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Reinventing Industrial Energy Use in a Resource-Constrained World

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Abstract

In an increasingly resource-constrained world, improving the energy efficiency of industry is essential. In addition to its environmental, security, and competitiveness benefits, energy efficiency delivers a return on investment that contributes to the profitability of enterprises. Using international technology and policy benchmarking, this chapter examines the energy productivity of U.S. industry and its role as a technology innovator, supplying next-generation green and clean technologies. After reviewing the barriers and drivers of improved practices drawing from international case studies, the chapter concludes that the dual goals of advancing energy efficiency at industrial plants and advancing product innovation are critical to promoting the productive use of energy.

Introduction

In an increasingly competitive and resource-constrained world, improving the energy efficiency of industry is essential for maintaining the viability of manufacturing, especially in a world economy where production is shifting to low-cost, less regulated developing countries. With the rapid growth of manufacturing and energy-intensive production in expanding economies such as China, India, and Brazil, there is an opportunity for new facilities to deploy the latest energy-saving and carbon-reducing technologies and practices. In the U.S. and many other industrialized economies, there is a substantial existing infrastructure of older, inefficient manufacturing facilities that need to be upgraded. The variable energy intensity of manufacturing processes across countries reflects these differences and suggests the potential for further improvement (IEA, 2009).

This chapter describes the progress made to date and the magnitude of the remaining opportunities, stemming both from broader use of current best practices and from a range of possible advances enabled by emerging technologies and innovations. It begins by focusing on the potential for improving energy efficiency in several major energy-consuming industries. After describing the principal barriers to deployment of energy-efficient technologies particularly in the U.S., it explores policy innovations that have successfully transformed industrial practices in five countries: the Netherlands, Denmark, India, Japan, and China. The goal is to identify lessons that can shift industry toward greater efficiency across the globe, thereby becoming part of the climate solution.

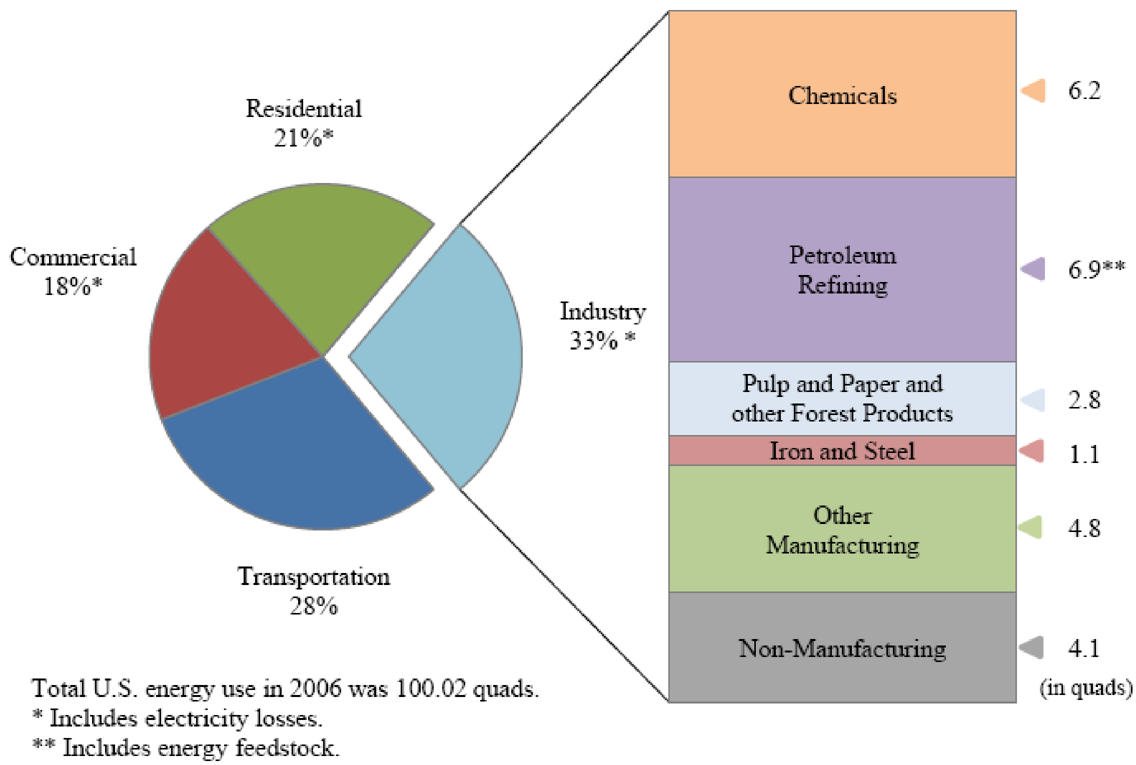
Recent Trends in Energy Productivity

Industry is the largest energy-consuming sector in most countries of the world, accounting for 37% of primary energy use worldwide (IPCC, 2007, p. 453). Large enterprises dominate most energy-intensive industries across the globe, especially in industrialized countries. In contrast, small- and medium-sized enterprises (SMEs) play greater roles in emerging economies. In India, for example, SMEs have significant shares in the metals, chemicals, food and pulp and paper industries, and they account for 50% of China's asset value and 75%

of its exports. These SMEs face special challenges when attempting to upgrade their energy efficiency due to limited technical and financial resources.

U.S. industrial energy use represents approximately one third of total U.S. energy consumption and about 8 percent of global energy use. A majority of this is consumed by five energy-intensive industries: chemicals, oil refining, iron and steel, pulp and paper, and cement (Figure 1). Less energy-intensive industries include the manufacture and assembly of automobiles, appliances, electronics, textiles, food, beverages, and other products. Since energy is a smaller portion of their overall costs, historically these industries tend to pay less attention to finding ways to cut energy use. However, current evidence shows this may be changing with an increased focus on reducing carbon footprints.

Figure 1. Energy Use in the US Industrial Sector in 2006 (Quadrillion Btu)



Source: EIA's Manufacturing Energy Consumption Survey (MECS, 2006)

The production of energy-intensive goods is likely to continue to increase worldwide, as populations and standards of living grow. However, an expanding proportion of this production is likely to be located in developing countries. For example, while the U.S. remains the world's largest producer of bulk chemicals and refined petroleum products, China has become the world's largest producer of steel, aluminum, and cement (IPCC, 2007, p. 451). Global competition for export markets, foreign investments, and raw materials is intensifying. The International Energy Agency (IEA) projects global industrial energy demand to more than double by 2030 (World Energy Outlook, 2009). Moreover, the IEA projects a convergence between developed and developing countries in terms of energy intensity by 2050 (IEA, 2003).

The significant shift to off-shore manufacturing to meet the demands of U.S. markets means that the U.S. is actually responsible for approximately 5 quads of additional industrial energy use: products imported into the United States in 2002 had an embodied energy content of about 14 quads, far surpassing the 9 quads of embodied energy of U.S. exports (National Academies, 2009). Similar trends are occurring in Europe and Japan. The energy embodied in international supply chains is a contentious issue in discussions about carbon footprint metrics and responsibilities for addressing climate change.

U.S. manufacturing has undergone significant change in production and value added over the last several decades, modifying their strategies to improve market competitiveness and increase profit. On the one hand, the forest products industries have enlarged their production of pulp and paper by 38% and 66%, respectively, since 1985. This industry shows a clear strategy of specialization in industrial production with an orientation toward high value-added products, reducing the production of commodities with lower market profit. On the other hand, the iron and steel industries have shrunk their production by 35% and 33%, respectively. In spite of these swings in production, in general the manufacturing industry has sustained a similar overall level of energy consumption with only a slight reduction of 420 Trillion Btu (or 1.9%) since 1978

(Table 1). The variation in trends across industries reflects shifts in composition in the economy, offshore movement of manufacturing, and advances in energy efficiency.

Table 1 Total US Industrial Energy Use: 1978-2006

(Excluding Non-fuel Uses of Coal, Oil, and Natural Gas, in Trillion Btus)

