertheless, the historical data shows that overall market prices had been trending downwards since 1992. The model then projected that these prices would fall in the years after, to $400, almost half the 1992 level, by 2030. Under these conditions, domestic paper and paperboard mills would find it increasingly difficult to pass along geographically defined cost increases, such as those associated with the climate policy, and the industry may

THE DOMESTIC PAPER AND PAPERBOARD INDUSTRY HAS BEEN SQUEEZED BY GLOBAL COMPETITION IN A MARKET CHARACTERIZED BY GROWING OVERCAPACITY, WHICH WOULD KEEP PRICES LOW.

[276] McKinsey/Ecofys, *EU ETS Review*.

[277] "Assistance for NewPage Workers Okayed, Rep. Petri Says," *US Fed News Service,* Including US State News, HT Media Ltd., August 27, 2008. *HighBeam Research,* http://www.highbeam.com (accessed February 8, 2009). According to the Pulp and Paper Products Council, these imports grew from 650,000 tons in 2000 to 1,200,000 tons in 2007, while over the same interval, domestic demand has been flat.

[278] Kathy Buckman Davis, "Shaping the paper industry's future," *Pulp & Paper,* Paperloop , Inc., May 1, 2002. *HighBeam Research,* http://www.highbeam.com (accessed February 9, 2009).

[279] "Domtar to permanently close Lebel-sur-Quevillon pulp mill," *PR Newswire,* PR Newswire Association LLC, December 18, 2008. *HighBeam Research,* http://www.highbeam.com, (accessed February 8, 2009.

[280] "Fitch: Paper & Forest Products - Challenges Ahead in 2009," *Business Wire,* December 12, 2008. *HighBeam Research,* http://www.highbeam.com, (accessed February 8, 2009).

[281] Matt Wickenheiser, "Modest recovery on the horizon."

consequently suffer the operating surplus reductions estimated for the NCPA scenario.

Technology and Policy Options

Based on *Annual Survey of Manufactures* industry data, annual new capital expenditures between 1992 and 2006 were the largest in absolute terms and as a share of revenues compared to the other energy-intensive industries in the HRS-MI study. This may reflect the greater capital-intensity of the paper industry compared to the other industries. Despite this trend, critics have claimed that the industry has not sufficiently invested in modernizing its plants. Moreover, capital expenditures as a share of total value of shipments have fallen for the industry—as it did for all the others—from nearly 10 percent in 1992, to only 4 percent in 2006.

As industry expert Kathy Buckman Davis has noted, while "paper machines have gotten larger and faster, and efficiencies have increased with incremental improvements, the fundamental papermaking process is the same as 100 years ago." To remain competitive in the increasingly global market environment, the domestic paper industry needs to fund new research and invest in piloting developments to explore how this should change, even as it continues implementing incremental improvements,

to maintain competitive over the next 5 to 10 years. But as Davis observed, "The highly capital intensive nature of making paper with today's methods in itself creates a high barrier to adapting new technologies, yet it is a barrier we must overcome if we are to remain competitive."

The industry's ability to develop and adopt new technologies, however, has been greatly weakened by the shedding of research departments within paper companies, and a corresponding loss of innovation capacity in the industry's supply chain and other supporting research organizations.[281] The challenge to make these improvements would be even greater with rising market-driven and policy-driven energy cost increases. On the other hand, many mills are expected to retire much of their aging technology over the next decade or two, creating an opportunity for new investments in advanced energy-saving technologies and processes.

Energy efficiency requirements.

Figure 7-7 illustrates that substantial energy efficient gains in the consumption of fuel energy in paper and paperboard manufacturing would be required to offset the additional costs from the Mid-CO_2 Price Policy, assuming no costs could or would be passed along to consumers. Fuel costs energy savings requirements would be substantial; it would rise from nearly 17 percent in 2012, the year the policy would go into effect, to 29 percent, by 2020. Electricity requirements would be more modest, but not insignificant, rising from 8 percent to 10 percent between 2012 and 2030.

Fuel energy is used for heat and power in every step of the papermaking process, from pulping through papermaking. It also is used to produce process steam used in

[282] Davis. "Shaping the paper industry's future."

Figure 7-7

Paper & Paperboard Industry – Cumulative Yearly Energy Efficiency Gains Required to Offset Climate Policy Costs

Data Source: HRS-MI
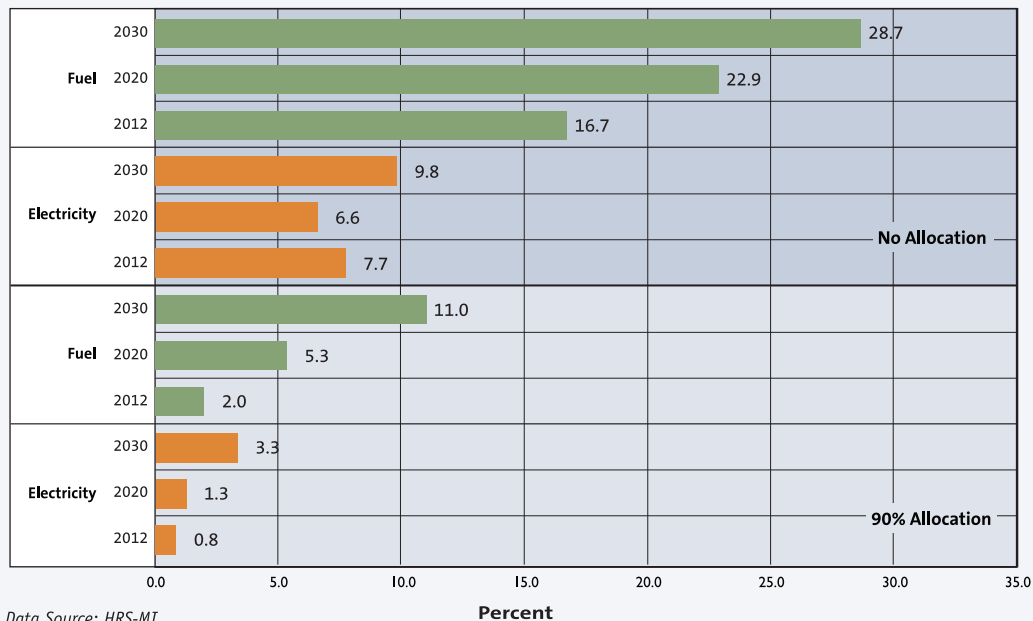
paper and paperboard production, especially in the drying process, though much of the steam consumed in kraft mills, is generated from the combustion of black liquor in the recovery boiler. Electricity is used to power the numerous fans, conveyors, pumps, and miscellaneous mechanical drive systems employed throughout the paper manufacturing process and facilities, but also for various steps in the papermaking stage.[282]

Over half the heat and power currently used in paper, paperboard and pulp production is generated onsite. Paper mills burn renewable biomass fuels for heat and power, in particular wood processing waste and other wood residuals from the wood chip feedstock and spent black liquor produced by the kraft chemical recovery. The kraft chemical process accounts for

about 80 percent of total U.S. pulping capacity. Making the gains required to offset the additional costs associated with fuel consumption therefore would require finding alternative, low-energy means for generating both steam and electricity, including greatly improving onsite generation of heat and power.

Technology options. The most promising new energy-saving technologies in papermaking, for meeting the energy-efficiency requirements, include black liquor gasification, new, energy efficient drying technologies, biomass energy projects ("biorefineries"), and recycling.

Black liquor gasification. Black liquor is a byproduct of the kraft chemical pulping process. Half the mass of wood is converted to usable fiber, the other half along with

The most promising new energy-saving technologies in papermaking include black liquor gasification, new, energy efficient drying technologies, biomass energy projects ("biorefineries"), and recycling.

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[283] DOE/ITP, *Profile of U.S. Pulp and Paper,* 70. For example, the DOE reports that the refining, screening, forming, pressing, and finishing operations in the papermaking stage of paper manufacturing rely entirely on electricity.

an equal amount of spent caustic cooking chemicals forms black liquor, which can be a low-grade fuel. Currently, the liquor is burned in large boilers (Tomlinson boiler) to recover energy in the form of steam, and recover cooking chemicals in the form of molten salt. Although the recovery boilers have become progressively more sophisticated since they were first used in 1930s, they are still thermally inefficient compared to coal or gas-fired power-producing boilers. Gasified black liquor can be burned in a gas turbine to produce electricity, and hot exhaust gas is then passed through a heat exchanger to produce steam for a power producing steam turbine; i.e., a combined cycle operation. Since gas turbines are more thermally efficient than steam turbines, gasification combined cycle operation can generate more electricity than combustion using the same fuel. This increase is great enough to make an integrated pulp and paper mill into a net exporter of electricity.

The American Forest and Paper Association (AF&PA) predicts that black liquor gasification (BLG) may be applied within the timeframe of this analysis in the United States, with the first mills in Europe projected to be operating with BLG by 2015. This would raise the average

energy efficiency by 10 to 20 percent, representing a savings of 300 PJ by 2025 to 2030. However, it believes that the benefits of gasification may not be adequate to promote retirement of existing conventional equipment before the end of their useful life. Aside from technical uncertainties, the AF&PA notes the prohibitive costs of the technology, especially in light of the capital constraints of the industry. For example, black liquor gasifiers can cost $300-500 million each, compared to $100 million for new recovery boilers. Therefore no significant penetration is thought to be likely as early as 2015 to have much impact on the industry's global energy use and GHG emissions.[283]

On the other hand, since more than 125 recovery boilers in North America are expected to reach their useful life over the next 10-15 years, these boiler can be replaced with the more profitable gasifiers if technical, regulatory, and economic hurdles can be overcome.[284] According to the IEA, demonstration gasifiers without a combined cycle have been installed or are being built at several pulp mills in the United States and Sweden. The gasifier still has some reliability problems, however, and the use of a gasifier with a gas turbine has not yet been demonstrated.[285]

Advanced paper drying systems. Drying is the most energy intensive step in papermaking. It consumes about 25-30 percent of total energy used in the pulp and paper industry. Energy is needed to remove the water used to process the fibers in the production of paper from pulp. There are several technologies with the potential of improving the efficiency of paper drying. According to the IEA, the technical potential to reduce energy use have been identified in many countries, with cost-effective

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[284] AF&PA email note, February 13, 2009.
[285] "Black liquor" background paper. Email from United Steel Workers International Union official, October 20, 2007.
[286] IEA, *Energy Technology Perspectives,* 425.

potential of from 15 to 20 percent. This includes small incremental improvements in machines and steam and motor systems. Also major improvements for paper machines, such as the long-nip press for paper machines, process integration of the steam system and heat recovery are also possible.[286] These include new process designs with a focus on more efficient water-removal techniques by a combination of increased pressing with thermal drying (the long nip press, the Condebelt design, or impulse drying). Although some technologies, such as the Condebelt process have been commercially installed, others, such as impulse-drying are still under development.[287]

Biomass energy generation. Biomass energy generation is another promising technology. As a study sponsored by the National Commission on Energy Policy reports, "For the U.S. pulp and paper industry to flourish, an essential ingredient is for it to transform itself into a proactive, sustainable biomass industry that not only produces its traditional pulp and paper products but also produces other products, such as transportation, electricity and intermediate hydrocarbon products for production chemicals and fertilizers."[288] The Flambeau River Papers plant is on its way towards becoming one of the first such integrated pulp and paper mills that also is a biorefinery (see Box 4). This approach not only allows the efficient use of black liquor, but other biomass fuels such as bark and wood chips. Each of these fuels can be used to produce synthesis gas, which after cleaning, can be combusted in a gas or combined-cycle turbine with high electrical efficiency.[289] The AF&PA reports that only a handful of biomass energy projects are under development, in pilot or early commercialization phase. It estimates that after successful demonstration, it would take about 3 to 5 years to build commercial scale plants, and about 5 to 7 years away before large amounts of energy production would be possible. However, the rate of adoption cannot be determined at this time, and it could take as long as 20 years before widespread deployment, depending on the availability of financing.[290]

THE FLAMBEAU RIVER PAPERS PLANT IS ON ITS WAY TOWARDS BECOMING ONE OF THE FIRST SUCH INTEGRATED PULP AND PAPER MILLS THAT ALSO IS A BIOREFINERY.

[287] Ibid., 426.
[288] IEA *Energy Technology Perspectives,* 427. The IEA reports that the first commercial installations of Condebelt technologies were in Finland, Korea. In contrast, impulse drying development started in 1980s and is progressing slowly, but no commercial system has yet been developed. Impulse drying improves the mechanical de-watering of paper and reduces the amount of water that needs to be removed in the drying process
[289] Rezaiyan, "Domestic Energy Parks," 3.
[290] IEA, *Energy Technology Perspectives,* 425
[291] American Forest & Paper Association (AF&PA), "Comments on IEA Indicators and Scenarios for the Pulp and Paper Industry." Written comments sent in email message from AP&FA staff, March 11, 2008.

Box 4

Flambeau River Papers and Other Examples

The Flambeau River Papers[292] story illustrates that with the right vision, strategy, entrepreneurship, and government assistance, even outdated paper mills could make a successful transition towards energy self-sufficiency. The Park Fall's paper mill was built in 1896, alongside the Flambeau River, deep in the forests of Northern Wisconsin. The Park Mill plant employed 300 workers, in a town of less than 3,000. The mill had been struggling for a long time. It used the largely outdated and expensive sulfite pulping process and its equipment was antiquated and in need of repair. Its three holder paper machines produced 420 tons per day (tpd) of coated paper using 140 tpd of hardwood sulfite pulp, 80 tpd of recycled paper and 120 tpd of direct entry clippings or purchased pulp.

In the mid-2000s, higher energy prices combined with strong international competition and stagnant demand forced the mill's then owner, Smart Papers, to go into bankruptcy. The mill's energy costs had escalated from $400,000 a month to $1.4 million a month. Concerned about the "terrible impact of the closure on the loggers and other businesses that depend on the mill," not to mention 300 of the town residents who would lose their jobs, William "Butch" Johnson, owner of Johnson Timber, went about trying to save the plant. Johnson was the primary timber supplier to the mill, with millions of dollars of trees aging on the mill's property.

With a $4 million Wisconsin commitment obtained from the state—aided by Wisconsin Governor Jim Doyle (D), Johnson bought the mill in 2006. The state support included a $2 million loan and $2 million grant, given with the objective of keeping people employed. Johnson also worked with Wisconsin's "Focus on Energy" program and CleanTech Partners (CTP) that helped the mill establish a plan to reduce energy costs and identify emerging technologies. They also assisted in project financing and the permitting process. The plan including implementing a number of energy savings projects, including investing new biomass-energy boilers, with the goal of making the now renamed Flambeau River Papers, the first fossil fuel free, energy independent, integrated pulp and paper mill in North America. There is no problem finding sufficient biomass in the vicinity of the mills. Loggers especially supported the idea because it would clean up slash and underbrush.

The mill's new owners also contracted with CellMark, to provide much of the mill's purchased soft wood pulp and market all of the mill's production. CellMark, a $2 billion paper products company headquartered in Sweden, is the world's largest paper and pulp marketing company. Also helping things along was a major order from the Government Printing Office, which required that the product be made of 30 percent post-consumer wastepaper. The mill is also selling a portion of the lignin produced from its hardwood sulfite line to produce sugarless sweetener, and the rest shipped to other companies for use in oil drilling or as hardener in concrete.

The Flambeau River Papers mill, reopened after just two years, reemployed almost all the original laid-off workers at the same pay and benefits as before. The new owners wanted to retain the workers who understood how the process worked. Many had more than 20 years of experience, and some as much as 40 years. Moreover, the mill has made steps towards becoming the first modern U.S.-based pulp mill biorefinery. Not only would the new biorefinery have a positive carbon impact of about 140,000 tons per

year, it will create an additional 100 new jobs in the Park Falls area.

A major step towards realizing that goal was taken in July 2008, when the U.S. Department of Energy announced that it would provide a grant to Flambeau River BioFuels to construct and operate a first-in-class biorefinery at the existing pulp and paper mill. In full operation, the biorefinery will produce at least 6 million gallons of liquid fuels per year in the form of renewable sulfur-free diesel. It would not rely on food-based feedstock materials, however, but rather on by-products or residuals from forest and agricultural sources. In addition the biorefinery will generate at least 1 trillion BTUS per year of process heat that would be sold to the Flambeau River Papers.[293]

Other Success Stories

There have been other successful attempts to modernize aging facilities and counteract the economic impacts of high energy costs:

- Georgia-Pacific, headquartered in Atlanta, Georgia, one of the world's largest manufacturers and marketers of paper products, purchased the current Old Town, Maine mill in 2000. The mill's history goes back to 1992, where a soda pulp mill was constructed to use the byproduct of a local saw mill. The plant currently employs about 440 people and spends $18 million in the local economy. Overcapacity, remote geographic location, energy and fiber costs made the mill less competitive, resulting in the shut-down of the entire tissue and converting complex in 2003. Although 300 employees retained their jobs in the pulping operation, over 300 workers lost their jobs with this permanent closure.

  However, in May 2003, thanks to creative thinking between the State of Maine, Georgia-Pacific and the United Steel Workers Local 1-080 (then PACE), a plan was generated that allowed the mill to restart more than half the equipment and call back 150 employees from the earlier layoff. The effort involved relocating a biomass boiler from Athens, Maine. Also critical was the training of the operators, technicians and maintenance personnel assigned to the energy saving boiler, with the assistance of the Maine Manufacturing Extension Partnership (MEP).[294]

- A NCEP-sponsored study evaluated the integration of synfuels and power production from biomass and coal in four pulp and paper mills in different regions of the country.[295] Its findings "show that coproduction of liquid transportation fuels, heat and electric power in plants that integrate biomass and coal gasification into existing pulp and paper mills can contribute significantly in moving the nation closer to energy independence." In particular, it claims that the "pulp and paper industry provides an ideal platform for economically viable synfuel production" from biomass and coal. Moreover, it concludes that the industry's infrastructure allows it to harvest and transport biomass at a low cost and the steam and electric power required on-site can be cogenerated using biomass-coal integrated plants.

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[292] Ostle, "Reopened Flambeau River Papers; "Flambeau River Biofuels Gets OK."

[293] "U.S. Department of Energy Awards Flambeau River BioFuels a Grant to Construct First-in-Class Facility for Production of Renewable Diesel to be Co-located at Pulp and Paper Mill in Park Falls, WI," July 15, 2008, http://market-research.typepad.com/fuel_cell_market_report/2008/07/us-department-o.html.

[294] Georgia-Pacific Corp n/k/a Domtar Pulp and Paper, Maine Manufacturing Extension Partnership, "Preserving 122 Years of Papermaking in Old Town, Maine," *Success Stories from the Field,* Manufacturing Extension Partnership, n.d., http://www.mep.nist.gov.

[295] Rezaiyan, "Domestic Energy Parks," vi.

Recycling of wastepaper. The pulping of recycled wastepaper largely uses mechanical energy with chemicals and heat added for greater wet strength. This process is less energy intensive than virgin fiber pulping for some grades of paper and paperboard. However, unlike the chemical (mainly kraft) pulping of wood chips, which generates spent liquor that is recovered and burned to produce internal heat and power (often returning surplus electricity to the grid), recycled paper manufacturers must depend entirely on purchased electricity and fuels, thus losing those energy savings. On the other hand, energy gains that would have gone into pulping in primary paper plants, far exceed the additional energy used in recycled paper plants. The greatest energy efficiency and economic gains may occur, though, when recycled wastepaper pulping capacity is added to existing integrated pulp and paper mills. This allows a greater replacement of virgin wood by wastepaper, saving energy in the pulping process, while using the wood surplus to produce biofuels or electricity.

As reported at the beginning of the chapter, both the wastepaper recovery rate and the recovery utilization rate have grown substantially over the past four decades. The former is now over one-half and the latter is over one-third, the total supply of new paper and paperboard. According to one estimate, the recycling of paper in the United States is at an all-time high, and Americans are recapturing about 300 pounds per person each year.[296] The trends suggest that these ratios are likely to grow in the coming years, and this growth would produce a positive gain in the paper industry's overall energy efficiency. More effective methods of collecting, preparing, and processing recovered paper could be an area of greater industrial and public investment, to help the

industry offset climate-driven energy costs.

Policy options to mitigate impacts. Figure 7-8 presents the results of the II-CPM simulations of the paper and paperboard industry, under the Mid-CO_2 Price Policy, comparing the consequences of a 90 percent allowance allocation policy with no allocation measure (assuming NCPA). As in the case of the other industries we examined in the HRS-MI study, production cost increases and operating surplus decline both would be substantially smaller in the allocation case, illustrating the cost mitigation benefit of that approach, should it be enacted along with the Mid-CO_2 Price Policy.

This obviously would allow paper and paperboard mills time to make incremental improvements, and ultimately larger scale investments in new process technologies that achieve significant energy savings, moving the industry down the path toward energy self-sufficiency, as exemplified by the Flambeau River Papers experience. However, short of such actions, by 2030, the industry would again be experiencing pressures to act to offset rising energy costs associated with the climate policy.

Conclusion

The results of the II-CPM simulations show that the U.S. paper and paperboard industry is potentially vulnerable to rising energy costs under a climate policy, unless policies to mitigate short-to-mid-term cost impacts are enacted and the industry makes investments in energy-saving technologies. Under the Mid-CO_2 Price Policy, between 2012-2030, the industry would see modest production cost increases, assuming no investments in energy-saving technologies

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[296] Knight Ridder Newspapers, "U.S. mills battle Chinese."

are made before then, which would translate into substantial reductions in the industry' operating surplus and operating margin. As a result, paper and paperboard companies' profitability could be cut into sufficiently to stimulate investment in energy efficiency or the implementation of other cost containment actions.

At the same time, the industry has available several advanced energy-saving technology options, which could help alleviate the cost pressures from the climate policy, if they are adopted early enough. These include gasification of black liquor in kraft mills, advanced paper drying systems, biomass energy generation, and improved recovery of scrap paper. Such initiatives not only could reduce industry costs and preserve domestic papermaking capacity, it could make U.S.

paper and paperboard mills more globally competitive and reduce, if not eliminate, their reliance on externally purchased fossil-based energy sources.

Barriers exist however to the successful adoption of these technologies, including technical feasibility, high costs, and the industry's lack of access to capital. Nevertheless, some U.S. paper and paperboard mills have already begun to move in the direction of energy self-sufficiency, lower GHG emissions, and greater competitiveness (e.g., Flambeau River Papers). However, policies such as the 90 percent allowance allocation measure and other federal R&D programs (e.g., a beefed-up DOE Industrial Technology Program) and incentives could enable the industry to make this transition on an industry-wide scale.

THE INDUSTRY HAS AVAILABLE SEVERAL ADVANCED ENERGY-SAVING TECHNOLOGY OPTIONS, WHICH COULD HELP ALLEVIATE THE COST PRESSURES FROM THE CLIMATE POLICY, IF THEY ARE ADOPTED EARLY ENOUGH.

FIGURE 7-8

Paper and Paperboard Production Costs and Operating Surplus, Mid-CO$_2$ Price Policy Above BAU, No Allocation vs. Allocation

HRS-MI

Legend: No Allocation - PC · 90% Allocation - PC · No Allocation - OS · 90% Allocation - OS

Chapter 8
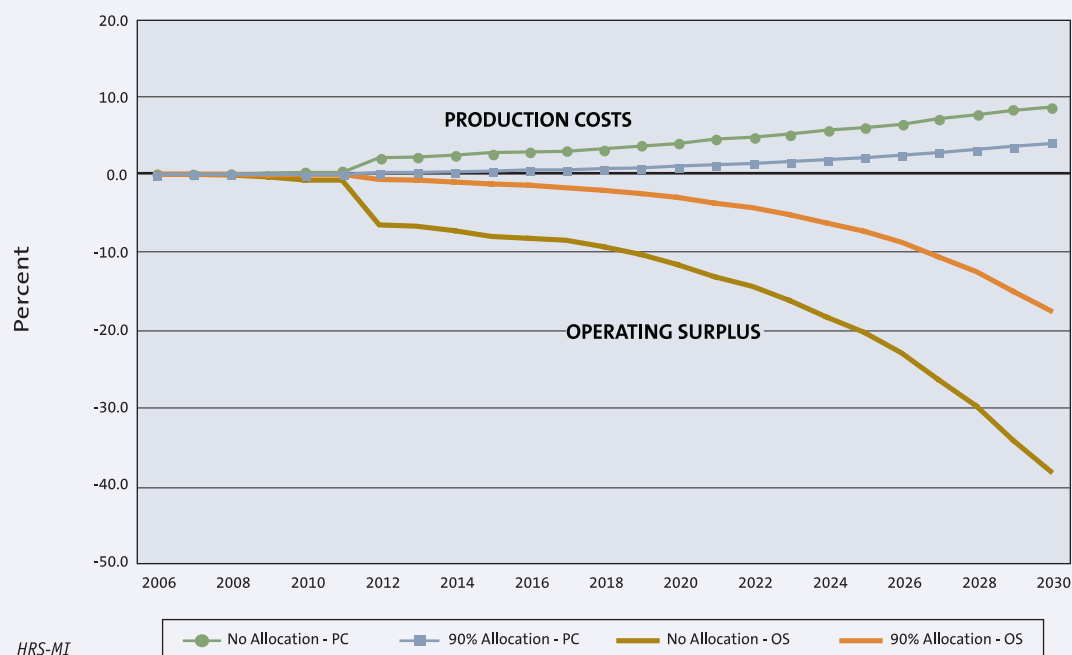
Chemicals Manufacturing— Chlor-Alkali & Petrochemicals

Chemicals manufacturing is one of the largest manufacturing industries in the U.S. economy. In 2006, it shipped a total of more than $637 billion worth of goods and employed 869,000 workers.[297] In 2005, there were over 9,500 firms with 13,200 establishments that manufacture chemical products, located in every state in the union. These include businesses of every size, including 1,425 medium-sized manufacturing plants with 100-500 employees, and 3,405 large facilities with more than 500 employees, which employ more than 85 percent of workers in the industry. Chemicals manufacturing is also the largest exporting sector in the U.S. economy. In 2006, the U.S. chemicals industry exported $135.1 billion and imported $142.8 billion producing a trade deficit of $7.7 billion.[298]

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[297] American Chemistry Council (ACC), *2007 Guide to the Business of Chemistry* (Washington, DC, 2007), 5, http://www. americanchemistry.com.
[298] Ibid.

The chemicals industry produces over 70,000 products used in every sector of the economy. It is a primary supplier of intermediate inputs to agriculture, other manufacturing industries, construction, and service industries, as well as thousands of consumer goods. Major manufacturing sector customers include rubber and plastic products, textiles, apparel, petroleum refining, pulp and paper, and primary metals. It also consumes 26 percent of its own output to produce downstream products that are intermediate goods used in other industries or in end-use products.

The chemicals industry produces over 70,000 products used in every sector of the economy.

Chemicals manufacturing (NAICS 325) has five major divisions.[299] Its largest sector, *basic chemicals* (NAICS 3251), which accounted for more than a third of the total dollar output of the chemicals industry,[300] consists of several smaller industrial sectors. These include *inorganic chemicals* (including alkalies and chlorine, industrial gases, acids and inorganic pigments), *petrochemicals and derivatives* (including organics), and *synthetic materials* (such as plastic resins, synthetic rubber, and man-made fibers).

In the HRS-MI study, we examined two important, highly energy-intensive industries within the basic chemicals sector: *petrochemical manufacturing* (32511) which includes establishments that manufacture acyclic (aliphatic) hydrocarbons (ethylene,

propylene, and butylenes), and cyclic aromatic hydrocarbons (benzene, toluene, styrene, xylene, ethyl benzene, and cumene) made from refined petroleum or liquid hydrocarbons; and, *alkalies and chlorine (chlor-alkali) manufacturing* (325181), comprised of establishments primarily engaged in manufacturing chlorine, sodium hydroxide (i.e. caustic soda), and other alkalies.[301]

Below is a synopsis of some of the principal characteristics of the petrochemical and chlor-alkali manufacturing industries:

Petrochemical manufacturing

Structure and location. According to 2005 Census Bureau data, the U.S. petrochemical industry is comprised of 34 firms with 45 establishments employing nearly 7,400 workers, including 24 large manufacturing facilities with more than 500 employees. About 70 percent of petrochemicals and downstream derivatives are produced in facilities in the Gulf Coast region. Because the refining industry is the major supplier of raw materials for ethylene production, more than 50 percent of all ethylene plants are located at petroleum refineries.

Production and shipments. In 2006, U.S. petrochemical manufacturers produced 127.5 billion pounds and shipped $60.8 billion worth of goods.[302] Ethylene is the largest volume product made by the industry. Others include propylene and benzene. These products are feedstock used in the production of a very large number of derivative chemical products, many in turn used to produce further downstream products that are inputs for many different industries. For example, ethylene is used

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[299] These are basic chemicals, specialty chemicals, pharmaceuticals, consumer products, and agricultural chemicals.
[300] ACC, *2007 Guide*.
[301] See Box 1, Chapter Two. See also Census Bureau, *ASM* (2005).
[302] Ibid.

to produce ethylene dichloride, used in turn to produce vinyl chloride, and then polyvinylchloride (PVC) used in pipes, siding, windows, pool liners and other construction items.

International trade. The U.S. petrochemical industry ended 2007 with a net trade deficit, with 3.1 million metric tons or $2.8 billion worth of imports, exports of 1.5 million metric tons ($1.6 billion) and net imports of 1.6 million metric tons ($1.2 billion). Trade flows between U.S. and Canadian buyers and sellers far outpaced trade with any other country. Canada is an especially large net exporter of petrochemicals to the United States. Other major trade partners include South Africa, Mexico, Norway and Belgium (see Table 8-A).

Chlor-alkali manufacturing

Structure and location. The chlor-alkali industry has 29 firms with 47 establishments employing nearly 7,800 workers, including 25 establishments with over 500 employees.[303] The vast majority of chlorine production takes place in the South, where companies are located to take advantage of low electricity prices and reasonable labor costs. Chlor-alkali plants in the United States are aging. A 2000 Lawrence Berkeley National Laboratory report indicates that most U.S. chlor-alkali plants were 20-25 years old at the time, and some were considerably older.[304]

Production and shipments. U.S. chlor-alkali firms produced 32.5 million short tons valued at $6.4 billion.[305] Chlorine is used in downstream products (e.g. vinyl, phosphene, HCL, solvents), in water treatment and in

other industrial processes, such as in pulp and paper manufacturing. Caustic soda finds applications in the production of organic chemicals, pulp and paper, inorganic chemicals, alumina refining, soaps and detergents, textiles, water treatment, food industry, among others.

International trade. The chlor-alkali industry has a large positive trade balance, with net exports of 7.2 million metric tons, worth $1.1 billion. In both industries, trade flows between U.S. and Canadian buyers and sellers far outpaces trade with any other country. Canada is a net importer of U.S. chlorine and alkaline products. Other major trade partners include Mexico, Brazil, Japan, and Australia (see Table 8-B).

Industry Structure and History

As in other manufacturing sectors, the chemicals industry has undergone restructuring, consolidations, and offshore movements over the past three decades. The share of sales held by the top ten chemicals companies declined from a little under 30 percent in the beginning of the eighties to a little under 22 percent in 1993. This prompted the industry to go through a wave of mergers and acquisitions (M&A) and consolidations, resulting in concentration in the sector to rise back up to the 30 percent range over the past decade.[306]

Consolidation was especially evident in the basic chemicals sector, including

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[303] Census Bureau, *SUSB* (2005).

[304] Ernst Worrell, Dian Phylipsen, Dan Einstein, and Nathan Martin, "Energy Use and Energy Intensity of the U.S. Chemical Industry," *Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory* [LBNL-44314], April, 2000, 31.

[305] Census Bureau, *ASM* (2005).

[306] ACC, *2007 Guide*, 137, see figure 13.11.

petrochemicals and downstream intermediate producers. Overall, between 1998 and 2005, the petrochemical industry lost 7 firms and 13 establishments, including 9 establishments with over 500 employees, corresponding to a net loss of 3,000 jobs, which was a 31 percent drop over this period.[307] The number of U.S. ethylene producers fell from 28 in 1980 to 16 in 2000. The number of "downstream" products, including ethylene dichloride (EDC), styrene and polymers such as PVC (polyvinyl chloride) resins, also declined.[308] In contrast, the chlor-alkali industry saw no change in the number firms; it actually gained in the number of total establishments, including one large plant with over 500 workers. Total employment in this industry grew by 50 percent from 1998, to 7,784 in 2005.[309]

The consolidations were a strategic response by companies to improve their market leadership positions in industries where cost reductions are limited and technological innovations to improve yields are largely incremental in nature. As an American Chemistry Council (ACC) report observed, "size does appear to matter."[310] The classic means for achieving lowering costs is to increase economies of scale. By expanding the scale of their plants and capital requirements, many basic chemicals plants could reduce and spread costs over more units of output. For example, in steam cracking for ethylene, the size of the typical world-scale cracker grew from 1.5 billion pounds in 1990 to 3.1 billion today.[311]

As in other manufacturing sectors, the chemicals industry has undergone restructuring, consolidations, and offshore movements over the past three decades.

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[307] Census Bureau, *SUSB*.

[308] The number of U.S. producers of PVC (polyvinyl chloride) resin, for example, fell from 20 to 13 during the 1980s and 1990s. ACC, *2007 Guide* 137.

[309] Census Bureau, *SUSB*.

[310] ACC, *2007 Guide*, 137.

[311] Ibid. The drivers behind the M&A and consolidation wave included high costs of "greenfield" construction of world-scale capacity compared to expanding existing capacity, growing pressures on profit margins, the low cost of debt at the time, and pressures to assert market leadership.

