Advancing Energy Productivity in American Manufacturing

ALLIANCE TO SAVE ENERGY

Using less. Doing more.

Alliance Commission on National Energy Efficiency Policy

JANUARY 2013

PREAMBLE

The Alliance Commission on National Energy Efficiency Policy (the Commission) was organized to study energy-efficiency policies, programs, and opportunities, and to make consensus recommendations on the next generation of domestic policies, programs, and practices to ensure that the U.S. can double its energy productivity (twice as much gross domestic product [GDP] from each unit of energy) from 2011 to 2030.

The work of the Commission will include an assessment of the current state of energy efficiency in the U.S. economy; a review and assessment of the best local, state, and national practices; and the development of a set of recommendations on policies and programs for the next administration and the 113th Congress to achieve the stated goal of doubling U.S. energy productivity by 2030.

This report, Energy Productivity in American Manufacturing, is one of seven research reports that assess the current state of efficiency within the economy and review the best local, state, and national practices. These assessments will be used to support and provide the technical basis for the Commission's efforts to develop a set of recommendations for doubling the nation's energy productivity. The other reports will address the following areas: history and business case of energy efficiency; transportation, land use and accessibility; residential and commercial buildings; power generation and smart grid; natural gas infrastructure; and, systems integration.

To provide a comprehensive assessment to the Commission, the last report identified as "systems integration" will be a comprehensive analysis of the other research reports to identify common areas of consideration and areas of interdependency. It will also identify opportunities for the various sectors of the economy to work together.

RESEARCH TEAM

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INTRODUCTION

This paper was prepared for the Alliance to Save Energy's Commission on National Energy Efficiency Policy (ACNEEP) to describe industrial energy productivity trends, projections, opportunities, and barriers. Focusing on manufacturing, it discusses industrial energy efficiency investments, technologies, human behavior aspects, and government and governance issues to help ACNEEP explore energy productivity policy options.

The goals of enhanced energy productivity (that is, better performance outcomes for a given input of energy, or reducing energy use for a given amount of output) are aligned with the goals of industrial economic productivity. In this sector, perhaps more than others, the search for cost-effective ways to increase energy productivity meshes with the individual interests of private industrial firms as well as the nation's interest in economic development. The sector can contribute to the Commission's goal of doubling U.S. energy productivity by 2030 both directly, by improving the energy productivity of manufacturing operations, and indirectly, by producing products and materials that enhance energy efficiency and productivity in buildings, transportation, utilities, and other sectors.

Overall, our analysis concludes that there are large opportunities for improving the energy productivity of American manufacturing—perhaps by at least one-third by 2035, with greater gains possible. Such gains are anticipated from structural trends in the sector, as well as from the adoption of energy efficiency technologies, measures, and practices. Methods to reduce a firm's energy requirements tend to occur through investments that also save on the use of materials, water, and other resources, thus further supporting the company's performance. Even so, many barriers impede the adoption of cost-effective energy efficiency measures and contribute to underinvestment in such measures. Government policies should aim to overcome these technical and other barriers as a way to increase energy productivity and, in so doing, increase U.S. manufacturing productivity. We review policies to address these barriers, so as to capture the opportunities for enhanced energy productivity in manufacturing.

BACKGROUND AND CONTEXT

The U.S. industrial sector, which includes manufacturing, mining, agriculture, and construction activities, is critical to national economic strength and well-being, and to advancing the quality of life for all Americans. The sector is also a very large consumer of energy. Energy efficiency enhancements can help strengthen U.S. economic productivity and competitiveness, improve energy reliability and security, and mitigate adverse effects on the environment. New technologies, improved products and processes, energy management systems (EnMS), and recovery of otherwise wasted energy and materials all offer opportunities.