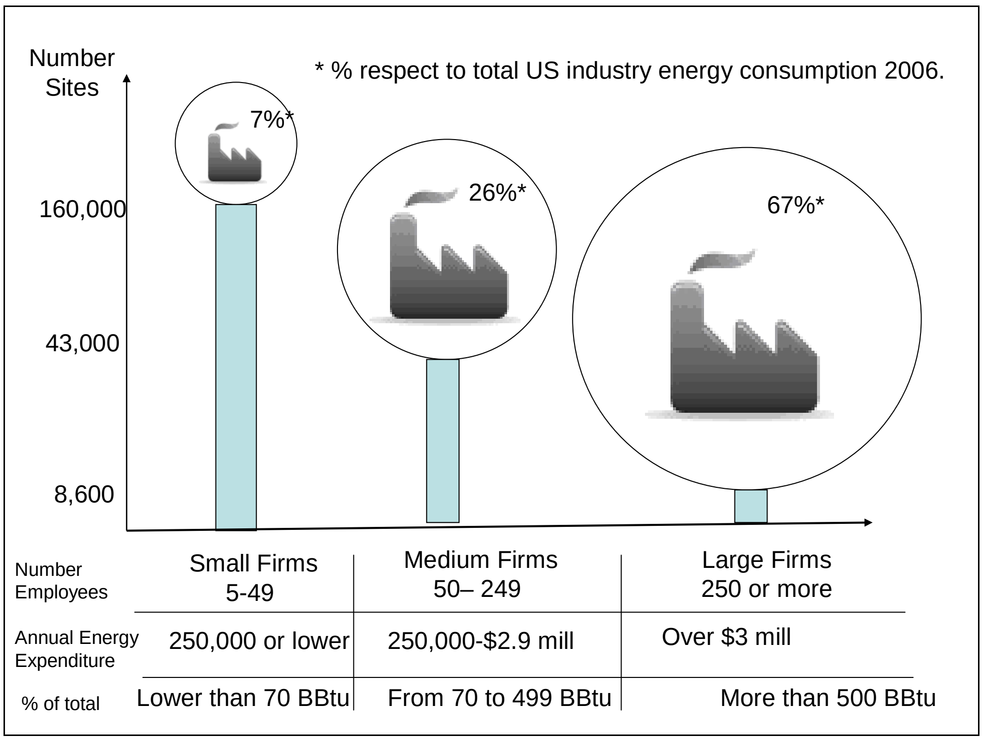
Industry	1978	1985	1990	1995	2004	2006	Change 1978/2006
Wood Product Mfg. (321)	637.6	523.1	592.1	674.5	695.7	642.9	0.80%
Paper Mfg.(322)	2,384	2,662	3,161	3,168	3,141	2,902	22%
Printing and Related Support Activities (323)	161	147	195	219	233	183	13%
Petroleum and Coal Products Mfg. (324)	3,091	2,006	3,365	3,373	3,916	3,743	21%
Chemical Mfg. (325)	4,204	3,047	4,218	4,216	4,063	4,284	1.90%
Nonmetallic Mineral Product Mfg. (327)	1,617	1,165	1,289	1,235	1,322	1,466	-10%
Primary Metal Mfg. (331)	5,005	2,427	2,730	2,737	2,702	2,716	-46%
Fabricated Metal Product Mfg. (332)	664	576	645	747	718	708	6.60%
Other Manufacturing (339)	4,549	4,220	4,584	5,345	5,301	5,252	0%
Total (Manufacturing)	22,313	16,773	20,781	21,713	22,092	21,893	-1.90%

NOTE: NAICS codes are presented in parenthesis.

SOURCE: U.S. Department of Energy, U.S. Energy Intensity Indicators, Trend Data, Industrial Sector, available at: http://intensityindicators.pnl.gov/trend_data.stm.

The U.S. manufacturing industry has more than 211,000 plants of which 76% are small firms (with 5 to 49 employees), 20% are medium size firms (50 to 249 employees), and only 4% correspond to large firms (more than 250 employees). With respect to energy consumption the distribution has an inverse relationship, with large firms consuming 67% of the total industrial energy consumption, followed by medium firms with 26%, and small firms with only 7% of the total industrial energy consumption (see Figure 2.)

Figure 2. U.S. Industrial Classification respect to energy consumption

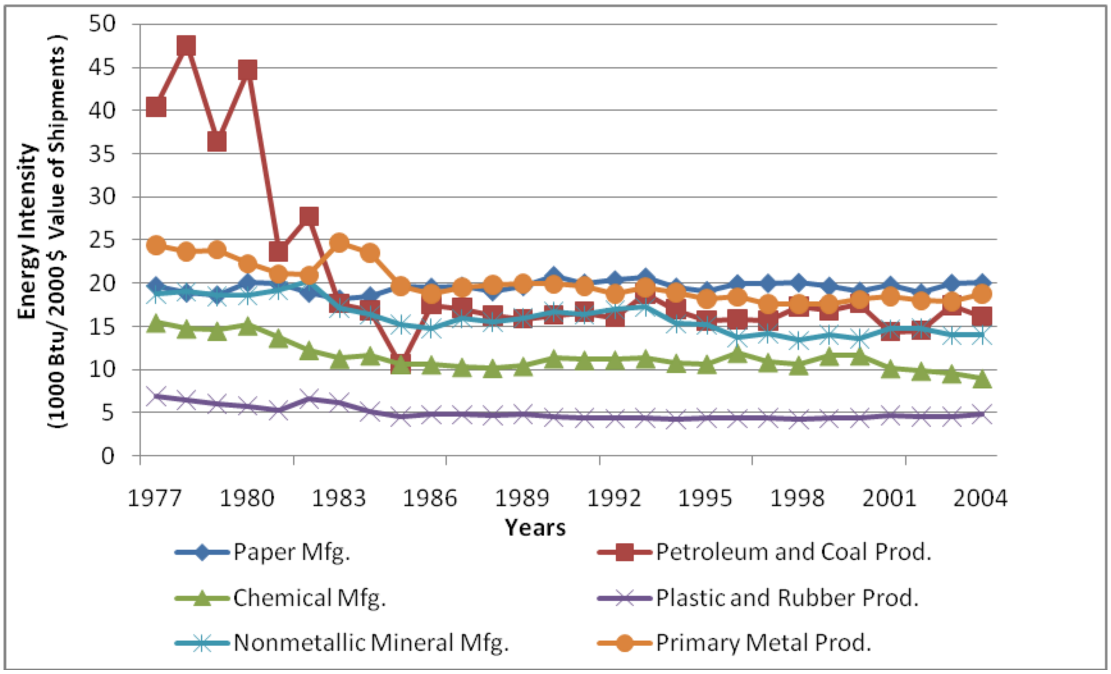


Source: MECS 2006 and U.S. CENSUS Bureau office 2007

The increase in production of some manufacturing industries, such as pulp and paper, chemicals, and cement has not been accompanied by a proportionate increase in energy consumption. Many of these expanding industries have reduced their energy intensity (measured as total energy use per value of shipment). This improvement in energy productivity is explained by advances in production technologies and better operational practices, which were particularly important following the oil crises in the 1970s.

The petroleum and coal products manufacturing industry experienced a particularly significant improvement in energy intensity with a reduction of 60% in 2004 relative to 1977, followed by chemical manufacturing with a 42% reduction, plastic and rubber with 31%, nonmetallic minerals with 25% and primary metals with 23%. Pulp and paper was the only industry of this group that did not decrease in energy intensity (Figure 3).

Figure 3. Changes in Energy Intensity in Six Key US industries (1977-2004)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

Advances in engineering, materials, thermodynamics, sensors and controls, and information technologies, among others, offer the potential to transform industrial processes in response to emerging climate change policies. As the era of cheap energy comes to an end, successful manufacturers will increasingly focus on technological innovations that allow for order-of-magnitude reductions in energy consumption and the substitution of fossil fuels for renewable and other low-carbon energy resources.

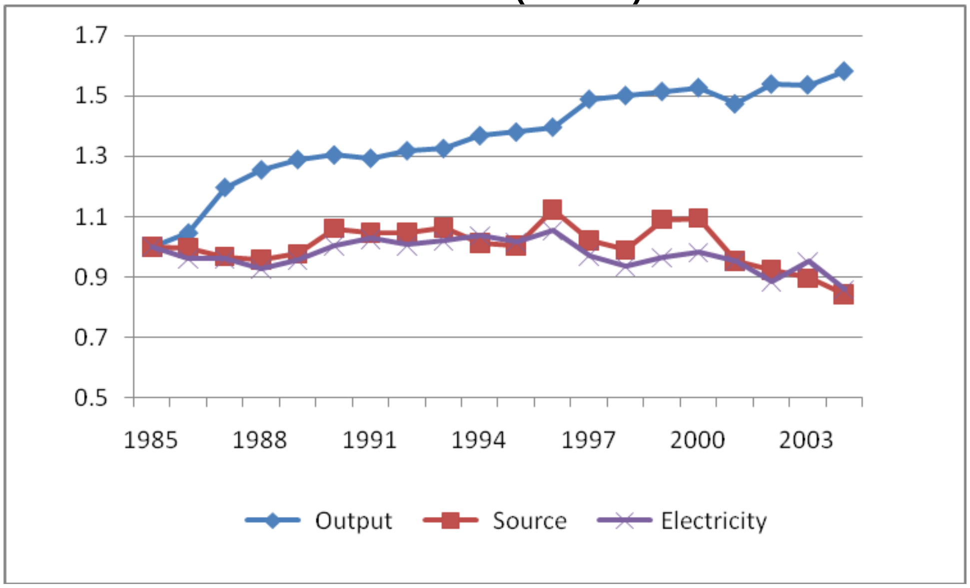
In today’s power generation and utilization infrastructure, with large-scale centralized power plants and dispersed end-use locations, mismatches between thermal needs and waste heat streams occur. If systems were optimized so that wasted energy was recycled into productive uses, tremendous overall energy savings could be achieved. This can be done by cascading and recycling the energy embodied in hot exhaust gases, low-grade fuels that are typically flared, and high-pressure steam and gas (Casten and Ayres, 2007). Combined heat and power is a key efficiency technology in this area.

To illustrate some of the technological opportunities that may transform industrial complexes, consider technological drivers of change in five of the nation’s most energy-intensive industries.

Chemical and Petroleum Refining

Chemicals and petroleum are among the most important industries in the U.S. The U.S. chemical industry is the world's largest producer with 170 companies and more than 2,800 facilities abroad and 1,700 foreign subsidiaries or affiliates operating in the United States. (EIA 2001). This industry increased its gross output by 58% between 1985 and 2004 (based on $ 2000), an increase that occurred in conjunction with a 15% reduction in electricity consumption and a 14% drop in energy intensity (Figure 4). Thus, its drop in energy intensity following the Arab oil embargo of 1973-74 has been overtaken by declining energy intensity in more recent years.