International Markets

The chemicals industry is highly globalized, characterized by increasing world production and trade volumes and an intensifying competition for markets by producers. The United States and the European Union are the world's largest producers of chemical products. U.S. chemicals exports accounts for 11 percent of the world total exports, and are greater than U.S. agricultural exports and aerospace exports combined. Historically, chemicals exports and imports have tended to track closely together, with exports exceeding imports, producing a net trade surplus up until 2001. From 2002 on, however, imports have outpaced exports, resulting in a net trade deficit of 7.7 billion in 2006. These deficits are the first the industry had seen since at least the 1920s, the earliest reliable trade data available.[312]

Although Canada is source of the largest U.S. imports and exports of chemicals, the largest U.S. trade surpluses are with Mexico and other Latin America/Caribbean countries combined, and the Asia/Pacific region. The largest net exporters of chemicals to the United States include Europe (especially Ireland) the Middle East (except Saudi Arabia), and Russia and other central/eastern Europe nations. On the whole, the U.S. trade position has been deteriorating with most regional blocs. This deterioration has been attributed to a strong dollar, weak demand abroad, and a continuing surge of fine chemical and finished pharmaceutical imports, especially from Western Europe.[313]

But not all chemical subsectors have deteriorated in their trade positions to the same degree. Pharmaceuticals and specialty chemicals have suffered the greatest trade deficits. Basic chemicals, on the other hand, have enjoyed a healthy trade surplus, of $16.5 billion in 2006. Within basic chemicals, though, some industries have had growing trade deficits, while others have enjoyed surpluses. For example, petrochemical imports have outpaced imports for over a decade, while chlor-alkali maintains a strong trade surplus.

The ACC, however, warns about the impact of the declining trade balances for the many downstream manufacturing industries that produce consumer and industrial products that contain chemicals. For example electronics contain chemicals in the form of photoresists, etching chemicals, resins on printed circuit boards, and plastics housing. As a result, the "chemistry may no longer occur in the United States." Other major downstream industries suffering from large and growing deficits include apparel, computers, transportation equipment, textile mill products, plastics and rubber, primary metals, oil and gas, and electrical equipment and appliances. With the loss of markets to overseas competitors, and the shifting of manufacturing operations offshore, especially to China, the ACC notes that the "U.S.-based chemical products

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[312] Ibid., 71.

[313] Ibid., 57-73.

Figure 8-1

Petrochemicals U.S. Imports, Exports and Trade Balance, 1997-2007
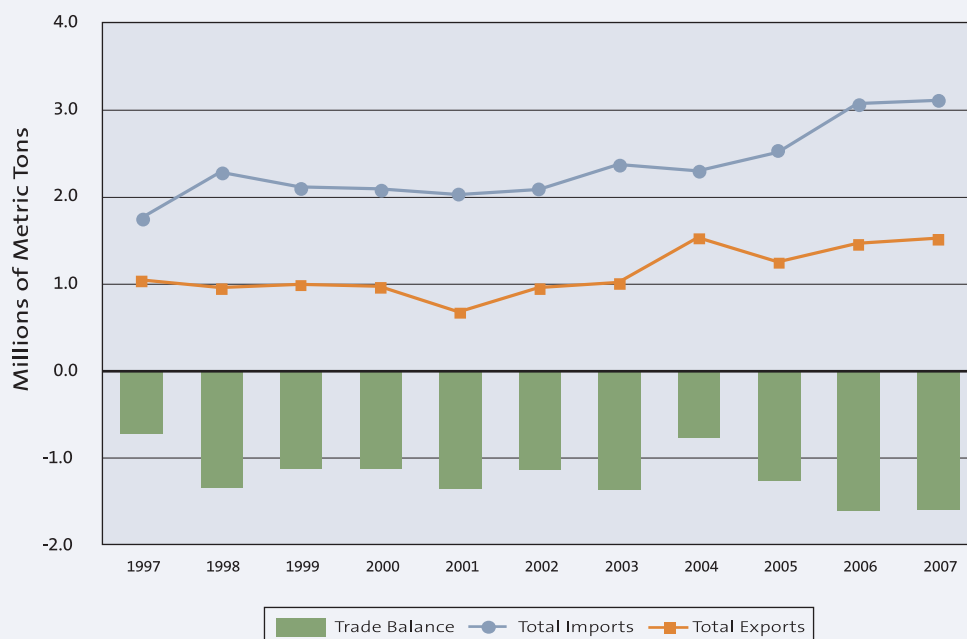
USITC, HRS-MI

that would be used to make those goods domestically are potentially lost," as well.[314]

Petrochemicals. As Figure 8-1 shows, the petrochemical sector has experienced a net trade deficit since at least 1997, with imports growing a little faster than exports over the past few years. In 2007 U.S. petrochemical imports were double the amount of exports, yielding net import trade deficit of 1.6 million metric tons. Canada is by far America's largest trading partner (see table 8-A), accounting for the largest share of U.S. imports, exports and net imports. South Africa is a distant second, followed by Norway, the Netherlands, and United Kingdom as the largest exporters of

petrochemicals to the United States. Other important exporters include Saudi Arabia and Brazil.

As developing and transitioning countries around the world, notably the Middle East (Saudi Arabia) and China, build up their petrochemical capacity, U.S. petrochemical companies will face increasing challenges to their market positions and profitability. The United States, Western Europe, and Japan had long dominated the production of primary petrochemicals, not only supplying their own domestic needs, but also exporting to other parts of the world.[315] In 2000, the United States was the world's largest ethylene producer.

As developing and transitioning countries around the world build up their petrochemical capacity, U.S. petrochemical companies will face increasing challenges.

[314] Ibid., 73.

[315] Global Insight, "U.S. Petrochemicals on a Moderate Rebound Course…for Now!," Perspectives, June 29, 2007, http://globalinsight.com/Perspective/.

A number of world-scale petrochemical complexes have since been built in other parts of the world, especially by countries with vast reserves of crude oil and natural gas, such as Saudi Arabia. More than 50 percent of all new capacity investment in ethylene plants in the next five years is predicted to be in the Middle East.[316] By 2015, the Middle East is projected to surpass Europe in ethylene capacity, rising to 20 percent from 10 percent today.[317] Since these countries have smaller domestic demand, they export a significant share of their petrochemical production. Other countries have also have added petrochemical capacity over the past two decades to support their own growing economies and to export to other countries, including Singapore, the Republic of Korea, China and Taiwan.[318]

The start-up of plants in these and other countries (Thailand, Malaysia, Indonesia, and Brazil) has effectively diminished the export markets available to the United States, making it (and Western Europe and Japan) vulnerable to imports from low-cost producers. China also has been rapidly developing its own petrochemical capacity and Russia is expected to invest in the next few years. China remains a big export market, and its petrochemical demand is expected to continue rising by about 9 percent annually through 2012, compared to only 1.8 percent per year for the United States and Europe.[319] But if it follows the same development pattern it followed with other major manufacturing industries, China may itself become a net exporter.

As a result, the U.S. industry's lower growth rates led to its restructuring over the last two decades. In 2004, the United States, Western Europe, and Japan only accounted for half of world bulk petrochemical production.[320] But as developing nations' capacity comes on-stream there could result a global petrochemical oversupply, significantly eroding prices and U.S. producers' bottom-line.[321]

The U.S. petrochemical industry started to see signs of improvement in 2006. After suffering a slowdown as a result of the U.S. Gulf hurricanes, partly due to end-users rebuilding depleted inventories, the industry's volumes grew in 2007. But high feedstock energy costs and an expected oversupply of petrochemicals on the world market could cause the deterioration of U.S. market conditions in a few years, forcing major U.S. petrochemical firms to reconsider domestic investments or consider movement offshore. As a Dow Chemical executive acknowledges, his company, "and others in the industry are investing and moving production overseas to be closer to the growing markets for our products and where we can supply those same markets with more competitive energy and feedstock supplies."[322]

Chlor-alkali. The trade statistics for the chlor-alkali industry tells a different

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[316] Dow Chemical, "North American Petrochemicals: Walking a tight rope," *News Center*. Speech of Dr. Ramesh Ramachandran, CERI 2005 North American Natural Gas Conference and Calgary Energy Show 2005, March 7 2005, http://news.dow.com/.

[317] "US petrochemical industry takes a backseat in global supply-demand," *Technical Articles & Reports on Plastic Industry*, plastemart.com, n.d., http://www.plastemart.com/upload/Literature/US-petrochemical-market.asp.

[318] Sean Davis and Jamie Lacson, *Petrochemical Industry Overview*, Abstract, SRI Consulting CEH Report, March 2005, http://www.sriconsulting.com/CEH/Public/Reports.

[319] "US petrochemical industry takes a backseat."

[320] Davis and Lacson, *Petrochemical Industry Overview*.

[321] Global Insight, "U.S. Petrochemicals on a Rebound."

[322] Dow Chemical, "North American Petrochemicals."

story. As Figure 8-2 shows, the chlor-alkali industry has been a strong exporter over the past decade. World exports of chlor-alkali products to the United States in 2007 was 1.9 million metric tons, U.S. exports to the rest of the world was 9.1 million metric tons, for a net trade surplus of 7.2 million metric tons. Table 8-B shows the principle sources of U.S. imports and recipients of U.S. exports, and sources of U.S. net imports. Canada again is the largest chlor-alkali importer to the United States, and the

largest export recipient. The next largest exporters of chlor-alkali to the United States include Taiwan, Japan, Korea, and Belgium. Mexico, Brazil, Japan, and Australia are the next largest recipients of U.S. exports.

While the U.S. chlor-alkali industry currently appears to be in relatively good economic health, it has to be noted that its business is very cyclical. Periods of low profitability are normally followed by periods of sufficiently high margins to justify investment in new

WHILE THE U.S. CHLOR-ALKALI INDUSTRY CURRENTLY APPEARS TO BE IN RELATIVELY GOOD ECONOMIC HEALTH, ITS BUSINESS IS VERY CYCLICAL.

TABLE 8-A

LEADING U.S. TRADE PARTNERS IN PETROCHEMICALS, CUMULATIVE 1997-2007

IMPORTS TO U.S. (1000 mt)		U.S. DOMESTIC EXPORTS (1000 mt)		NET U.S. IMPORTS (M-X) (1000 mt)	
Canada	18,590	Canada	2,972	Canada	15,617
South Africa	1,136	Mexico	1,968	South Africa	1,114
Norway	722	Belgium	1,161	Norway	705
Netherlands	565	France	826	United Kingdom	347
Belgium	414	Netherlands	441	Portugal	231
France	370	India	436	Italy	209
United Kingdom	368	Germany	425	Saudi Arabia	169
Italy	356	China	289	Netherlands	124
Saudi Arabia	286	Taiwan	280	Brazil	60
Brazil	239	Brazil	178	Russia	59

Source: USITC   mt=metric ton

Figure 8-2
Alkalies and Chlorine U.S. Imports, Exports and Trade Balance, 1997-2007

Millions of Metric Tons

Trade Balance [X-M] — Total Imports to U.S. — Total U.S. Exports

USITC, HRS-MI

capacity. The industry suffered from a major slump between mid-2000 until 2003, with poor profitability, a situation made worse by the spike in natural gas prices in North America in 2001 and 2003. This resulted in rationalization of capacity in North America, Europe and Japan. By 2004, because of a considerable rise in prices, the industry was once again profitable, though its gains were partly offset by higher energy prices. Similarly, very high prices for caustic soda has led to significant profit gains for the chlor-alkali industry in 2008.[323]

Although the United States has maintained a leading position in the world in alkalies and chlorine production, chlor-alkali demand

and capacity has been growing rapidly in emerging economies. SRI Consulting estimates that as of July 2008, more than 500 companies produced chlor-alkali products at over 650 sites worldwide, with a total annual capacity of about 62.8 million metric tons of chlorine. About half of these plants are located in Asia, although many are relatively small. In addition, many small sodium hydroxide plants continue to operate in Western Europe and Japan. But because of stagnating markets and concerns over an impending phase out of mercury cell production, which accounts for 50 percent of Western European capacity, several plants have shutdown in recent years. Because the chlor-alkali applications are relatively mature

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[323] Erik Linak, Stefan Schlag, and Kazuteru Yokose, "Chlorine/Sodium Hydroxide," Abstract, SRI Consulting, September 2008, http://www.sriconsulting.com/CEH/Public/Reports/733.1000.

in the United States, Western Europe and Japan, and consumption in these regions is expected to grow slowly, little capacity expansion is expected.[324]

On the other hand, developing regions over the past decade have rapidly built up capacity to meet their burgeoning demand. Prior to the current economic crisis, global demand for chlorine was expected to grow by 2.2 percent a year to 55.5 million metric tons by 2009, and analysts predicted that chlorine production capacity would expand by 9 percent. Demand and capacity for caustic soda production also was expected to grow at a healthy rate. China in particular increased its capacity between 2004 and 2008 by about 50 percent, and its consumption of chlorine and caustic soda was expected to grow at a strong rate between 2007 and 2012.[325] Merchant Research & Consulting, Ltd. has estimated that developing countries could soon account for 75 percent of the demand for

BECAUSE THE CHLOR-ALKALI APPLICATIONS ARE RELATIVELY MATURE IN THE UNITED STATES, WESTERN EUROPE AND JAPAN, AND CONSUMPTION IN THESE REGIONS IS EXPECTED TO GROW SLOWLY, LITTLE CAPACITY EXPANSION IS EXPECTED.

TABLE 8-B
LEADING U.S. TRADE PARTNERS IN CHLOR-ALKALI INDUSTRY, CUMULATIVE, 1997-2007

SOURCE OF U.S. IMPORTS (1000 mt)		U.S. DOMESTIC EXPORTS (1000 mt)		NET TO U.S. IMPORTS (M-X) (1000 mt)	
Canada	9,648	Canada	12,152	Germany	219
Taiwan	1,506	Mexico	9,372	Italy	103
Japan	986	Belgium	9,041	Norway	96
Korea	947	France	4,054	Sweden	87
Belgium	917	Netherlands	3,872	United Kingdom	19
France	731	India	2,806		
Mexico	681	Germany	2,752		
Germany	545	China	2,136		
China	500	Taiwan	1,477		
Saudi Arabia	389	Brazil	1,277		

Source: USITC   mt=metric tons

[324] Ibid.
[325] Ibid.

chlorine.[326]

The demand for chlorine closely tracks the demand for downstream goods—such as PVC tubes, frames and doors, polyurethane insulation in construction—that have chlorine inputs. Hence, it mirrors changes in the economy, which affect the markets for these goods, as well as for caustic soda, which similarly is used by large numbers of industries. As the United States and the rest of the world experience an economic slowdown in the wake of the financial crisis, demand for chlor-alkali products will most likely slow considerably, and investment in new capacity will probably suffer, especially in the emerging economies.

CHEMICALS PRODUCTION AND ENERGY USE

The basic chemicals sector is among

FIGURE 8-3
CHEMICAL MANUFACTURING PRODUCTION CHAIN
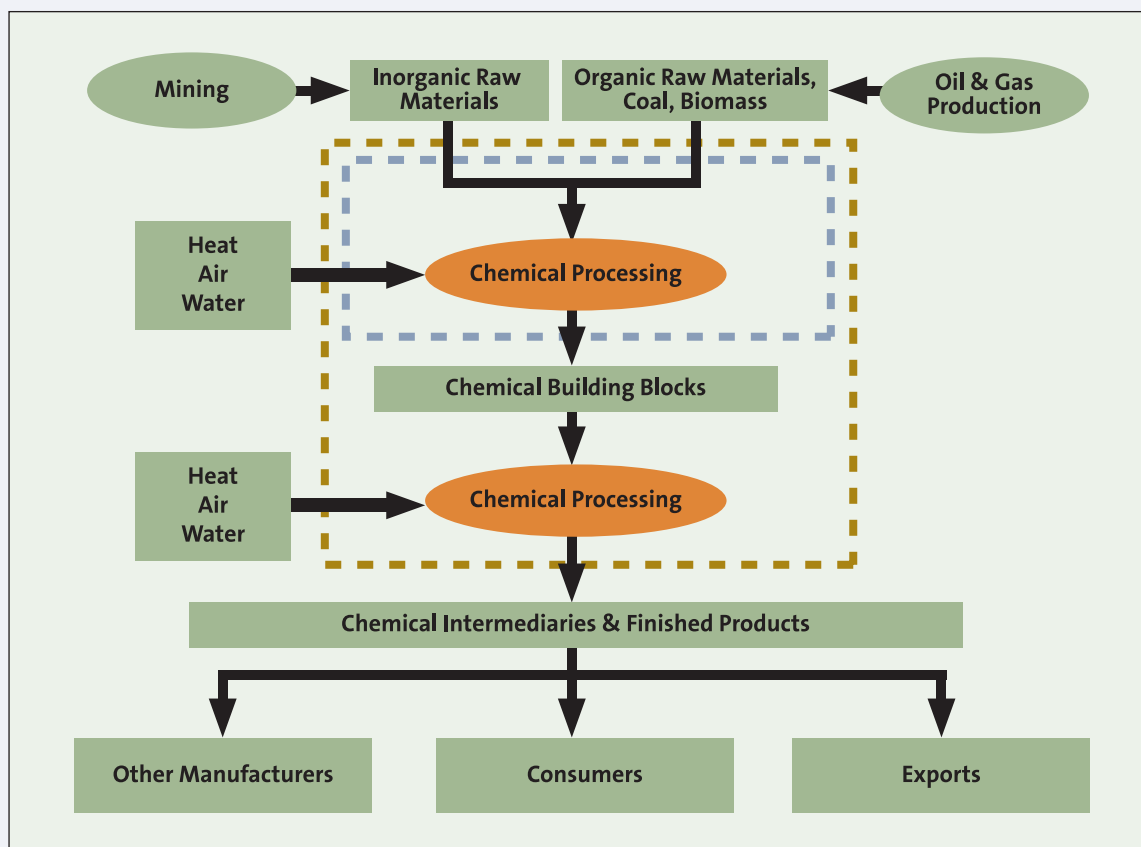
Source: ACC, 2007 Guide to the Business of Chemistry, 23.

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[326] Merchant Research & Consulting, Ltd., "Developing countries account for 75% of chlorine demand," *Chlorine Market Research* (abstract), July 2007, http://mcgroup.co.uk/researches/C/0715.

Figure 8-4

Bulk Petrochemical Production, 1996-2006
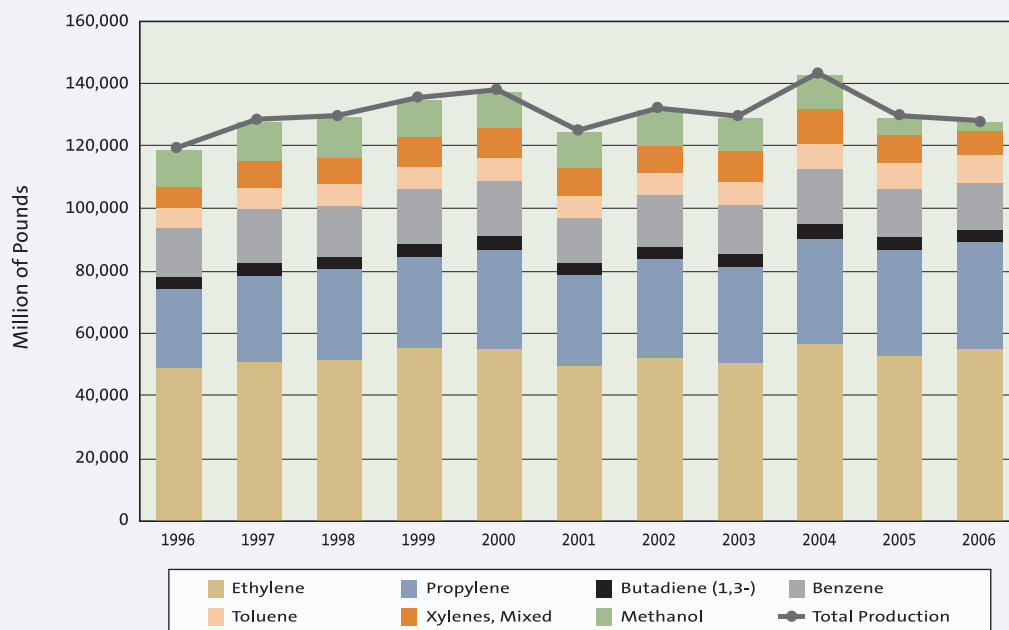
Source: American Chemistry Council

the most energy intensive in chemicals manufacturing. Its divisions reflect the two principal types of chemistry—*organic* and *inorganic*. Organic inputs, like oil and natural gas, contain hydrocarbons, which form the backbone of final organic chemicals outputs. Few chemicals use oil and natural gas directly as raw materials. Normally, they are processed into natural gas liquids such as ethane, propane or heavier liquids such as naptha and gas oil. These raw materials are then refined to produce primary outputs like benzene and ethylene.

Inorganics include compounds of two or more natural elements. For example, salt, a simple compound formed from sodium and chlorine can be broken down by electrolysis to produce chlorine and caustic soda (sodium hydroxide). Chlorine is a common inorganic chemical, widely used by industry and consumers (e.g. the paper industry uses chlorine to bleach paper pulp); caustic

soda is used extensively in manufacturing processes and in production of soap and detergents.

Figure 8-3 illustrates the generic production chain that characterizes chemicals manufacturing. The II-CPM analysis of the chemicals industries focuses solely on the first stage, which produces bulk chemicals, the building blocks for intermediate and derivative chemical products that may go through further processing to produce final, end-use consumer products.

Petrochemical production.
Figure 8-4 illustrates the outputs of the largest product subdivisions within the petrochemical industry. Petrochemical manufacturing relies on energy inputs for fuel and power for its operations, and for feedstock or raw materials in the manufacture of organic chemicals. Many reactions need large amounts of heat, pressure, and/or electricity. Natural gas

The basic chemicals sector is among the most energy intensive in chemicals manufacturing.

FIGURE 8-5

ETHYLENE PRODUCTION FLOW CHART
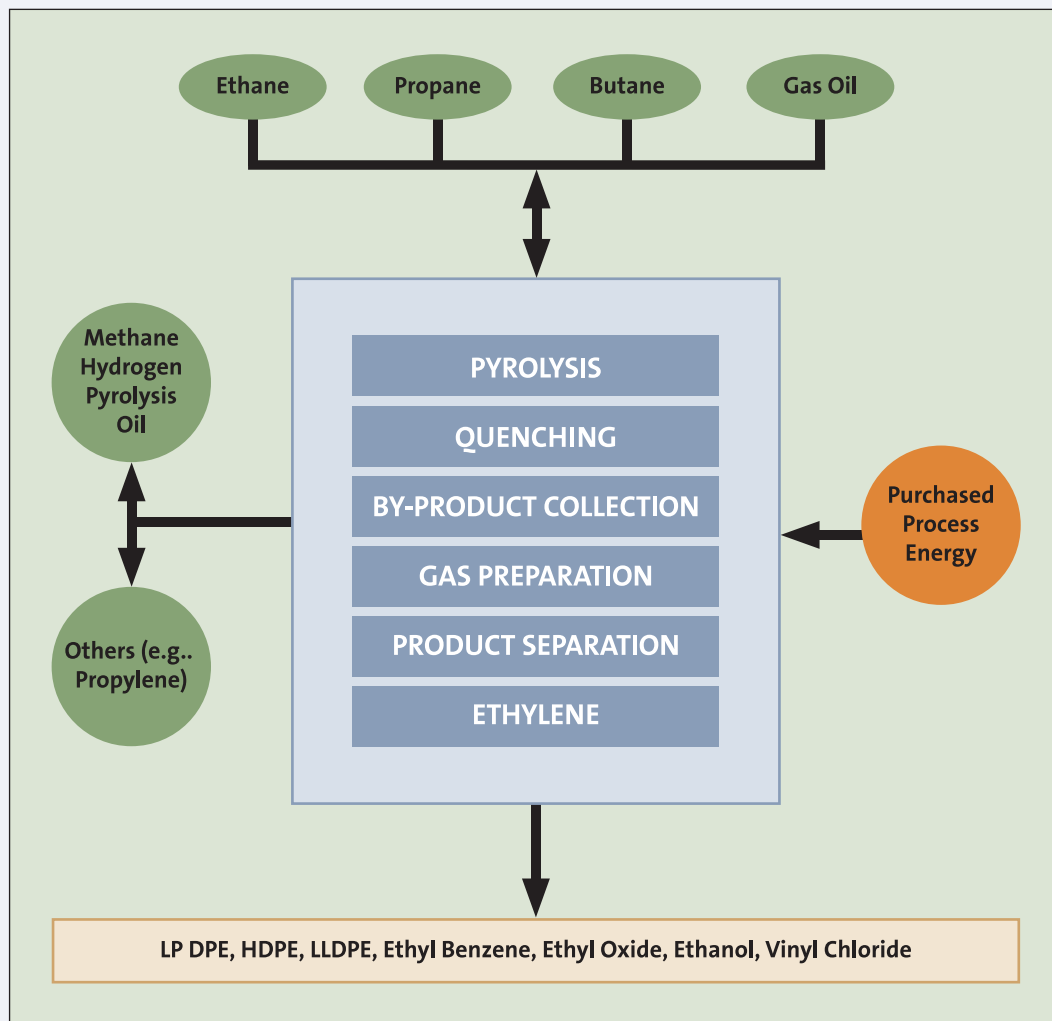
Source: Matthias Ruth, Brynhildur Davidsdottir, and Anthony Amato, "Climate change policies and capital vintage effects: the cases of US pulp and paper, iron and steel, and ethylene," *Journal of Environmental Management* 70 (2004) 235-252:241, fig. 34 .

NATURAL GAS LIQUIDS OR LIQUEFIED PETROLEUM GASES (LPG) ARE THE MAIN HYDROCARBON FEEDSTOCK USED IN U.S. BULK PETROCHEMICAL MANUFACTURING.

liquids—ethane, propane and butane—or liquefied petroleum gases (LPG) produced via natural gas processing or through petroleum refining processes are the main hydrocarbon feedstock used in U.S. bulk petrochemical manufacturing. European and most other foreign petrochemical manufacturers, in contrast, rely on petroleum-based naptha and other heavy liquids.[327]

Bulk petrochemicals are basic building blocks used as the starting point for tens of thousands of chemical products. They include aromatics such as benzene, toluene and xylenes, and "olefins" such as ethylene,

[327] ACC, *2007 Guide,* 106. About 3.21 quads of energy consumption (52 percent of the total)—naptha and other heavy liquids (43 percent) natural gas liquids (43 percent), natural gas (13 percent) and coal (1 percent)—are used as hydrocarbon feedstock in chemicals manufacturing.

propylene and butadiene, and methanol. More than 90 percent of all organic chemistry is derived from these seven petrochemicals.

Organic intermediates represent the next step via further chemical conversion of the bulk petrochemicals and/or incorporation of chlorine, nitrogen, or oxygen to include such products as acetone, ethylene dichloride, formaldehyde, propylene oxide, phenol, and styrene, among many others. Sometimes multiple steps are required to produce intermediate products of desired composition. These products in turn are used in downstream derivatives such as plastic resins, synthetic rubber, man-made fibers, surfactants, dyes and pigments, and inks, among others. Ultimately, over 70 percent of petrochemicals end up as plastic resin, synthetic rubber or synthetic fibers. Bulk intermediates and organic chemicals are used by other chemical manufacturers and in the automotive, building and construction, consumer/institutional, electrical/electronic, furniture/furnishing, and packaging industries.

The production and energy flows for the petrochemical industry are illustrated in Figure 8-5, which portrays the manufacturing process for ethylene, the largest petrochemical industry.

In ethylene production, most hydrocarbons are not burned as fuel but used as feedstock. The hydrocarbon feedstock (such as ethane or naptha) are subject to intense heat or 'cracked' in a pyrolysis furnace, where they are separated into gaseous products and then rapidly cooled and compressed into final products. Most

of the energy requirements are for carrying out the pyrolysis process. The type of feedstock used, and to a lesser extent other processing conditions, determine ethylene yield and process energy requirements.[328] In the United States, ethane is the primary feedstock used in steam cracking (45 percent), followed by propane (27 percent), and naptha and gas oil (27 percent).[329]

Petrochemical companies have become greatly concerned about the rising costs of feedstock resulting from the record high crude oil prices. Major feedstock costs have been successfully passed through to downstream consumers, resulting in strong financial gains. However, if crude oil prices rise much higher or to earlier peak levels, especially at a time of global slowdown, such as today, it will become harder to pass along costs. Crude oil prices and the rate of growth of the global economy have the greatest impact on future performance of the petrochemical industry, as the price of crude oil would heavily influence the raw materials costs of petrochemical production.[330]

Chlor-alkali production.
The chlor-alkali industry, which produces

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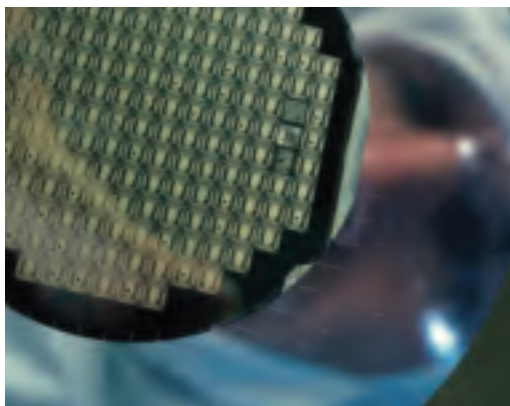
[328] Ruth et al, *Climate Change and Capital Vintage Effects,* 241. These conditions include temperature, pressure, and residence time.
[329] Worrell et al, "Energy Use and Energy Intensity," 12. Lighter feedstocks such as ethane produce higher ethylene yields. Heavier feedstocks require higher temperatures and pressures, that requires more energy to crack. But they also produce more co-product yields (methane, butadienes, benzene, and toluene).
[330] "Petrochemical Industry Slowdown Depresses Profitability-Trough by 2010," *Chemsystems Online,* November 30, 2007, http://www.chemsystems.com/about/cs/news/archive.cfm.

Figure 8-6
Chlorine-Alkalies Production, 1996-2006
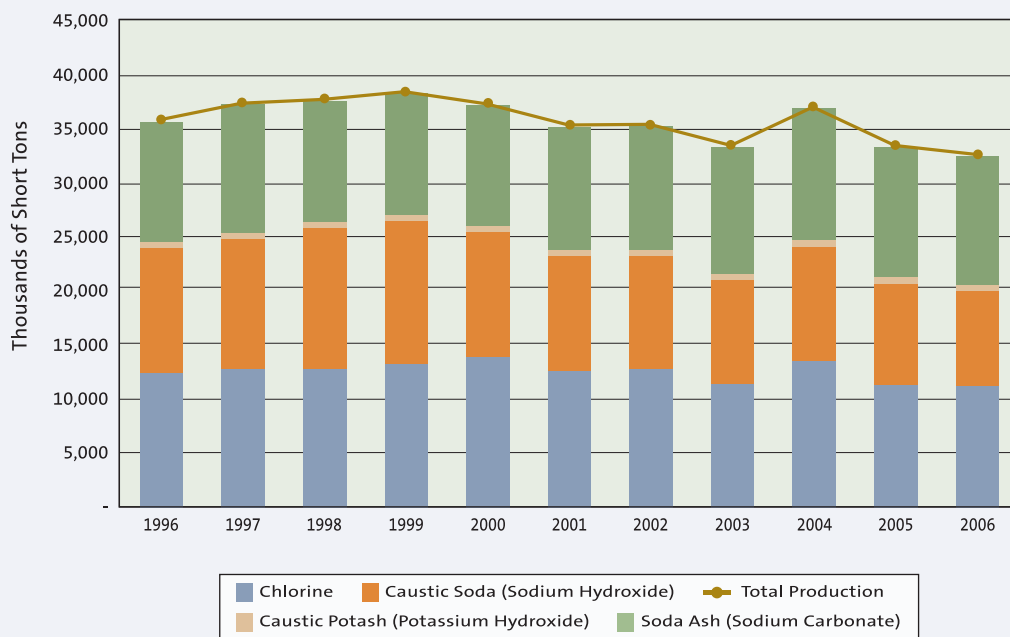
Source: American Chemistry Council

alkalies and chlorine, is a major sub-sector within the inorganic chemicals sector. Figure 8-6 presents a breakdown of the products produced in the chlor-alkali industry, of which chlorine and caustic soda are the largest segments. The chart shows that after a peak in 1999, production slowed in all categories until 2003, spiked up in 2004, and then fell to its lowest levels in a decade in 2005 and 2006.

Figure 8-7 presents the production flow chart for alkalies and chlorine. The manufacturing of chlorine gas is an energy intensive process, using between 25 to 40 gigajoules (GJ) (worldwide average) of primary energy per metric ton of chlorine

produced,[331] with electricity accounting for 40 to 50 percent of variable production costs.[332] The process consists of converting a brine solution into two co-products through electrolysis: chlorine gas and sodium hydroxide (caustic soda). Three main electrolysis cell types are used to separate and produce chlorine gas and caustic: mercury flow, diaphragm, or membrane. Diaphragm and membrane cells require an additional step of concentrating the solution to make caustic soda, so that it can meet market specifications. The membrane cell requires the least energy to operate and currently is considered state-of-the-art technology.[333] Yearly U.S. production of chlorine has been around 11 to 13 million

The manufacturing of chlorine gas is an energy intensive process, using between 25 to 40 gigajoules of primary energy per metric ton of chlorine.

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[331] Worrell et al, "Energy Use and Energy Intensity," 30, figure 7.

[332] Linak et al, "Chlorine/Sodium Hydroxide."

[333] Worrell et al, "Energy Use and Energy Intensity," 30, figure 7.