This discussion focuses on the manufacturing portion of the industrial sector. Despite the decline in manufacturing's share of the U.S. economy in recent years, the United States remains the world's largest manufacturer, accounting for 21% of global manufacturing, with China (15%) and Japan (12%) in the second and third positions.[1] In 2009, manufacturing accounted for about $1.1 trillion or about 11.2% of U.S. gross domestic product (GDP) as well as 60% of total U.S. exports.[2] United States manufacturing directly employed 11.8 million people (about 9% of the U.S. workforce) in 2009 and indirectly supported another 6.8 million jobs in other sectors (transportation, professional services, wholesaling, finance, agriculture, real estate, etc.), adding up to 18.6 million jobs or about one-sixth of American private sector jobs.[3] Further, in 2010 the average American manufacturing worker received $77,186 in pay and benefits, as compared to $56,436 for the average nonmanufacturing worker.[4]

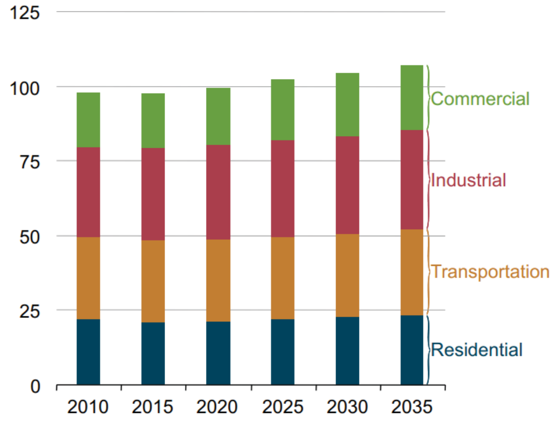

Figure 1. Primary energy use by end-use sector, 2010-2035 (quadrillion Btu)
Source: DOE, "AEO 2012," fig. 72, 76.

INDUSTRIAL ENERGY CONSUMPTION

The economic and employment importance of industry and manufacturing is matched by its large energy impacts. Total U.S. industrial energy consumption in 2010 was about 30 quadrillion (Q or quad) British Thermal Units (Btu) (about 31 Q in 2011) or about 31% of total U.S. consumption. Of this about 26 Q (in both 2010 and 2011) or about 27% of total U.S. consumption was from manufacturing.[5]

Figure 1 shows the U.S. Department of Energy (DOE) Annual Energy Outlook 2012 (AEO 2012) estimate of 2010 primary energy consumption by major U.S. sectors along with reference case projections through 2035. This illustrates the proportion and scale of industrial energy use as compared to other sectors.

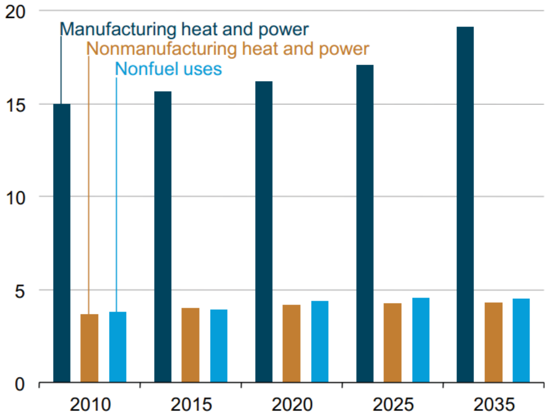

Figure 2. Industrial delivered energy consumption by application, 2010-2035 (quadrillion Btu). Delivered energy does not include losses during electrical generation and energy transmission.
Source: DOE, "AEO 2012," fig. 82, 81.

Figure 2 breaks out 2010 and reference case projections of delivered energy for manufacturing heat and power, nonmanufacturing industrial heat and power, and industrial nonfuel uses (including chemical feedstock, coke for steelmaking, and asphalt for construction). Over three quarters of the manufacturing consumption was for heat and power (including electricity), with the balance for nonfuel consumption. (Note: Figure 2 presents delivered rather than primary energy; it does not include electrical generation, transmission, and distribution losses.)

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[1] *United Nations, Statistics Division 2009, as cited by the National Association of Manufacturers in its Facts about Manufacturing. However, IHS Global Insight indicates that in 2010 China's share of global manufacturing reached 19.8%, edging out U.S. share of 19.4%. Marsh, "China Noses Ahead."*