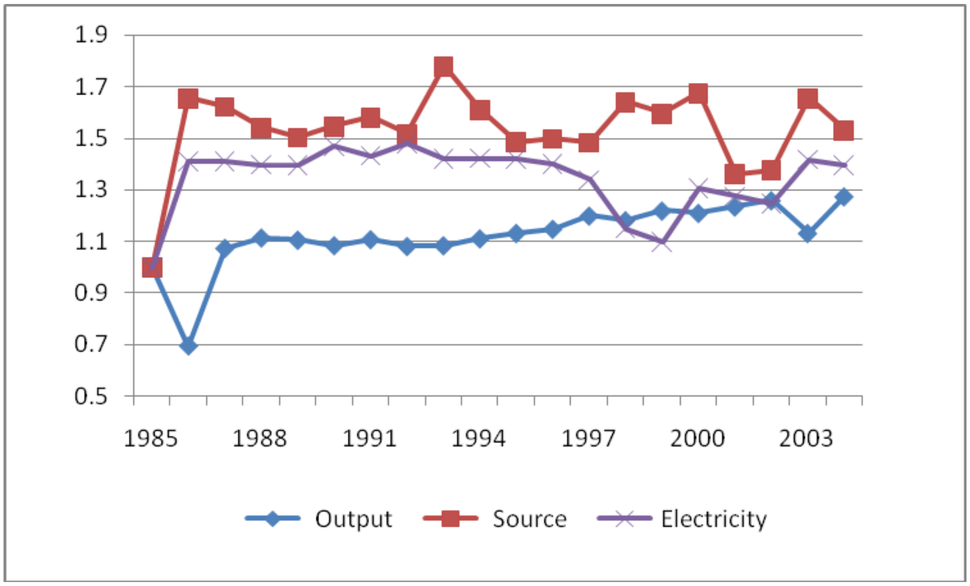
Figure 4. Chemical Products Energy Consumption and Intensity Indexes (1985=1)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

The United States is also the largest producer of refined petroleum products in the world, with 25 percent of global production and 163 operating refineries. This industry's gross output increased by 27% between the years 1985 and 2004; at the same time it increased its electricity consumption by 40% and its energy intensity by 53% (Figure 5).

Figure 5. Petroleum and Coal Products Energy Consumption and Intensity Indexes (1985=1)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

Benchmarking data indicate that most U.S. petroleum refineries can economically improve energy efficiency by 10-20 percent (LBNL, 2005), and analysis of individual refining processes indicate even larger energy savings possibilities (DOE, 2006c). Common technologies include high-temperature reactors, distillation columns for liquid mixture separation, gas separation technologies, corrosion-resistant metal- and ceramic-lined reactors, sophisticated process control hardware and software, pumps of all types and sizes, and more efficient steam generation (DOE, 2006c).

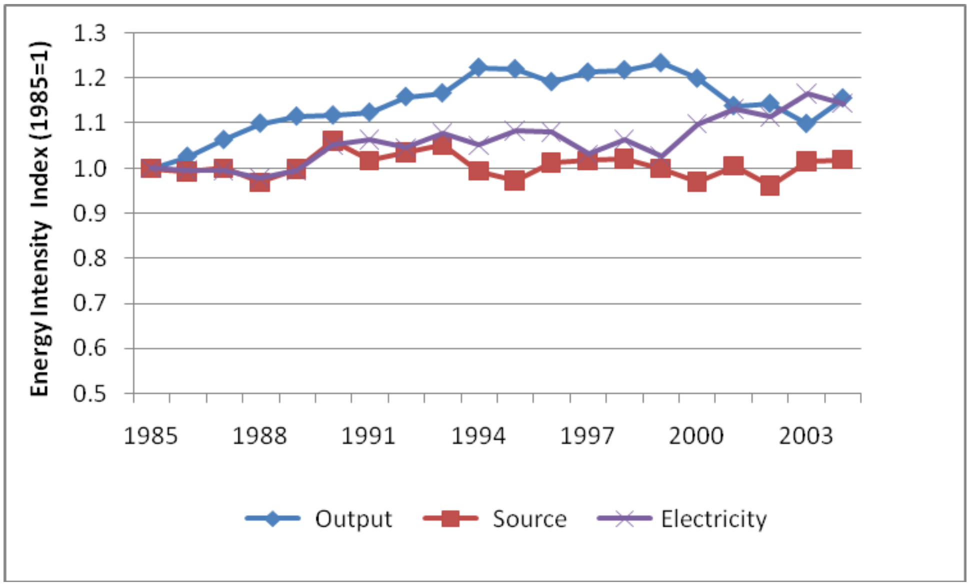
Distillation is the largest energy-consuming process in industry. In the chemicals and petroleum industries, it uses about 53 percent of the total energy required for industrial separations. Potential technological improvements to distillation processes include technologies such as latent heat integration, multiple-effect distillation, and solution-thermodynamics-altering azeotropic or extractive distillation. Material methods, notably membrane and micro- and nano-particle separation methods, offer tantalizing possibilities. The challenges are in developing materials and methods with high throughput, high selectivity, low energy requirements, resistance to fouling, durability and affordable costs (National Academies, 2009).

Membrane separation is the most widely applicable of all technologies for reducing energy of separation processes in the petroleum, chemical and forest products industries (Nenoff et al., 2006; Banerjee et al., 2008). Zeolites are one of the kinds of materials to achieve separations that would not require direct heat. However the zeolite approach leaves the capturing material with the target material attached, so some removal process is required. Membranes may be made of organic materials for relatively low-temperature processes, inorganic materials such as ceramics for high temperature use, or a combination of the two. Membranes are currently used successfully to separate light hydrocarbons as well as hydrogen from gas streams, the separated light hydrocarbons have uses with values considerably higher than that of fuel.

Pulp and Paper Industry

The U.S. pulp and paper industry is a global leader with 34% of the world's pulp production and 29% of the world's paper and paperboard production (Freeman 1998). The industry increased gross output between the years 1985-2004 by 15.6% with an increase in electricity consumption of 14.6% compared to 1985 with little changer in energy intensity (Figure 6). Nevertheless, a much lower energy intensity results when the value of shipments is replaced by the total tonnage of production. Measured in this way, the energy intensity for pulp and paper decreases by 15%.

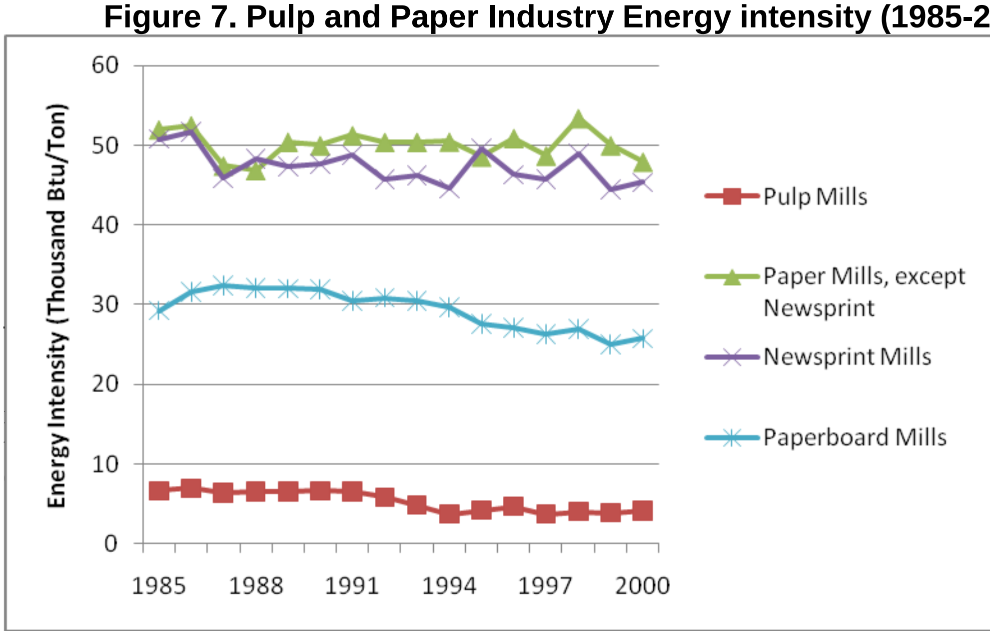
Figure 6. Pulp and Paper industry Energy Consumption and Intensity Indexes (1985=1)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

The principal products of this industry are pulp, paper, newsprint and paperboard. Mills for each of these products have shown important improvements in energy use, especially the pulp mills decrease of 39% in energy intensity in the period 1985-2000, followed by paperboard mills with 23%, and paper mills and newsprint with 9% and 11%, respectively (Figure 7). Recycling also conserves a great deal of energy and represented roughly 40% of total paper production in the U.S. in 2005 (Houser et al, 2008). This percentage of recycling is lower than the 69% waste paper pulp in UK (Confederation of Paper Industry 2009). US paper recycling has enough capacity to double of its current levels.[1]

Figure 7. Pulp and Paper Industry Energy intensity (1985-2000)



or permanent
replace those
sidered as the

Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

Several energy-efficient methods of drying have been developed, many of which are cost-effective today. One of these, a systems approach, involves using waste heat from heat-generating processes including from power generation and ethanol production, as the energy source for evaporation (Thorp et al., 2007). These opportunities to recycle waste heat are only practical if the power production does not use condensing turbines – that is, if it is relatively inefficient – or if the ethanol distillation is conducted at relatively high temperature and pressures. Advanced water removal technologies can also reduce energy use in drying and concentration processes substantially (DOE, 2005a). ORNL and BCA, Inc. (2005) estimate that membrane and advanced filtration methods could significantly reduce the total energy consumption of the pulp and paper industry. High-efficiency pulping technology that redirects green liquor to pre-treat pulp and reduce lime kiln load and digester energy intensity is another energy-saving method for this industry (DOE, 2005a). Modern lime kilns are available with external dryer systems and modern internals, product coolers and electrostatic precipitators (DOE, 2006c).