Figure 8-7
Chlor-Alkali Production Process
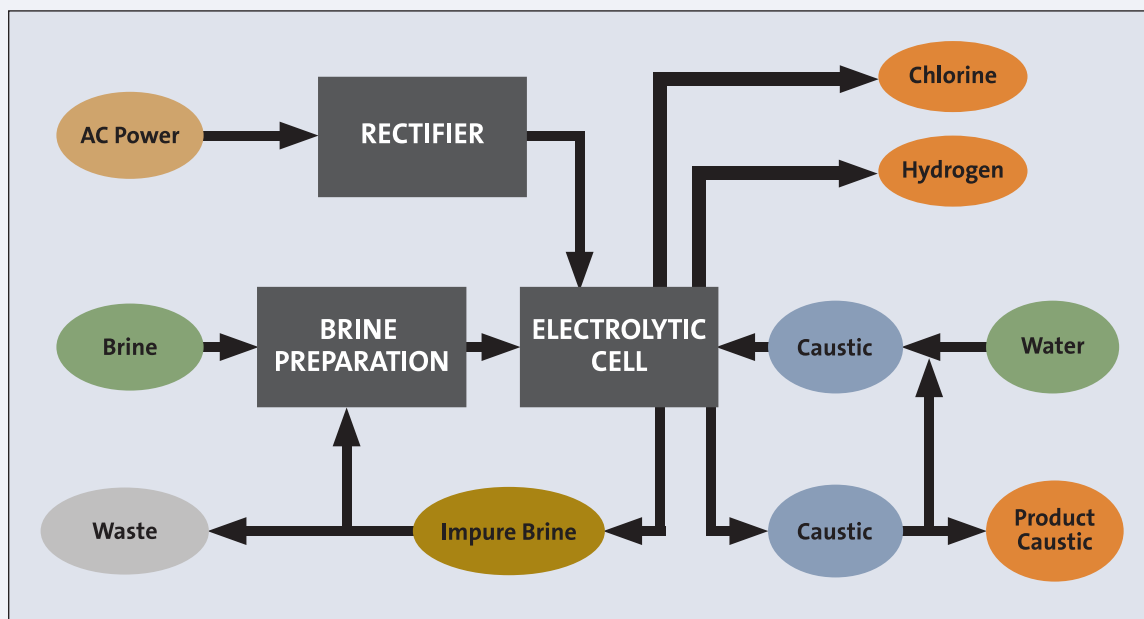
Source: Ernst Worrel, Dian Phylipsen, Dan Einstein, and Nathan Martin, "Energy Use and Energy Intensity of the U.S. Chemical Industry," *Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory*, LBNL-44314, April, 2000, 30, figure 7.

tons. At this time, only 18 percent of chlorine is produced using the membrane technology. About 70 percent is produced using the diaphragm cell and 12 percent using the mercury cell.

Climate Policy Impacts On Petrochemical Manufacturing

Petrochemical manufacturing is one of the most energy-intensive industries in the HRS-MI study. Yet, according to the II-CPM simulations, the Mid-CO$_2$ Price Policy would have very modest impacts on the industry's costs, operating surplus (profits), and operating margins (profit margins). These results reflect assumptions and contingencies, such as market price projections, energy mix data and energy price variations, and credit allocation for feedback energy use. Uncertainty about materials and energy cost data that was available to the study also raises additional questions about the results of the II-CPM simulations, which needs further research to possibly provide more realistic results than presented at this time.

In any event, the U.S. petrochemical industry has long been concerned with energy costs, since its primary feedstock is derived from hydrocarbon fuels (petroleum, natural gas). Although in recent years the industry has been financially strong—at least until the current economic crisis—rising energy costs (in particular, natural gas) have prompted some large manufacturers to explore making investments in offshore

ACCORDING TO THE II-CPM SIMULATIONS, THE MID-CO$_2$ PRICE POLICY WOULD HAVE VERY MODEST IMPACTS ON THE INDUSTRY'S COSTS.

facilities closer to cheaper and abundant energy supplies, rather than expanding their domestic capacity. Hence, even an incremental increase in energy costs arising from a climate policy, which would apply only the United States, could influence domestic producers' future location and investment decisions.

Production cost structure (BAU).

Figure 8-8 illustrates the main production cost components for the BAU case. In 2006, materials costs accounted for two-thirds of total costs, energy costs for 30 percent, and labor for only 3 percent. Energy feedstock accounts for the bulk of energy costs, fuel energy accounts for just a fraction, and electricity costs are all but negligible.

Material costs. As the figure shows, material costs swung downward until almost doubling, between 1992 and 2006. They were projected by the II-CPM, using *ASM* and Global Insights data to peak in 2008, before gradually diminishing back to about $400 per short ton, by 2030.

Labor costs. Reflecting improvements in labor productivity, labor costs would decline absolutely and relatively. Between 1992 and 2006, labor costs fell about 20 percent. They were projected to decline to half the 2006 level by 2030. Labor costs accounted for a 6 percent share of total costs, in 1992. By 2006 this share had fallen to 3 percent, and by 2015 it was only one percent, where it stayed through 2030.

In 2006, materials costs accounted for two-thirds of total costs, energy costs for 30 percent, and labor for only 3 percent.

Figure 8-8
Petrochemicals Real Unit Production Cost Components, Business As Usual, 1992-2030
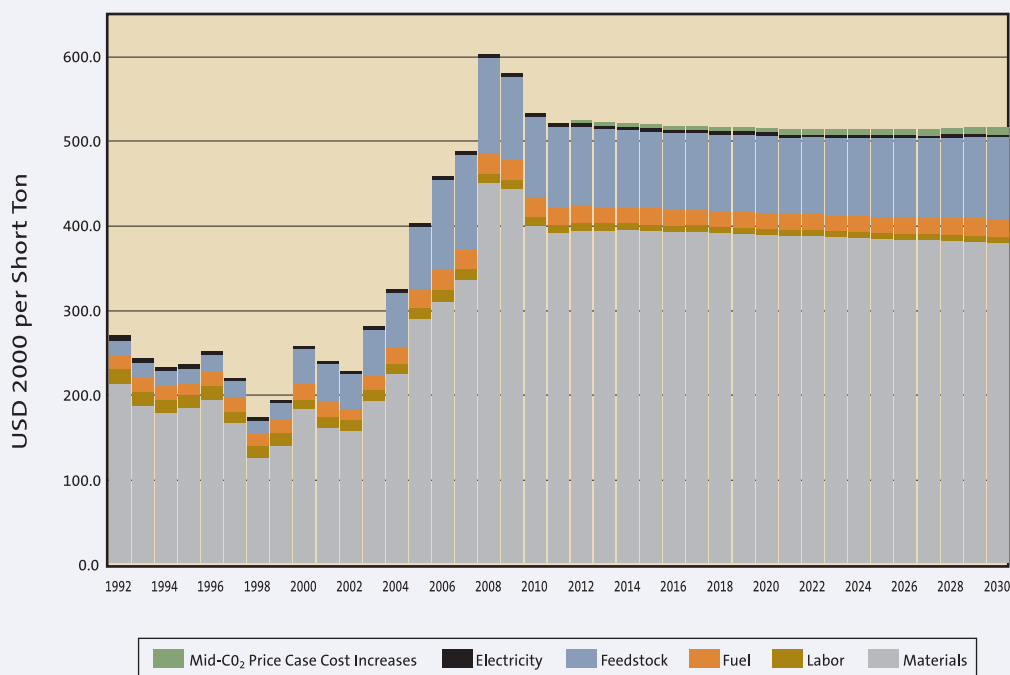
Source: HRS-MI

TABLE 8-C
PRODUCTION COSTS, ENERGY SHARE AND ENERGY COST COMPONENTS PETROCHEMICAL MANUFACTURING

Item	2006	2020		2030	
	Value	Value	% above BAU	Value	% above BAU
Production Costs (USD 2000/ton)					
BAU	457	508	—	506	—
Mid-CO$_2$ Price Case Above BAU	—	5	*1.0*	9	*1.7*
Energy Share of Production Costs (Percent)					
Mid-CO$_2$ Price Case	*29.6*	*23.2*	*0.8*	*25.3*	*1.3*
Energy Cost Components (USD 2000/ton)					
Mid-CO$_2$ Price Case:					
Total Energy Costs	135	119	*4.4*	130	*7.1*
Fuel Costs	24	23	*19.0*	28	*33.1*
Electricity Costs	4	4	*8.6*	4	*13.1*
Feedstock Costs	107	92	*1.2*	98	*1.2*

Energy costs. Energy feedstock accounts for the largest share of the industry's energy costs. As a share of total costs, total energy costs accounted for a fifth in earlier years, grew by 44 percent in 2006, and then was projected to grow to 30 percent by 2030. Total energy costs grow by about 3½ times 1992 levels, peaking in 2008. They then were projected to fall steadily through by about 14 percent, by 2030. As a share of total production costs, total energy costs were about 30 percent in 2006. They were projected to fluctuate around one-quarter of the total, most years thereafter, in the BAU scenario. Total energy costs are also substantially larger than labor costs; they were about 2-3 times the latter from 1992 through 1999. They would steadily climb to 17 times greater the labor costs by 2030. Energy costs were estimated to grow from only about 30 percent to a third of materials costs in 2030. In contrast, the energy-labor ratio in policy case would rise to over 19 times, and energy-materials to 35 percent, by 2030.

ENERGY AND PRODUCTION COST IMPACTS.
Table 8-C summarizes the production cost impacts projected by the II-CPM simulations for the petrochemical industry, assuming no mitigating actions to reduce energy costs and the implementation of climate policies only in the United States. The table shows the small cost increases above the BAU, which would rise to only 1 percent in 2020 and 1.7 percent in 2030. This is much lower than any other of the energy-intensive industries in the HRS-MI study, and even lower than the non-energy-intensive secondary aluminum industry. Yet, the energy cost share of total production costs for the industry, was 30

UNDER THE MID-CO$_2$ PRICE POLICY, OVERALL ENERGY COSTS WOULD INCREASE BY A LITTLE OVER 4 PERCENT IN 2020, RELATIVE TO BAU, AND BY 7 PERCENT IN 2030.

FIGURE 8-9

PETROCHEMICALS PRODUCTION COSTS, MID-CO$_2$ PRICE CASE ABOVE BAU ENERGY COST COMPONENTS, 2012-2030

Source: HRS-MI

percent in 2006. But by 2020, it would fall to under a quarter of the total, only about 1 percent greater than the BAU share, where it would remain through 2030. This share would change very little under the policy case.

Figure 8-9 schematically compares the growth in energy costs in the policy case, relative to BAU, attributed to the different energy components consumed in petrochemical manufacturing. Feedstock accounts for the largest share of energy inputs—about 80 percent of total energy costs in 2006, compared to 18 percent for energy fuels and 3 percent for electricity (see Table 8-C).

Under the Mid-CO$_2$ Price Policy, overall energy costs would increase by a little over 4 percent in 2020, relative to BAU, and by 7 percent in 2030. The feedstock role in the energy cost increase under the climate policy would actually shrink over time, to 75 percent of total energy costs, in 2030, only 1.2 percent over BAU. Fuel costs for heat and power would grow relatively and absolutely under the climate policy, to 33 percent higher than BAU and would be 21 percent of total costs in 2030. Electricity would not grow relatively to other energy sources, but would be about 13 percent higher than BAU, in 2030

Feedstock energy mix variations. These results reflect assumptions about the energy

source used as feedstock in petrochemical manufacturing, based on the DOE's MECS data, which assumes that all but a small amount of energy fuel used as feedstock is liquefied petroleum gas (LPG) or natural gas liquids (NGL). The former is a petroleum derivative; the latter is made from natural gas. The EIA NEMS price data used in the II-CPM to characterize the energy sources in the BAU and policy cases (see Chapter Two and Appendix B) only projected prices for LPG. Price data for NGL were not available. The study therefore assumed that *all* the energy feedstock was LPG using EIA price projections to characterize the climate policy impacts. Although the prices of LPG are roughly double the prices of natural gas, the EIA projections showed very small variations in the prices of LPG, in the policy case, relative to BAU (see Table 2-C). As a result, the policy impact on the cost of processes that rely heavily on LPG for feedstock (and heat and power), such as petrochemical manufacturing, would be small, a conclusion consistent with the II-CPM simulations.

In contrast, fuel energy costs—mostly natural gas, some LPG and a small amount of coal used for heat and power—rose significantly relative to feedstock and electricity. These large increases reflected the greater price volatility for natural gas and coal in particular in the EIA energy price projections for the policy case relative to BAU. A source at the American Chemistry Council suggested to us, however, that much if not most of the fuel used as feedstock may in fact be NGL rather than LPG—especially ethane and propane—basic building blocks of ethylene and other bulk petrochemical production in the pyrolysis process.[334] We subsequently did a rough estimate of what the cost impacts might be if it was assumed that a portion or all the feedstock energy consumed as feedstock was in fact NGL. In particular, estimates of the impacts were done assuming that 10 percent, 50 percent and 100 percent of the feedstock was actually NGL, rather than LPG.

In addition, for each assumption of the NGL share of total feedstock energy consumed, we made an additional assumption that the prices of NGL for the BAU and Mid-CO$_2$ Price Policy were assumed to equal those of natural gas. We thought that this estimate would establish a reasonable range of alternative impacts of the climate policy on the petrochemical feedstock costs.[335]

The results of this estimate showed that the changes in feedstock costs would result in increases in overall production costs relative to BAU, but in cost declines in absolute terms, ranging from as low as 1.2 percent above BAU to a high of 3.2 percent in 2020, and a low of 2 percent to a high of 5.5 percent in 2030. In short, if in fact U.S. petrochemical feedstock is in part, mostly or totally comprised of NGL rather than LPG, the results would range from small to modestly higher cost increases compared to the II-CPM results.

If in fact U.S. petrochemical feedstock is in part, mostly or totally comprised of NGL rather than LPG, the results would range from small to modestly higher cost increases.

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[334] Personal communication and emailed comments February 19, 2009.
[335] See Appendix B for a detailed explanation of these estimates, including the equations used to calculate the added costs resulting from different assumptions regarding NGL versus LPG consumption as feedstock in petrochemical manufacturing.

Operating surplus and margins (NCPA).

Assuming NCPA seems reasonable for this sector due to its very large operating surplus and margins (44 percent in 2006, see Figure 8-10 and Table 8D), probably caused by the high capital-intensiveness of petrochemicals. Not surprisingly, low production cost increases under the climate policy would produce a small dent in industry's operating surplus, relative to BAU: there would be only a 1.2 percent reduction in the operating surplus relative to BAU in 2020, and a slightly higher, 2.2 percent, reduction in 2030.

The operating margin change under the policy case also suggests very small impacts on industry's bottom line in the II-CPM simulations, under the assumptions about fuels and prices used in the study. The modeling results showed only a 0.5 percent reduction in the operating margin in 2020 and a 1 percent reduction in 2030. In short, we should expect, at most, only a very modest reduction of the industry's profits and profit margins by 2030 as a result of a climate policy, given the feedstock energy source assumptions used in the original II-CPM simulations.

Energy mix variation estimates. If, however, the industry actually consumed NGL as feedstock, instead of or in addition to LPG, which appears likely according to industry sources, the resultant operating surplus

reductions would be somewhat larger. A 10 percent NGL–90 percent LPG split would increase the operating surplus and operating margin impacts only slightly, even for the more volatile NGL price estimates. If we assume a 50-50 split, the operating surplus reduction could rise to 4 percent by 2030, and if a 100 percent NGL feedstock is assumed in lieu of LPG, the operating surplus reduction could grow to over 5 percent relative to BAU. Significantly, the operating margin reduction could range from nearly 2 in the 50 percent NGL case by 2030 and to 3 percent for the 100 percent NGL case, in 2030. Nevertheless, in absolute terms, the operating surplus and operating margin would be higher when using NGL, due to its lower price, compared to the II-CPM original simulations of the BAU and Mid-CO_2 Price Policy cases.

Operating surplus and market shares (CPA).

Under favorable market conditions, low cost and high operating surplus/margin under the Mid-CO_2 Price Policy, petrochemical companies might decide to pass along some or all of the additional costs (CPA) from the climate policy to their customers. Table 8-D shows that the operating surplus, operating margin (and therefore profit margin), and market share reductions would be very small and unlikely to threaten the industry's competitive position. Even if if the NGL-LPG scenarios represent more realistic

Figure 8-10
Petrochemicals Real Unit Production Costs, Compared to Domestic Market Price

Real Unit OS [Mid-CO$_2$ Price-NCPA]

Real Unit OS [BAU]

Real Unit OS [Mid-CO$_2$ Price Case–CPA]

USD 2000 per Short Ton

Legend:
- – – – *Domestic Market Price-CPA Cost Basis*
- **Domestic Market Price-NCPA**
- **Mid-CO$_2$ Price Production Cost**
- **BAU Production Cost**
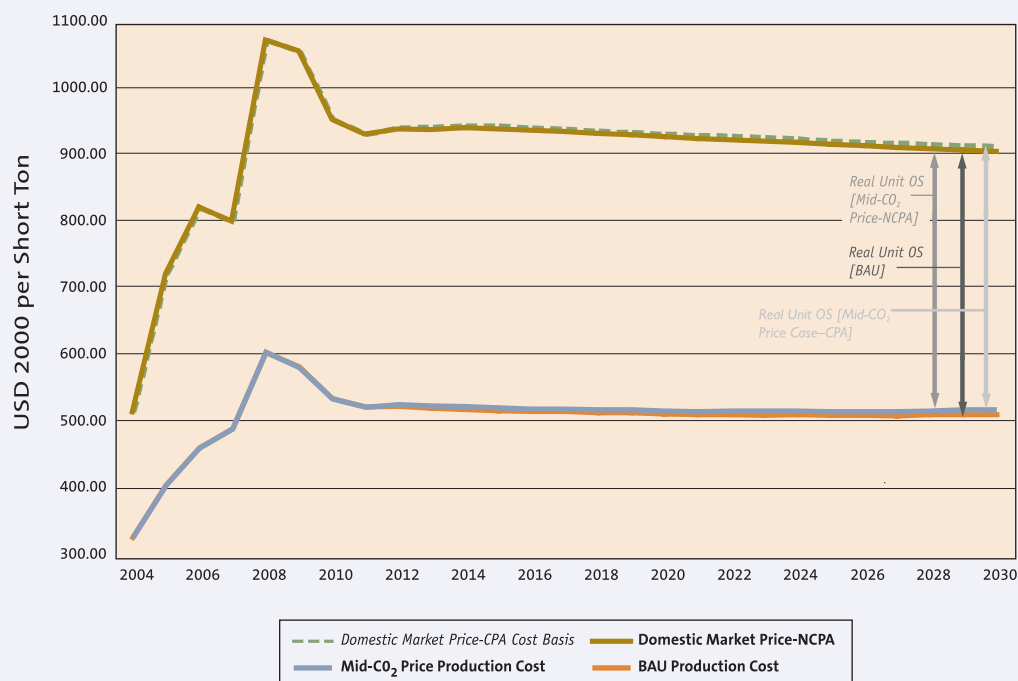
Source: HRS-MI

situations in the industry, the operating surplus impacts, relative to BAU would still be relatively modest and CPA may remain an option for petrochemical companies, depending on market conditions at the time. In any case, whatever the impacts, under Mid-CO$_2$ Price Policy (the core Lieberman-Warner proposal) it is likely that a credit would be given to the petrochemical industry for feedstock energy use, which would mitigate the economic impacts of the climate policy on the sector.

Petrochemical markets, prices and CPA. The extent to which the industry can pass along the added costs of feedstock and energy fuels under a climate policy would depend on the strength of domestic and international demand, the intensity of international competition, the extent of production oversupply, and the availability and price volatility of the primary feedstock. The petrochemical manufacturing is a global industry, which is especially sensitive to the availability and costs of raw materials, primarily hydrocarbons mostly sold on world markets. The prices of petrochemical products are strongly correlated—some say as much as 80 percent—with the cost of crude oil.[336] As a consequence, the industry is subject to a great deal of price volatility, tied to the price

It is likely that a credit would be given to the petrochemical industry for feedstock energy use, which would mitigate the economic impacts of the climate policy on the sector.

[336] "Petrochemicals firms take a stand against oil price volatility," *Market focus*, May 12003, 54-55, http://www.energyrisk.com..

Table 8-D
Operating Surplus, Operating Margin, and Market Shares Petrochemical Manufacturing

Item	2006	2020		2030	
		Value	% above BAU	Value	% above BAU
Operating Surplus (Million USD 2000)					
BAU	23.2	32.1	—	35.6	—
Mid-CO₂ Price Case Above BAU:					
NCPA	—	-0.4	*-1.2*	-0.8	*-2.2*
CPA [Cost Basis]	—	-0.03	*-0.09*	-0.05	*-0.14*
Operating Margin (Percent)					
BAU	*44.2*	*45.0*	—	43.9	—
Mid-CO₂ Price Case:					
NCPA	—	44.4	*-0.5*	42.9	*-1.0*
CPA [Cost Basis]	—	44.7	*-0.2*	43.4	*-0.4*
Domestic Market Share (Percent)					
BAU	*96.5*	*95.7*	—	*95.7*	—
Mid-CO₂ Price Case:					
CPA [Cost Basis]	—	95.6	*-0.08*	95.5	-0.14

NCPA=No Cost Pass-Along; CPA=Cost Pass-Along

fluctuations of petroleum and natural gas.

Crude oil prices are set in world markets and these would translate into higher prices for petrochemical products whose feedstock is petroleum based (naptha) across the globe. Natural gas prices are also volatile, but its markets are more geographically defined. When demand is strong and feedstock prices rise, producers can absorb or probably pass through additional energy costs. In recent years, U.S. producers benefited from a weak U.S. dollar, strong international demand, and natural gas and oil prices significantly higher than in the past.[337]

On the other hand, the increased profitability of petrochemical production spurred the large expansion of new petrochemical capacity in developing nations and has created increasing competitive pressures on manufacturers from developed nations (United States, Europe, Japan), that could limit U.S. producers' options in the face of higher energy and feedstock costs from a climate policy.[338] As noted above, the Middle Eastern region with access to abundant and inexpensive natural gas, has been developing new petrochemical complexes, adding huge production capacity to both

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[337] Global Insight, "U.S. Petrochemicals on a Moderate Rebound."
[338] Ibid.

meet the region's domestic demand and generate surpluses oriented towards exports,[339] to serve the vast and rapidly growing markets in Asia (especially China)— at least until the recent financial crisis and world economic slowdown.

In fact, there has been little new growth in U.S. petrochemical capacity and the opportunities for growth have been rapidly been migrating overseas. For example, as of 2002, chemical manufacturer Huntsman Corporation shifted almost 60 percent of its operations to Europe and Asia, with its largest operations in China.[340] In addition, the growth of new foreign capacity has cut into U.S. exports of petrochemicals and derivatives and encouraged the growth of imports into the United States.

As long as demand is strong and prices are going up, domestic petrochemical companies can maintain their profitability. But when demand weakens, and domestically available natural gas prices are high relative to other locations, U.S. companies start to reassess their bottom-line in comparison to global producers with access to cheap gas. As an industry official has noted, "when prices of gas move $1 per MMcf, it costs a company our size $35 million per year. A $5 spike costs us at least $150 million." Consequently, when energy prices swing upwards it creates a global ripple effect by driving petrochemical production overseas at the expense of domestic markets.[341] Under these weakened market conditions, as a Global Insight report observes, "a new energy price shock amidst a weak demand environment would be very detrimental to margins."[342]

Technology and Policy Options— Petrochemicals

Given the relatively low economic impacts from the Mid-CO_2 Price Policy on the petrochemical industry projected by the II-CPM, even with different assumptions regarding feedstock use (i.e., NGL versus LPG), the energy-efficiency requirements to offset these cost impacts would be modest.

The industry, in any event, is very concerned about rising energy costs and its impacts on future capacity and investments. Market-driven energy cost increases may in fact greatly exceed the climate policy-driven impacts, though the latter might, on the margin, impact longer-term investments and location decisions of petrochemical manufacturers facing higher energy prices in general. As a result, it remains in the industry's interest to continue investigating new energy-saving technology improvements, from short-term incremental improvements to longer-term advanced or alternative process technologies.

Energy efficiency requirements. Figure 8-11 illustrates the energy efficiency gains required for different fuel sources, including feedstock, fuel, and electricity, used in petrochemical manufacturing, to offset energy cost increases under the climate policy. Not surprisingly, the energy efficiency gains required for feedstock would be minimal— only about 1 percent through 2030. Fuel energy-efficiency requirements, and to a

The energy-efficiency requirements to offset these [climate policy-induced] cost impacts would be modest.

[339] "US petrochemical industry takes a backseat."
[340] Monica Perin, "Price fluctuations hit core of petrochemical industry," *Houston Business Journal,* November 7, 2003, http://houston.bizjournals.com/houston/stories/2003/11/10/story4.htm.
[341] *Ibid.*
[342] Global Insight, "U.S. Petrochemicals on a Moderate Rebound."

lesser extent the electricity requirements, would be much higher. However, the overall small size of the energy cost increases alone may not be sufficient to encourage companies to invest in energy-efficient saving technologies.

Technology options. According to the ACC, the chemicals industry has made substantial improvements in energy-efficiency over the past thirty years. One index indicates that the industry's energy intensity has declined by about 60 percent between 1974 and 2006, and a reduction in GHG intensity of about 40 percent in the same period. Further incremental improvements may be possible—and perhaps might be sufficient to offset the climate policy cost impacts, as long as they are as small as indicated in the II-CPM simulation results. Larger scale energy-efficiency improvements might require substantial investments over a longer time period, in more advanced process technology improvements, and perhaps consisting in the substitution of existing petrochemical production processes with low-carbon alternatives.

Combined heat and power generation (CHP)—the simultaneous generation of electricity and heat from a facility that is located very close to the manufacturing facility—is an important technology the industry has successfully implemented to reduce its energy use. Most CHP facilities use natural gas and create two forms of energy (electric power and steam) with the same amount of fuel, and are often twice as efficient as older coal-burning electric utilities. The ACC reports that CHP use by the chemicals industry accounts for nearly a third of all CHP used in manufacturing. Hence, applying CHP more widely than it

already is could provide additional energy-saving benefits.[343]

Other mid-to-longer term technology improvements that could reduce energy use and costs include high-temperature furnaces able to withstand more than 1,100ºC, higher-temperature CHP for the cracking furnace fostering greater gas-turbine integration, advanced distillation columns and combined refrigerator plants (see Table 3-D).[344]

The technology that may have the biggest long-term impact on the energy footprint of petrochemicals is substitution of fossil-fuel feedstock by biomass. Feedstock energy is different from conventional energy use in that the product cannot be produced without it. However, the feedstock type can be changed, and biomass is the only carbon neutral primary feedstock option. Producing naptha, for example, from biomass feedstock would reduce CO_2 emissions without altering the existing petrochemical production infrastructure. According to the IEA, though, because of the dispersed nature of the biomass feedstock, biomass processes are currently limited to small-scale production.[345]

Policy options to mitigate impacts. As we see for all the other industries in the study, the implementation of a 90 percent allocation allowance to offset energy price increases under the climate policy would greatly alleviate any economic impacts of a climate policy on the petrochemical industry. But with such low impacts projected by the II-CPM, it is not clear whether such an allocation should be applied in this case. On the other hand, more research is needed to determine the actual mix of feedstock energy sources used

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[343] ACC, *2007 Guide*, 111.
[344] IEA, *Energy Technology Perspectives*, 413.
[345] Ibid., 415.

Figure 8-11

Petrochemicals Industry – Cumulative Yearly Energy Efficiency Gains Required to Offset Climate Policy Costs
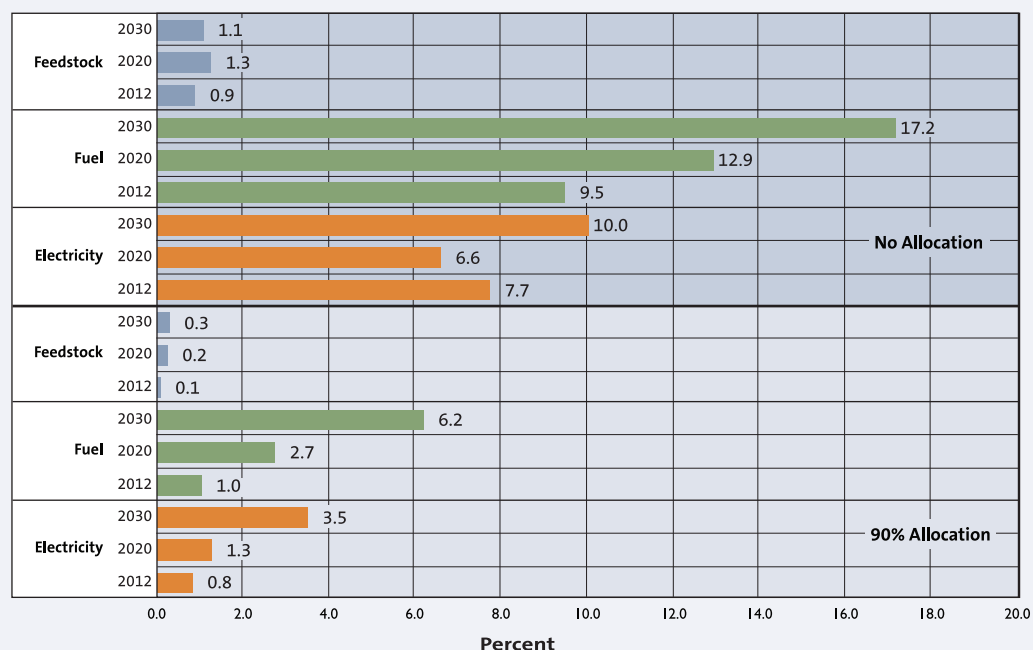
HRS-MI

by the industry and the past and expected in the future, and make new assessment of the cost impacts resulting from the climate policy. In any case, whether LPG or NGL are used as feedstock, the carbon content would be sequestered in petrochemicals products, rather than emitted as CO_2, which under the Mid-CO_2 Price Policy (Lieberman-Warner) would be compensated with a credit to the industry, to offset the cost impacts.

Climate Policy Impacts On Chlor-Alkali Manufacturing

In contrast to petrochemical manufacturing,

the chlor-alkali manufacturing industry is among the most susceptible industries to the impacts of climate policy on its profits and competitiveness. According to the II-CPM results, chlor-alkali would experience the second largest cost increases (see Figure 3-1) and third largest operating surplus reductions (see Figure 3-5) relative to BAU, under the Mid-CO_2 Price Policy. This industry's manufacturing processes are heavily reliant on both electricity and fuels for heat and power. At the same time, it is the least sensitive to foreign imports—and the only industry with a consistent trade surplus—and therefore possibly more able to pass the policy-driven costs along in efforts to maintain its profitability.

On the other hand, basic chemicals, such as chlorine and caustic soda, produced in this

In contrast to petrochemical manufacturing the chlor-alkali manufacturing industry is among the most susceptible industries to the impacts of climate policy on its profits and competitiveness.

Figure 8-12
Chlor-Alkali Real Unit Production Cost Components, Business As Usual, 1992-2030

Source: HRS-MI

Legend: Mid-CO₂ Price Case Cost Increases ■ Electricity ■ Fuel ■ Labor ■ Materials
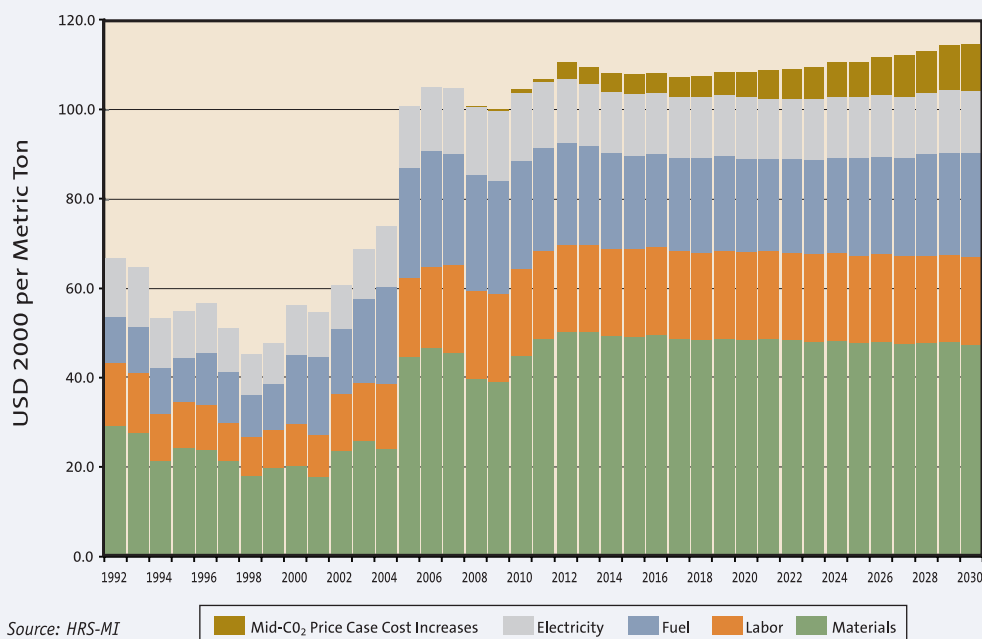
Table 8-E
Production Costs, Energy Share and Energy Cost Components Chlor-Alkali Manufacturing

Item	2006	2020		2030	
	Value	Value	% above BAU	Value	% above BAU
Production Costs (USD 2000 per ton)					
BAU	104	102	—	104	—
Mid-CO₂ Price Case Above BAU	—	6	*5.5*	10	*9.9*
Energy Share of Production Costs (Percent)					
Mid-CO₂ Price Case	*38.3*	*37.3*	*3.5*	*41.6*	*5.8*
Energy Cost Components (USD 2000 per ton)					
Mid-CO₂ Price Case:					
Total Energy Costs	40	40	*16.3*	47	*27.8*
Fuel Costs	26	25	*21.3*	32	*36.6*
Electricity Costs	14	15	*8.6*	16	*13.1*

industry are often upstream raw materials used in the production of downstream chemical products by the same company and at the same facilities. Manufacturers therefore would have to weigh whether it is more cost-effective to continue internal production of an increasingly expensive feedstock, or look elsewhere (i.e., offshore) for less expensive sources—or, alternatively, consider investment in newer, more energy-efficient chlor-alkali production technologies (e.g. the membrane cell).

Production cost structure (BAU).

Figure 8-12 presents the historical trends and projections for the production cost components for the chlor-alkali manufacturing processes in the BAU case. It also shows the additional energy costs that the industry would have to bear if the Mid-CO_2 Price Policy were enacted. As with the other industries, materials costs constitute the largest share of total production costs—fluctuating around 40 to 45 percent for the historical period and in the projections

through 2030. But the share of energy costs, and to a less extent of labor costs, also are sizable. The former have fluctuated around 40 percent historically, but were projected to fall to a little over a third of total costs. Labor costs have historically been around one-fifth of total costs, and were projected to remain at that level through 2030, for BAU.

Materials costs. Materials costs (for salt, salt water, limestone, trona ore) fell in absolute terms from 1992 through late 1990s before swinging up to about 15 to 20 percent below 1992 in early 2000s. They then grew dramatically in 2005 to about 50 to 60 percent of 1992 costs, and would stay high roughly at the same level throughout the projection period (2008-2030).