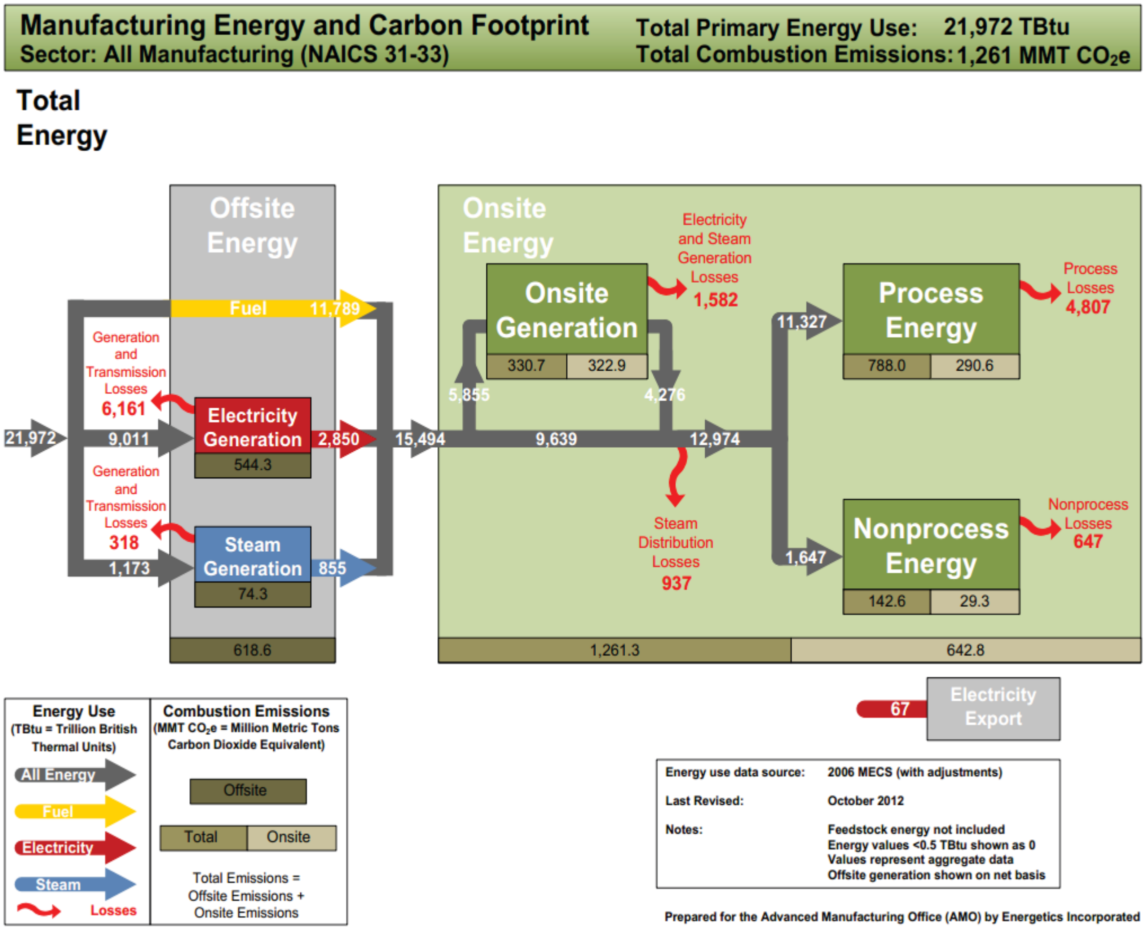
[2] *U.S. Department of Commerce, "The Competitiveness and Innovative Capacity of the United States", 6-1.*

[3] *Ibid., 9.*

[4] *U.S. Department of Commerce. "Compensation of Employees by Industry and Full-Time Equivalent Employees by Industry", as cited by the National Association of Manufacturers in its Facts about Manufacturing.*

[5] *DOE, "AEO 2012," interactive table browser.*

Figure 3, based on an adjustment of the DOE 2006 Manufacturing Energy Consumption Survey, provides the footprint of U.S. manufacturing energy use and combustion related carbon dioxide emissions. It offers an overview of offsite and onsite electric power and steam generation used in manufacturing as well as the disposition of energy between process and nonprocess uses (e.g., facility heating, cooling, lighting, and support, and onsite transportation). One notable feature is that even excluding process heating losses (that were not included in the analysis), about 52% of total energy input to manufacturing is lost, much of it (28% of total manufacturing energy use) in the generation of offsite electricity. Even if we look just at onsite energy use, about one-third of energy entering manufacturing facilities is lost.


Manufacturing Energy and Carbon Footprint
Sector: All Manufacturing (NAICS 31-33)
Total Primary Energy Use: 21,972 TBtu
Total Combustion Emissions: 1,261 MMT CO_2e

Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis

Prepared for the Advanced Manufacturing Office (AMO) by Energetics Incorporated

Figure 3. Manufacturing energy and carbon footprint (trillion Btu, million metric tons carbon dioxide equivalent).
Source: DOE, "Manufacturing Energy and Carbon Footprints."