Kraft processing is a prominent way to produce wood pulp. In most Kraft mills today, the black liquor produced from de-lignifying wood chips is burned in a large recovery boiler. Because of its high water content, the combustion of black liquor is inefficient, and the possibility of electricity production from secondary steam production is limited by the steam's low pressures. Gasification of black liquor not only allows efficient combustion, but also enables the use of a gas turbine or combined cycle process with a high electrical efficiency, thereby offering the potential for increasing the production of electricity within pulp mills. The surplus of energy from the pulp process also allows for the possible production of useful heat, fuels, and chemicals – that is, the operation of "bio-refineries" (Worrell et al., 2004, pp. 22-23).

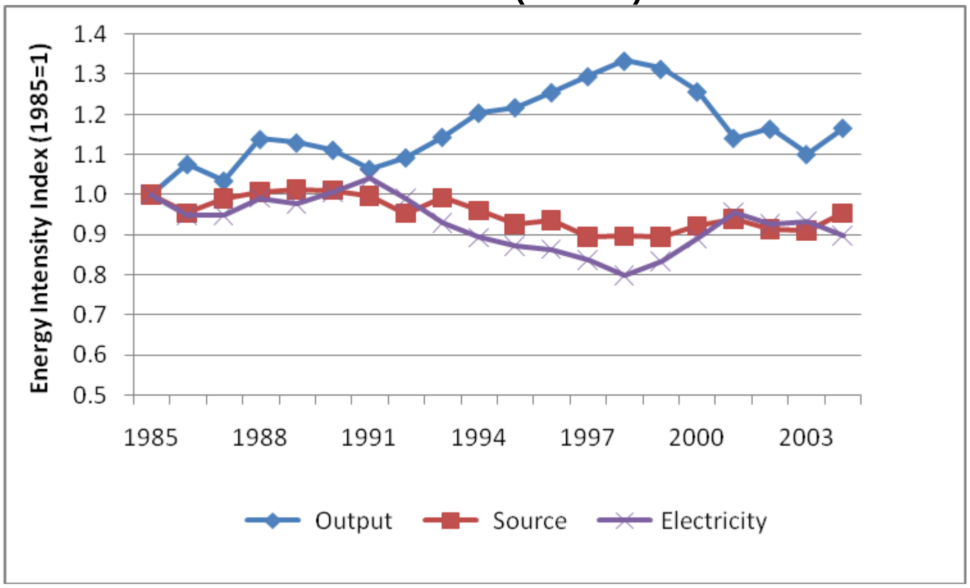
There are many novel sensors for a wide range of applications. In the papermaking industry, for example a fiber optic sensor measures paper basis weight to improve wet-end control in papermaking and make paper of a uniform basis weight and higher quality. It minimizes energy requirements. Another non-contacting laser sensor measures shear strength and bending stiffness. By measuring the rate of propagation of ultrasonic shock waves in the paper, this device could save the U.S. paper industry approximately $200 million annually in energy costs.[2]

Iron and Steel

The primary metal industry is composed principally of iron and steel and aluminium production. This industry has shown an impressive reduction of 46% in energy consumption during the last 30 years. This reduction has been a result of a 17% reduction in energy intensity – measured in terms of energy used per value of shipment – between 1985 and 2004, with a 11% reduction in electricity consumption (Figure 8). Recycling is widely utilized in this sector, with steel reaching rates of 83% in 2008. This contributes to declines in energy use in the sector (Steel Recycling Institute, 2009).

[2] See http://www.physorg.com/news4221.html.

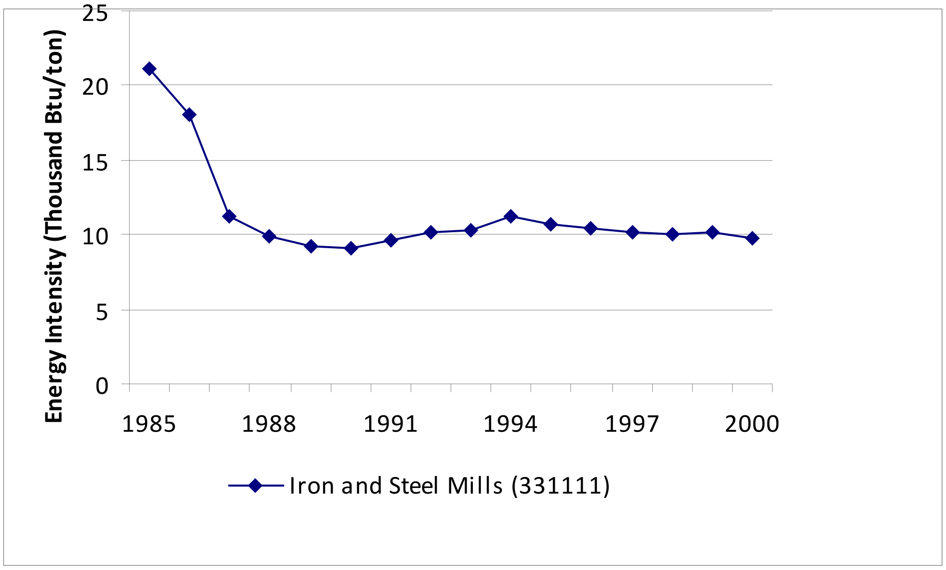
Figure 8. Primary Metal Energy Consumption and Intensity Indexes (1985=1)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

Figure 9 shows the 54% reduction in energy intensity in terms of the energy consumed per ton of iron and steel produced. Given the nearly complete penetration of recycled resources, other advances will be needed to enable improvements of a similar magnitude in the future.

Figure 9. Iron and Steel Mills Energy Intensity (1985-2000)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

There are two basic methods for producing crude steel: the blast furnace and basic oxygen furnace (BOF), which mainly use iron ore, and the electric arc furnace (EAF), which mainly uses reduced iron and pig iron. In 2006, integrated steelmakers produced roughly 43 percent of raw steel while EAF operations produced the remaining 57 percent (IEA, 2007 and Worrell and Neelis, 2006).

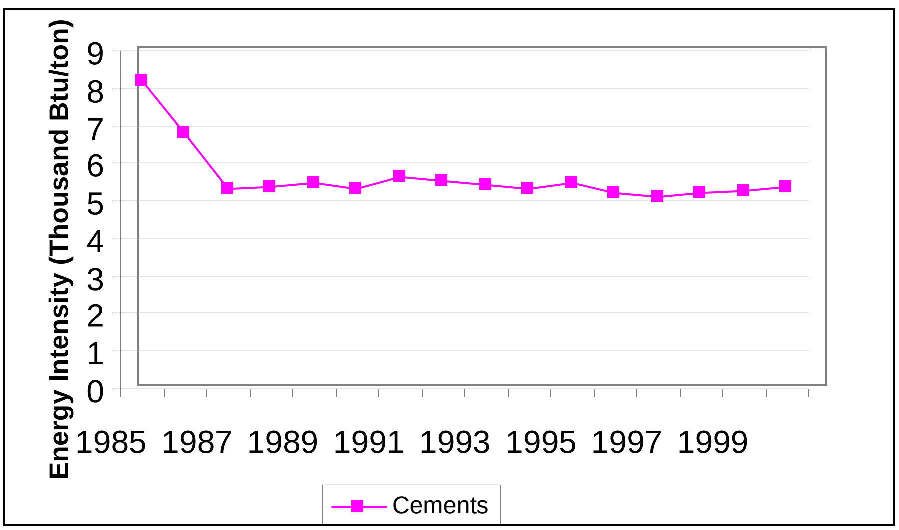
One must use caution in comparing countries as differences can be caused by the actual efficiency of production, the amount of recycled material, the process (BOF versus EAF), and the type of final product (Schipper, 2004). Energy efficiency depends on the size and age of the plant with larger and newer facilities often more energy efficient than smaller and older ones. Changes over time occur as a result of savings within plants or processes and shifts to plants and processes that are more energy efficient.

Technologies can be combined in various configurations in steel production, including the rotary hearth furnace (RHF), the Circofer process in which coal is charred and ore is partly metallized in a single first step and then completed in a bubbling second step, and the RHF with a submerged arc furnace; the energy consequences of these alternatives are unclear (Fruehan, 2008). Several revolutionary new steelmaking technologies are also under development, such as the use of hydrogen as an iron ore reductant or furnace fuel, and electrolytic or biometallurgical-based iron and steel production. Success with these could significantly reduce the carbon footprint of these industries.

Cement Industry

The U.S. cement industry consists of 39 companies that operate 118 cement plants in 38 states. While its production levels have grown since 1985, the industry's energy intensity declined by 35% between 1985 and 2000 (Figure 10).