Labor costs. Labor costs also shrunk in absolute terms, by around 34 to 35 percent from 1992 through the late 1990s until 2000. They then grew to about 40 percent above the 1992 level by 2008, and were projected to stay at that level through 2030. The jump in labor costs in 2005 paralleled the rise in materials costs, and a comparable growth in energy costs, all of which were then projected to remain somewhat higher than their values in prior years.

Energy costs. The costs of energy for the BAU case follow a similar pattern of falling during the 1990s and then were projected to grow steadily, to about 50 to 60 percent above their levels early in the 2000 decade. They were estimated to be in the range of double the costs of labor through 2030, for BAU, and nearly 2½ times greater under the Mid-CO_2 Price Policy. For the BAU case, energy costs ranged from 80 percent to roughly equal materials costs from 1992 through 1999, and then fluctuated between 100 and 150 percent through 2008. They then were projected to fall to, and stay at, roughly three-quarters materials costs through 2030 for the BAU case. They would be a little higher relative to materials costs

As with the other industries, materials costs constitute the largest share of total production costs.

Figure 8-13. Chlor-Alkali Production Costs, Mid-CO$_2$ Price Case Above BAU Energy Cost Components, 2012-2030. Y-axis: USD 2000 per Metric Ton. Legend: Electricity, Fuel. Source: HRS-MI
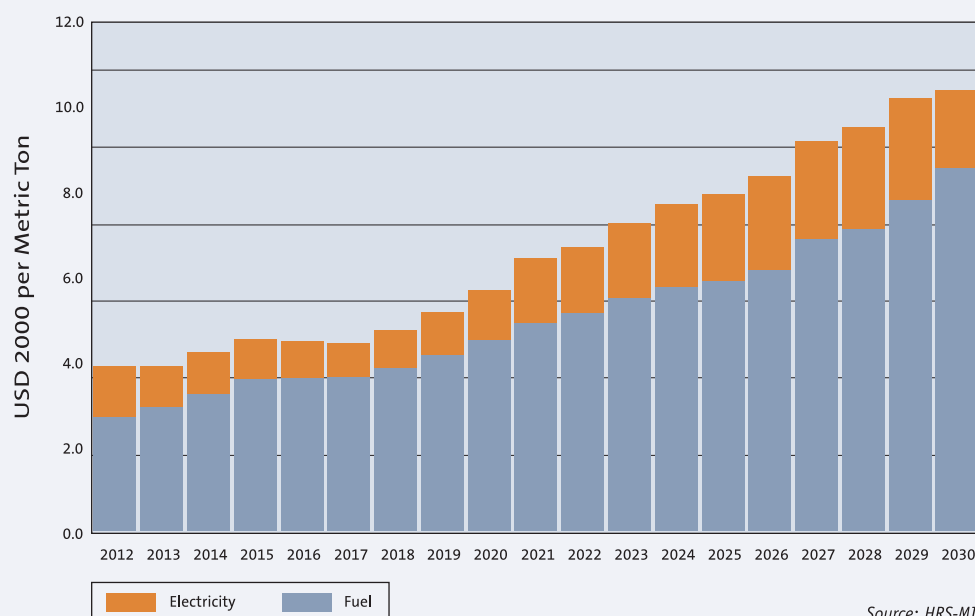
ENERGY AND PRODUCTION COST IMPACTS. Energy cost increases under a climate policy would be fairly significant according to the II-CPM. As Table 8-E shows, *total production costs would grow 5.5 percent by 2020 and nearly 10 percent by 2030, compared to BAU.* The energy share of total production costs was 38 percent in 2006. It was projected to remain roughly the same for BAU throughout the period when the Mid-CO$_2$ Price Policy would be in effect. However, the modeling results show that this share would grow nearly to 42 percent, 6 percent above BAU by 2030.

The role of the two main energy components—externally purchased fuel energy and electric power—responsible for this growth are illustrated in Figure 8-13,

and summarized in Table 8-E. Fuel costs would account for the lion's share of the rise in energy costs and consequently the overall growth in production costs. They represent about 60 percent of total energy costs and would increase by over a fifth by 2020 and over one-third by 2030, relative to BAU. Natural gas is the primary fuel consumed in the industry, followed by coal and LPG. The large price increases for the two former fuels under the climate policy are responsible for almost all the growth in fuel costs for chlor-alkali relative to BAU. Electricity growth is much more modest, rising only by 13 percent above BAU by 2030. This reflects the relatively moderate price increases for that energy source under the Mid-CO$_2$ Price Policy.

OPERATING SURPLUS AND MARGINS (NCPA). The chlor-alkali's operating surplus, assuming NCPA, is quite

large in the BAU case, but as Figure 8-14 shows, it would shrink by a sizable amount under the Mid-CO$_2$ Price Policy. This is partly the result of projected declining market price relative to the rapidly rising production cost curve under the climate policy.

Table 8-F shows that the reduction in the industry's operating surplus resulting from the Mid-CO$_2$ Price Policy would be substantial, 10 percent below BAU in 2020 and a shade under 20 percent in 2030. Operating margins also would shrink, by 3.6 percent in 2020 and 6.6 percent in 2030. The growing scale of both the operating surplus and operating margin reductions, over this period could begin to translate into a noticeable diminishment in the industry's profitability, leading chlor-alkali producers to seriously explore options for containing their energy costs, contingent on its financial situation and market conditions.

OPERATING SURPLUS AND MARKET SHARES (CPA). Faced with diminishing profitability, the industry might also consider passing along the costs to customers (CPA), to preserve its profit margins and minimize operating surplus reductions. But with higher prices come lower market shares, as lower cost foreign imports replace domestic production and sales. Because the chlor-alkali industry currently enjoys a net trade surplus (exports exceeds imports), the pressures of foreign competition may not be as great as for other industries, and cost pass-along may be more of an option. In any event, as Table 8-F shows that, under the cost basis CPA assumption, the industry would see a decline of less than 1 percent of its domestic market share, which would still total around 90 percent, as a result a CPA choice under the Mid-CO$_2$ Price Policy. This is equivalent to a reduction in production of 270,000 metric tons of chlor-alkali products,

FACED WITH DIMINISHING PROFITABILITY, THE INDUSTRY MIGHT ALSO CONSIDER PASSING ALONG THE COSTS TO CUSTOMERS (CPA), TO PRESERVE ITS PROFIT MARGIN.

FIGURE 8-14

CHLOR-ALKALI REAL UNIT PRODUCTION COSTS, COMPARED TO DOMESTIC MARKET PRICE

Real Unit OS [Mid-CO$_2$ Price-NCPA]

Real Unit OS [BAU]

Real Unit OS [Mid-CO$_2$ Price Case—CPA]

- - - *Domestic Market Price-CPA Cost Basis* — **Domestic Market Price-NCPA**
— **Mid-CO$_2$ Price Production Cost** — **BAU Production Cost**

Source: HRS-MI

out of a total net domestic output of 34.6 million metric tons. The industry's operating surplus also would be diminished by less than 1 percent, which would translate into a negligible impact on its profits.

Chlor-alkali markets, prices and CPA. Given the dramatic revenue reduction projected under a NCPA assumption, and the projected gains if costs were passed along, manufacturers in the chlor-alkali industry may decide to pass along some or all their additional costs, despite modest losses in market shares. Given the low import vulnerability of this industry—up until now it has been a net exporter—cost pass-along may be a reasonable response by chlor-alkali producers to offset and prevent future major economic harm. But market conditions could greatly influence chlor-alkali companies' decisions about passing along cost increases or investment choices in response to them.

The chlor-alkali industry is very cyclical. Years of low profitability have been followed by periods with sufficiently high margins to justify reinvestment. For example, in mid-2000 to 2003, the industry suffered a major slump, with poor profitability, a situation exacerbated by a rise in natural gas prices in North America in 2001 and 2003, which led to the rationalization of capacity. However,

the 2004 industry regained profitability as prices also grew considerably, although some of the increase was offset by higher energy costs.[346]

U.S., Western European and Japanese chlor-alkali markets are mature, and demand is expected to grow slowly. Because chlorine is difficult to economically store and transport, chlorine and caustic soda are usually produced in close proximity to their end-users, which primarily include chemicals manufacturers and pulp and paper mills.[347] As noted above, most new capacity growth therefore is expected in less developed regions of the world, to meet growing domestic demands for chlor-alkali products as their economies growth, the economic slowdown starting in late 2008 notwithstanding.

China in particular was expected to increase its capacity by 50 percent from 2004 to 2008, and until the global economic slowdown, its consumption of chlorine and caustic soda was expected to growth at a strong rate through 2012.[348] Chemical Market Associates has estimated that China would add more than 80 percent of total new chlor-alkali capacity between 2008 and 2013. However, this could lead to an overcapacity situation in the near term.[349] International oversupply and declining

[346] Linak, et al, "Chlorine/Sodium Hydroxide."

[347] U.S. Department of Energy, Office of Industrial Technologies (DOE/OIT), *Energy and Environmental Profile of the U.S. Chemical Industry.* Prepared by Energetics, Inc. (May 2000), 177.

[348] Linak, et al, "Chlorine/Sodium Hydroxide."

[349] "CMAI Analyzes Evolving Chlor-Alkali Market Dynamics," *Worldwide Databases,* January 1 2009. *HighBeam Research.* http://www.highbeam.com (accessed 14 February 17. 2009)

Table 8-F

Operating Surplus, Operating Margin and Market Shares Chlor-Alkali Manufacturing

Item	2006	2020		2030	
		Value	% above BAU	Value	% above BAU
Operating Surplus (Million USD 2000)					
BAU	1,722.4	1,924.4	—	1,791.6	—
Mid-CO$_2$ Price Case:					
NCPA	—	-192.5	-10.0	-356.8	-19.9
CPA [Cost Basis]	—	-7.7	-0.4	-14.1	-0.8
Operating Margin (Percent)					
BAU	31.6	35.5	—	33.3	—
Mid-CO$_2$ Price Case:					
NCPA	—	32.0	-3.6	26.7	-6.6
CPA [Cost Basis]	—	34.3	-1.2	31.2	-2.1
Domestic Market Share (Percent)					
BAU	93.8	89.7	—	89.7	—
Mid-CO$_2$ Price Case:					
CPA [Cost Basis]	—	89.3	-0.4	89.0	-0.7

NCPA=No Cost Pass-Along; CPA=Cost Pass-Along

domestic, if not global, demand would put a downward pressure on chlor-alkali prices, making it harder for domestic manufacturers to absorb additional energy costs or pass them along to consumers.

Technology and Policy Options— Chlor-Alkali

In the study, we reviewed some of the technology investment options and evaluated a public policy option that could help the chlor-alkali industry mitigate the economic costs of a climate policy. We first found that the industry would need to achieve fairly substantial energy-efficiency gains to offset these costs.

At the same time, although there are incremental heat, power and process technologies and a major process technology that the industry already is moving towards, which could greatly reduce the industry's energy costs, there remain barriers to their successful implementation. More research is needed to evaluate these options, their potential for generating sufficient energy-savings, and the timing, cost, and technical barriers to their successful implementation.

Finally, we found that a 90 percent allowance allocation policy would alleviate some of the short-to-mid-term cost pressures on U.S. chlor-alkali manufacturers, which could buy time, if not encourage them to make the transition to new energy-saving technologies and advanced chlor-alkali manufacturing processes.

A 90 percent allowance allocation policy would alleviate some of the short-to-mid-term cost pressures on U.S. chlor-alkali manufacturers.

Energy efficiency requirements. Figure 8-15 illustrates the energy efficiency gains that would be required in the chlor-alkali industry to offset the production costs that would result from the Mid-CO_2 Price Policy. The largest gains required would be to offset fuel energy cost increases. These rise from a little over 10 percent in 2012, immediately after the policy would go into effect, to about 19 percent in 2030. Electricity gains required would be around 7 percent in 2020 and 10 percent in 2030. Because fuel costs are the primary source of cost increases in the chlor-alkali industry, according to the II-CPM simulations, the primary emphasis on energy-saving measures and technologies should be on making efficiency improvements in the delivery and use of heat and power.

Technology options. According to the International Energy Agency (IEA), the best opportunity for reducing energy use and costs of the chlor-alkali industry is to substitute membrane technologies for the mercury and diaphragm production methods currently in place. Membranes are a chemical separation process. Separation processes are among the most energy-intensive operations in the chemical industry, which includes distillation and extraction. They use up to 40 percent of all energy consumed in the chemical industry and can account for more than 50 percent of plant operating costs.[350]

Membranes selectively separate one or more components from a liquid or gas. They can replace energy-intensive separation processes in a wide-range of industries, including food processing, chemicals, paper, petroleum refining and the metals industries. About 20 percent of the membranes in the United States are used in the production of chemicals and industrial gases. However, the development of membrane reactors, which combine chemical conversion and separation in a single reactor, is an area that still needs a considerable amount of research.[351]

If the current membranes cells are replaced by more advanced cells using new state—of-the-art technology (i.e., the oxygen-consuming cathode), energy savings of at least 30 percent could be realized. Even more significant savings are possible by replacing diaphragm and mercury cells with the new energy-efficient membrane cells. In fact, because the membrane technology has been optimized, major energy savings cannot be achieved with additional modifications, unless the newer technology is adopted.

However, because of the relatively low cost of electricity in past years and the high capital investment required, U.S. firms have been resistant to invest in the new energy-efficient chlor-alkali process, unless there is a short-term boost to their competitiveness. At the same time, investments in the new technology have already been made in Europe and Japan, where energy prices are higher and environmental regulations stricter than in the United States.[352] U.S. electricity prices, however, have risen over the past decade, which would be augmented by a climate policy. Coupled with sufficient investment incentives, this may provide some encouragement for U.S. chemical companies to make the transition to new cell technologies.

> The best opportunity for reducing energy use and costs of the chlor-alkali industry is to substitute membrane technologies for the mercury and diaphragm production methods currently in place.

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[350] IEA, *Energy Technology Perspectives,* 420.

[351] Ibid., 421, also Table 7-19. The IEA also notes that membranes for important energy consuming separations in the chemical industry may need a few decades for development and deployment.

[352] Project Summary Form (CPS1797), FY 2004 Materials, Glass, and Sensors Project and Portfolio Review, Advanced Chlor-Alkali Technology Project, Dr. Jerzy Chlistunoff (PI), Los Alamos National Laboratory, n.d., http://www.pdfdownload.org/pdf2html/pdf2html.php?url=http%3A%2F%2F www1.eere.energy.gov%2Findustry%2Fimf%2Fpdfs%2F1797chlor-alkalisum.pdf&images=yes.

Figure 8-15. Chlor-Alkali Industry – Cumulative Yearly Energy Efficiency Gains Required to Offset Climate Policy Costs. Horizontal bar chart, Percent (0.0 to 20.0) on x-axis. No Allocation: Fuel 2030 = 18.5, Fuel 2020 = 14.2, Fuel 2012 = 10.5; Electricity 2030 = 9.8, Electricity 2020 = 6.6, Electricity 2012 = 7.7. 90% Allocation: Fuel 2030 = 6.6, Fuel 2020 = 3.0, Fuel 2012 = 1.2; Electricity 2030 = 3.3, Electricity 2020 = 1.3, Electricity 2012 = 0.8. Source: HRS-MI.
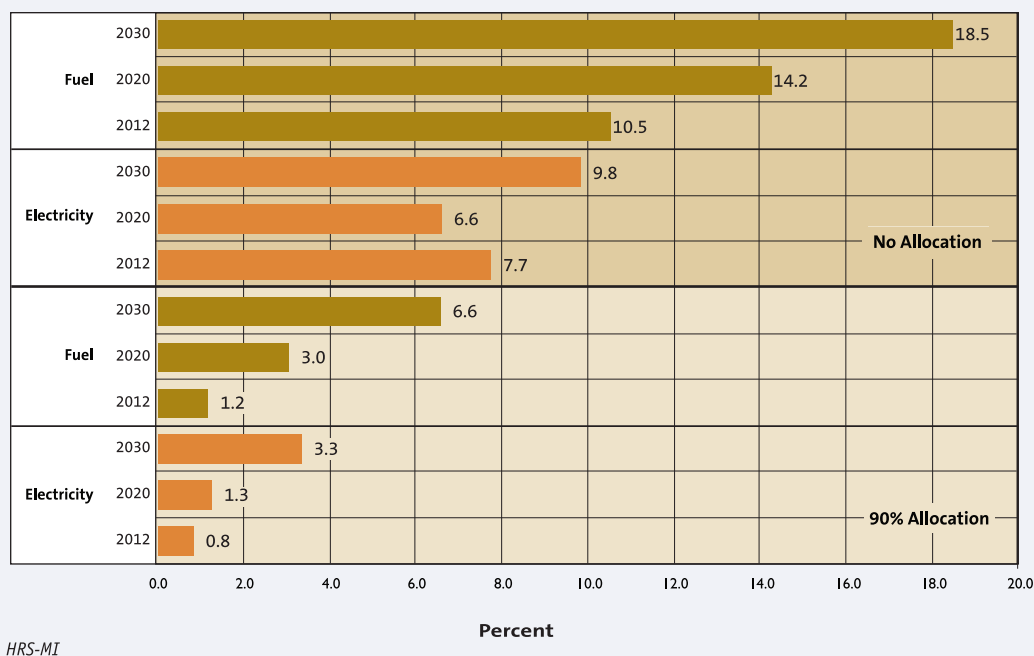
Policy options to mitigate impacts. Figures 8-15 and 8-16 illustrate the potential mitigating benefits of the 90 percent allocation measure on the economic impacts of the Mid-CO_2 Price Policy on the industry. The cumulative energy efficiency gains required for both fuel and electricity in the allocation case would be only about one-tenth than that needed if there were no allocation, in 2012. By 2020, the requirements in the allocation case would be one-fifth that of the no allocation case, and by 2030, the requirement would fall to one-third the allocation case. The diminishing mitigating effects over time reflect the 2 percent annual reduction in the allocation offset.

Similarly, Figure 8-15 shows the substantially lower cost increase and operating surplus reduction that would result from implementing the allocation measure; as in all other industries, the chlor-alkali industry would realize a 74 percent gain in 2020 and a 54 percent gain in 2030. By 2020, real unit production costs would fall from 5.5 percent to 1.5 percent, above BAU, and operating surplus would diminish from 10 percent to about 3 percent, below BAU. By 2030, production costs would shrink from 10 percent to 4.6 percent above BAU, and operating surpluses would decline from nearly 20 percent to 9 percent, below BAU.

Conclusion

The II-CPM simulations results show that enactment of a mid-price climate policy would have widely different impacts on the

Investments in the new technology have already been made in Europe and Japan, where energy prices are higher and environmental regulations stricter than in the United States.

Figure 8-16

Chlor-Alkali Production Costs and Operating Surplus, Mid-CO$_2$ Price Policy Percent Above BAU, No Allocation and 90% Allocation Options (NCPA)

HRS-MI
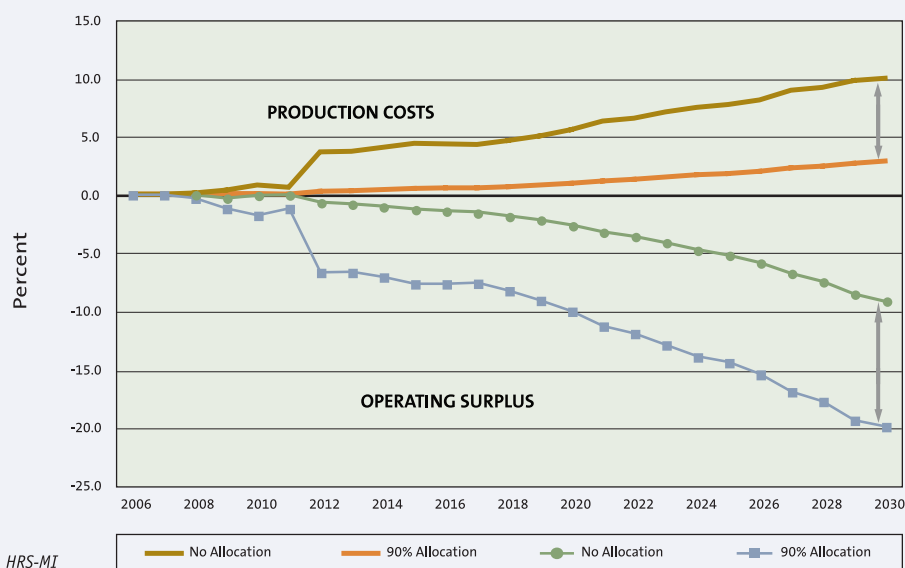
petrochemicals and chlor-alkali industries. Although both industries are highly energy-intensive—the former heavily dependent on hydrocarbon-based feedstock, the latter on natural gas and electricity—the different energy mixes and the projected price variations for their primary energy sources under the climate policy result in, on the one hand, relatively small impacts on the petrochemical industry, yet large and potentially troubling impacts on the chlor-alkali industry, on the other.

Under the assumptions regarding the nature of the energy mix and prices used in the II-CPM simulations and with no mitigating action being implemented to reduce the impact of a climate policy, the petrochemical industry would experience very modest increases in its production costs, which would translate into only small reductions in its operating surpluses, operating margins, and ultimately its profits. In contrast, the

chlor-alkali industry would experience some of the largest impacts on all these economic variables of any industry in the study.

At the same time, because both industries are relatively less sensitive to import substitution, under favorable market conditions, when demand is robust and prices for their goods are rising domestically and internationally, they may more easily be able to pass-through their costs to users of their products. However, both industries are more vertically integrated with producers of derivative and downstream products, which rely on the processing and incorporation of their products (e.g., PVCs), than other sectors analyzed in this study. The downstream producers tend to be more price sensitive and perhaps less able to pass-through new costs in the global markets they operate within, than their basic materials suppliers. Therefore, to fully understand the implications of climate policy-driven energy

cost increases, it might be necessary to examine the ripple effect of petrochemical and chlor-alkali cost increases, if they are passed through, on the profitability and competitiveness of their major downstream customers.

Both industries are also very sensitive to the volatility of energy prices, in particular, natural gas, which under conditions of weakened demand and falling product prices, have led some chemicals firms—especially in petrochemicals—to consider building new capacity in, or sometimes shifting their operations to, foreign locations with abundant and cheap energy supplies, rather than upgrading or expanding their domestic facilities. Cost pass-along in these situations is less feasible, and even incremental impacts on production costs and profits from a climate policy could influence firms' location and investment decisions, in efforts to maintain their margins.

Our examination of technology and policy options found that corresponding to the II-CPM cost, operating surplus, and profit margin findings, the petrochemical industry would require small energy-efficiency gains to offset rising climate policy-driven energy costs. The required gains for the chlor-alkali industry, in any case, were estimated to be quite large, consistent with the substantial cost and profit impacts projected by the II-CPM.

Both shorter and longer-run energy-saving technology options are available to the industries—and being researched by them—but the usual financial, technical, and timing issues need to be addressed to determine the economic feasibility of implementing these options, under the additional energy cost pressures from a climate policy. Both industries could benefit from incremental improvements from continued application of CHP, heat recovery, advanced sensors and

process controls, and similar energy-saving applications. These in principle could help offset the relatively projected modest cost impacts in the petrochemical industry, and could help over the short-run if they were implemented in the chlor-alkali industry.

However, the larger longer-term technology improvements—membrane cells in chlor-alkali, more advanced cracking furnaces, biomass feedstock in petrochemical manufacturing—needed to offset the industries' more substantial profit reductions in later years, would require more research, development and demonstration of their technical and commercial feasibility, before companies would be willing to make the substantial investments required to replace their older, existing production facilities. At the same time, because the domestic chlor-alkali industry reportedly is characterized by aging, and in some cases very old, plants, the industry may be more ready to replace some or most existing capacity with modernized, advanced membrane cells over the next decade or so, though other enabling policies may also be needed.

Finally, the enactment of the 90 percent allowance allocation measure would greatly mitigate the cost impacts of the Mid-CO_2 Price Policy for both industries, though the issue is disputable if the petrochemical industry were to receive a credit for the carbon "sequestered" in its products. The allocation policy also would be important to mitigate short-to-medium term impacts on the chlor-alkali industry. In any event, we believe that other, supplemental policies might be needed to encourage chemicals manufacturers to adopt both incremental and advanced low-carbon and low-emissions process technologies over the next 10 to 15 years, to help them cope with increasing energy prices.

Shorter and longer-run energy-saving technology options are available to the industries, but financial, technical, and timing issues need to be addressed.

Appendix A LITERATURE REVIEW

Until recently, the economic debate around climate change largely centered around the macroeconomic impacts of policies to reduce greenhouse emissions. When the U.S. Department of Energy's Energy Information Administration analyzes different pieces of climate legislation, it mostly calculates projected impacts on broad economic indicators, such as GDP, total consumer spending, and industrial output. Many other studies, by environmentalists and academic economists, use general equilibrium models that also mostly yield economy-wide impacts, though some contain industrial input-output (I-O) modules, which can calculate distributional effects, mainly at a high level of sector aggregation.

Over the past two years, some of the debate has shifted to climate policy impacts on the competitiveness of large energy-intensive, import-sensitive industries, and the best measures to mitigate these impacts. Unfortunately, only a limited number of studies have attempted to systematically evaluate climate policies and their impact on the manufacturing sector, especially on energy-intensive industries. The HRS-MI study is a new addition to this small group. In this study, we have attempted to quantify the increased production costs resulting from policies that impose a price on carbon emissions, and the subsequent impacts on manufacturers bottom-lines and production output. We further evaluated these industries under different assumptions concerning the ability of import-sensitive manufacturers to pass along their new cost increases to consumers of their products, both domestically and in global markets.

In this study, we have attempted to quantify the increased production costs resulting from policies that impose a price on carbon emissions.

In contrast to other traditional economic analyses, however, in the HRS-MI study we employed a System Dynamics modeling approach that explicitly represents the causal relations underlying the system analyzed, using differential equations that allow for a dynamic simulation of the impacts of various policy proposals. This approach is in line with important pioneering research performed by University of Maryland environmental economics professor Matthias Ruth and several of his graduate students in the late 1990s and early 2000s with Environmental Protection Agency support.[1]

COMPARING METHODOLOGIES

Every methodology, as well as its applications, has strengths and weaknesses. These depend on the specific characteristics of the methodology (its foundations) and on the issues being analyzed (its application). An overview of the optimization, econometrics and simulation approaches are presented below. A more detailed comparison of models used for climate policy analysis follows.

Optimization models, which generate "a statement of the best way to accomplish some goal,"[2] are normative, or prescriptive, models. In fact, these models provide information on what to do to make the best of a given situation (usually the current one) and do not generate insights on what might happen in such a situation or what the impact of actions may be. Policymakers often use optimization tools to define what the perfect state of the system should be in order to reach their goals. They seek

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[1] B. Davidsdottir and M. Ruth. 2005. "Pulp Non-Fiction: Dynamic Modeling of Industrial Systems," *Journal of Industrial Ecology* 9, no. 3 (2005): 191-211; M. Ruth, B. Davidsdottir and A. Amato, "Climate Change Policies and Capital Vintage Effects: The Cases of US Pulp and Paper, Iron and Steel and Ethylene," *Journal of Environmental Management* 7, no. 3 (June 2004): 221-233; and, M. Ruth, B. Davidsdottir, and S. Laitner, "Impacts of Energy and Carbon Taxes on the US Pulp and Paper Industry," *Energy Policy* 28 (2000): 259 – 270.

[2] J. D. Sterman, "A Skeptic's Guide to Computer Models." In Barney, G. O. et al. (eds.), *Managing a Nation: The Microcomputer Software Catalog* (Boulder, CO: Westview Press, 1988) 209-229.

information that allows them to formulate policies intended to reach such a perfect state of the system and, in turns, their goals.

For a given situation, optimization models use three main inputs: (1) the goals to be met (i.e. objective functions), (2) the areas of interventions and (3) the constraints to be satisfied.[3] As a consequence the output of an optimization model identifies the best interventions that would allow reaching the goals (or to get as close as possible to it), while satisfying the constraints of the system.[4]

The challenges related to optimization models include the correct definition of an objective function, the extensive use of linearity, the lack of feedback and lack of dynamics. Such models usually do not provide forecasts, but some of them such as MARKAL,[5] NEMS,[6] and MESSAGE[7] provide snapshots of the optimum state of the system with time intervals of 5 or 10 years. Such models use exogenous population and economic growth rates, among others.

Every methodology has strengths and weaknesses. These depend on the specific characteristics of the methodology (its foundations) and on the issues being analyzed (its application).

Optimization models can be very useful in defining the optimum solution (target) given a specific situation, on top of which specific policy proposals are formulated. Optimization can also be applied to issues and systems that are relatively static and free of feedback. Such properties can be found in analyses focused on very short-term time frames. When analyzing the impact of policies in social, economic, and ecological systems, on the other hand, longer time frames are required, limiting the

usefulness of optimization techniques.

Econometrics measures economic relations, running statistical analysis of economic data and finding correlations between specific selected variables. Econometric exercises include three stages—specification, estimation, and forecasting.[8] The structure of the system is specified by a set of equations, describing both physical relations and behavior, and their strength is defined by estimating the correlation among variables (such as elasticities: coefficients relating changes in one variable to changes in another) using historical data. Forecasts are obtained by simulating changes in exogenous input parameters that are then used to calculate a number of variables forming the structure of the model (e.g. population and economic growth). Econometrics uses economic theory to define the structure of the model. The quality and validity of projections is

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[3] Ibid.

[4] International Institute for Applied Systems Analysis (IIASA) *Model MESSAGE,* Command Line User Manual, Version 0.18 (2001); IIASA, Achieving a Sustainable Energy System (2002).

[5] L.G. Fishbone, G. Giesen, G. Goldstein, H. A. Hymmen, K. J. Stocks, H. Vos, D. Wilde, R. Zöcher, C. Balzer, H. Abilock. *User's Guide for MARKAL.* IEA Energy Technology Systems Analysis Programme (1983); R. Loulou, R., G. Goldstein, and K. Noble, *Documentation for the MARKAL Family of Models.* IEA Energy Technology Systems Analysis Programme (2004).

[6] U.S. Department of Energy, Energy Information Administration EIA, *The National Energy Modeling System: An Overview* (2003).

[7] IIASA 2001 and 2002

[8] Sterman, "Skeptic's Guide to Computer Models."

therefore highly connected to the soundness of the theory used to define the structure of the model.

The most important limitations of econometrics are related to the assumptions characterizing the most commonly used economic theories: full rationality of human behavior, availability of perfect information and market equilibrium. When looking at the results produced by econometric models, issues arise with the validation of projections (that cannot backtrack historical data) and with the reliability of forecasts that are based on historical developments and on exogenous assumptions. The analysis of unprecedented events or policies that have never been applied leaves room for uncertainty given that econometrics provides little insights on the mechanism that generate changes in the system.

While optimization models are prescriptive and econometric models do not provide extensive insights on the functioning of the system analyzed, *simulation models* are descriptive and focus on the identification of causal relations influencing the creation and evolution of the issues being investigated. Simulation models are in fact "what if" tools that provide information on what would happen in case a policy is implemented at a specific point in time and within a specific context.

Simulation models aim at understanding what the main drivers for the behavior of the system are. This implies identifying properties of real systems, such as feedback loops, nonlinearity and delays, via the selection and representation of causal relations existing within the system analyzed. The results of the simulation would then show the existence of correlations in a dynamic manner, which are

the assumptions underlying econometrics.

On the other hand, the main assumptions of simulation models are those causal relations forming the structure of the model: instead of using economic theories, simulation models represent theories of how the system actually works. In other words, instead of fitting existing theories to the issues being analyzed, *simulation models propose a theory of their own, highly customized and tailored around the issues to be analyzed and the peculiarities of the system.*

The validation of such models takes place in different stages, and the most peculiar tests when compared to optimization and econometrics, is the direct comparison of projections with historical data, which simulation models can backtrack, and the analysis of structural soundness with respect to reality.[9] Potential limitations of simulation models include the correct definition of boundaries and a realistic identification of the causal relations characterizing the functioning of systems being analyzed.

SIMULATION MODELS AIM AT UNDERSTANDING WHAT THE MAIN DRIVERS FOR THE BEHAVIOR OF THE SYSTEM ARE.

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[9] Y. Barlas, "Formal Aspects of Model Validity and Validation in System Dynamics," *System Dynamics Review,* 1996.

Existing Studies

Several recent studies have attempted to quantify the macroeconomic impacts of U.S. climate policy scenarios.

Most studies that have attempted to measure the impacts of different climate policies have largely focused on the U.S. economy as a whole. There has been a relative dearth of studies focusing on manufacturing, though there has been more attention in recent years as policymakers started debating about concerns of industry and labor unions. Some of these are reviewed below.

Macroeconomic impact studies.

Several recent studies have attempted to quantify the macroeconomic impacts of U.S. climate policy scenarios. A recent survey of these studies notes that the estimates of the change in overall economic output in 2030 have ranged between 0.5 percent above and 1.5 percent below the projected baseline, depending on the design of the policy in question.[10] An Energy Information Administration (EIA) analysis of GHG-

intensity goals[11] also projected very small impacts on the U.S. economy overall, with modest consumer energy prices rising from 4 percent to 7 percent in 2020 and only a 0.07 percent drop in GDP below business-as-usual in 2020.

The EIA recently examined the impacts of the *Lieberman-Warner Climate Security Act of 2007* (S. 2191) and several variations of the bill,[12] based on different assumptions (severely limited use of international offsets, higher costs for lower-carbon (nuclear, biomass, coal with carbon capture and sequestration (CCS)) electricity generation; limited alternative generation technologies, and combined limited alternatives and no international offsets). The Lieberman-Warner analyses and a comparison with the Bingaman-Specter Climate bill (S. 1766) were conducted under AEO 2008 Reference Case assumptions.[13]

The EIA analysis estimated that between 2009-2030 cumulative real GDP losses

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[10] Trevor Houser et al, *Leveling the Carbon Playing Field: International Competition and US Climate Policy Design.* (Washington, DC: World Resources Institute and Peterson Institute for International Economics, 2008).

[11] U.S. Department of Energy, Energy Information Administration (EIA), *Energy Market Impacts of Alternative Greenhouse Gas Intensity Reduction Goals,* [SR/OIAF/2006-01] (Washington, DC, March 2006), Tables 2a and 2b, 11-12.