Figure 10. Cement Energy Intensity (1985-2000)



Source: DOE 2010, U.S. Energy Intensity Indicators. Trend data

The cement manufacturing process involves three components: the mining and preparation of inputs; the chemical reactions that produce clinker; and the grinding of clinker with other additives to produce cement. The feed for older kilns is a slurry of inputs, the wet kiln process, while large new plants mix dry materials for introduction to the kiln. Energy use varies with the process and characteristics of the plant, but in general about 90 percent of the energy use, and all of the fuel use, occurs in the manufacture of clinker in the kiln. The chemical process that converts limestone to lime, produces roughly the same amount of carbon dioxide gas as that generated by the energy used in its production for coal-fired kilns. Technologies that allow production of cement with a lower per-ton share of clinker thus yield multiple benefits.

Upgrading a kiln from wet to dry, and from a long dry kiln to a pre-heater, pre-calciner kiln results in major energy efficiency gains but for a price that requires a payback period of at least ten years. Worrell et al. (2004) conclude that these upgrades are attractive only when an old kiln needs to be replaced. More incremental upgrades could yield commercially attractive benefits including advanced control systems, combustion improvements, indirect firing, and optimization of components such as the heat shell. While opportunities vary with specific plants, the combination of these activities appears to yield an improvement in energy use on the order of 10 percent. Recovering heat from the cooling stage also yields substantial savings. If the heat is used for power generation, it can save up to half of the electricity used in the clinker process. However, taking full advantage of the heat recovery savings may require other major upgrades (National Academies, 2009).

Changing the chemistry of cement to reduce the need for calcination can decrease the high share of clinker that characterizes U.S. production. Options for blended cements include fly ash and steel slag. Fly ash may be particularly promising as it is a coal combustion byproduct that can be reused in many different contexts, such as construction and pavement. Worrell et al. (2004) identify potential energy savings of up to 20 percent from deployment of blended cement technologies, and larger carbon dioxide emission reductions. Advanced technologies with potential to further improve energy efficiency and emissions include carbon capture and storage technology, fluidized bed kilns, advanced comminution technologies, and the substitution of mineral polymers for clinker (Worrell et al, 2004; Battelle, 2002).

Potential Energy Savings in Energy-intensive Industries

Numerous studies have shown high energy-savings potential in energy-intensive U.S. industries. A recent study of the National Academies (2009) compiled these studies for five industries for 2020. The results are summarized in Figure 11.

The chemical manufacturing industry was analyzed by three studies. The estimates of energy savings in 2020 in the US chemical industry are wide ranging from 3.1% savings estimated by NREL (2002), 5% of savings presented by McKinsey, and more than 18% of saving estimated by Energetics Inc. (2007).

The petroleum refining industry's energy savings in 2020 are presented in three recent studies. The lowest estimate of 5% of energy savings is provided by McKinsey and Company (2008). The intermediate range of savings, between 12 to 24%, was published in a study of LBNL (2005). The highest estimate is a range of 28-65% of savings published in a DOE (2006c) report.

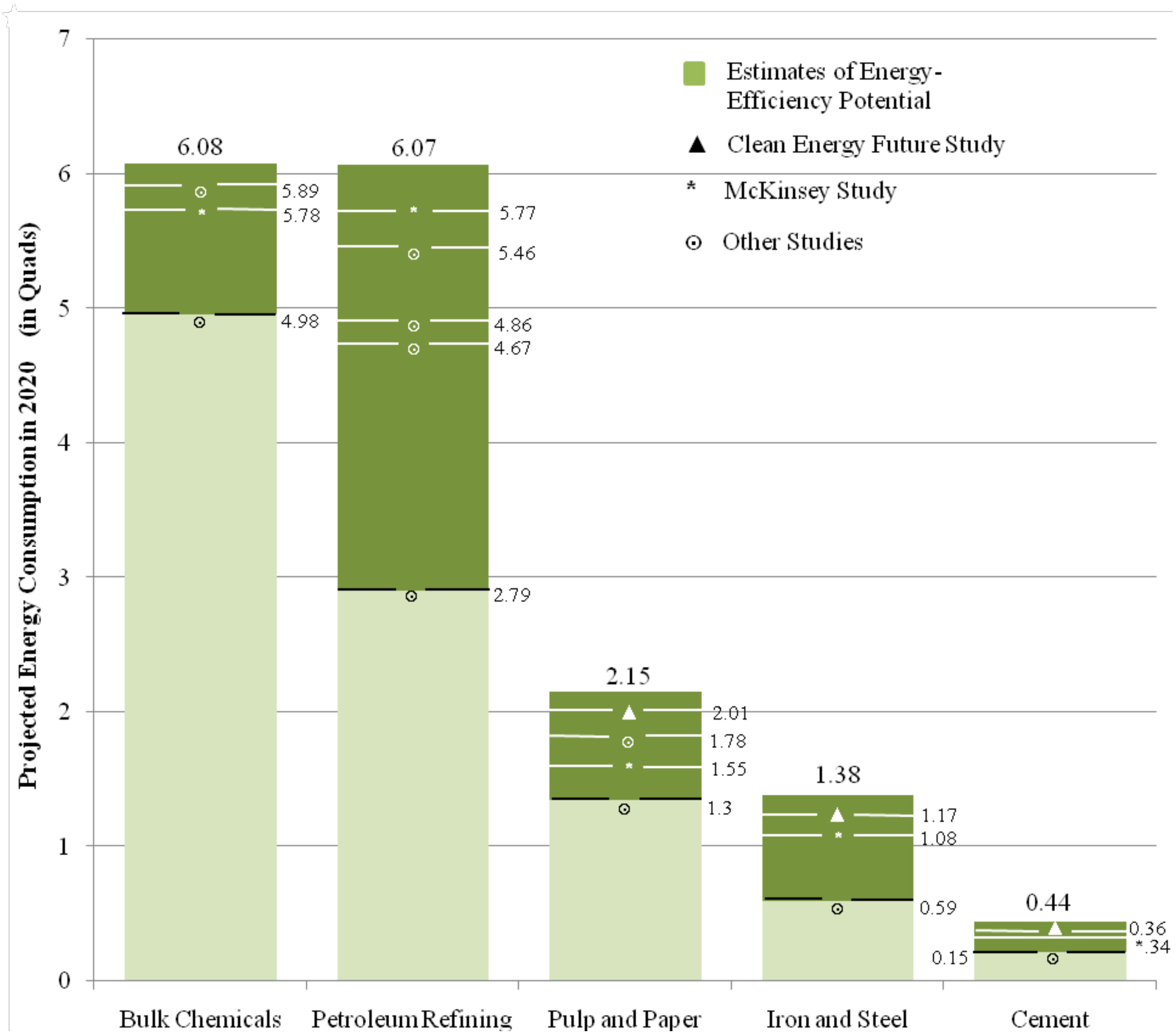
The pulp and paper industry also represents a significant potential for energy savings through its process improvement. Estimates of achievable energy savings range from 6.1% in the CEF study to 37% of energy savings estimated by the study by Jacobs and IPST (2006).

The iron and steel industries also offer an important opportunity for energy savings. McKinsey and company (2008) estimated 22% of energy savings potential in 2020. The AISI study (2005) provided a significantly higher level of energy savings potential of 58% of current energy use.

Finally, three studies analyzed energy savings potential in the cement industry. The lower estimation of energy savings potential is presented by the CEF Study (Brown and Levine, 2000) with 19% of saving in 2020, followed by McKinsey and Company with 23% savings. The highest potential of savings is presented in the study of Worrell (2004), with 67% of energy saving in 2020.

By applying these percentage savings potentials to the AEO Business-as-Usual forecast of future industrial energy consumption in the U.S., it is possible to compare and contrast the studies in a common framework (Figure 11).

Figure 11. Potential for Improving Energy Efficiency in 5 Key Industries in 2020



Source: Authors, based on National Academies (2009)

If similar efforts were implemented worldwide, particularly in the rapidly expanding economies of Brazil, Russia, India, and China – the BRIC countries –

these energy savings could be multiplied several times. Of course, greenfield industrial complexes start with the advantage of more advanced equipment such as dry kilns, electric arc furnaces, and lime kilns with external dryer systems.

Barriers to Technological Innovation in Industry

Energy efficiency tends to thrive in a culture of innovation, where companies are committed to progressive thinking (McKinsey, 2008, p. 8). The broader application of high-efficiency industrial technologies, on the other hand, is impeded by a range of technical, corporate, regulatory, and workforce barriers. These include:

- Technical risks
- Lack of specialized knowledge
- High transaction costs for obtaining reliable information
- Relatively high initial costs
- Lack of access to capital
- Unfavorable fiscal policies
- Unfavorable regulations
- External benefits and costs

Companies must consider the *technical risks* of adopting a new industrial technology. When energy costs are low, industry has little incentive to make investments in efficiency measures, particularly if there are uncertainties about the benefits and impacts of novel approaches can be significant. Small technology changes, particularly in large integrated process plants, can lead to major changes in process and product performance. In today's manufacturing environment with 24/7 operations, reliability and operational risks represent major concerns for industry. The need to keep a process running in a predictable fashion, for example, often overrides the inclination to replace equipment with a more efficient model. An historic example is provided by the American steel industry, where companies continued to build open hearth furnaces after World War II, despite the demonstration of superior basic oxygen furnaces. The old technology was familiar and the new technology was considered to be a risk (National Academies, 2009). A more modern and streamlined version of the vetting process is used by the Dow Corporation, which has a group established to present energy-efficiency upgrades for a plant. These “Tech Centers” work with efficiency experts on staff to assess the quality and reliability of proposed plant upgrades. They then work with production managers and jointly make an implementation decision about proposed upgrades as described in Prindle (2010).