[12] U.S Department of Energy, Energy Information Administration (EIA), *Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007*, [SR/OIAF/2008-01] (Washington, DC, April 2008).

[13] See Energy Information Administration (EIA), *Annual Energy Outlook 2008*, [DOE/EIA-0383(2008)] (Washington, DC, April 2008).

ranged from 0.2-0.6 percent for the Lieberman-Warner cases, and was 0.03 percent for S. 1766. It similarly estimated impacts on the industrial sector. These were relatively higher than overall economic and consumption impacts projected by the study, but were still small. Real cumulative drops in industrial shipments below the reference case ranged between 1.3-3.6 percent, and 0.7 percent for Bingaman-Specter. The loss in consumption in 2030 was, correspondingly, 2.9-7.4 percent, and 1.7 percent respectively.[14]

A report of the MIT Joint Program on the Science and Policy of Global Change[15] assessed the Bingaman-Specter proposal along with several other cap-and-trade proposals including legislation that had been offered by Lieberman-McCain and Sanders-Boxer, which specify emission reduction goals of 50-80 percent below the 1990 level by 2050. The MIT study concluded that other proposals, especially the Sanders-Boxer bill, would result in somewhat larger economic impacts than the Bingaman-Specter bill. However, like the EIA studies, it only provides a top-down, highly aggregated picture of what happens in the economy under different scenarios. It could not realistically portray the cost impacts and opportunities at the individual manufacturing sector level.

The general equilibrium modeling approach used by EIA and other similar macroeconomic studies at best evaluate industry impacts at the 3-digit sector levels, and are not designed to assess energy-intensive industries at a sufficiently disaggregated level. The EIA model also has difficulty accounting for international trade flows and competition, which can significantly limit the ability of domestic manufacturing industries to adjust to U.S. climate policy-induced energy price increases. For example, the EIA 2006 analysis of an earlier version of the Bingaman-Specter bill projected a trade *surplus* of $677 billion by 2030. This of course is highly unlikely, as the United States had a trade deficit of over $700 billion in 2007 that will be very hard to reverse, even with a weaker U.S. dollar.

Manufacturing and sectoral studies.

A relatively small number of studies have attempted to examine climate policies and their implications for manufacturing industries in any depth. One set of studies are largely qualitative—they don't quantify policy impacts on industry sectors, but include in-depth industry profiles, and evaluate different energy and climate policy options in light of industry analyses[16] perhaps including supplemental economic modeling. Another set of studies apply modeling tools in attempts to quantify these impacts.[17]

A relatively small number of studies have attempted to examine climate policies and their implications for manufacturing industries in any depth.

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[14] EIA, *Energy Market and Economic Impacts of S. 2191*.

[15] S. Paltsev et al, "Assessment of U.S. Cap-and-Trade Proposals," *MIT Joint Program on the Science and Policy of Global Change, Report 146* (April 2007).

[16] U.S. Environmental Protection Agency (EPA), *Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes, Final Report,* Prepared by ICF International. [EPA 100-R-07-003] (March 2007); McKinsey Global Institute (MGI), *Curbing Global Energy Demand Growth: The Energy Productivity Opportunity* (San Francisco, CA: McKinsey&Company, May 2007); Houser et al, *Leveling the Playing Field*.

[17] Richard D. Morgenstern, Mun Ho, Jhih-Shyang Shih, and Xuehua Zhang, "The near-term impacts of carbon mitigation policies on manufacturing industries," *Energy Policy 32* (2004): 1825-1841; Richard D. Morgenstern, Joseph E. Aldy, Evan M. Herrnstadt, Mun Ho, and William A. Pizer, *Competitiveness Impacts on Carbon Dioxide Pricing Policies on Manufacturing.* (Washington, DC: Resources for the Future, 2007); McKinsey & Company and Ecofys, *EU ETS Review, Report on International Competitiveness*, (European Commission, Directorate for Environment, December 2006); Julia Reinaud, *Industrial Competitiveness Under the European Union Emissions Trade Scheme,* IEA Information Paper, (International Energy Agency (IEA), February 2005); Davidsdottir and Ruth. "Pulp Non-Fiction"; Ruth, Davidsdottir and Amato, "Climate Change and Capital Vintage"; and, Ruth, Davidsdottir, and Laitner, "Impacts of Energy and Carbon Taxes."

In the first group, an Environmental Protection Agency report[18] analyzed current energy usage and expected future consumption trends within 12 manufacturing sectors, with the following objectives: assess opportunities to increase energy efficiency and reduce emissions; identify barriers (especially regulatory) to improving sector performance with respect to energy use; and propose policy options the EPA could pursue to address these barriers, promote energy efficiency and reduce use of emissions-intensive energy sources. The sectors examined include key energy-intensive manufacturing industries, such as alumina and aluminum (NAICS 3313), cement (327310), chemical manufacturing (NAICS 325), forest products (inclusive of pulp and paper (322) and wood products (321)), iron and steel (331111), and petroleum refining (32411, 324110). Though largely qualitative and statistical, the report drew on the DOE's *Scenarios for a Clean Energy Future* (CEF), the EIA's *Annual Energy Outlook 2006*, and the EIA's 2002 Manufacturing Energy Consumption Survey

(MECS).[19] Based on the CEF study, which was published in 2000 and used consumption data from 1998, the EPA study developed "base case" and "best case scenarios" for the 12 sectors it analyzes.[20]

A McKinsey Global Institute report[21] presents the findings of a research project that examined energy demand in major regions and sectors, how company and consumer behaviors affect demand, and the impact of existing energy policies. Recognizing that the energy debate has largely centered on the challenges to securing future energy supply and promoting alternative fuel sources, it notes the need for a better understanding of the size of the "demand abatement opportunities and how these can be captured in an economically sound way." The study built a model of global energy demand and productivity evolution to 2020, and as part to its industrial sector analysis, it conducted case studies of specific energy-intensive industries, including chemicals (ethylene, ammonia, alkalies and

> THE MCKINSEY STUDY NOTES THE NEED FOR A BETTER UNDERSTANDING OF THE SIZE OF THE "DEMAND ABATEMENT OPPORTUNITIES AND HOW THESE CAN BE CAPTURED IN AN ECONOMICALLY SOUND WAY."

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[18] EPA, *Energy Trends in Manufacturing*.

[19] U.S. Department of Energy, Energy Information Administration, Manufacturing Energy Consumption Survey (MECS), (2002), http://www.eia.doe.gov/emeu/mecs/contents.html.

[20] EPA, *Energy Trends in Manufacturing*

[21] MGI, *Curbing Global Energy Demand*..

chlorine), steel, and pulp and paper. The report concludes that there were enough opportunities to boost energy productivity to generate energy savings equal to the entire U.S. energy consumption today, and that capturing these opportunities could substantially reduce demand growth without hurting economic growth. However, it argues that market forces alone are not sufficient. There is a need for targeted policies to "overcome the policy distortions and market imperfections that are currently acting as barriers to capturing higher levels of energy productivity."

A joint World Resources Institute (WRI)/ Peterson Institute for International Economics (PIEE) report[22] looks at methods to maintain a "level playing field" for U.S. industry under domestic climate policy. It evaluates the effectiveness of a wide-range of policy options in achieving the goals of preventing decline of output by US producers, prevent "emissions leakage," and create incentives for other countries to reduce emissions, as well as other economic and environmental policy issues. Towards these ends, it examines the economic and trade flows of key carbon-intensive industries (steel, aluminum, chemicals, paper, and cement), and evaluates a number of current legislative proposals. The report argues that given the limited role of the exposed sectors in the US economy—representing only 3 percent of U.S. economic output and less than 2 percent of the nation's workforce—policy measures "need to be targeted rather than comprehensive." It further concludes if efforts to contain costs for carbon-intensive manufacturing are not "properly considered," they can "harm other industries and raise the cost of reducing emissions for the economy as a whole."

RFF industry studies. Along with the qualitative studies outlined above, there have been recent efforts to quantify the impacts of carbon mitigation policies on energy-intensive manufacturers. A 2004 RFF research effort attempted to measure the near-term impacts of carbon mitigation policies on manufacturing industries. RFF has currently updated and expanded this work.[23] The RFF researchers attempt to model international trade flows, more realistically portray limits on companies' ability to pass along costs, and allow better assessment of companies' use of energy efficient technology. A later article[24] reports on results from this and other related ongoing work at RFF, comparing them to two

POLICY MEASURES "NEED TO BE TARGETED RATHER THAN COMPREHENSIVE." …IF EFFORTS TO CONTAIN COSTS FOR CARBON-INTENSIVE MANUFACTURING ARE NOT "PROPERLY CONSIDERED," THEY CAN "HARM OTHER INDUSTRIES.

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[22] Houser et al, *Leveling the Playing Field.*
[23] Morgenstern et al. "Near-term impacts."
[24] Morgenstern et al, *Competitive Impacts.*

other studies that attempt to measure the impacts of the European Union's Emissions Trading Scheme (EU ETS) on vulnerable manufacturing industries.[25]

Morgenstern, Ho, Shih, and Zhang study. The early RFF study[26] estimated the near-term impacts of a tax on CO_2 emissions (via either an emissions trading scheme or upstream carbon tax) on a somewhat disaggregated (four digit industry classifications) set of domestic manufacturing industries potentially relevant in the policy process. It also compared these results to a downstream policy focused exclusively on the electric power industry. It first constructed a detailed picture of carbon use by individual manufacturing industries. The additional costs of adding a fixed uniform cost per ton of carbon were calculated by multiplying the per ton tax (or permit charge) with the current level of carbon usage in an industry. The costs of an industry' inputs include the costs of capital, labor, and intermediate goods, which were partitioned into energy-related inputs and non-energy inputs. The study utilized an input-output (I-O) framework that allowed construction of inter-industry accounts including final demand for a long list of commodities.

This methodology enabled calculations of the percentage increase in the prices of 361 commodities and the percentage increase in production costs for a comparable number of industries per dollar of carbon charge and total production costs for each industry (product of the percentage cost increase and the level of industry output. The findings also showed the percent cost increase due to cost components, including fuel, electricity, and intermediate inputs. Rankings and statistical analysis illustrated the highly concentrated distribution of industries and

commodities that are the most vulnerable to a carbon charge. As the report concludes, "a small number of manufacturing industries bear a disproportionate burden of the carbon mitigation policy." Petroleum refining tops all the rankings; on the commodity list, it would see an estimated price increase of 0.68 for each additional dollar of carbon charge. The increase for the 25th ranked commodity (chemicals and chemical preparations) was only about a tenth as large. Among the entire list, prices vary by two orders of magnitude. There's a similar high level of concentration and ranking among industries regarding cost increases.

The researchers recognized the static nature of their study. They are focused on the near-term impacts before industries can make adjustments versus the long-run

25 McKinsey/Ecofys, *EU ETS Review;* Reinaud, *Industrial Competitiveness.*
26 Morgenstern et al. "Near-term impacts."

when changes in capital and technology can be made. They assumed that there are no substitutions among inputs, which they claim is a common assumption at the detailed input level. They also assumed 100 percent pass through of the costs for all industry sectors, which may not be true for the most energy-intensive industries (such as steel and aluminum) and other industries. Another important assumption they made is that imports are not changed by the carbon charges, which is equivalent to assuming that trade policies are put into place that exactly offset the cost advantage of local producers. This too is an unrealistic assumption as import competition may be a significant factor in affecting market share and outputs. The RFF researchers more recent work has attempted to address these caveats.

Morgenstern, Ho, and Shih study. In a more recent effort, reported in the

later article,[27] RFF researchers Richard Morgenstern, Mun Ho, and Jhih-Shyang Shih employed a simulation model of the U.S. economy, incorporating trade flows and an international sector, to estimate the industry-level impacts of pricing CO_2 emissions. The study evaluated broader industry categories at a higher level of aggregation (3-digit NAICS) than the earlier Morgenstern study. It examines cost impacts over the immediate and near-term and then the long-term. It first considers near-term options for industry for responding to higher energy costs and that of other intermediate goods from a CO_2 pricing policy. If output prices are unchanged, the higher costs will cut into profits. However, if prices are raised to cover the higher costs, sales will decline. In the short run, it was assumed that companies would not have the ability to respond to higher prices. They cannot raise prices for outputs, alter production technologies or

<div style="color: brown; font-variant: small-caps;">

If output prices are unchanged, the higher costs will cut into profits. However, if prices are raised to cover the higher costs, sales will decline.

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[27] Morgenstern et al, *Competitive Impacts.*

make process adjustments.

It then simulated the response for each industry using a model of the U.S. economy to estimate the impact of higher prices on sales, assuming that after the immediate time horizon, there will be an upward pressure on prices to recover the higher costs. The model allows buyers (other firms, households, and exports) to choose between domestic suppliers and importers. The model then estimated the expected changes in output for different industries under a \$10-per-ton CO_2 charge, making the assumption that an industry-wide increase in product prices equals the increase in calculated costs. In all sectors, the decline in sales reflects the elasticity of demand.

Over the longer-run, the study considers that higher prices would at first increase revenues, offsetting the initial rise in costs,

but eventually there would be declines in sales, employment, and profits as customers switch to substitute goods or overseas suppliers whose prices do not reflect a carbon-charge. Firms also would substitute some inputs for others and implement ways to save energy and reduce costs. Switching to less carbon-intensive inputs and technologies would ameliorate prices and demand effects relative to effects in the immediate and near term. Morgenstern, Ho, and Shih recognize that the long-term impact of carbon-pricing policy on a given industry reflects competing changes, and "may be larger or smaller in net than it is over immediate and near term horizons." The final results of this modeling analyses were recently published in a discussion paper, but are not reviewed in this report.[28]

Aldy-Pizer study. Joseph Aldy and William Pizer are employing a very different

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[28] Mun S. Ho, Richard Morgenstern, and Jhih-Shyang Shih, "Impacts of Carbon Policies on U.S. Industry," Discussion Paper, [RFF DP 08-37] (Washington, DC:Resources for the Future, November 2008). A quick review of this study, however, indicates that Ho, Morgenstern, and Shih found that over the immediate and short-term, energy-intensive industries, including the ones we examined in the HRS-MI study, would experience substantial adverse impacts from a cap-and-trade climate policy. However, using a computable equilibrium model they found that industries at a higher level of aggregate (2-3 digit NAICS) would eventually adjust to these impacts. Hence, their results tracks well with our own findings for comparable industry levels, but suffered from limits, due to their modeling approach, to estimate longer-term impacts at the industry level we examined.

approach.[29] They are conducting a strictly econometric analysis of data on energy prices and industry performance across a number of countries and industries, to evaluate how policy-induced changes in the cost of fossil energy affect industry-level output, employment, and other metrics of competitiveness. The analysis relies on historical data to examine the competitiveness of past electricity price charges over the short or medium timeframe, controlling for a range of other relevant factors. The study focuses on industry categories at a more disaggregated industry level than the Morgenstern, Ho, and Shih study, examining specific energy-intensive industries comparable to those examined in the EU studies (and the current study). It also compares industry behavior across several countries, including Australia, Canada, New Zealand, the United Kingdom, and the United States, over the period of 1978-2000, which were chosen because they have the same labor market flexibilities. The analysis consists of providing statistical estimates of the average effect of electricity prices on the output of manufacturing industries, controlling for the subject industry' GDP, and other factors. These estimates are then used to explore how a given CO_2 price would increase energy prices and cause output declines in particular industries.

EU ETS studies. Two recent, detailed studies of the impacts of the European Union Emissions Trading Scheme (EU ETS) on the competitiveness of European manufacturing industries, one by McKinsey and Ecofys and the other by International Energy Agency (IEA) economist Julia Reinaud, are based on case studies of key industry sectors.[30] The focus of these studies is on narrower, more energy-intensive industrial categories than typically analyzed in such studies. The analyses started with a straightforward computation of how permit allocation schemes would increase industry costs, from a particular CO_2 charge, assuming that the GHG policy is implemented across the whole EU bloc of nations, not on a global basis.

McKinsey/Ecofys study. The McKinsey/Ecofys study[31] measured the bottom-line impact of CO_2 charges on the economic margins for a given industry, expressed as a percentage of total costs. These impacts were calculated by adding all the cost increases for input factors (e.g., electricity to the costs of direct emissions and allowances). They then estimated the potential to pass through the cost increase to customers on the basis of the competitive situation and market mechanism in the industry. Finally, assuming 95 percent of required allowances covered are granted for free, they calculated the net impact on industry costs. The calculation was based on a CO_2 price of 20 Euro per metric ton of CO_2 emissions (roughly $31 per metric ton, at current exchange rates), and an electricity price increase of 10 Euro per MWh (approximately $16 per MWh).

The industries they evaluated include electric power, steel (BOF, EAF), pulp and paper (chemical pulp for market, and mechanical, thermo-mechanical, and recovered fiber pulp and paper), cement, refining and aluminum. These industries account for over 90 percent of all emissions from the trading sectors in the EU. They included aluminum in the study because it is a very large electricity consumer. The McKinsey/Ecofys study differs from other studies, including the RFF and Reinaud/IEA analyses, in that it factored in the varied

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[29] Reviewed in Morgenstern et al, *Competitive Impacts*.

[30] McKinsey/Ecofys, *EU ETS Review*; Reinaud, *Industrial Competitiveness*; These also are reviewed in Morgenstern et al, *Competitive Impacts*.

[31] McKinsey/Ecofys, *EU ETS Review*.

capabilities of each industry to pass through cost increases on average across Europe, based on the researchers own industry expertise and the published literature. Others studies either assume 100 percent cost pass along or no cost pass through. For example, BOF steelmaking is assumed to be able to pass-through 6 percent of costs; EAF steelmaking, 66 percent, pulp and paper production, 50 percent in chemical pulping and 0 to 20 percent for paper from integrated processes, cement, 0 to 15 percent; aluminum, 0 percent; and refining, 25 to 75 percent.[32]

Reinaud/IEA study. The study by Julia Reinaud, for the International Energy Agency,[33] assessed the short to medium term impacts of the EU ETS on international competitiveness of EU industries, including cost impacts, loss of output, and the possibility of emissions leakage. It estimated both the direct and indirect costs associated with emissions trading for several industries (steel, pulp and paper, aluminum, cement) and the likely impact of the EU emissions trading system on

> The study by Julia Reinaud, for the International Energy Agency, assessed the short to medium term impacts of the EU ETS on international competitiveness of EU industries.

measures of competitiveness, such as loss in output, including the reduction in demand and production for each industry. Direct costs include the additional costs resulting from an industry's compliance with an emissions cap, for a given CO_2-emissions charge. Indirect costs are incurred as a result of rising prices of purchased electricity associated with CO_2-charges. It is assumed that fossil-fuel electric power generators will fully pass through their emissions compliance costs to consumers, which includes these industries. The study assumed an average allowance price of 10 Euros per metric ton of CO_2 in its calculations. It also examined the impacts for two allowance assumptions: free allowances covering either 98 percent or 90 percent of CO_2 emissions needs.[34]

Reinaud recognized that an important issue is an industry's ability to pass through carbon cost increases associated with emissions trading onto product prices. Increased costs can either be absorbed by an industry through a reduction in its operational earnings or passed along to consumers through product price increases, which should be followed by a reduction in sales. She noted that a "crucial question" is a sector's ability to maintain its profits while sustaining output levels. If perfect competition in these industries' markets is assumed, product price increases from carbon costs would not be able to be passed through, resulting in modest to significant reductions in operational earnings. If an industry passes on total carbon costs to consumers, it would incur a reduction in its production demand. Reinaud assumed total pass through and, applying demand elasticities for each industry from the literature, measured the resulting loss of

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[32] Ibid.

[33] Reinaud, *Industrial Competitiveness.* Reinaud also has done a recent *Policy and Carbon Leakage, Impacts of the European Emissions Trading Scheme on Aluminum*, (International Energy Agency (OECD/IEA), October 2008).

[34] Reinaud, *Industrial Competitiveness.*

COMPARISON OF ESTIMATED COST IMPACTS IN RFF AND EU ETS STUDIES

(Percent of unit production costs for $10/t CO_2)

Industry	Morgenstern, Ho, and Shih — Unit Cost Increase (%)		McKinsey/Ecofys			Reinaud/IEA	
	Energy	All Intermediate Inputs	Cost Increase (%)	Net of Free Allowances (%)	Net Allowances and Cost Pass-through (%)	Cost Increase (%)	Net of Free Allowances (%)
Paper & Printing	1.10	1.11	—	—	—	—	—
Pulp & Paper*	—	—	0.4 - 2.7	0.2-2.2	0.0 (50%) to 1.7-2.2 (0%-20)	—	—
Newsprint	—	—	—	—	—	3.62	0.95
Primary Metals	1.73	1.58	—	—	—	—	—
BOF Steel	—	—	6.20	1.00	0.6 (6%)	5.89	0.63
EAF Steel	—	—	1.00	0.90	0.20 (66%)	1.65	0.63
Primary Aluminum	—	—	4.10	4.10	4.1 (0%)	2.70**	2.70**
Secondary Aluminum	—	—	0.20	0.20	0.2 (0%)		
Chemicals & Plastics	0.62	0.45	—	—	—	—	—
Petroleum	2.49	2.50	—	—	—4.5 to −0.9 (25%-75%)	—	—
Petroleum Refining	—	—	7.40	0.90		—	—
Nonmetallic Minerals	1.06	1.07	—	—	−0.6 to 1.4 (0%-20%)	—	—
Cement	—	—	13.10	1.40		14.47	1.77
Fabricated Metals	0.19	0.53	—	—		—	—
Machinery	0.09	0.39	—	—		—	—

*   Range for all pulp and paper production processes including chemical market pulp, chemical, mechanical, thermo-mechanical, and wastepaper

**   Denotes figures for aggregate aluminum industry (primary and aluminum)

Source: Morgenstern et al (2007)

IF AN INDUSTRY PASSES ON TOTAL CARBON COSTS TO CONSUMERS, IT WOULD INCUR A REDUCTION IN ITS PRODUCTION DEMAND.

demand for the given CO_2 charge and each of the allowance allocation options (95 and 90 percent).

COMPARISON OF RESULTS

Care should be taken in trying to make meaningful comparisons of the findings from these studies, not to mention relating them to the findings of the HRS-MI study. The studies focus on different geographical regions (United States, EU, and other nations, e.g., Aldy-Pizer study), policy options and levels of industrial aggregation (3-, 4- or higher digit NAICS categories), and employ different data sets, models and methods for defining and calculating impacts (e.g. CGE models vs. System Dynamics, as well as correlation vs. causality), and assumptions regarding issues such as how to characterize and measure competitiveness, and

COMPARISON OF ESTIMATED OUTPUT IMPACTS IN RFF AND EU ETS STUDIES

Industry	Morgenstern, Ho, and Shih	Aldy-Pizer	Reinaud/IEA	
	Effects on Output (%)	Effects on Output (%)	Demand Reduction (%)	Elasticity
Paper & Printing	-0.48	—	—	—
Newsprint	—	—	*1.44*	*-1.88*
Primary Metals	-1.54	—	—	—
BOF Steel	—	-5.96*	*0.79*	*-1.56*
EAF Steel	—		*0.36*	*-1.56*
Primary Aluminum	—	-3.01**	*2.09****	*-0.86*
Secondary Aluminum	—			
Chemicals & Plastics	-0.96	—	—	—
Petroleum	-0.42	—	—	—
Nonmetallic Minerals	-0.66	—	—	—
Cement	—	—	*0.29*	*-0.27*
Fabricated Metals	-0.27	*-1.75*	—	—
Machinery	-0.66	*-3.92*	—	—

  * Aldy-Pizer figures for Iron & Steel (inclusive of BOF and EAF steelmaking).
 ** Aldy-Pizer figures for Nonferrous Metals (inclusive of aluminum, and other nonferrous metals).
*** Denotes figures for aggregate aluminum industry (primary and aluminum).

Source: Morgenstern et al (2007)

industries' ability to pass through their cost increases to consumers. Despite these many differences, the diversity of approaches and data help judge the reasonability of any particular finding.

Tables A-1 and A-2 compare findings of the RFF and EU reports.[35] The Reinaud/IEA results were interpolated to match the 95 percent free allocation in the McKinsey/Ecofys study, and both EU sets of results were scaled to match the $10 per metric ton of CO_2 price used in the U.S. analyses.[36] Since the results are expressed in terms of per dollar increases in carbon charges, it is tempting to scale up to match the higher carbon charges used in the other RFF and EU studies. However, the RFF authors themselves caution against that, noting that "because of the static nature of the analysis, our inability to consider changes in taxes or government spending, and other limitations, the most plausible interpretation of the results is in terms of relative as opposed to absolute impacts."[37]

Cost impacts. The results from Morgenstern, Ho, and Shih not surprisingly show very modest cost impacts for the industry sectors examined, which are all at high levels of aggregation (3-digit NAICS). However, following the point made in Morgenstern (2004), the relative impacts are in line with expectations, in that the more energy-intensive sectors (petroleum, primary metals, nonmetallic minerals, and paper and printing) experience greater impacts from a carbon charge than less energy-intensive sectors (e.g., fabricated metals and machinery). Chemicals and plastics are still higher than the latter, but somewhat smaller than the other energy-intensive sectors, even though it contains many of the most energy-intensive industries at lower levels of aggregation

(petrochemicals, alkalies and chlorine, ammonia). On the other hand, as Table 4A shows, chemicals manufacturing is relatively less energy-intensive than other major energy-intensive sectors at that level, and the plastic sector (which is a downstream set of industries from basic chemicals) is only a little more energy-intensive than fabricated metals products.

The EU studies calculated impacts for industries that are comparable to the ones examined in the current study, and consequently it will be interesting to see how they compare to our results. Indeed, McKinsey/Ecofys calculated impacts for BOF and EAF steelmaking and for several varieties of paper processes, which are at more disaggregated level than the HRS-MI study. The McKinsey/Ecofys figures also include impact net of free allowances and taking into account assumptions about cost pass along (show in parentheses in that column). The result of the allocations analysis (which approximate 95 percent coverage of industry emissions) shows that the somewhat substantial cost impacts for

Care should be taken in trying to make meaningful comparisons of the findings from these studies, not to mention relating them to the findings of the HRS-MI study.

[35] These are largely adopted from Morgenstern et al, *Competitive Impacts*.

[36] Results from Morgenstern et al. "Near-term impacts," summarized above, are not presented.

[37] Morgenstern et al, *Competitive Impacts*.

the steel, petroleum refining and cement industries are far lower after the allocations. There is no difference for the aluminum and paper sectors as the allowances only cover emissions costs, which are minimal for these industries.

Cost categories. The bases for calculating cost impacts varied for the different studies and for the HRS-MI study. The EU studies calculated direct costs associated with emissions compliance and indirect costs from purchasing electricity. Aldy and Pizer only examine changes in electricity costs in their econometric study. Morgenstern, Ho and Shih add the cost increases from electricity and fuel (but not energy feedstock) and the increase in costs from intermediate goods, whose prices reflect rising energy costs in their production. As discussed below, we calculate cost increases from purchased fuels and electricity, as well as purchased energy used as feedstock. Neither Morgenstern et al nor the HRS-MI study have attempted to incorporate emissions compliance costs. However, the fuel prices used as inputs in the HRS-MI analysis were calculated to reflect the cost of emissions compliance in the policy scenarios they are associated with. The HRS-

MI study however did not incorporate the increased costs of non-energy intermediate goods due to higher energy costs, though Morgenstern et al shows that these costs were minimal for the most energy-intensive industries, such a primary metals.[38]

Policy options. The EU studies both focused on analyzing cost and output impacts of the EU's ETS. Aside from the different cost categories used, they evaluated the impact of allowance allocation alternatives—McKinsey/Ecofys looked at a 95 percent allocation, Reinaud/IEA compared a 92 percent and 99 percent allocation. Morgenstern et al notes that "the various domestic policy proposals currently under consideration in the United States are less specific on the issue" of free allowance allocations.[39] While Morgenstern and his RFF colleagues do not directly evaluate allocation alternatives, they have estimated the share of emissions allowances needed to cover an industry's emissions levels that would be needed to compensate energy-intensive industries for losses under a CO_2 pricing policy. In the HRS-MI, we modeled industry impacts for mid-priced climate policy scenarios (and a business-as-usual case), as well as a preliminary analysis of a

Aldy and Pizer only examine changes in electricity costs in their econometric study. Morgenstern, Ho and Shih add the cost increases from electricity and fuel.

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[38] Ibid.
[39] Ibid.

90 percent allowance allocation based on raised energy costs due to climate policies. We also calculated costs and energy-efficiency gains that would be required to offset higher energy costs under the different climate policy scenarios.

Time horizons, cost pass along and output impacts. All the studies attempt to distinguish between short and long-term industry responses. The initial EU and RFF cost calculations assumed short-term time horizon: manufacturers would have little time to respond by adopting new technologies or processes to reduce their costs, and would tend not to immediately raise their product prices to offset higher energy costs from a carbon emissions charge. Over the long-run, the studies assumed industries will pass along their costs and adjust production to increased market competition in response to higher prices. Morgenstern et al. and Reinaud attempted to calculate production (or demand) changes assuming 100 percent

cost pass through to consumers (see Table A-2). Aldy-Pizer also estimate output impacts for a carbon emissions charge. Both Reinaud and Aldy-Pizer's results were for narrower categories of energy-intensive manufacturing, in contrast to the 3-digit industries evaluated by Morgenstern et

al. McKinsey/Ecofys' handling of what it called the mid-term estimates cost impacts assumed different, more realistic cost pass through ratios, which tended to be small for energy-intensive sectors. The HRS-MI industry models, as discussed below, examined both no cost pass along and 100 percent pass along scenarios for different industries and under different policy scenarios.

Static versus dynamic simulation. The EU and RFF studies evaluated production costs and output changes associated with a fixed carbon-dioxide charge. McKinsey/Ecofys based its analysis on a 20 Euros per metric ton CO_2, Reinaud/IEA on 10 Euros per metric ton, and the RFF studies base their analysis on a $10 per metric ton CO_2 emissions charge. These were all scaled to a dollar or Euro quantity for purposes of comparison, as shown in Tables A-1 and A-2. The EU and RFF approaches, however, do not easily evaluate changes in costs and outputs in response to comprehensive, climate policy alternatives over time, which would require accounting for varying carbon charges associated with changing cap levels as specified for particular policies.

In contrast, in the HRS-MI study we did not tie the impact analyses to a specific fixed carbon emissions charge. Instead, it relied on the EIA/NEMS modeling runs simulating different climate scenarios to generate a set of associated fuel price projections through 2030. The HRS-MI approach allowed a dynamic modeling of variations in cost impacts in response to the different pricing scenarios, based on the representation of causal relation and feedback loops underlying the real systems. This can enable a direct comparison of the impacts of policy alternatives characterized by different policy elements, such as policies with cost-containment mechanisms (safety valve, offsets) allocation scenarios, or trade adjustment provisions.

OVER THE LONG-RUN, THE STUDIES ASSUMED INDUSTRIES WILL PASS ALONG THEIR COSTS AND ADJUST PRODUCTION TO INCREASED MARKET COMPETITION IN RESPONSE TO HIGHER PRICES.

THE II-CP MODEL
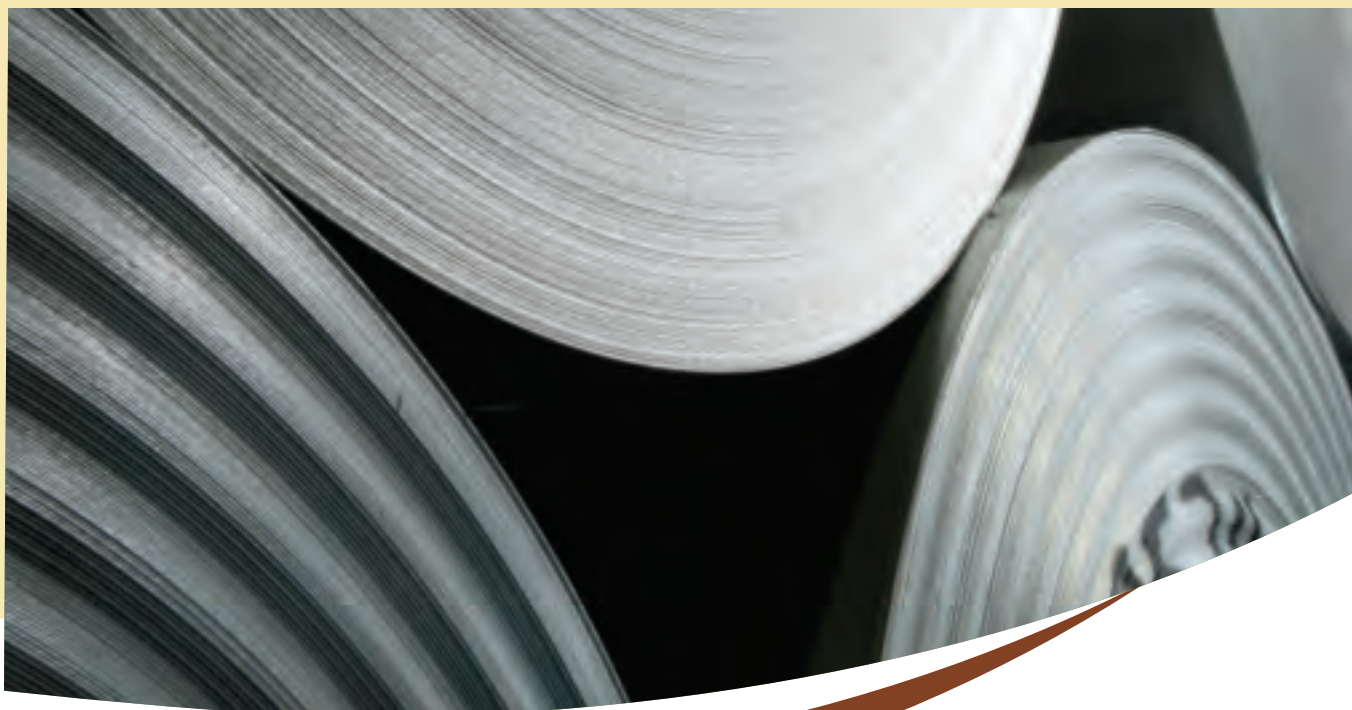
The HRS-MI research project involved developing detailed economic and energy profiles of energy-intensive manufacturing industries, including the collection and processing of historical economic data, and construction of substantial system dynamics industry sector models, employing a powerful, flexible, transparent, and interactive tool based on the Vensim© modeling platform, supported by group model building sessions (see Chapter Two). Specifically, we constructed and employed the Integrated Industry-Climate Policy Model (II-CPM) to simulate several carbon-pricing policy scenarios, allowing comparisons of their impacts over time (through 2030) on the competitiveness of six specific energy-intensive manufacturing industries (4 to 6-digit NAICS codes)—iron and steel, primary and secondary aluminum, paper and paperboard, petrochemicals and chlor-alkali manufacturing— from four broad (3-digit NAICS) manufacturing sectors (primary metals, paper, chemicals).

One of the first objectives of the analysis was to identify what the main causal relations and feedback loops underlying the structure of energy intensive manufacturing sectors are. Such loops are then responsible for the creation of the behavior of the system and allow for the identification of the main levers driving it. The analysis of the structure of the model and the modalities in which the behavior is produced lead to the identification of elements of policy resistance, responsible for the creation of side effects. The model therefore could provide inputs to both policy formulation and evaluation.

Specifically, the study's modeling work followed the three-phased approach (described in Chapter Two and illustrated in Figure 2-1) outlined below:

Modeling production costs—the basic production cost models for each of the chosen industries were constructed;

Modeling market dynamics—the industry production cost models were then extended and broadened to enable modeling of market dynamic features, that accounted for international trade flows and their impacts on the industries' bottom-lines and outputs, under the different GHG emissions pricing scenarios and under different market assumptions (e.g., regarding cost pass along);

Assessing investment options and policy alternatives—the modeling results were used to inform analyses of investment and policy options, the third leg of the HRS-MI study, for the different industries. However, although no direct modeling of investment issues was attempted, we looked at the energy efficiency improvements required

to offset increasing energy costs and undertook a preliminary modeling of an important policy alternative aimed at offsetting cost and market impacts.

In addition to the primary modeling work above, we carried out several sensitivity studies using the industry models to examine variations in the results from different assumptions about key model variables, notably materials costs, domestic and world prices, elasticities of demand and energy efficiency improvement rates.

Climate Policy and Energy Price Scenarios

The HRS-MI study simulated a cap-and-trade policy scenario, with and without a 90% allowance allocation, based on recent legislation and a business-as-usual (BAU) scenario, which assumed no climate policies are enacted into law throughout the study period. The models simulated market conditions and policy impacts from 1992 through 2030, though the policy case was assumed not to go into effect until 2012 (except some credits for early action, starting from 2008).[40] The key provisions of the policy case and the BAU scenario are summarized below (see also Table 2-B and discussion in Chapter Two):

Business-As-Usual (BAU)—based on the EIA's *Annual Energy Outlook* 2008 Reference Case, including provisions of H.R. 6, the Energy Independence and Security Act, and assumes a continuance of other current laws and regulation;[41]

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[40] For further discussion of these elements see EIA, *Energy Market and Economic Impacts of S. 2191*
[41] Ibid.

Table B-1
Carbon-based Fuels and Electricity Pricing Scenarios

Energy Prices ($2000 per MBtu)	2006	2020 Mid-CO_2 Price Policy	2030 Mid-CO_2 Price Policy
Electricity	15.42	16.09	17.11
Percent above BAU	—	*8.6*	*13.1*
Natural Gas	6.57	6.51	8.69
Percent above BAU	—	*22.2*	*39.0*
Metallurgical Coal	3.04	6.01	8.65
Percent above BAU	—	*104.7*	*180.0*
Liquefied Petroleum Gas	16.91	14.48	15.25
Percent above BAU	—	*0.5*	*-0.1*
Coal Coke	9.11	18.02	25.94
Percent above BAU	—	*104.7*	*180.0*
Residual Fuel	7.77	9.01	11.81
Percent above BAU	—	*26.7*	*43.1*
Distillate Fuel	13.15	14.31	17.30
Percent above BAU	—	*14.1*	*24.0*

Source: EIA, HRS-MI

Lieberman-Warner Climate Security Act of 2007 (S. 2191)[42]—an economy-wide cap-and-trade policy, referred to as the *Mid-CO_2 Price Policy* in this report, that incorporates elements of the earlier Bingaman-Spector Low Carbon Economy Act of 2007 (S.1766), including international compliance provisions, but with more aggressive emissions reductions, and no "technology accelerator payment" (safety valve) price mechanism.

Fuel and electricity price projections resulting from the implementation of the Mid-CO_2 Price Policy were calculated using EIA's National Energy Modeling System (NEMS).[43] The EIA uses NEMS to analyze energy sector and energy-related impacts of various GHG emission reduction proposals. NEMS projects emissions of energy-related CO_2 emissions resulting from the combustion of fossil fuels, which represents about 84 percent of total U.S. GHG emissions today. NEMS was also used for projections of the EIA's *Annual Energy Outlook 2008,*[44] which also was the reference case (BAU) in the HRS-MI study.

The EIA/NEMS generated energy price projections for each policy case—for

The models simulated market conditions and policy impacts from 1992 through 2030, though the policy case was assumed not to go into effect until 2012.

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[42] U.S. Congress, *America's Climate Security Act of 2007*, 110th Congress, 2nd Session, 2007.

[43] U.S. Department of Energy, Energy Information Administration (EIA), *The National Energy Modeling System* (NEMS), *An Overview* (Washington, DC, 2003).

[44] EIA, *Energy Market and Economic Impacts of S. 2191*.

electricity and five fuel types, including metallurgical coal, natural gas, liquefied petroleum gas, residual fuel and distillate fuel—were used as inputs into the HRS-MI models, to characterize the poicy scenarios. That is, the price projections for each policy scenario were the principal independent (i.e. exogenous) variables employed in calculating industry cost and market impacts associated with that policy. These are summarized in Table 2-C in Chapter Two, and repeated below in Table B-1.

It is likely, especially in light of the discrepancies in the historical trend of oil prices in the last few years, and the recent economic slowdown, that actual future energy trends will deviate, perhaps substantially, from the EIA model's projections. The best that the NEMS model can do, incorporating an optimization model for the energy sector and a macro model for the economy, is try to estimate future projections based on past experience and trends, as well as using exogenous assumption on future technology improvements, which may or may not in the end match reality. For this reason, our interpretation of the cost projections based on these price data emphasized the relative changes for the policy cases with each other and the BAU, rather than absolute values in the future projections. We also did some sensitivity analyses looking at wide variations in important cost factors (such as material cost) that could shed light on possible changes in the II-CPM projections resulting from different price assumptions.

Scenarios and Policy Options

Table B-2 summarizes the variety of scenarios and sensitivity analyses simulated with the II-CPM in the study. They include (1) core scenarios, (2) investment analyses, (3)

policy options to mitigate implementation costs and (3) sensitivity analyses related to material costs, market prices and industries' responsiveness to changes in market prices. Each scenario is described and the main outputs used for the analysis are listed. A description of the model structure for the core scenarios is given later in this appendix. Discussions of the modeling approaches and issues for the cost pass-along, energy-efficiency gains, allocation policy scenario and sensitivity cases are given immediately below. Explanations of industry specific cost factors, such as for aluminum and petrochemicals are also provided below.

Cost pass-along scenarios.
Whether producers are able to pass the cost along to the market depends on a variety of factors, including their strength (e.g. production capacity utilization, operating surplus and profitability), market demand, and international competition. Nevertheless, even if companies are in very good operating and financial shape, various side effects and synergies may arise in the medium-to-longer term. The simulation of cost pass along scenarios aimed at bringing clarity to this issue and improving the understanding of the complex mechanisms linking pricing to domestic and international competition. We used the II-CPM to simulate two cost pass-along scenarios for each industry, one assuming that no costs from the policy case are passed through (no cost-pass-along or NCPA) and 100 percent of costs are passed along (cost pass-along or CPA).

If costs are passed along in the domestic environment, U.S. product prices will rise compared to foreign producers. As a consequence, profit margins will be maintained, at least for a while, but U.S. market shares will decline, as U.S. goods are substituted by cheaper foreign imports, cutting industries' total revenues and profits in the long run.

Whether producers are able to pass the cost along to the market depends on a variety of factors, including their strength (e.g. production capacity utilization, operating surplus and profitability), market demand, and international competition.

TABLE B-2
MODEL SCENARIOS

SCENARIO	DESCRIPTION	OUTPUTS
Comparisons of same outputs for policy cases and domestic and import market shares and production outputs (quantities): absolute values (US $2000) and relative to BAU trends.		
Core Scenarios: Carbon Pricing Policies	Impact of the Mid-CO_2 Price Policy relative to business as usual (BAU) on six energy-intensive industries (primary and secondary aluminum; iron & steel & ferroalloys; paper & paperboard; petrochemicals; chlor-alkali).	Comparisons of real ($2000) outputs, % above BAU: production costs; energy costs; energy share of production costs; operating surplus [OS] and operating margin [OM].
Cost Pass-Along	Compares the policy and BAU cases for pass along of policy driven energy cost increases: No Cost Pass-Along (NCPA) and Cost Pass-Along (CPA, 100% cost pass-through to offset increasing costs or maintain margins).	Comparisons of same outputs for policy cases and domestic and import market shares and production outputs (quantities): absolute values (US $2000) and relative to BAU trends.
Comparisons of same outputs for policy cases and domestic and import market shares and production outputs (quantities): absolute values (US $2000) and relative to BAU trends.		
Required Energy Efficiency Gains	Assesses energy efficiency gains required to offset increased energy costs, and potential costs, and potential cost savings if these efficiency gains are made. Both NCPA and CPA scenarios examined.	Energy efficiency gains (%) needed to offset energy consumed and costs above BAU; Cumulative additional costs (or savings) of increased energy prices (or energy efficiency gains)
Policy Options: assess impact of policies designed to mitigate, offset or compensate economic costs of carbon pricing scenarios on industries.		
Allowance Allocation (With Energy Efficiency Analysis)	Assesses economic impact of allowance allocations equal to 90% of price increases to compensate industries for higher energy costs; Estimates energy efficiency needs required relative to core cases as above.	Production costs, energy costs, OS and OM. Energy efficiency gains required and cumulative additional costs determined as above for the allowance cases.
Sensitivity Cases: examine changes in model outputs resulting from changes in key variables. Approximate changes in assumptions associated with different economic conditions.		
Material Costs, Domestic and World Prices	Assesses how a rise in material costs could affect policy case impacts on industries under different conditions: materials costs increase 3% per year. Examines NCPA and CPA-emulated scenarios.	Production costs (total and unit), energy costs, operating surplus and margin. Comparisons of quantities and percent differences from core cases.
World Prices	Assesses potential impact of declining world prices with no comparable decline in U.S. costs, comparing consequences for different policy scenarios.	Production costs (total and unit), energy costs, operating surplus and margin.
Elasticities	Assesses impact of model results, especially changes in outputs and market shares for different elasticities of demand for each industry. CPA scenarios only.	OS and OM, and market shares. Compares outputs for core policy cases and sensitivity cases.
Energy Efficiency	Compares the Mid-CO2 Price Policy and BAU cases assuming industries annually increase (invest in) energy efficiency by 5 percent, and potential cost savings if these efficiency gains are made. NCPA only.	Comparison of production costs, energy costs, OS and OM. Potential cost savings relative to core cases based on OS for selected years.

On the other hand, if costs are not passed along, U.S. manufacturers will see their costs go up relative to prices, cutting into their operating margins and profits.

Cost pass-along scenarios in this study are calculated in two ways: (1) by fully transferring the increase in production cost (with respect to the baseline scenario), generated by the implementation of climate change policies, to the domestic market price (*cost-basis CPA)*; and (2) by fully transferring the percentage increase in production cost on to the price, not the change in its absolute value, thereby preserving original operating and profit margins *(margin-basis CPA)*. In the latter case, the operating margin, or the actual margin per each unit sold, would remain the same as in the base case, so that the profitability of the industry is not impacted by the simulated policy change.

Comparisons of cost pass-along scenarios (CPA) are expressed in production outputs and market shares. For any given year, an industry's import market share was calculated by taking the ratio of industry's import and its total "new" supply (assumed equal to domestic demand), which is equal to its production plus imports minus exports. Domestic market share is calculated simply by subtracting the import market share from 100 percent.

Required energy efficiency gains.

Drawing on II-CPM simulation results for each industry, we calculated the energy efficiency gains for any given year that would be required to offset the additional costs resulting from the climate policy. Calculations were based on the core policy case, and carried out for the NCPA scenarios. To calculate the required gains for each industry, we estimated how much energy efficiency improvement would be needed to reduce energy consumption for three main energy categories (electricity, energy fuels and energy feedstock), as a percentage of the BAU reference levels, to offset the additional production costs associated with the policy cases. These calculations were done in four steps:

1. Compare the energy cost in the alternative scenarios with respect to the reference case, to identify the additional energy cost related to the policy cases simulated;

2. Calculate the energy-equivalent (in kWh and Btu) of the cost for energy (aggregated by fuel type) and electricity consumption, both for direct energy use and feedstock;

3. Calculate additional energy consumption (in kWh and Btu) corresponding to the increased energy expenditure simulated with the alternative policy cases. This is obtained by dividing the incremental fuel expenditure by the average fuel cost for each selected industry (e.g. calculated as fuel expenditure over fuel consumption);

4. Finally, calculate the efficiency improvement required to offset the increasing cost for electricity, direct fuel use and feedstock, under the simulated policy scenario.

Two types of calculations were made in step 4. One entailed dividing the incremental energy consumption (associated with the higher energy cost under the policy case) by total fuel consumption (for BAU), for a given year. Since the results of these estimates turned out to be year specific—they could vary widely from year to year—a second set of estimates were done.

These involved summing the *cumulative* incremental energy consumption (associated

with the added energy costs) from the year the policy went into effect (2012) to a given year, and dividing that quantity by the cumulative total energy consumed from the initial year to the same given year. The "cumulative" energy efficiency calculations therefore smoothed out potential yearly variations, and tended to be smaller than the yearly gains. The required energy-efficiency gains cited in the main body of the report are the cumulative gains calculated using this second method.

Allowance allocation. In order to evaluate a policy that would offset the energy cost increases from the carbon-pricing policies, we ran II-CPM simulations of each industry including a 90 percent allowance allocation starting in 2012, and phasing out by 2 percent per year.

Energy prices accounting for the allowance allocation were calculated by using reference and policy-related prices calculated by NEMS for all energy sources. First, the difference between energy prices in the selected policy case and the BAU scenario were calculated. Secondly, the 90 percent allowance was applied to the energy price differential in 2012 to obtain the 10 percent of the total incremental cost that is not covered by the

allowance. Finally, this cost (i.e. 10 percent of the original incremental cost generated by the simulation of the selected policy case) was added on top of the BAU set of prices obtained from the simulation of NEMS to obtain the new energy prices accounting for the 90% allowance allocation.

Alternative market scenarios. Using the II-CPM, we simulated a variety of alternative scenarios (i.e. sensitivity analyses), with the aim of reducing uncertainty and increase confidence in the results of the analysis by showing different future paths for the industries we studied. Some of these scenarios addressed concerns raised by industry groups, such as the possibility of rising material costs and the extent to which these additional costs could be passed along to the market, or the affect of lowering world prices in a global market with low-cost foreign competitors not bound by a comparable climate policy.

These scenarios include:

Rising Material Costs: A recurring question in meetings with industry stakeholders, was how unexpected increases in the costs of production factors other than energy, but still influenced by it, such as materials or labor, would affect the results of the II-CPM simulations. A related question was how unanticipated increases in key energy sources, especially those used as feedstock in production processes (e.g., natural gas, coke) would affect the results. To help address these questions, we conducted a sensitivity analysis with the II-CPM, assuming a 3 percent *nominal* yearly increase (exponential) in the cost of materials, domestic and world prices.

- ***Material Cost Scenario:*** Material and capital costs grow at 3 percent annual rate starting from 2009 (nominal dollars), assuming that only domestic manufacturers experience this cost

increase, and they are not able to pass the costs along to the market price. This approximates a situation in which localized conditions drive up material costs for domestic manufacturers;

- *Material Cost and Domestic Price Scenario:* The additional material cost is passed through by the domestic manufacturers, but manufacturers in the rest of world (ROW) do not experience cost increases;

- *Material Cost, Domestic Price and World Price Scenario:* Domestic and ROW manufacturers experience the same materials cost increase (such as scrap metals), and prices are passed through globally (i.e., domestic and world prices rise proportionally with material cost increases, or increase by the exact amount represented by the increasing material cost).

Declining World Price Relative to US Prices: An additional world price scenario assumed a 3 percent *nominal* decline in world prices (WP), starting in 2009, which approximates a situation where international competitors are able to push down world market prices because of declining costs, relative to the United States, which would cause declines in U.S. manufacturers' operating margins. This might approximate a situation in which foreign competitors (such as China) flood the global and domestic markets with low cost goods, generated by the combination of increasing production capacity coming on stream and a decline in foreign domestic demand due to a global economic slowdown.

Changing Market Elasticity Values: The cost pass-along cases simulated using the II-CPM used derived elasticities of demand, i.e., the relative change in demand for a product associated with a relative change in its price, based on historical foreign import quantities

and prices relative to U.S. prices. To examine how different elasticities might affect the results of the II-CPM simulations, we carried out industry simulations for the policy cases comparing the original (reference) CPA simulations with CPA simulations assuming a high (above the reference elasticity) and low (below the reference), for each industry.

Energy Efficiency: Various rates of energy efficiency improvements were simulated with the II-CPM. The high energy efficiency scenario assumes a yearly increase in energy efficiency for each energy form consumed for direct use, but not for energy feedstocks, starting from 2009. In this scenario, energy efficiency increases by 5 percent a year starting from 2009, including the baseline increase of 0.25 percent simulated for all industries and scenarios. The cumulative savings emerging from energy efficiency improvements under this scenario were calculated for selected time periods and are assumed to represent the upper limit of investments that industries would be willing to make to achieve these gains.

Industry specific estimates.

Two additional industry specific sets of calculations were made drawing on the II-CPM simulation results and additional data from other references: (i) estimates of the additional costs from the production and consumption of alumina and carbon anodes, and the subsequent operating surplus, margin impacts, under the climate policy, in the primary aluminum industry; and, (ii) estimates of the additional costs and impacts from a climate policy in the petrochemicals industry if alternative assumptions about feedstock energy were made (NGL vs. LPG).

(i) Additional Carbon Costs in Primary Aluminum. As discussed in Chapter Seven (and referenced in this appendix), insufficient data was available, using

the II-CPM, to calculate the additional costs associated with the production and consumption of alumina and carbon anodes in primary aluminum production. Nevertheless, we were able to still do some rough estimates. According to a DOE technical study, a total of 4.64 million Btus of energy for heat and power is required to produce a metric ton of carbon anode. However, consumption of the pitch binder and petroleum coke feedstock in the use of carbon anodes, is equivalent to 17.4 Btus per metric ton of carbon anode. [45]

Estimations of the additional energy costs associated with the production of carbon anodes were carried out by taking the difference in cost for each energy fuel consumed using the EIA NEMS projected prices for the BAU and policy cases (quantity of energy consumed multiplied by the policy price less the BAU price). Estimated cost projections of petroleum coke for a BAU and policy case (following the price trends of residual oil) enabled a reasonable, if rough estimate of the cost differential for the feedstock energy consumed. For a given year, the total incremental added energy costs for fuel energy and feedstock to make and use a metric ton of carbon anode was multiplied by 0.45 to obtain the added energy to produce a metric ton of primary aluminum ingot.

Based on DOE data, it was possible to make a similar calculation of the added costs from the production of a metric ton of alumina, which was not factored into the calculation of added costs under a climate policy for primary aluminum production. Production of a metric ton of alumina requires an estimated 12.8 million Btus of energy (from natural gas, fuel oil, electricity, bituminous coal, and diesel). The added costs for a

metric ton of alumina were calculated by multiplying the quantity of each fuel consumed, by the difference between the EIA NEMS projected prices for the policy case less the BAU price. This amount was then multiplied by 1.93 to determine the total incremental energy costs consumed in alumina production, used to make a metric ton of primary aluminum ingot. Finally, since about half the alumina consumed in U.S. smelters is imported—and therefore the added costs from a U.S.-based carbon charge would not apply—this quantity was divided in half.

The calculated additional energy costs from carbon anodes were then added to the calculated added energy cost from alumina production to give the total added costs from the climate policy, over and above the cost increases estimated by the II-CPM for the primary aluminum industry. Based on these estimates, it was also possible to calculate new production cost, operating surplus, operating margin and profit margin curves for the industry.

(ii) Alternative Petrochemicals Feedstock Scenarios. The DOE's MECS data did not distinguish between the quantities of LPG and NGL consumed as feedstock in petrochemicals manufacturing. The EIA NEMS energy prices for the policy and BAU cases were only available for LPG. We therefore originally assumed that the total feedstock was LPG, and used the EIA NEMS generated prices for LPG in the II-CPM simulations. However, to determine how these results would change if NGL comprised some or all of the feedstock in petrochemicals manufacturing, we estimated what the added costs might be for feedstock consumption, if it was assumed that 10 percent, 50 percent and

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[45] William T. Choate and John A.S. Green, *U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits and New Opportunities,* Prepared under contract to BCS, Inc., for the U.S. DOE Energy Efficiency and Renewable Energy (Washington, D.C., February 2003), esp. Appendix F.

100 percent of the feedstock consumed, formerly assumed to be LPG, was actually NGL. We made an additional assumption, based on EIA data, that NGL prices were equivalent to that of natural gas, including its variation under the policy case.

For each feedstock consumption assumption (i.e., 10, 50, and 100 percent LPG substitution by NGL), we made new energy cost estimations for the BAU and policy cases, and compared the differences to the original incremental cost impacts, assuming 100 percent LPG feedstock. That is, assuming that R percent of the feedstock was NGL, *for any given year*, we could calculate the new additional feedstock costs relative to BAU (ΔC_N) as shown in the equations below:

$$C_{BAU_N} = C_{BAU_o} - R * Q * P_{LPG_{BAU}} + R * Q * P_{NGL_{BAU}}$$

$$C_{POL_N} = C_{POL_o} - R * Q * P_{LPG_{POL}} + R * Q * P_{NGL_{POL}}$$

$\Delta C_N = C_{POL_N} - C_{BAU_N}$ = New added feedstock costs relative to BAU

where:

C_{BAU_N} = New feedstock energy cost, BAU

C_{POL_N} = New feedstock energy cost, Mid-CO_2 Price Policy

C_{BAU_o} = Original feedstock energy cost (in II-CPM simulations), BAU

C_{POL_o} = Original feedstock energy cost, Mid-CO_2 Price Policy

R = NGL percent of quantity of feedstock energy consumed

Q = Quantity of feedstock energy consumed (MBtus)

$P_{LPG_{BAU}}$ = Price of LPG, BAU case;

$P_{LPG_{POL}}$ = Price of LPG, Mid-CO_2 Price Policy

$P_{NGL_{BAU}}$ = Price of NGL, BAU case
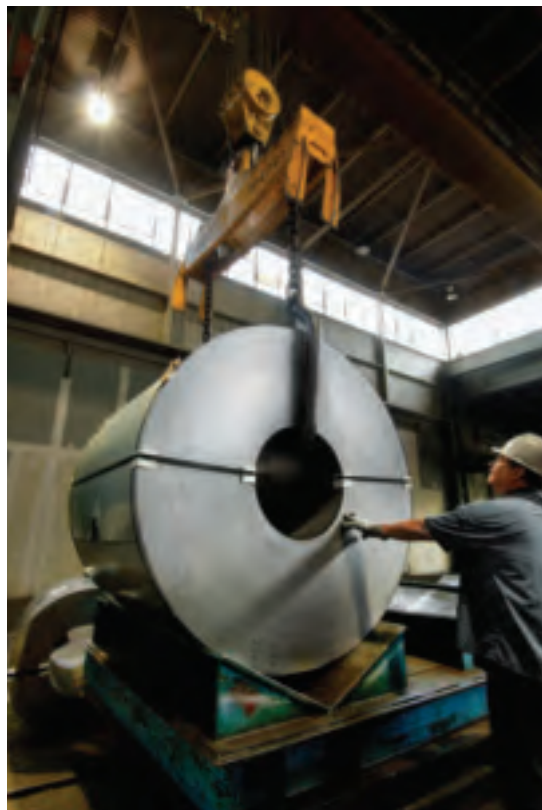
$P_{NGL_{POL}}$ = Price of NGL, Mid-CO_2 Price Policy

In addition. we assumed that $P_{NGL_{BAU}}$ and $P_{NGL_{PO}}$ would equal the BAU and Mid-CO_2 Price Policy case prices of natural gas, respectively, used in the II-CPM simulations, historically and projected through 2030.

We could then calculate the subsequent impacts for the different scenarios on total production costs, operating surplus, and operating margin (see Chapter Eight).

Data Sources

The primary data sources we used to customize and calibrate the industry models include:

The U.S. Department of Energy's Industrial

Technologies Program (ITP), which was a major source of studies, reports, energy profiles, and technology roadmaps for examining production processes, technologies, and energy flows for each sector. The DOE also provides statistical data on energy use by industry sector in its quadrennial Manufacturing Energy Consumption Survey (MECS);

The U.S. Census Bureau's Annual Survey of Manufacturers (ASM),[46] which publishes detailed annual data, going back to 1992, on the value of shipments, value added, materials and energy costs (purchased electricity and fuels), labor compensation and capital expenditures at fairly a disaggregated NAICS (and prior to 1997, the Standard Industrial Classification or SIC system) level;

The United States International Trade Commission (USITC) database,[47] which provided detailed export and import data (dollar values, quantities, import charges) by industry (pegged to NAICS categories) and country;

Industrial trade association databases, which include extensive statistical references and supplemental documents about their industries. These organizations, which became involved with the project through a series of meetings, include the American Iron and Steel Institute (AISI), the American Forest and Paper Association (AF&PA), the American Chemistry Council (ACC), and the Aluminum Association. Valuable industrial data also is available on their and other industry websites, including the international counterparts to these organizations;

Global Insight (GI), which provided data

projections on market prices that were then used to define market prices and materials cost trends in the II-CPM simulations;

The U.S. Geological Survey (USGS), which publishes mineral commodity reports and other references that provide production and other useful information on the metals industrials (i.e., iron and steel and aluminum and alumina).

See Tables B-4 though B-5 for a full list of exogenous inputs used to calibrate the II-CPM.

Numerical and Modeling Assumptions

The main numerical assumptions used to calibrate the model are presented in the Table B-3. As in all modeling exercises, the principal assumptions used in developing the structure of the model constrain and influence the results that it generates. Key assumptions used in the industry models include the link between GDP, demand and production output, assumptions about labor, material, energy and capital cost projections, demand elasticities, and market prices. We discussed most of these assumptions with industry representatives, to fully incorporate their view and understanding of the market/industry characterized in the II-CPM. Many assumptions were directly simulated and tested in real time during group modeling sessions and meetings.

(i) GDP and demand projections—A key assumption used in the model for each industry is that production is influenced

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[46] U.S. Census Bureau, *Statistics for Industry Groups and Industries, (Annual Survey of Manufactures),* [M05(AS1)] (Washington, DC: November 2006) ("Census Bureau, ASM").
[47] U.S. International Trade Commission (USITC), *Interactive Tariff and Trade DataWeb,* available at http://dataweb.usitc.gov/

INDUSTRY	MARKET PRICE (DOMESTIC AND ROW) AND MATERIAL COSTS	LABOR COSTS	FEEDSTOCK ENERGY COSTS	GDP/DEMAND
Steel	Indexed to GI prices projections, 3% average growth rate 2008/2030	*Compensation:* Constant in real terms *Labor Intensity:* long term trend then flattens in 2016	Natural gas, coal and coke feedstock	Long-term trend: slightly declining ratio. 2.48% average growth rate 1992/2030
Primary Aluminum	Indexed to GI prices projections, 1% average growth rate 2008/2030	*Compensation:* Constant in real terms *Labor Intensity:* constant	No feedstock (petroleum coke counted as materials costs)	Constant demand/GDP ratio. 1.63% average growth rate 1992/2030
Secondary Aluminum		*Compensation:* Constant in real terms *Labor Intensity:* constant	No feedstock	
Paper & Paperboard	Indexed to GI prices projections, no growth over the period 2008/2030	*Compensation:* Constant in real terms *Labor Intensity:* long term trend then flattens in 2020	No feedstock	Long-term trend: slowly decreasing ratio. 0.53% average growth rate 1992/2030
Petrochemicals	Indexed to GI prices projections, 3% average growth rate 2008/2030	*Compensation:* Constant in real terms *Labor Intensity:* long term trend then flattens in 2020	Natural gas and LPG feedstock	Long-term trend: slowly decreasing ratio. 1.67% average growth rate 1992/2030
Alkalies & Chlorine	Indexed to GI prices projections, 2% average growth rate 2008/2030	*Compensation:* Constant in real terms *Labor Intensity:* constant	LPG feedstock	Long-term trend: slowly decreasing ratio. 0% average growth rate 1992/2030, 0.2% growth rate after 2007
Other Assumptions and Specifications	• Compensation: long term trend takes into account forecasted inflation (CBO/EIA) and historical increase in compensation. • Energy Intensity: based on MECS 2002 and energy efficiency increasing by 0.25% per year in reference case for future projections. • Steel production assumes a continuation of historical trends for BOF and EAF production.			

by demand, which in turn is impacted by GDP growth. This assumption historically has generally held true—increasing GDP generates an increased demand for steel, aluminum, paper and chemicals; all are basic materials used as or to produce intermediate goods and end-use goods widely used in manufacturing, as well as in other industry sectors, such as construction and agriculture. The study's assumptions about the GDP/demand ratios were generally confirmed in discussions with industry representatives, and in one instance, time series projections of GDP growth in relation to demand were provided by industry analysts. In sum, except for the aluminum sector (primary and secondary), we assumed a long-term steady decline in the GDP/demand ratio, which was equivalent to a slow growth rate for product demand (2.48 percent average annual growth rate for steel, 0.53 percent for paper and paperboard, 1.67 percent for petrochemicals, and 0.2 percent for chlor-alkali, after 2007 through 2030. Aluminum is assumed to have a constant demand/GDP ratio over the long-term, with a 1.63 percent average yearly growth rate in demand between 1992-2030.

(ii) Market prices, material, capital, labor and energy cost assumptions—We initially assumed in the models, that labor, material and capital expenditures would follow the historical trends. For example, U.S. labor productivity has steadily improved (partly because less competitive plants have closed as result of industry consolidations and offshoring) for each industry. Thus, we assumed that labor costs per unit would continue to gradually decline as well. However, industry representatives in several sectors thought that most of these improvements have already been made, and that labor productivity gains are likely to slow in the coming years. Based on historical trends and industry recommendations we made the following assumptions:

- Material costs would follow market price trends in the models' projections. Several tests were conducted to estimate the correlation existing between market prices and material costs, following the rationale that (1) raw materials price changes according to variations in their present and expected global demand and supply and that (2) industries experiencing a global cost increase in raw materials are normally going to increase their prices. Since cost projections were not available, projected market prices were used to obtain reasonable values for material and capital costs. The correlation analysis of historical price values with historical material and capital costs, using *ASM* data for the period 1992 − 2007 (or 1997 − 2007 when data were not available), gave the following results:

  - Primary Aluminum: $R^2 = 0.70$;
  - Secondary Aluminum: $R^2 = 0.93$;
  - Steel: $R^2 = 0.95$;
  - Paper: $R^2 = 0.74$;
  - Petrochemicals: $R^2 = 0.92$;
  - Chlor-Alkali: $R^2 = 0.92$.

- Projected market prices (domestic and international) and materials and capital cost were estimated using *ASM* historical data and Global Insight (GI) projections. For the period 2008-2018, projected prices and material and capital costs were calculated using future GI yearly price changes, applied to the *ASM* data for 2007; while for projections relative to the period 2019-2030, longer term trends (2011-2018) extrapolated from GI data were applied. A more detailed description of the method and steps of the calculation is presented below.

Selected GI data series for projecting prices until 2030:

- *Aluminum* (primary and secondary): Aluminum, London Metals Exchange (LME) Spot, AM close cash price, updated 06 September 2008;

- *Steel:* Producer Price Index (PPI), Iron and Steel, updated 06 September 2008;

- *Paper:* Paper Uncoated White Bond No. 4 83-Bright 20 Lb Sheets, updated 06 September 2008;

- *Petrochemicals:* PPI, Petrochemicals, updated 10 September 2008;

- *Alkalies and Chlorine:* PPI, Chlorine, updated 06 September 2008;

Market Price (domestic and international) and material and capital costs calculations:

For *steel, petrochemicals and alkalies and chlorine*, the industries for which GI PPI data series were available, market prices were calculated as follows:

Quarterly data points from GI were converted to yearly data, through the calculation of their annual average. This was necessary to keep data consistency with the II-CP Model, which use yearly data as input.

Yearly PPI were normalized using a consistent and uniform base year, 2007. GI PPI data had different base year for steel (1982), petrochemicals (2003) and alkalies and chlorine (1980).

Future domestic/international prices and material costs were calculated by multiplying ASM domestic/international prices and material costs in 2007 by the GI PPI normalized to 2007. As a consequence, the 2010 domestic market price for steel products is calculated as: 2007 ASM price times the 2010 value of the GI PPI

normalized to 2007.

For *aluminum and paper* data, using respectively LME and uncoated white paper prices, the calculation of projected values followed the following steps:

- Quarterly data points from GI were converted to yearly data, through the calculation of their annual average.

- Yearly prices were converted into indexes (relative prices) using a consistent and uniform base year, 2007.

- Future domestic/international prices and material costs were calculated by multiplying ASM domestic/international prices and material costs in 2007 by GI prices normalized to 2007.

- Material costs and capital costs were combined into single cost variable for purposes of the cost and market analyses. Capital expenditures historically have been only a small fraction of overall value of shipments, compared to materials expenditures. Industry averages for 1992-2008 range from 1.9 percent

> **FUTURE DOMESTIC/ INTERNATIONAL PRICES AND MATERIAL COSTS WERE CALCULATED BY MULTIPLYING ASM DOMESTIC/ INTERNATIONAL PRICES AND MATERIAL COSTS IN 2007 BY THE GI PPI NORMALIZED TO 2007.**

of lack of pricing data for these petroleum products, these energy feedstocks were not originally accounted for separately as an energy cost in the II-CPM, but included as material costs in the production cost models. Thus, the energy-cost impacts on primary aluminum from climate policies initially estimated by the II-CPM may in fact be understated.