Lack of specialized knowledge of energy engineering and energy management is another impediment to adoption. Industrial managers can be overwhelmed by the numerous products and programs that tout energy efficiency, and without in-house energy experts, may find it risky to rely on third party-information to guide investments. For example, plant managers at the United Corporation Technologies (UTC) find it difficult to rely solely on facility experts and has created a special energy-focused team to work directly with their 300 facilities to identify savings opportunities (Prindle, 2010). To make optimal energy-efficiency decisions, plant managers must have working knowledge of a massive number of technologies (McKinsey, 2008). External expertise is available, but manufacturers generally do not support third-party installers or consultants such as energy services companies (ESCOs) and utilities (CCTP, 2010; Prindle, 2010). Energy consulting firms often lack the industry-specific knowledge to provide accurate energy and operational cost assessments, and many industrial operations don’t have in-house engineering resources to sort through or analyze the information.

This barrier is exacerbated by *high transaction costs for obtaining reliable information* (Worrell and Biermans, 2005). Researching new technologies and collecting other relevant information consumes time and resources, especially for small firms, and many industries prefer to expend human and financial capital on other investment priorities. Overall, corporate decision-makers are predisposed towards investments which result in more output. Although the reduction of costs through investments in efficiency may have the same impact as increases in productivity on overall profit, there is a tendency for investments to be focused on increasing revenue as opposed to decreasing costs. In some cases, industrial managers and decision-makers are simply not aware of energy efficiency opportunities and low-cost ways to implement them. In others, they don't believe they have enough time or money to research new technologies. In more progressive companies, divisions are established to root out these savings (Prindle, 2010).

Relatively high initial costs for industrial energy-efficiency improvements can be an impediment to investments. New energy-efficient technologies often have longer payback periods than traditional equipment and represent a greater financial risk since there is significant uncertainty about future energy prices. Senior managers also often postpone capital investment and refurbishment because they are uncertain about the longevity of their companies (McKinsey, 2008, p. 9). The global economic downturn beginning in 2008 has exacerbated concerns about enduring profitability.

The *lack of access to capital* is one of the most significant barriers to energy efficiency improvements in industry. Projects to improve energy efficiency have to compete for financial and technical resources against projects that achieve other company goals and against more familiar technologies. A large share of capital goes toward meeting government standards for health, safety, security, and emissions; the remaining discretionary capital is then allocated to other goals such as product improvement, production expansion, and (finally) cost savings such as energy efficiency. Although, in theory, firms might be expected to borrow capital any time a profitable investment opportunity presents itself, in practice firms often ration capital – that is, they impose internal limits on capital investment (Canepa and Stoneman, 2004). As a result, companies impose high ROI requirements on efficiency investments (CCCSTI, 2009). In addition, if the technology involved is new to the market in question, even if it is well-demonstrated elsewhere, the problem of raising capital may be further complicated.

In the United States, existing *fiscal policies are often unfavorable to investments in end-use efficiency*. The current federal tax code discourages capital investments in general, as opposed to direct expensing of energy costs. More specifically, tax credits designed to encourage technology adoption are limited by alternative minimum tax rules, tax credit ceilings, and limited tax credit carryover to following years; these limitations prevent the credits from being used to their full potential by qualified companies. Furthermore, outdated tax depreciation rules require firms to depreciate energy efficiency investments over a longer period of time than many other investments (Brown and Chandler, 2008). Significant utility company interconnection fees, overly layered permitting processes, and lack of net-metering policies provide disincentives for manufacturing plants to capture waste energy for the generation of electricity in combined heat and power systems (CCCSTI, 2009). However, in response to increasing peak demand and growing strain on existing capacity, utilities are pursuing demand response and energy efficiency strategies with industry.

Existing *regulations can also be unfavorable* to industrial energy efficiency. EPA's New Source Review (NSR) Program can also hinder energy efficiency improvements at industrial facilities. As part of the 1977 Clean Air Act Amendments,[3] Congress established the NSR program and modified it in the 1990 Amendments, but exempted old coal plants and industrial facilities from the New Source Performance Standards (NSPS) to be set. NSPS standards are intended to promote use of the best air pollution control technologies, taking into account the cost of such technology and any other non-air quality, health, and environmental impact and energy requirements. However, investment in an upgrade could trigger an NSR, and the threat of such a review has prevented many upgrades from occurring. NSR thus imposes pollution controls where they

[3] P.L. 95-95; 91 Stat. 685.

are least needed and artificially inflates the value of the dirtiest plants. Altogether, these effects have led some critics to question whether the NSR program and the NSPS have resulted in higher levels of pollution than would have occurred in the absence of regulation (Brown and Chandler, 2008; List, 2004).

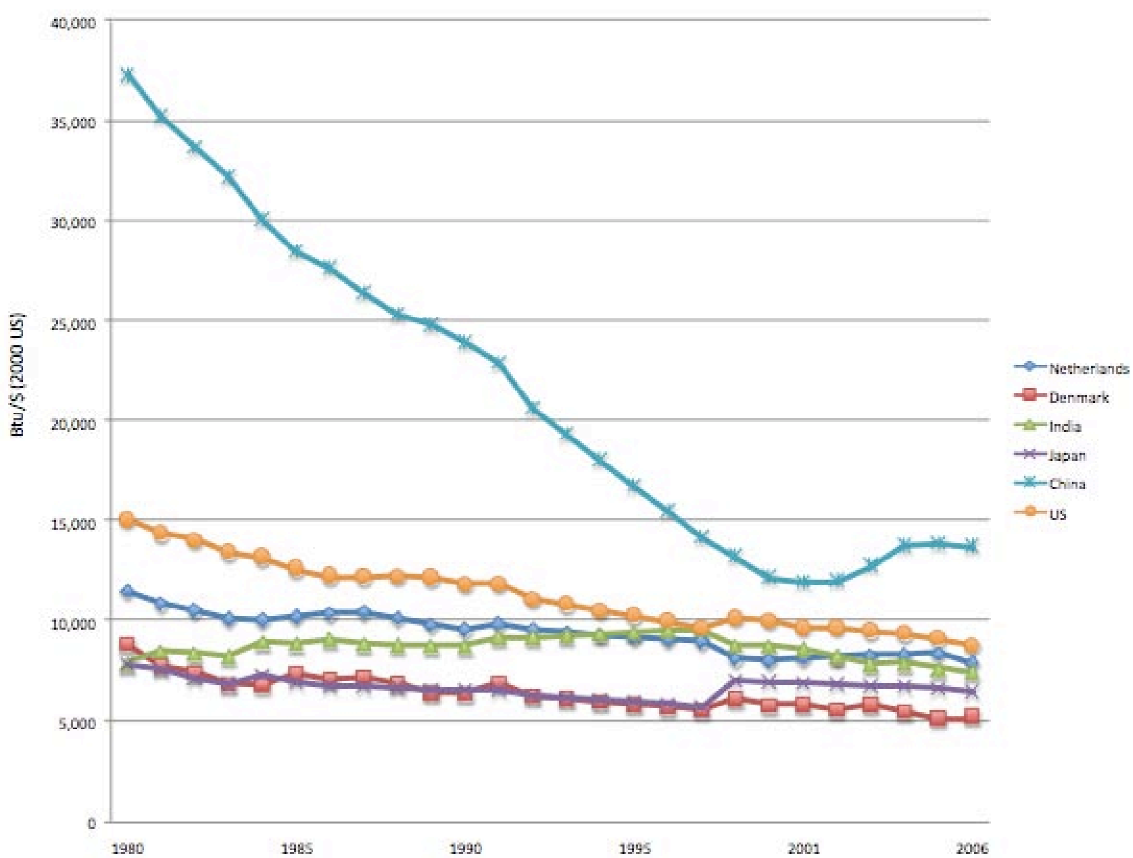
External benefits and costs are difficult to value and inhibit reduction of greenhouse gas (GHG) emissions by industrial plant managers. In general, companies invest in emissions reduction or other environmental improvements only when the investments are offset by lower energy or raw material costs or other cost benefits. Suppliers, who typically introduce innovations to the industrial sector, are often reluctant to expend resources in developing GHG emissions-reducing technologies without an assured market. Policy uncertainty and the absence of an international climate agreement is also leading to competitiveness concerns and reduced cooperation across firms.

Given all of these inhibitors to reinventing industrial energy use, can energy and/or tax policies influence future course of innovation? Would restrictions on greenhouse gas emissions become a driver for change? Evidence from other countries is encouraging, as is the experience of some U.S. federal programs and individual State initiatives.

Policy Drivers of Change

A variety of approaches have been utilized globally to promote industrial energy efficiency. This section describes some of the lessons learned by the Netherlands, Denmark, India, Japan, and China, and concludes with a summary of the policies utilized in the United States. While many of these nations have similar policies in place, their differences and points of success and policy innovation are highlighted here. The trajectory of these countries' energy intensity from 1980 through 2005 suggests an improvement in energy efficiency overall for each country, punctuated by periodic slippages (Figure 12). Between 1980 and 2005, China underwent a marked increase in energy efficiency. Still, even with this massive improvement, China today is only slightly more efficient than the United States was in 1980, and has recently undergone an increase in energy intensity The graph suggests a more gradual improvement across the other five countries.

Figure 12. Energy Intensity Trends in Selected Countries: 1980-2006



Source: Energy Information Administration, International Energy Annual

The Netherlands has taken a proactive stance on industrial energy efficiency, beginning with their Long Term Agreements on Energy Efficiency with industry beginning in 1992. These agreements were established through an understanding by industry that the government is closely observing energy consumption and will not initiate strong regulations so long as industry meets the targets (Nuijen and Booij, 2002). This program had a goal of increasing energy efficiency by 20% over a 1989 baseline by 2000. The results were better than anticipated, achieving a 22% savings in affected industries, which represent 90% of industrial energy consumption in the Netherlands. The country experienced annual net savings of roughly €700 million annually, increasing the competitiveness of Dutch-produced goods in the global market. These agreements were established through an understanding by industry that the government is closely observing energy consumption and will not initiate strong regulations so long as industry meets the targets (Nuijen and Booij, 2002). Should be moved up front and better explained

The Netherlands established a second phase of the Long Term Agreements in 2000 to operate until 2012. In this phase, the most energy intensive industries will be benchmarked to comparable industries worldwide. The affected industries must be best in class in energy efficiency, and in return, the government will not implement additional stringent climate change policies. Curiously, analysis of the benchmarking mechanisms suggests that estimated energy savings will be smaller than under a continuation of the first phase of the Long Term Agreements (Phylipsen, Blok, Worrell, and de Beer, 2002). This is due to a change in the policy from continued energy savings in the original Long Term Agreements to a benchmarking standard in the second phase. With the expiration of the second phase in 2012, it remains to be seen whether the initial increase in efficiency gains will be maintained over the entire period. Other industries remain covered under the goals of the Long Term Agreements.

Denmark is another European country that has taken extensive steps to address industrial energy efficiency. The Danish government also has a negotiated agreement like the Dutch, but the unique implementation of other energy policies has made Denmark the world leader in installed combined heat and power (CHP) capacity, which is more impressive when the size of the country is taken into account.

Denmark's push for energy efficiency began following the OPEC oil embargo of the early 1970s. Taxes on petroleum based fuels were levied, which were eventually expanded to fossil fuels and eventually an outright carbon tax in 1992.

The constant presence of these taxes has created a strong incentive for energy efficient technologies, including CHP, especially when combined with some regulatory and financial incentives through the Heat Supply Laws (IEA 2009). With grid connectivity guaranteed in Denmark, the ease of implementation for power producing efficiency measures like CHP has been greatly increased.

As a developing country, India does not have quite the same historically coordinated effort that the Europeans exemplify. Its industry makeup is also different, supporting more small and medium sized companies (World Bank, 2008). The government has attempted to incentivize energy service companies to enter the industrial sector, but has had a difficult time doing so. Despite these difficulties, India is currently less energy intensive than the U.S. (Figure 11), and aspires to match the efficiency of Japan (Lamont, 2009).

India's newest approach to the problem is innovative. They have introduced an energy efficiency trading program designed to reduce energy intensity 5% a year through certificate trading. It is expected this market will be worth $15 billion and will cover nine sectors by 2015 (Lamont, 2009). This approach is very similar to other markets for efficiency credits, but India mandates the reductions and the program is designed like a cap-and-trade program. This is a unique approach for a developing country, with the expected outcome of more rapid deployment of efficient technologies throughout the Indian economy.

The two oil crises of the 1970s also spurred the government of Japan to start actively pursuing industrial energy efficiency policies. By 1991, Japan had achieved a 35% improvement in energy efficiency, but started to see its energy intensity rise. Japan implemented a new set of policies in 1993 to further energy efficiency throughout industry and its economy in general. Tax credits for small and medium-sized industry were established, as were a large number of low-interest loans, which covered both the purchase of highly efficient equipment and cogeneration installations (Sato, 2000).

In 2006, Japan updated its efficiency goals in response to rising energy prices and the anticipation of increasing global energy demand. The New National Energy Strategy featured five focus areas for energy, including energy efficiency. With the Energy Conservation Frontrunner Plan, the goal of improving energy efficiency 30% by 2030 was established. To achieve this ambitious goal, Japan's Ministry of Economy, Trade and Industry mandates energy management plans for industry, the appointment of a certified energy manager for each business, and the introduction of benchmarking for industrial sectors (Energy Conservation Center, Japan, 2009). Future progress is expected to come from a number of bills addressing climate change currently working through the Japanese government, with Tokyo launching Asia's first mandatory carbon trading scheme in early April, 2010 (Soble, 2010)

From 1980 through 2000, China experienced a reduction in national energy intensity of 65% (Zhang, 2003). These reductions were the result of process and technological changes, as well as structural shifts throughout Chinese industry. Rapidly developing countries typically see an increase in energy intensity; China was able to buck this trend through a series of policy reforms allocating capital towards energy efficiency and developing energy service conservation and energy management centers, which act similarly to energy service companies (Wang 1995, Sinton et al 1999). China intended to continue this trend, with goals and mandates in the Energy Conservation Law of 1997 (ECL) and the 10th Five-Year Plan.

However, China has recently faced difficulties with these goals. The early 2000s saw energy consumption outpace GDP growth, and thus saw an *increase* in energy intensity for the first time in decades. Part of this increase was almost certainly driven by difficulties in implementation of the ECL itself, which required provincial energy plans that were slow to develop and difficult to enforce (Wang 1999).

Noting the deteriorating conditions, the Chinese government announced a mandatory reduction in energy intensity of 20% by 2010 in late 2005. Initial responses were not sufficient to reverse the trend, inspiring new policies and strategies to meet the mandate (Lin et al, 2006). The ECL was revised, tax policy was modified for export products, tax credits for efficiency investments were granted, and numerous buildings and appliance policies came into effect, being adopted in the 11th Five-Year Plan. The Top-1000 Energy Consuming Enterprises program has promoted energy-efficiency throughout large-sized industry.

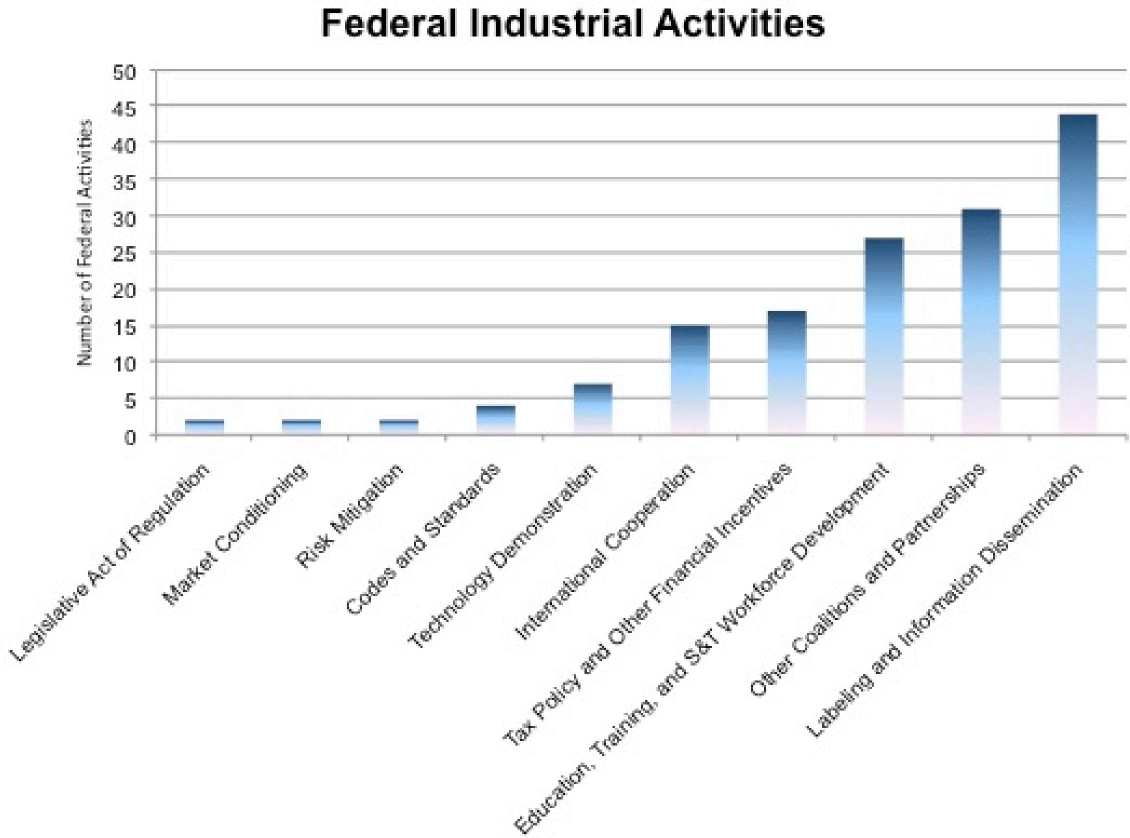
It is anticipated that these top energy-consuming businesses will contribute 25% of the overall efficiency gains required by the 11th Five-Year Plan, and additional businesses are being added to the program. The end-result of these policies has placed China on a path towards reaching its mandates and reducing energy intensity once again (Zhou et al, 2009). Even so, with highly energy consumptive industries including steel, cement, etc., experiencing increasing demand for their products as the global economy recovers from the recent recession, continuing the progress may prove difficult, and increases in overall consumption are virtually guaranteed (See “Why China Matters” by Buijs)

Just before the December 2009 Copenhagen Summit began, China announced a commitment to reduce the carbon intensity of its economy to 40-45% below 2005 by 2020. This will require a 4% reduction in GHG emissions each year from projected emissions increases, at the same time when China’s economy could grow at an annual rate of 8% or higher. Achieving such a goal may involve expanding the scope of major efficiency improvements to China’s smaller industrial facilities in addition to potentially imposing new regulations and continuing to close inefficient plants (Friedman, 2009). Others have estimated that the 40% goal represents the business-as-usual case for China, and will be easier to meet with faster economic growth. Both the 40% and 45% emissions trajectories still push global emissions beyond the IEA 450 ppm CO_2 scenario, so even if China is successful in achieving its own goals, the world would need greater efforts to stay below 450 ppm CO_2 (Seligsohn and Levin, 2010).