- The model assumes that there will be a small, steady gain in energy efficiency of 0.25 percent per year for all industries.

- Labor compensation projections were based on historical long-term trends, while labor-intensity follows the long-term trend and then flatten out for all industries in later years. The long-term trend in labor compensation takes into account forecasted inflation (CBO/EIA) and historical increases in compensation.

(secondary aluminum) to 6.7 (paper and paperboard) and 4.4 percent for all industries. In combining materials and capital expenditures, a tacit assumption was made that materials and capital costs would vary in the same proportion in future years.

- Natural gas, coal and coke are feedstock used in blast furnaces of integrated steel mills power in the iron and steel industry. Coke may be produced offsite and purchased by steelmakers or produced onsite from coal. Natural gas and LPG are feedstock in petrochemicals. These costs needed to be subtracted from the *ASM* materials costs data; the purchased fuel and electricity expenditures in the ASM tables, which were subtracted out from the ASM materials cost figures, do not include the costs of energy feedstock.

- Petroleum coke and to lesser extent pinder pitch, both petroleum derivatives, are the primary materials of carbon anodes used in the electrolysis process employed by aluminum smelters in primary aluminum production. Because

Modeling Challenges and Issues

Several structural characteristics raised special challenges for the study in constructing these linkages, as well as obtaining the data needed for carrying out calculations. These issues can be characterized as: (a) setting appropriate industry boundaries; (b) evaluating major industry sub-segments; (c) modeling scrap, recovery and recycled waste; (d) accounting for internal energy generation; (e) obtaining sufficient, consistent and comparable data sets; and (f) establishing appropriate proxy variables. These problems were not always separable, as data availability and quality in the end often influenced where industry

boundaries were set, for purposes of enabling modeling calculations.

(a) Industry boundaries—The study focused on energy-intensive industries at the 4- to 6-digit NAICS levels. Consistency with the NAICS system is important, because most industry statistics collected by the federal government is gathered and presented according to the NAICS categories. Chemicals manufacturing (325) is a very large and diverse industry sector, with seven 4-digit NAICS divisions. This includes the basic chemicals sector (3231), which in turn consists of a large number of distinct industries, including petrochemicals, inorganic chemicals, industrial gases and synthetic dyes and pigment manufacturing. For reasons mentioned above, we decided to focus on two important, distinct industries falling within this group, petrochemicals (32511) and chlor-alkali manufacturing (325181), within the inorganic chemicals sector.

(b) Industry sub-segments—Aside from the data difficulties associated with the formal NAICS-assigned industry categories, we had difficulties distinguishing between major segments within an industry that may entail distinct production processes or for which there was overlapping activities existing within and outside the industry boundaries. Nevertheless we had to work with the given structure of industry data based on NAICS.

- The iron and steel mills sector has two major divisions, each characterized by different production technologies— integrated mills which use blast furnace and basic oxygen furnace (BOF) technologies to process (mostly) iron ore, and mini-mills that use electric arc furnace (EAF) to process (mostly) steel scrap. Although industry

production data were obtained for the two segments, government NAICS-based databases do no distinguish between them. Since these divisions have different energy footprints and compete in the same markets, we simulated these segments to the extent data made it possible. But, more work is needed to fully model them as distinct activities. Consequently, the modeling results for the iron and steel industry represent a weighted average of these two large segments.

- Pulp production is an internal operation within paper and paperboard mills, but some pulp—called market pulp—is produced in separate pulp mills (NAICS 32211), and sold to paper and paperboard mills. Calculations of energy cost impacts on paper and paperboard production costs should account for energy use in market pulp purchased and used in paper and paperboard production (about 7 percent).[48] But market pulp consumed by domestic paper and paperboard mills would need to be deducted from their material costs, a very difficult calculation with the available data. Moreover, there is no easy way to know how much market pulp domestic mills consume—industry sources indicated that most of it is probably exported. Aggregating pulp mills with paper and paperboard mills gets around these obstacles, but creates difficulties in calculating unit production costs for paper and paperboard products. Hence, we chose to model the paper and paperboard mills industries alone (32212,3), which in any case account for the overwhelming bulk of the paper industry' output.

(c) Scrap, recovery and waste recycling—The

WE HAD DIFFICULTIES DISTINGUISHING BETWEEN MAJOR SEGMENTS WITHIN AN INDUSTRY THAT MAY ENTAIL DISTINCT PRODUCTION PROCESSES.

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[48] According to DOE MECS data, pulp mills equal about 6 percent of combined paper and paperboard manufacturing purchased energy consumed, and about 11 percent of total energy consumed (including onsite generated energy) for these sectors.

steel, aluminum and paper industries engage in the substantial reuse of recovered or recycled materials (scrap steel, recovered aluminum, recycled wastepaper) in their production processes. Production from recycled materials in each of these industries outstrips primary production from raw materials (iron ore, bauxite/aluminum oxide, wood chips). In steel and aluminum, a large portion of recovered metals are scrap left over from production processes, i.e, 'new' scrap. The remainder in these sectors, and all the recycled paper, is "old use", from recycling the material content in end-use consumer products (autos, cans, newspapers and office paper). In steel, scrap is used in both integrated mills and mini-mills, but largely defines the latter sector. Recovered aluminum is primarily used in secondary smelters. Wastepaper, however, is used in both paper mills and paperboard mills, though data on the breakdown of this use for the two types of mills in not readily available.

> **BECAUSE MATERIALS REUSE IS SO LARGE AND SUCH AN IMPORTANT PART OF THESE INDUSTRIES' PRODUCTION PROCESSES IT WOULD BE IMPORTANT TO INCORPORATE RECYCLED MATERIALS INTO THE INDUSTRY MODELS.**

Because materials reuse is so large and such an important part of these industries' production processes it would be important to incorporate recycled materials into the industry models. In addition, the use of recovered material can have significant impacts on the industries' energy use and costs. Because of a lack of data, however, characterizing recovered materials in the sector models at this time was limited.

- In steel, we ran into the industry sub-segment issue described above.

- In aluminum, we obtained sufficient energy-related data about the secondary aluminum sector, which is scrap based, allowing us to fully model the primary and secondary aluminum sectors. However, there is need for a better understanding of the recycling markets and their relationship to the production sectors, to accurately portray production trade-offs resulting from different impacts associated with climate policies. That is, to what extent would the low energy-intensive secondary smelters increase their outputs relative to primary smelters as a result of higher energy costs? And to what extent would rising scrap costs, resulting from escalating overseas demand (e.g, from China) offset this competitive advantage?

- Wastepaper is treated as a materials input in the model, and we projected relative paper and paperboard outputs

from virgin fiber and recovered wastepaper based on historical trends.

(d) Internal energy generation—Otherwise known as "auto-generation," heat and electric power generated within production facilities from recycling combustible materials and waste and co-generation are important sources of energy consumed in paper and pulp and steel industries, and to a lesser extent in petrochemicals and chlor-alkali manufacturing.

- Over half the heat and power used in paper, paperboard and pulp production is generated onsite. Paper mills burn renewable biomass fuels for heat and power, particularly wood processing waste and other wood residuals from the wood chip feedstock and spent black liquor produced by the Kraft chemical recovery. The Kraft chemical process accounts for about 80 percent of total US pulping capacity.

- Integrated steel mills use recycled coke oven and blast furnace gases in the co-generation of heat and electrical power used in iron and steelmaking processes.

- The chemical manufacturing industries also burn purchased fuels and feedstock in the cogeneration of heat and electricity.

The more manufacturers internally generate heat and power, the less reliant they are on purchased energy sources, which can help reduce their energy costs. Investments in processes and technologies that can increase the amount of onsite energy production could help offset the added costs of fossil fuels and electricity resulting from carbon-pricing policies. Although internally generated energy was accounted for in the energy accounting used to calibrate the models (all energy

consumption data is MECS based), more work would be required to fully integrate internal generation into the models so it is possible to better address these investment options.

(e) Available and consistent data—The most formidable and time-consuming challenges we confronted in modeling the subject industries concerned obtaining consistent, reliable and appropriate data. Not the least of the project's data problems included, on the one hand, the availability of historical time series that went back far enough in time to ground the modeling exercise, and on the other, for some types of statistics, the availability of sufficiently recent data. Comparing and matching one category of data (i.e., value of shipments, production costs) with another (i.e., production output) occasionally created obstacles, as well, usually linked to industry boundary problems.

Each of the major data sources used in the study presented its own challenges:

- The manufacturing financial and energy data sets the project used, the former supplied by the U.S. Census Bureau, the latter by the U.S. Department of Energy, are provided in NAICS format from 1997 on and in SIC format prior to 1997. SIC industry categories are not always in a one-to-one correspondence with the NAICS industries. On the one hand, primary aluminum, paperboard mills, pulp mills, alkalies and chlorine and electrometallurgical ferroalloy products matched up exactly in both systems. On the other, paper mills, petrochemicals and iron and steel mills in NAICS are comprised of parts of several industries classified in the SIC system.[49] Census provides an online guide to help bridge between the two classification systems, when comparing data across the 1997

> **The most formidable and time-consuming challenges we confronted in modeling the subject industries concerned obtaining consistent, reliable and appropriate data.**

divide.[50] This was used to estimate all the data sets presented in SIC format for the years prior to 1997.

- The *ASM* provides the most complete and authoritative set of economic and financial data at a highly disaggregated industry level on a yearly basis back to 1992. This includes value of shipments, value added, and materials, energy, labor, and capital expenditures. The energy data includes purchased electricity expenditures (and quantity) and purchased fuels expenditures. The *ASM* series was used as the principal source of data for historical information on production costs. Aside from the NAICS-SIC cross-walk problem, the *ASM* suppresses some data because of disclosure concerns. Definitional issues also cropped up concerning some industry boundaries associated with NAICS categories, as mentioned above. One industry source even admitted difficulty in determining what is included in NAICS "because it is on an establishment basis," and didn't think that "Census has a good handle on this either."

- The Department of Energy's MECS is the principal source of energy use data (in physical quantity and BTUs) in manufacturing, down to the 6-digit NAICS level. Data is provided for four categories—*"first use"* energy, i.e., energy consumed for all purposes, *offsite-produced fuel* consumed for heat, power, and electricity generation either purchased or transferred from offsite into an establishment, *total energy consumed as fuel* for heat, power, and electricity generation, and *energy used as a nonfuel (feedstock)*. The MECS data suffers from several drawbacks that required various kinds of estimations to address. First, many more data points than in the *ASM* were suppressed ostensibly to avoid disclosure of company proprietary information. Second, as with the ASM data, it was necessary to develop a bridge between the NAICS-based data for later years and SIC-based data prior to 1997. Third, MECS only collects data every four years, resulted in a limited number of data points to work with—1991, 1994, 1998, and 2002. Finally, the latest data from MECS is only from 2002, which does not necessarily reflect energy use in these sectors today.[51]

[49] Census Bureau, *ASM* (2006). The NAICS paper mills industry (32212) includes all of the former SIC paper mills sector (2621, which includes newsprint mills), plus parts of the sanitary paper products industry (SIC 2766) and surgical . appliances and supplies (3842). Petrochemicals (32511) is comprised of parts of cyclic crudes and intermediates (SIC 2865) and industrial organic chemicals, n.e.c. (2869). Iron and steel mills (331111) consists of almost all of the former blast & steel mills industry under SIC (3312) and a part of the primary metal products, n.e.c. sector (3399).

[50] U.S. Census Bureau, *Economic Census: Bridge Between NAICS and SIC Manufacturing,* (Washington, DC, 1997) http://www.census.gov/epcd/ec97brdg/.

[51] The DOE is nearly completed with its survey for 2006 manufacturing energy use, which unfortunately was not available in time for use in this study.

THE ASM PROVIDES THE MOST COMPLETE AND AUTHORITATIVE SET OF ECONOMIC AND FINANCIAL DATA AT A HIGHLY DISAGGREGATED INDUSTRY LEVEL ON A YEARLY BASIS BACK TO 1992.

- Each industry association provided the project with detailed statistical reports with a variety of data that include historical trends and recent year production, shipments, and trade, and in some instances, materials and energy use, recycled materials, employment and finances.[52] The data tend to cover both the total industries and their principal subdivisions. Production and recycling data for each industry and its sub-segments are the most important for this phase of the study. Matching this data to the *ASM* and MECS data in the appropriate NAICS categories was one of the challenges that had to be addressed. Although some of the reports had financial data, the project primarily relied upon the *ASM* to maintain consistency.

- The Department of Energy sponsored several different kinds of reports on every energy-intensive manufacturing sector that originally was part of its Industries of the Future program. These include energy and environmental profiles, technology roadmaps, energy bandwidth studies, and studies on theoretical minimum energy use, among others. These reports have been invaluable sources of information for the study, their only shortcoming being that most were produced prior to 2004 and many before 2000. Hence, their analyses and data may be outdated in some instances.

- The models required import and export data for each industry sector, matched to their NAICS categories and levels. The task was made easier by the fact that the federal government collects detailed data on all products coming into and leaving the country. The U.S. International Trade Commission's (USITC) provides an excellent, user-friendly, online trade data inquiry system *(DataWeb),* which we used to extract almost all the trade data we needed from this huge database, in downloadable form for each sector. The Aluminum Association also provided detailed historical trade data applied in developing the aluminum industry model. However, because of the huge quantity and degree of detail, extracting the data and organizing them into a useful form was somewhat tedious and time consuming. Nevertheless, for each sector, at its 6-digit NAICS level, we extracted the value and quantity data for U.S. general imports (general customs value, first unit of quantity, import charges) and U.S. domestic exports (F.A.S. ("free along ship") value and first unit of quantity) for the all the major net importing nations and the world. Except for the Aluminum Association data, which was available back to 1995, all the USITC data extracted was for 1997 through 2007.

(f) Proxy variables—As noted in the text, because of data limitations we decided to calculate a new variable, called "operating" surplus, which was a proxy for "profits," for which it was not able find adequate data for except for two industries (steel and paper). Operating surplus is calculated by subtracting production costs (materials and capital expenditures, energy expenditures (fuel, feedstock, electricity), and labor compensation) from total industry revenues, measured as "value of shipments" in the *ASM*. We also defined another new variable,

The models required import and export data for each industry sector, matched to their NAICS categories and levels.

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[52] See for example, American Iron and Steel Institute (AISI), *2006 Annual Statistical Report,* (Washington, DC, 2007); American Forest & Paper Association (AF&PA), *Paper, Paperboard & Wood Pulp, 2007 Statistics, Data Through 2006* (Washington, DC, 2007); The Aluminum Association, *Aluminum Statistical Review for 2006* (Washington, DC, 2007); and American Chemistry Council (ACC), *2007 Guide to the Business of Chemistry,* (Washington, DC, 2007). This data was provided in both hard copy and electronic form.

"operating margin" which is the share of operating surplus of total shipments, a rough proxy for the traditionally used profit margins. An operating surplus includes several overhead-related costs (such as SG&A, sales, general and administrative costs), depreciation, interest on capital, and other expenses that could be considered part of the industry's fixed costs associated with production. It also includes profits and taxes not yet paid out. However, using the operating surplus and margin data, we could infer the potential impacts of the climate policy on an industry's profitability, and when it would begin to seriously consider actions to reduce its energy costs—such as investing in energy-saving technologies or cutting capacity.

Technical Model Description

Using the II-CPM, we simulated the impacts of energy price changes resulting from different carbon-pricing policies on the competitiveness of selected energy-intensive industries, especially in the face of international competition. We further examined possible industry responses, and identified and provided a preliminary evaluation of potential opportunities to mitigate these impacts.

Feedbacks. The main feedbacks included in the model therefore identify the effect of increasing energy prices and material cost on (1) market share, through the simulation of cost pass-along scenarios, and on (2) improvements in energy efficiency needed to offset growing energy expenditure.

The feedback representing market responses accounts for all domestic production cost changes and their impact on domestic market share. These include changes in labor, material and energy costs, which accounts for electricity, direct fuel and feedstock use. Energy consumption was defined using production demand and prices impacts, accounted for in the market share calculation.

Similarly, the feedback loop representing the impact of increasing energy efficiency, calculated efficiency improvements using a reference exogenous input, which represents business as usual longer-term technology improvements, and the impact of increasing energy prices. Increasing energy efficiency has an impact, in turn, on energy consumption and expenditure.

Principal modules. The structure of the simulation models we created to carry out the analysis of climate change impacts on the competitiveness of energy-intensive manufacturing sectors include modules customized to the aluminum (primary and secondary), steel, paper and chemicals (petrochemicals and alkalies and chlorine) sectors.

A generalized model was first developed and then customized to represent (1) the cost structure of the six industries analyzed, (2) the impact of international markets and (3) investment options in energy efficient capital and technology.

The *cost structure module*, which adopts the *ASM* industry classification (NAICS), calculated total production costs as the sum of energy, labor, capital and material costs. Energy costs were calculated for electricity, direct and feedstock fuel consumption. The energy sources considered included electricity, coal, coal coke, distillate fuel oil, residual fuel oil, LPG and natural gas. In addition, operating surplus and operating margin were calculated for all industries, using both total revenues and production costs.

Figure B-1

Sketch of the Main Factors Influencing Operating Surplus
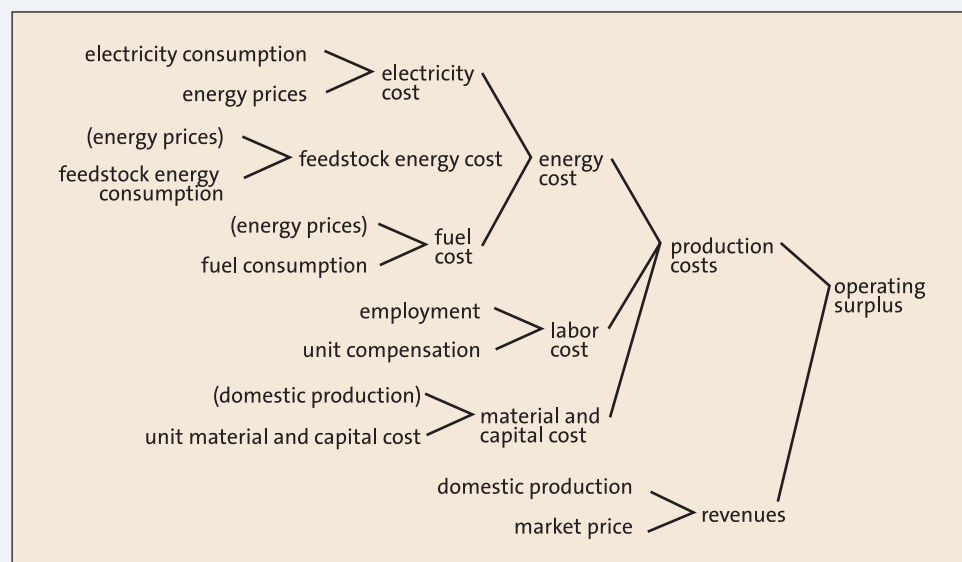
Domestic production, both for domestic consumption and export, was defined using GDP (exogenous input obtained from NEMS[53]) and domestic market share, which was calculated in the *market module*. This module calculated domestic market share, its most important endogenous variable, using the ratio between domestic and international prices. International import prices are exogenously calculated using import quantities and customs values, plus import charges, for the main exporters to the US (e.g. Canada, Russia, Venezuela, Brazil, EU15, China and rest of the world, for the aluminum sector). Market share was used to define domestic production (both for domestic consumption and export) out of total demand (for domestic consumption and export).

The *investment module* was used to estimate the potential impact of investment in energy efficiency on total production cost and profitability. Fuel intensity (demand per unit of production) was exogenously calculated with MECS data and projected using various assumptions including: (1) baseline technological development (i.e. 0.25 percent a year), and (2) energy efficiency improvement that compensates the increase in energy cost correspondent to the pricing scenarios considered.

The following overview presents the structure of the model for the primary aluminum industry, providing detailed technical explanations of the calculations (including equations) of the main variables carried out by the principal modules. The other five sectoral modules differ from it in their parameterization and the peculiarities of the industry analyzed (e.g. absence of feedstock energy).

Fuel intensity (demand per unit of production) was exogenously calculated with MECS data and projected using various assumptions.

[53] EIA, *The National Energy Modeling System*.

Table B-4
Cost Structure Module, Constants and Table Functions

Variable Name	Type of Variable	Source for Estimation
Average electricity cost per KWH	Time Series	NEMS (EIA – AEO 2008)
Coal price	Time Series	NEMS (EIA – AEO 2008)
Coke price	Time Series	NEMS (EIA – AEO 2008), calculated
Demand per unit of GDP	Time Series	ASM
Distillate fuel oil price	Time Series	NEMS (EIA – AEO 2008)
Employment per unit of output	Time Series	ASM, calculated
GDP deflator table	Time Series	NEMS (EIA – AEO 2008)
Internal energy production per unit of output	Time Series	MECS
LPG price	Time Series	NEMS (EIA – AEO 2008)
Market price	Time Series	ASM
Natural gas price	Time Series	NEMS (EIA – AEO 2008)
Non energy coal intensity	Time Series	MECS, calculated
Non energy coke intensity	Time Series	MECS, calculated
Non energy distillate fuel oil intensity	Time Series	MECS, calculated
Non energy LPG intensity	Time Series	MECS, calculated
Non energy natural gas intensity	Time Series	MECS, calculated
Non energy residual fuel oil intensity	Time Series	MECS, calculated
PC labor cost	Time Series	ASM
Residual fuel oil price	Time Series	NEMS (EIA – AEO 2008)
Unit material cost	Time Series	ASM
US GDP	Time Series	NEMS (EIA – AEO 2008)

Cost Structure Module

The cost structure module calculates total production costs as the sum of energy, labor, capital and material costs.

Purpose and Perspective

The cost structure module calculates total production costs as the sum of energy, labor, capital and material costs. In addition, operating surplus and operating margin are calculated, using both total revenues and production costs (see Figure B-I, Table B-4)

Domestic production, both for domestic consumption and export, is the main endogenous input to the cost structure module. Domestic production uses GDP (exogenous input) and domestic market share, calculated in the market module.

Explanation

Major Assumptions

- The cost structure given by the *ASM* was adopted (NAICS);

- MECS data were used to calculate the energy intensity for various energy sources (both off-site and feedstock); for future projections a 0.25 percent yearly improvement in energy efficiency was assumed;

- Operating surplus was calculated as total revenues (value of shipments) minus labor, capital, material and energy costs, as reported in the *ASM*.

Functional Explanation

Total US aluminum demand was calculated using GDP and aluminum intensity. The projection for GDP was taken from the Congressional Budget Office (CBO) and the EIA. Aluminum intensity was calculated as GDP over aluminum demand:

Total aluminum demand = US GDP(Time) * ALUMINUM DEMAND PER UNIT OF GDP(Time)

Domestic aluminum production, for domestic consumption and export, is equal to total aluminum demand multiplied by the market share of US aluminum producers. Domestic aluminum production was disaggregated into primary and secondary production. Primary production is assumed to be the residual factor for domestic production. The market share of secondary production was calibrated according to assumptions provided by the Aluminum Association:

Domestic primary aluminum production = total domestic aluminum production –domestic secondary aluminum production

Domestic secondary aluminum production = scrap aluminum consumption share * total domestic aluminum production

Cost Structure Module, Constants and Table Functions

The total production cost of aluminum production was calculated as the sum of labor, energy and capital and material costs:

Aluminum total production cost=aluminum energy cost + aluminum labor cost + aluminum material and capital production cost

Labor costs are calculated as employment multiplied by the unit labor compensation. Total employment was obtained by multiplying domestic production by labor requirements per unit of output. Material and capital costs were calculated as unit cost multiplied by domestic primary aluminum production:

Aluminum labor cost = total aluminum employment * ALUMINUM LABOR COST TABLE(Time)

Total energy costs were calculated as the sum of electricity and fuel costs, both for direct and feedstock energy use. Fuel (direct) and feedstock energy costs were calculated for various energy sources, including coal, coal coke, distillate fuel oil, residual fuel oil, LPG and natural gas. Demand for each specific energy source, such as natural gas, was calculated as primary aluminum production multiplied by natural gas intensity. Expenditure for such fuel was calculated by multiplying consumption by natural gas price.

Aluminum fuel cost = aluminum coal consumption*COAL PRICE(Time) + aluminum distillate fuel oil consumption * DISTILLATE FUEL OIL PRICE(Time) + aluminum LPG consumption * LPG PRICE(Time) + aluminum natural gas consumption * NATURAL GAS PRICE(Time) + aluminum residual fuel oil consumption * RESIDUAL FUEL OIL PRICE(Time) +

Total energy costs were calculated as the sum of electricity and fuel costs, both for direct and feedstock energy use.

aluminum coke consumption * COKE PRICE(Time)

Electricity expenditure was calculated by multiplying consumption by price and accounts for internal production (which is subtracted from total energy demand):

Total electricity demand for aluminum production = ((domestic primary aluminum production) * ALUMINUM INDUSTRY ELECTRICITY INTENSITY(Time)) – internal aluminum electricity production

The operating surplus was calculated as total revenues (i.e. value of shipments) minus total production costs (i.e. labor, energy, capital and material cost). The operating margin was instead calculated as operating surplus over revenues:

Aluminum operating surplus=aluminum revenues-aluminum total production cost

A variety of indicators were also provided. These included total unit costs, as well unit labor, energy and material and capital cost. All monetary values were calculated both in nominal and real terms (in USD 2000).

Market Module

Purpose and Perspective

Domestic market share was the main endogenous variable calculated in the market module. Market share is used to define domestic production (both for domestic consumption and export) out of total demand (for domestic consumption and export). Domestic price was the main endogenous input for the market module, in the cost pass-along scenarios, calculated in the cost structure module (see Figure B-II, Table B-5).

The market module calculated domestic market share using the ratio between domestic and international prices. International import prices were calculated using import quantities and customs values, plus import charges, for the main exporters to the US (e.g. Canada, Russia, Venezuela, Brazil, EU15, China and ROW, for the aluminum sector)

Explanation

Major Assumptions

- Major exporters to the U.S. were calculated using data from the U.S. International Trade Commission and industrial trade associations, which include the American Iron and Steel Institute (AISI), the American Forest and Paper Association (AF&PA), the American Chemistry Council (ACC), and the Aluminum Association;

- Price differentials between domestic and foreign markets were assumed to be the main drivers for domestic market share;

- Domestic market share was calculated using the domestic/foreign price ratio and an elasticity parameter estimated using historical data from 1992 to 2007.

Functional Explanation

The calculation of domestic market share accounts for a delay representing longer term contracts and the inertia of the system in spite of short term price changes. Market share was therefore calculated as initial market share multiplied by the delayed relative ratio of domestic/foreign prices, with respect of 1992, which is raised to the power of the elasticity estimated using historical data from 1992 until 2007 and further calibrated to obtain the best fit to data.

Figure B-II

Sketch of the Main Factors Influencing Operating Surplus
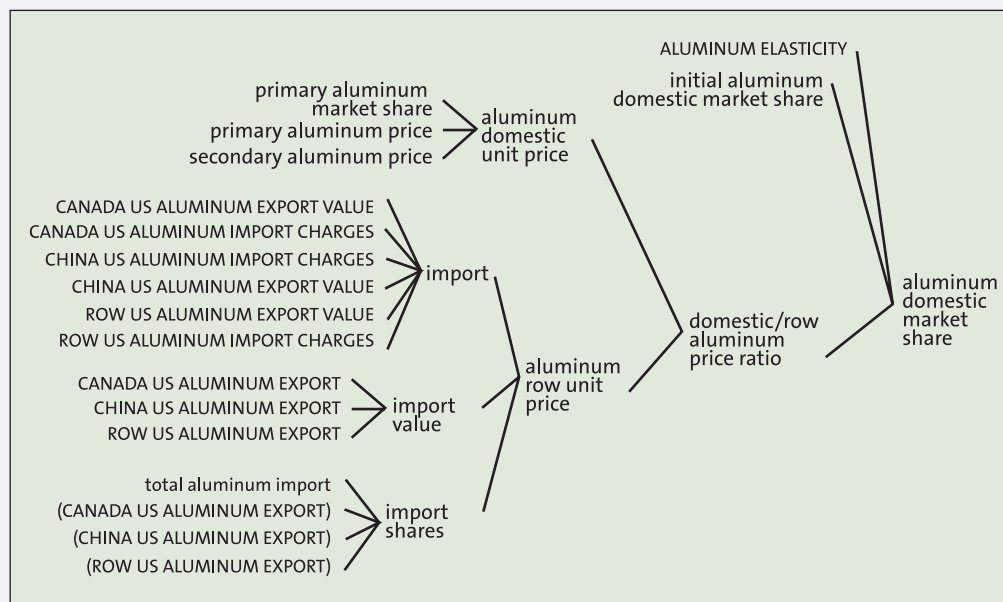
Table B-5

Market Module, Constants and Table Functions

Industry Sector	Type of Variable	Source for Estimation
Country US aluminum export	Time Series	ASM
Country US aluminum export value	Time Series	ASM
Country US aluminum import charges	Time Series	ASM
Elasticity of domestic production to price	Constant	ASM, estimated
Initial US domestic market share	Constant	ASM

Aluminum domestic market share = INITIAL US ALUMINUM DOMESTIC MARKET SHARE / (Delayed Relative ROW And US Aluminum Prices Ratio) ^ ALUMINUM ELASTICITY

The value for elasticity was obtained through optimization, using a linear programming function provided by Vensim©. This value was then revised to improve fitting with the latest historical data points

Table B-6
Market Module, Elasticity Values

Aluminum	Optimization (1992-2006) Model	0.87 1.00	Trend accuracy (2004 - 2006)
Steel	Optimization (1992-2006) Model	0.77 1.00	Trend accuracy (1997 - 2002)
Paper	Optimization (1992-2006) Model	0.62 0.75	Trend accuracy (2000-2004)
Petrochemicals	Optimization (1992-2006) Model	0.10 0.20	Trend accuracy (2002 - 2006)
Alkalies & Chlorine	Optimization (1992-2006) Model	0.125 0.15	Trend accuracy (lack of data for the years 1992 through 1996)

The calculation of domestic market share accounts for a delay representing longer term contracts and the inertia of the system in spite of short term price changes.

available, to represent the longer term trend of domestic market share and also to better incorporate the recent effect of increasing prices on market share (see Table B-6).

The average international import price was calculated as the weighted average of country export prices to the US and export quantities to the US. Country export prices to the US were calculated by dividing the sum of custom value of export and import charges by export quantities.

    Aluminum row price=
        brazil us aluminum export price * brazil
        us aluminum export share +
        canada us aluminum export price *
        canada us aluminum export share +
        china us aluminum export price * china
        us aluminum export share +
        EU15 us aluminum export price * EU15
        us aluminum export share +
        russia us aluminum export price * russia
        us aluminum export share +
        venezuela us aluminum export price *
        venezuela us aluminum export share +
        row us aluminum export price*row us
        aluminum export share

Canada us aluminum export price=
    (CANADA US ALUMINUM EXPORT
    VALUE(Time) + CANADA US ALUMINUM
    IMPORT CHARGES(Time)) / CANADA US
    ALUMINUM EXPORT(Time)

Investment Module

Purpose and Perspective

The investment module was used to estimate the potential impact of investment in energy efficiency on total production cost and profitability. Fuel intensity (demand per unit of production) was calculated with MECS data and projected using various assumptions including: (1) baseline technological development (i.e. 0.25 percent a year), and (2) energy efficiency improvement that compensates the increase in energy cost correspondent to the pricing scenarios considered (see Figure B-III, and Table B-7).

Energy demand was calculated for coal, distillate fuel oil, LPG, natural gas, residual fuel oil and coal coke.

SKETCH OF THE MAIN FACTORS
INFLUENCING ALUMINUM FUEL COSTS
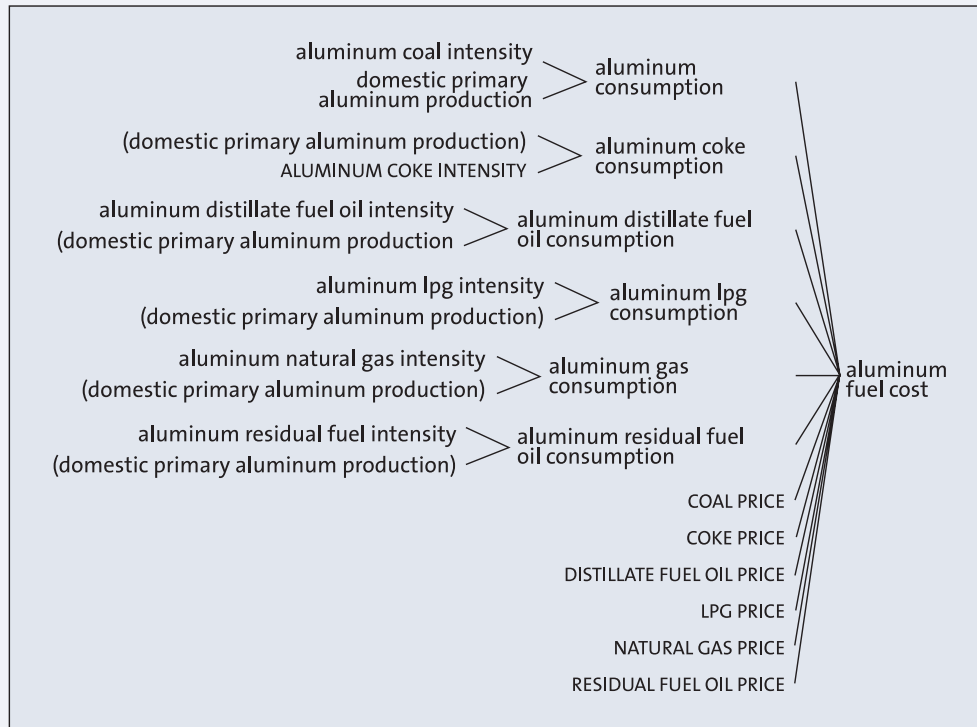
TABLE B-7
INVESTMENT MODULE,
CONSTANT AND TABLE FUNCTIONS

Variable Name	Type of Variable	Source for Estimation
Coal intensity	Time Series	MECS, calculated
Coke intensity	Time Series	MECS, calculated
Distillate fuel oil intensity	Time Series	MECS, calculated
Electricity intensity	Time Series	MECS, calculated
LPG intensity	Time Series	MECS, calculated
Natural gas intensity	Time Series	MECS, calculated
Residual fuel oil intensity	Time Series	MECS, calculated

ALTERNATIVE SCENARIOS

Rising Material Costs. A recurring question in meetings with industry stakeholders, was how unexpected increases in the costs of production factors other than energy, but still influenced by it, such as materials or labor, would affect the results of the II-CPM simulations—i.e., how they would change the projected impacts of carbon-pricing policies on the cost structures, profits and operating surpluses of the industries we examined. Material costs in particular were raised several times as a concern, given their dominant share in the industries' production costs. For example, how would increases in the costs of raw materials (e.g., bauxite/alumina, iron ore, virgin fiber) or recycled scrap materials (wastepaper, scrap metals) or other important inputs (limestone, oxygen) affect the modeling results?