The policies pursued by different nations illustrate the variety of approaches used to promote industrial energy efficiency. In the United States, the implementation of federal activities is distributed amongst federal agencies, with more than a dozen involved in the administration of 72 currently funded and active deployment programs working on energy efficiency in industry (CCCSTI, 2009).

Reflecting the importance of informed decision-making, remedying a lack of specialized knowledge and addressing incomplete and imperfect knowledge barriers are important policy priorities in the U.S. context. As a result, “Labeling and information dissemination” are the most common type of deployment program targeting industrial energy efficiency (Figure 13).

Figure 13. Federal Industrial Energy Efficiency Policies and Measures Operating in the United States, in 2009



Source: CCCSTI Energetics Deployment Database, September 2009

In the U.S., the focus has been significantly less driven by regulation. Instead, there are many public-private partnerships with industry, For example, programs like Save Energy Now, administered through the Department of Energy's Industrial Technologies Program, work with large industrial partners in energy-intensive industries to identify areas of significant efficiency gains. Save Energy Now recognizes industrial energy efficiency leaders and works through the supply chain as well.

The Industrial Technologies Program also works with small and medium-sized firms through the audits performed by the Industrial Assessment Centers at universities throughout the country. This program identifies cost-effective opportunities for energy efficiency throughout the firms' operations. Unfortunately, implementation of these recommendations was only 47% from program initiation in 1981 through 2007 (DOE, 2007), suggesting that significant benefits are not being captured.

Another public-private partnership in the U.S. couples the government with manufacturers to reduce energy intensity by 2.5% or more per year. This is done through energy management standards, which almost always include a comprehensive energy plan and an energy manager to oversee the implementation of the plan. This type of project ensures that equipment continues to operate as efficiently as possible, as energy use is constantly monitored.

Finally, the multi-agency Climate Change Technology Program has begun to work recently on addressing barriers to industrial efficiency through crosscutting policy options. A workshop was held with a mix of academics and industry leaders to discuss the barriers to industrial energy efficiency and preferred policy responses. Some of the policy options being considered include establishing a national energy efficiency resource standard, enabling municipalities to establish clean energy property tax liens, superior energy performance standards, and making third party financing available for industrial energy efficiency upgrades. All of these policies would represent a significant step forward in addressing significant financing, regulatory, and information barriers to industrial energy efficiency (Brown, Jackson and Cox, 2010).

Manufacturing the Next Generation of Green Technologies

Most of the current dialogue focuses on new technology that lowers industry's energy use. In some cases, more important energy savings come from adapting the new technology for use in other sectors. For example, developing a new generation of fuel cells may lead to greater savings in motor vehicles. Other possibilities include "on-demand" manufacturing that applies ink-jet printing systems to three-dimensional fabrication, or new plastics that double as integrated photovoltaic systems (Laitner and Brown, 2005). This role of industry in the development of emerging technologies highlights even greater energy savings than might be apparent from looking at industry's own energy use patterns alone. With the growing focus on corporate sustainability, industry is adopting a much broader view of its energy and environmental responsibilities, extending its concern to issues surrounding the sustainability of the products and services it offers and including the sustainability of its chain of suppliers. Walmart, for example, has included indicators of energy sustainability in metrics used to select product and service providers.[4] Accordingly, contractors with minimal environmental impacts are preferred.

Walmart is not alone in this initiative, as many other corporations have taken voluntary action to reduce the GHG emissions of their operations. These efforts are not yet operating at the scale needed to address the challenges of climate change and energy (Southworth, 2009); however, they appear to be expanding as corporate commitments to sustainability grow, and as consumer and shareholders demand greater effort (Prindle, 2010).

Industry is often viewed as a recipient of new technologies to meet production demands. While many innovations are created at research hubs like top tier universities, industry is often a source of technological innovation as well. In the energy realm, many next-generation technologies in areas such as fuel cells, solid-state lighting, and biofuels, are being developed by industry alone and also in public-private partnerships. Industry is not just a recipient of new technologies, but in fact plays a key role in developing the next wave of energy technologies.

Fuel cells provide a useful example. Different sectors of industry are innovating to create different uses and applications of fuel cells. Honda was recently recognized for its innovations in the use of fuel cells in transportation vehicles, winning awards and having their FCX Clarity model named the 2009 world green car. Honda reports that this vehicle is 2-3 times more fuel-efficient

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[4] Jim Stanway, Walmart, personal communication, 2007.

than gasoline-based vehicles, and gets 1.5 times better fuel economy than a hybrid electric-gasoline vehicle (Honda, 2009).

However, personal transportation is not the market where fuel cells have really seen competitive advantage and uptake; that distinct honor resides with auxiliary power units, marine systems, and forklifts. In fact, a recent Department of Energy report found that 3 KW proton exchange membrane (PEM) fuel cell-powered forklifts currently have total system costs nearly half that of their conventional lead-acid battery counterparts (DOE, 2008). Industry is actively experimenting with at least six different fuel cell technologies and innovations continue in all areas (DOE, 2009).. As sales continue to increase, it is expected the technology will continue down the learning curve and costs will decrease.

Another example where industry is leading through innovation is the search for super-efficient solid-state lighting. This area of innovation is generally in light emitting diode (LED) technology. LEDs are much more efficient generators of light than incandescent and fluorescent lighting technologies, and they also have longer lifetimes. LEDs are useful in many applications, including traffic and street lighting, indoor lighting, and flat screen displays. This varied application list results in companies from different sectors being involved in RD&D, from Sony to Philips. While the U.S. government enters into many public-private partnerships and provides assistance in overcoming barriers (such as product testing standards) to deployment, the variety of applications for solid-state lighting technologies have industry leading the way in innovation (Building Technologies Program, 2009).

Finally, industry is developing next-generation biofuels that are sustainably produced with a near net-zero carbon footprints. Some promising examples are cellulosic ethanol and algae-based biofuels. BP Biofuels has a number of partnerships for developing feedstocks and technology, representing over $2 billion in private investment between seven companies (Semans and deFontaine, 2009). These companies are working together to develop cellulosic ethanol while respecting the environmental, agricultural, and social impacts producing feedstocks can create (Scotti, 2009). ExxonMobil has teamed with renowned geneticist Craig Venter and his start-up, Synthetic Genomics, to develop genetically modified algae as a source of biofuels. An initial investment of $600 million has been made, and Exxon has publicly acknowledged it intends to invest billions more for commercialization and deployment once R&D is sufficiently advanced (Johnson, 2009).

Many of the new technologies are being developed in public-private partnerships, representing the shared interest of developing new, more efficient and environmentally friendly next generation technologies. Fuel cells, solid-state lighting and cellulosic and algal-based biofuels all represent significant advances in currently deployed technologies, but all still face significant barriers. The public-private interfaces in each of these areas help to overcome many of the economic barriers. The potential for increased efficiency and sustainability in the next generation of technologies stand to show that industry itself is a driver of innovation.

Conclusions

The dual goals of advancing energy efficiency at industrial plants and advancing product innovation for broader use are both critical to promoting the more productive consumption of energy in a resource-constrained world. Developing and deploying more efficient technology is the key to reducing carbon intensity in industry. Advanced industrial technologies and best practices in energy management are already working to improve energy efficiency and lower GHG emissions. These efforts have helped the industrial sector diminish GHG emissions in some of the nation’s most energy-intensive industrial facilities.

Still, barriers to broader application of technologies suitable for commercialization in this sector remain. As a result, independent studies using different approaches agree that the economic potential for improved energy efficiency in industry is large. Of the 34.3 quads of energy forecasted to be consumed by U.S. industry in 2020 (EIA, 2008), 14 to 22 percent could be saved through the implementation of cost-effective energy-efficiency improvements

(National Academy of Sciences, 2009). Large mismatches abound between the thermal needs and waste heat streams of industrial facilities served by large-scale centralized power plants. If systems were optimized so that the vast majority of wasted energy was recycled into productive uses, industrial energy consumption could be cut tremendously.

Comparisons of the energy content of manufactured products across countries underscore the potential for U.S. industry to reduce its energy intensity. Japan and Korea, for instance, have particularly low levels of industrial energy intensity. Many energy-intensive industries have devoted considerable resources to increasing their energy efficiency. For many other industries, energy represents a small fraction of their costs and is not a priority. Until the chief executives of U.S. industry become a force for clean energy and environmental progress, the challenges of climate change and resource depletion cannot be adequately addressed.

Ultimately, we need to transform the vision of industry as a necessary evil exiled to remote locations to avoid contaminating pollution. Instead, imagine a future where concepts of industrial ecology are taken to an extreme, so that people will want these facilities and jobs in their communities. Because they are clean and green, people want to live close to industrial parks to reduce their commute to work, expand their commitment to community, and help make industry part of the climate solution. The public's imagination has been captivated by zero-energy buildings and cars that operate like pollution vacuum cleaners. Now we need a new vision of industry – factories-of-the-future with minimal resource requirements, that clean up our ecosystems, contribute to human health, produce valuable goods, and improve standards of living.

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