The II-CPM simulations incorporated assumptions about future materials costs based on industry feedback and the literature, and also extrapolations of historical trends, which may not hold true in the future. All modeling projections suffer from this same limitation. It is possible that prices for these inputs will rise higher or faster than currently anticipated. For example, until the economic crisis beginning at the end of 2008, demand for many of these inputs were growing, in response to developing countries such as China, India, and Brazil building up their own capacity in the steel, aluminum, paper and chemicals industries.

A related question was how unanticipated increases in key energy sources, especially those used as feedstock in production processes (e.g., natural gas, coke) would affect the results of the analysis. Concerns were raised many times in industry stakeholder meetings about the accuracy of NEMS modeling assumptions and energy price projections, and the implications for the HRS-MI study's results. Indeed, the price of oil already has soared and declined way beyond and below the EIA's NEMS-based AEO 2008 reference case projections.

To help address these questions, we conducted a sensitivity analysis with II-CPM, assuming a 1.15 percent real (3 percent nominal) yearly rate of increase in the cost of materials. The simulations were run for both CPA and NCPA scenarios, which examine the impacts of changing energy prices resulting from different policies. For simplicity, only NCPA scenarios are presented, to better distinguish the first order impact of changing market conditions from secondary endogenous responses. In these scenarios, the materials cost projections for any given industry remain the same for the energy policy case and the BAU reference case. However, we conducted the simulations for three additional assumptions, to examine

the implications of an exogenous materials cost increase under different conditions:
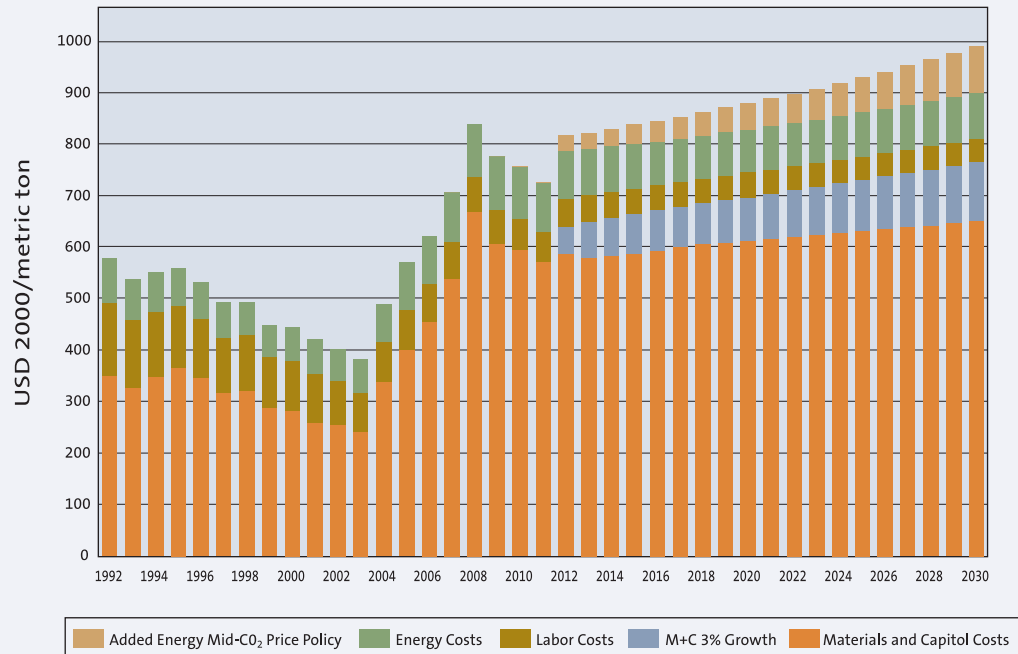
Material Cost (MC) Scenario: Material and capital costs grow at a 1.15 percent real annual rate starting from 2009 assuming that only domestic manufacturers experience this cost increase, and they are not able to pass the costs along to the market price. This approximates a situation in which localized conditions drive up material costs for domestic manufacturers;

Material Cost and Domestic Price (MC+DP) Scenario: The additional material cost is passed along by the domestic manufacturers, but manufacturers in the ROW do not experience cost increases;

Material Cost, Domestic Price and World Prices (MC+DP+WP) Scenario: Domestic and ROW manufacturers experience the same materials cost increase (such as scrap metals), and prices are passed through globally (i.e., domestic and world prices rise proportionally with material cost increases, or increase by the exact amount represented by the increasing material cost).

These scenarios are largely speculative. However, there may be some real world situations that could apply and the sensitivity simulations provide additional perspectives on what might happen if unexpected exogenous rises in materials costs occur.

Figure C-I illustrates how rising materials costs (MC and MC+DP) would affect industry production cost structures, using in this case, the iron and steel industry as an example. The orange columns represent the yearly materials and capital costs for the industry for the core policy scenarios. The blue represents the growth in materials costs through 2030. By 2030, materials costs would rise to 21 percent of the non-growth material costs in real terms (for the iron and

Figure C-I

Iron & Steel Real Unit Cost Comparisons: 1.15% Real Materials Cost Increase

USD 2000/metric ton

Legend: Added Energy Mid-CO_2 Price Policy | Energy Costs | Labor Costs | M+C 3% Growth | Materials and Capitol Costs

HRS-MI

steel industry). The brown represents the labor costs each year, which are assumed to remain the same for all scenarios. The green columns represent the energy costs for the BAU reference case, and the tan represents the additional energy costs associated with the Mid-CO_2 Price Policy case: the green and tan columns together represent the total energy costs for the Mid-CO_2 Price Policy case.

As the figure illustrates, the net result of the materials costs growth would be to elevate the total cost curve accordingly, but would not in any way affect energy cost increases for the policy cases. That is, the BAU baseline has shifted upwards, and the total production costs for the new BAU and policy cases have risen accordingly. In

the new scenarios, materials costs would account for a larger share of the totals, and the energy cost shares of the total would decline accordingly. However, the *changes* in total costs, in absolute terms, for a policy case relative to the BAU would be the same for the MC and no MC scenarios. As a proportion, however, the policy-related energy increases would represent smaller shares of total costs, due to the share of materials costs.

Figure C-II compares the operating surplus curves for BAU and Mid-CO_2 Price Policy cases for the iron and steel industry for the baseline and MC scenarios. The figure illustrates that the operating surplus curves for the MC growth scenario (but no cost pass along) are moved downwards,

reflecting rising production costs, and corresponding loss of operating surplus for the BAU and policy cases.

The figure also illustrates the BAU operating surplus baselines for the MC+DP scenarios and MC+DP+WP scenarios for the iron and steel industry. The latter assumes that the materials costs are experienced globally, and all manufacturers, domestic and foreign would increase their prices proportionally to their increases in production costs. These baselines are higher than the BAU No Growth curve, because manufacturers in these scenarios proportionally get the same profit margin out of a larger price. However, demand does not decrease significantly enough to offset this gain. This is more or less is what has happened over the last few years.

The former is similar to the CPA scenarios with no MC growth, in that manufacturers now would pass on their proportional increases in costs to a proportional increase in their domestic market price. However, because they would be competing with foreign importers not subject to a comparable materials cost increase, they would lose domestic market shares and cut production. The losses in production would translate to losses in the operating surplus.

Figure C-III provides an explanation for the different MC related scenarios and how they would affect the policy case

AS A PROPORTION, HOWEVER, THE POLICY-RELATED ENERGY INCREASES WOULD REPRESENT SMALLER SHARES OF TOTAL COSTS, DUE TO THE SHARE OF MATERIALS COSTS.

FIGURE C-II
Iron & Steel Real Operating Surplus: 1.15% Real Materials Cost Increase vs. No Growth
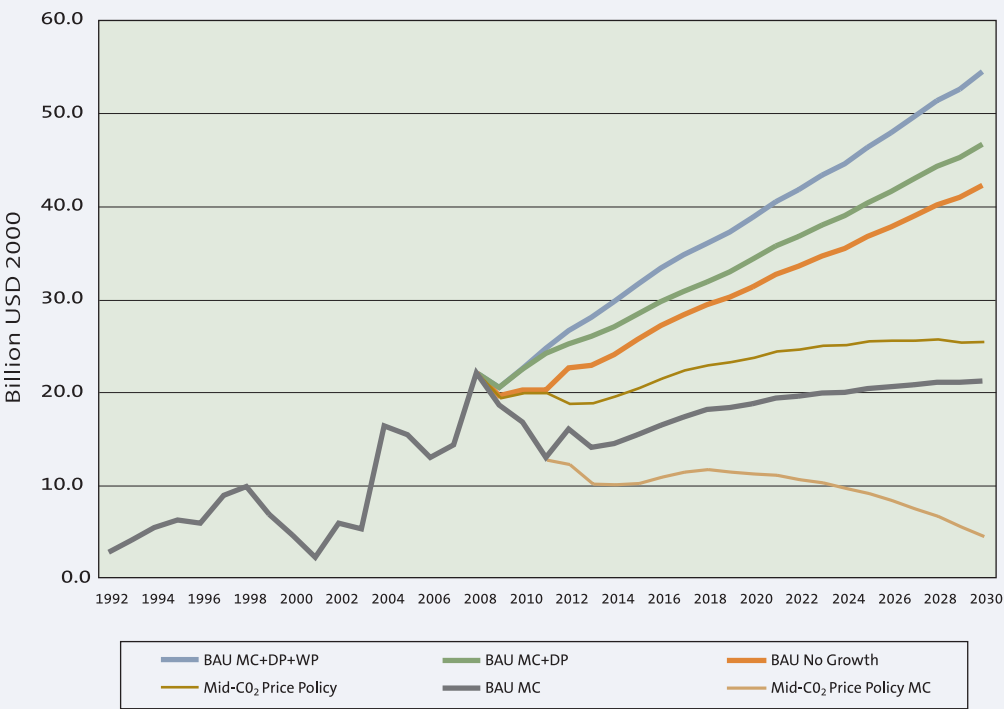
Legend:
- BAU MC+DP+WP
- BAU MC+DP
- BAU No Growth
- Mid-CO₂ Price Policy
- BAU MC
- Mid-CO₂ Price Policy MC

HRS-MI

simulations. It compares the real unit production cost curves for the BAU and Mid-CO_2 Price Policy cases, for the MC no growth and growth scenarios. As illustrated here, the BAU baseline and the policy case would be elevated by the same amount, and the relative difference between the policy case and its associated BAU would remain the same. That is, increasing the cost of materials would not affect the policy impacts on production costs relative to the BAU, *in absolute terms*.

However, in the new BAU growth scenario, with no cost pass-through, the market price is the same as the no growth price. While the Mid-CO_2 Price Policy curve for the no MC growth scenario indicates a shrinking

operating surplus that would prompt some iron and steelmakers to cutback production, the Mid-CO_2 Price Policy curve for the MC scenario would likely cross the market price shortly after 2030, indicating that the theoretical "shut-down" point had been reached, which would potentially trigger serious reductions in domestic steelmaking, if no countervailing actions were taken by manufacturers to reduce their costs.

If cost pass-along is assumed, whether domestic only (MC+DP) or worldwide (MC +DP+ WP), then the difference between the BAU and Mid-CO_2 Price Policy curves for the MC cases would widen again. The difference between the two cost pass-along scenarios, as noted, is that the domestic

MATERIALS COSTS ARE EXPERIENCED GLOBALLY, AND ALL MANUFACTURERS, DOMESTIC AND FOREIGN WOULD INCREASE THEIR PRICES PROPORTIONALLY TO THEIR INCREASES IN PRODUCTION COSTS.
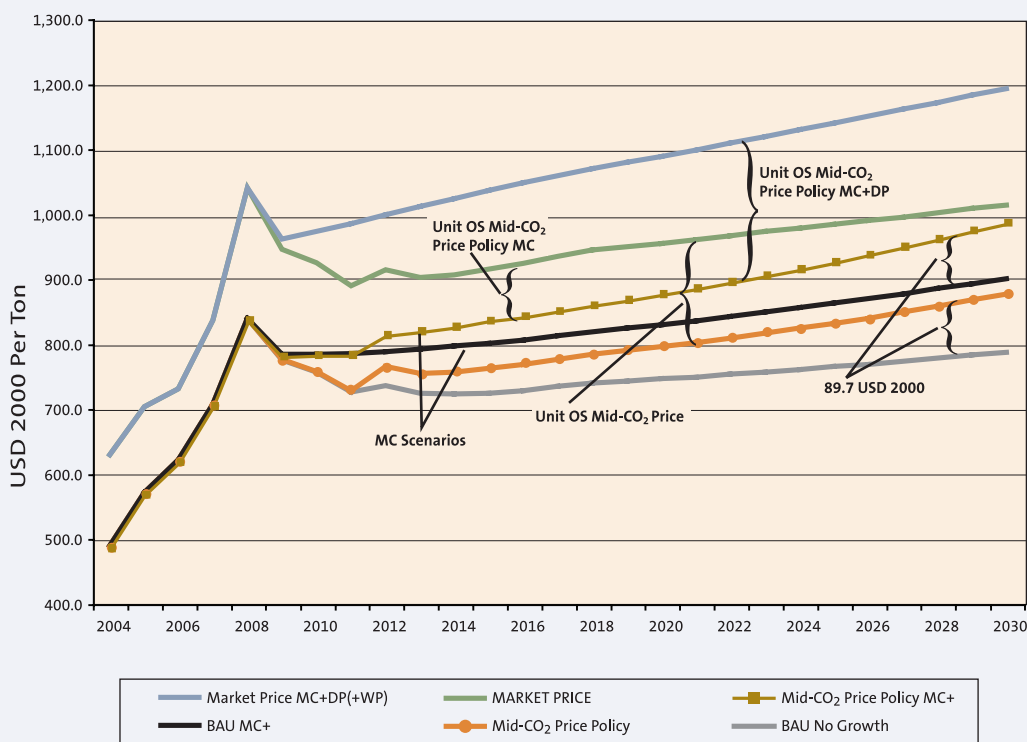
FIGURE C-III
IRON & STEEL REAL UNIT PRODUCTION COSTS

Unit OS Mid-CO_2 Price Policy MC+DP

Unit OS Mid-CO_2 Price Policy MC

Unit OS Mid-CO_2 Price

MC Scenarios

89.7 USD 2000

USD 2000 Per Ton

Legend:
- Market Price MC+DP(+WP)
- MARKET PRICE
- Mid-CO_2 Price Policy MC+
- BAU MC+
- Mid-CO_2 Price Policy
- BAU No Growth

HRS-MI

industry would lose market share to foreign importers, while in the later, domestic manufacturers would preserve both market share and their operating surpluses (and profits). Although, the figures illustrate the sensitivity results for the iron and steel industry, the pattern would be the same for all the other sectors.

On a final note, the MC growth analyses also suggest what might happen in the case of an exogenous, non-policy related increase in energy costs. These increases too would move up the BAU baseline, and there would be similar impacts for the policy cases under the MC scenarios. For example, if natural gas price increases only affected domestic manufacturers, there would be the equivalence of a MC no cost-pass along scenario. The resultant shrinking of operating surpluses, even for the BAU cases, could move many of the industries towards their theoretical breakeven points, if not their shut-down points. Evidence of this kind of impact was seen in the recent decision by Dow Chemicals to invest in new offshore

locations with cheaper sources of natural gas, rather than expanding U.S. capacity, despite rising demand, because the prices of domestically available supplies of the energy source had risen too high (see Chapter Eight).

Changing Elasticity Values

The cost pass-along cases simulated using the II-CPM used derived elasticities of demand, i.e. the relative change in demand for a product associated with a relative change in prices, based on historical foreign import quantities and prices relative to U.S. prices. The selection of elasticities in economic models is one of the most difficult and uncertain challenges for modelers, as the impacts on projected industry bottom-lines and market shares, which impact production output, can be greatly influenced by the elasticities employed. The results of the model simulations could vary, perhaps significantly, if different demand elasticities are assumed.

The Reinaud/IEA study,[54] for example, assumed different elasticities than those II-CPM, though these might be more applicable to EU markets, which was the focal point of the study. Reinaud assumed an elasticity of 0.86 for the aluminum industry, 1.56 for the steel industry (both BOF and EAF segments) and 1.88 for paper. It should be noted that the analysis of different elasticity values proposed in the HRS-MI study was applied to a set of assumptions that make it possible to extract, and exclusively focus on, the net impact that the climate proposition being simulated would generate. In fact it was assumed that market

Evidence of this kind of impact was seen in the recent decision by Dow Chemicals to invest in new offshore locations rather than expanding U.S. capacity.

[54] Reinaud, *Industrial Competitiveness*.

prices, both domestic and international, would follow nominal trends projected by Global Insights.

To examine how different elasticities might affect the results of the II-CPM simulations, we therefore carried out industry simulations for the policy cases comparing the original (reference) CPA simulations with CPA simulations assuming a high (above the reference elasticity) and low (below the reference), for each industry. Since cost structure is not affected by changing the demand elasticities, the primary impacts of the different elasticities would be on the industries' domestic market shares and operating surpluses and profits. A higher elasticity of demand in the model means that if U.S. prices rise by an incremental amount relative to foreign importers, U.S. manufacturers would lose a larger share of their sales to imports than for a comparable price increase in the reference scenarios (i.e., at the original elasticity level). That is, domestic market shares would decline by a greater amount than the original cases. Similarly, a lower elasticity would translate into a smaller loss in sales and markets to foreign imports.

Figure C-IV compares the market share impacts for the Mid-CO_2 Price Policy case for the iron and steel industry, for the high, low and reference elasticities. The market

The cost pass-along cases simulated using the II-CPM used derived elasticities of demand, i.e. the relative change in demand for a product associated with a relative change in prices.

share curves are shown relative to their BAU baselines, which however are different for the different elasticities. The BAU simulation for an industry is based on the prices for consumed energy sources provided in the AEO 2008 reference case. For the BAU cases, the II-CPM market dynamics module calculates market shares and operating surpluses by comparing the *ASM*-supplied U.S. prices, and GI indexed future trends, for domestically produced goods and ROW prices for imported goods. The elasticity used in a scenario dictates the amount of the domestic market share that is allocated based on the ratio of U.S. and ROW prices.

For aluminum, paper and paperboard, and petrochemicals, the differences between the BAU domestic market share and operating surplus curves, for the high, low and reference elasticity scenarios, would be negligible—less than 1.5 percent—for the domestic market share and operating surplus simulations. However, for the chlor-alkali industry the high and low elasticity BAU curves would be 3 percent lower and higher, respectively, than the BAU reference curve. For the steel industry, the high and low BAU curves would be 3 percent and 4 percent, lower and higher, respectively than the reference BAU. There would be larger changes in steel and chlor-alkali because there were large differences between the initial price ratio, in 1992, and the one

Table C-1
Elasticity Sensitivity Cases
Domestic Market Shares Relative to BAU

Industry & Policy Case	2020			2030		
	Low	Ref	High	Low	Ref	High
Aluminum						
Mid-CO$_2$ Price Policy	-0.9	-1.2	-1.4	-2.1	-2.6	-3.0
Iron & Steel						
Mid-CO$_2$ Price Policy	-4.1	-5.4	-6.7	-7.1	-9.3	-11.5
Paper and Paperboard						
Mid-CO$_2$ Price Policy	-1.0	-1.5	-2.0	-1.9	-2.8	-3.7
Petrochemicals						
Mid-CO$_2$ Price Policy	-0.1	-0.3	-0.4	-0.2	-0.5	-0.7
Chlor-Alkali						
Mid-CO$_2$ Price Policy	-0.3	-0.8	-1.4	-0.6	-1.6	-2.6
Elasticity Values	*Low*		*Reference*		*High*	
Aluminum	0.75		1.00		1.25	
Iron & Steel	0.75		1.00		1.25	
Paper and Paperboard	0.50		0.75		1.00	
Petrochemicals	0.10		0.20		0.30	
Chlor-Alkali	0.05		0.15		0.25	

FIGURE C-IV
ELASTICITY SENSITIVITY CASES: IRON AND STEEL DOMESTIC MARKET SHARES MID-CO₂ PRICE POLICY (CPA)

Low Elasticity — Reference Elasticity — High Elasticity

HRS-MI

For aluminum, paper and paperboard, and petrochemicals, the differences between the BAU domestic market share and operating surplus curves, for the high, low and reference elasticity scenarios, would be negligible.
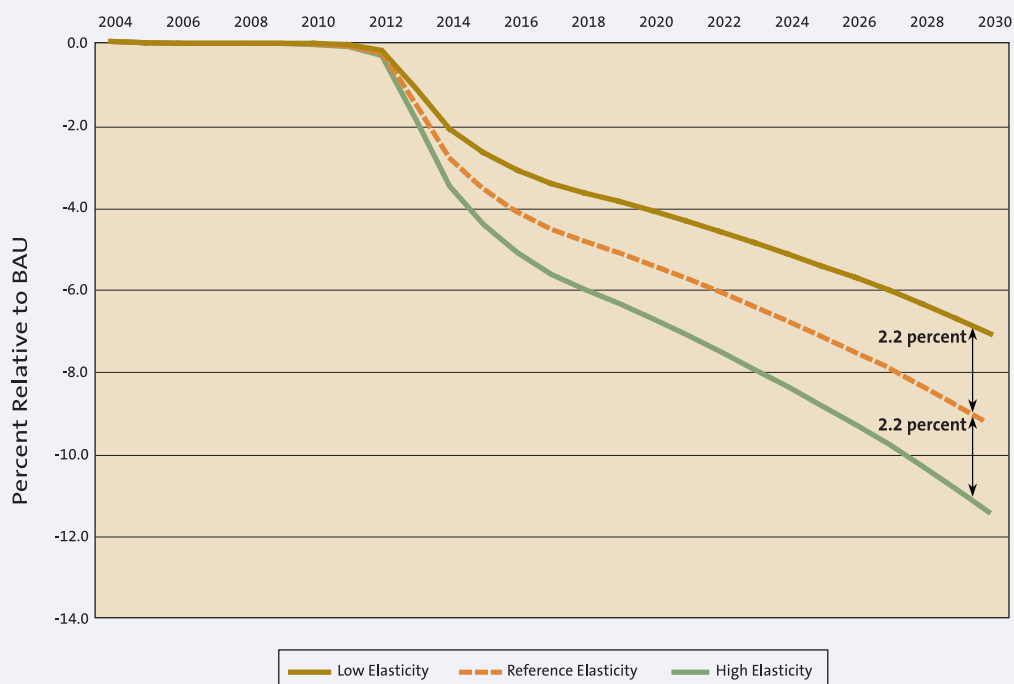
projected in 2007. This means that the price differential, though small in the case of steel, would still result in structural changes for the industry: in other words, the industry has been changing consistently over the last 15 years and small changes in price—high sensitivity—may create stronger impacts. The other industries seem to be more stable and resilient to price changes.

In any event, for a given elasticity scenario, we measured the policy case impacts relative to BAU baseline calculated with that elasticity. For iron and steel, market share losses were estimated to reach 11.5 percent for the high elasticity case, compared to 7.1 percent for the low case, a greater than 4

percent difference, in 2030, for the Mid-CO₂ Price Policy case. However, the differences between the two elasticity variations and the reference scenario would be relatively small, which would hold true for all the other industries, as illustrated in Table C-1.

Nevertheless, in the high elasticity scenarios for the Mid-CO₂ Price Policy case, in particular, by 2030, steel would experience not inconsequential market share losses, compared to the reference and low elasticity cases. These modest changes in market share for the other industries, produced exclusively by the implementation of the provisions being analyzed, would translate into declines in industries' operating

Table C-2
Elasticity Sensitivity:
Operating Surplus Relative to BAU (Percent)

Industry & Policy Case	2020				2030			
	Low	Ref	High	NCPA	Low	Ref	High	NCPA
Primary Aluminum								
Mid-CO$_2$ Price Policy	0.9	0.4	-0.1	-6.4	-1.3	-2.4	-3.4	-16.5
Secondary Aluminum								
Mid-CO$_2$ Price Policy	-0.4	-0.9	-1.4	-3.1	-2.4	-3.5	-4.5	-8.3
Iron & Steel								
Mid-CO$_2$ Price Policy	9.4	7.4	5.4	-24.0	17.7	13.9	10.3	-39.6
Paper and Paperboard								
Mid-CO$_2$ Price Policy	-2.1	-2.6	-3.1	-11.7	-13.4	-14.3	-15.1	-38.4
Petrochemicals								
Mid-CO$_2$ Price Policy	2.8	2.7	2.7	-1.2	4.9	4.7	4.4	-2.2
Chlor-Alkali								
Mid-CO$_2$ Price Policy	13.5	12.8	12.1	-10.0	26.0	24.5	23.0	-19.9

surpluses (and profits) relative to their BAU baselines for the high elasticity scenario compared to the reference and low elasticity cases.

Table C-2 shows the results of the CPA (margin) elasticity simulations for all the industries, calculating the operating surpluses, relative to the respective BAUs, for the Mid-CO$_2$ Price Policy case.

It also compares the results with the NCPA operating surplus values. In all instances the NCPA operating surpluses losses would be much greater than the CPA cases. The differences between the low, reference and high elasticity CPA values in contrast would be relatively small.

On the other hand, the Reinaud/IEA study assumed somewhat larger elasticity levels

SINCE COST STRUCTURE IS NOT AFFECTED BY CHANGING THE DEMAND ELASTICITIES, THE PRIMARY IMPACTS OF THE DIFFERENT ELASTICITIES WOULD BE ON THE INDUSTRIES' DOMESTIC MARKET SHARES.

TABLE C-3

REAL OPERATING SURPLUS: DECLINING WORLD PRICES (WP), RELATIVE TO CORE CASES

Industry Sector	2020	2030
Aluminum	-34%	-52%
Iron and Steel	-45%	-69%
Paper and Paperboard	-20%	-34%
Petrochemicals	-9%	-18%
Chlor-Alkali	-8%	-14%

for the iron and steel (1.56) and paper and paperboard (1.88) industries than even the high elasticity values we examined in the study. Reinaud/IEA's aluminum elasticity, though, is well within the range used in the HRS-MI analysis. It can be assumed that the iron and steel industry would experience even greater market share and operating surplus losses relative to the II-CPM projections.

FOR IRON AND STEEL, MARKET SHARE LOSSES WERE ESTIMATED TO REACH 11.5 PERCENT FOR THE HIGH ELASTICITY CASE, COMPARED TO 7.1 PERCENT FOR THE LOW CASE, A GREATER THAN 4 PERCENT DIFFERENCE, IN 2030, FOR THE MID-CO_2 PRICE POLICY CASE.

DECLINING WORLD PRICE RELATIVE TO U.S. PRICES

An additional world price scenario assumed a 1.15 percent real decline in world prices (WP), starting in 2009, which approximates a situation where international competitors are able to push down world market prices because of declining costs relative to the United States. We estimated that this would cause declines in U.S. manufacturers' operating margins. Only NCPA scenarios were simulated. This is a hypothetical, if not provocative scenario, which aims at starting a conversation on what the

most likely and insightful scenarios should be analyzed when carrying out such an exercise. It assumes a situation in which U.S. manufacturers would not be able to lower their prices in the face of declining world prices. This might approximate a situation in which foreign competitors (such as China) flood the global and domestic markets with low cost goods, generated by

the combination of increasing production capacity coming on stream and a decline in domestic demand due to a global economic slowdown.

Table C-3 shows the operating surplus for the WP decline case relative to the Mid-CO_2 Price Policy case. The percent change correlates with the relative magnitudes of the elasticities for the different industries. The aluminum and steel industries have the highest elasticities, and this is reflected in the WP case operating surpluses projected and shown in the table below. Paper and paperboard, with a smaller elasticity, still has sizable operating surplus losses for the WP case compared to the normal case.

Petrochemicals, followed by chlor-alkali, have significantly smaller elasticities, and accordingly much smaller declines in the industries' operating surplus.

The correlation between the magnitude of operating surplus losses and the industry elasticities, reflects the relative loss of domestic market shares resulting from lowering the world price compared to U.S. market prices, placing U.S. manufacturers at a greater competitive disadvantage. Declining world prices corresponds to the lowering of production costs for ROW producers and exporters while U.S. production costs remain the same—or increase as a product of climate policies.

DECLINING WORLD PRICES CORRESPONDS TO THE LOWERING OF PRODUCTION COSTS FOR ROW PRODUCERS AND EXPORTERS WHILE U.S. PRODUCTION COSTS REMAIN THE SAME.

TABLE C-4
SENSITIVITY CASE: 5% PER YEAR EFFICIENCY GROWTH 2008-2030 (NCPA)

Industry Sector	2020	2030
Decline in Added Costs		
Primary Aluminum	41.4%	62.4%
Secondary Aluminum	42.8%	63.9%
Iron & Steel	33.1%	48.3%
Paper & Paperboard	42.5%	63.6%
Petrochemicals	9.5%	15.6%
Chlor-Alkali	42.8%	64.0%
Unit Production Cost Savings (% Non-Efficiency Scenario)		
Primary Aluminum	11.7%	20.4%
Secondary Aluminum	2.4%	5.0%
Iron & Steel	5.6%	9.9%
Paper & Paperboard	7.7%	16.3%
Petrochemicals	2.2%	4.0%
Chlor-Alkali	16.0%	26.6%

* Energy efficiency gains for fuel and electricity consumption only. Feedstock not affected.

Lower domestic market share means reduced production and sales for an industry, which translates into a lower operating surplus.

Energy Efficiency

The purpose of estimating required energy efficiency gains to offset higher energy costs in light of the discussion of technology options, is primarily aimed at setting the boundaries for a far more in-depth analysis of industry investment responses to climate change policies. As noted before, manufacturers in energy-cost impacted sectors would have many different possible choices, from making investments in energy-efficient technology, to passing along their costs to consumers at the risk of losing market shares, to reducing their production output or shutting down capacity.

To get a further understanding of how improving energy efficiency could benefit manufacturers, adding more grist for a future analysis, we ran a sensitivity analysis using the II-CPM, assuming a yearly 5 percent energy efficiency gain from 2008-

2030. The gains were assumed for only fuel and electricity consumption, not feedstock. We made no assumptions about what kind of energy efficiency improvements might be undertaken by an industry, what the cost of such investments to achieve such a growth rate might be, or even if the scale of improvements are even possible. Hence, this is purely a hypothetical exercise. We made calculations only for the NCPA scenario.

With those caveats, Table C-4 shows that there would be a dramatic reduction in energy costs for the Mid-CO_2 Price Policy case with the 5 percent efficiency rate compared to the baseline Mid-CO_2 Price Policy simulation. By 2020, a yearly 5 percent energy efficiency gain would result in a range of 30 percent to 45 percent reduction in energy-related costs, rising to 48 percent to two-thirds by 2030, relative to BAU. The only exception concerns the petrochemicals sector, where lower impacts are projected due to the assumption of making improvements only in fuel and electricity use, but not feedstock (roughly 90 percent of fuel use in the petrochemical sector is feedstock energy). Hence, in the other sectors, the improvements would

apply to their total energy costs, but for petrochemicals, and in smaller part for iron and steel, only to a fraction of their total energy costs.

More significant, the bottom half of the table shows how the reduction in energy costs would translate to the industries' production costs. These quantities, of course, reflect the relative share of energy costs to the industries total production costs, which also includes the costs of materials, capital, and labor. Comparing these numbers to the real unit costs above BAU shown earlier in the report, for each industry and policy case, for almost all the industries most if not all the costs would be offset—indeed, they would be greatly surpassed—by the cost savings from the hypothetical improvements in energy efficiencies. In fact, these data suggest that even if there was a 5 percent per year energy efficiency gain only up to 2020, most or all of the policy-driven energy costs would be offset up through 2030.

In other terms, for most of the industries and policy cases, the new production costs for the policy scenarios, with a 5 percent rate, would be lower than the BAU case without the efficiency improvement. For example, the real unit production costs in the paper and paperboard for BAU in 2020 was projected to be 421 USD 2000 per ton. Without the efficiency rate gain, unit costs would rise to 438 USD 2000 in the Mid-CO_2 Price Policy case. However, in the 5 percent efficiency rate scenario, the unit cost for the Mid-CO_2 Price Policy case would be 404 USD 2000, 7.7 percent lower than the non-efficiency Mid-CO_2 Price Policy case, and 3.9 percent lower than the original BAU level. Of course this begs the question of whether the technology options exist for the industries to achieve this level of yearly efficiency gains—which actually is quite large—and whether the industries would have sufficient economic incentives and available capital to invest in these gains, even if the technologies existed. But that would have to be the subject of future research.

Even if there was 5 percent per year energy efficiency gain only up to 2020, most or all of the policy-driven energy costs would be offset up through 2030.

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The savings below are achieved when PC recycled fiber is used in place of virgin fiber. Your project uses 8490 lbs of paper which has a postconsumer recycled percentage of 25%.

18 trees preserved for the future

51 lbs waterborne waste not created

7,574 gallons wastewater flow saved

838 lbs solid waste not generated

1,650 lbs net greenhouse gases prevented

12,628,875 BTUs energy not consumed

In keeping with our environmental initiatives, we engaged a printer that is carbon neutral, FSC certified, and an EPA Climate Leader Partner. This project was printed on FSC certified paper using vegetable-based inks.