PROJECTIONS FOR FUTURE ENERGY USE

Looking to potential future energy use, the AEO 2012 reference case projects a 49% increase in industrial shipments between 2010 and 2035, but only a 15% increase in energy consumption.[6] This means the amount of energy needed per dollar of production and sales is projected to decrease significantly. Much of this energy productivity gain can be attributed to projected changes in industrial structure as the share of less energy-intensive manufacturing, such as computers, plastics, and transportation equipment, grows relative to energy-intensive manufacturing, such as aluminum, cement, chemicals, food products, glass, iron and steel, paper, and petroleum refining. The reference case also reflects improved energy efficiency and productivity (reduced energy intensity) of heat and power offsetting some of the growth in energy use. Further, the reference case projects modest decreases in purchased electricity's share of manufacturing energy use due to small increases in combined heat and power (CHP) systems, which reduce the need for purchased electricity and are a more efficient use of fuel. Improved electricity use efficiency, such as from more efficient motors, is also projected.[7]

[6] *DOE, "AEO 2012," 81.*
[7] *DOE, "AEO 2012," 81.*

In addition to the reference case, DOE prepares numerous other cases based on differing economic, technical, and policy assumptions. Of particular note are low and high economic growth scenarios. Growth in shipments[8] and energy use during 2010 through 2035 under low, high, and reference economic growth cases for high energy intensity industries is presented in Figures 4 and 5 and for selected non-energy intensive manufacturing and nonmanufacturing industry in Figures 6 and 7.

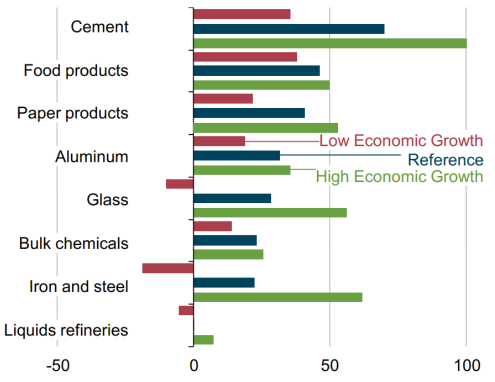


Figure 4. Cumulative growth in value of shipments from energy-intensive industries in three cases, 2010-2035 (%).
Source: DOE, "AEO 2012," fig. 84, 82.

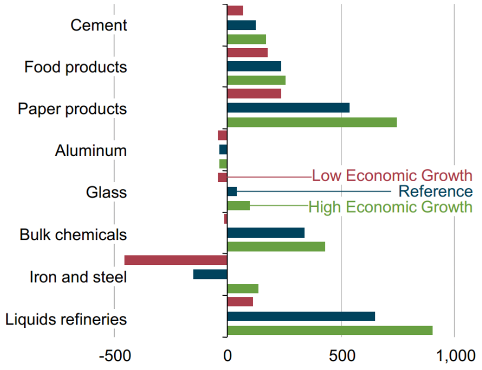


Figure 5. Change in delivered energy for energy-intensive industries in three cases, 2010-2035 (trillion Btu).
Source: DOE, "AEO 2012," fig. 85, 82.
Note: Delivered energy does not include losses during electrical generation and energy transmission.

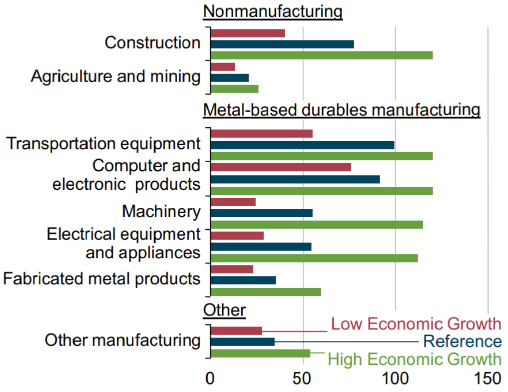


Figure 6. Cumulative growth in value of shipments from non-energy-intensive industries in three cases, 2010-2035 (%).
Source: DOE, "AEO 2012," fig. 84, 82.

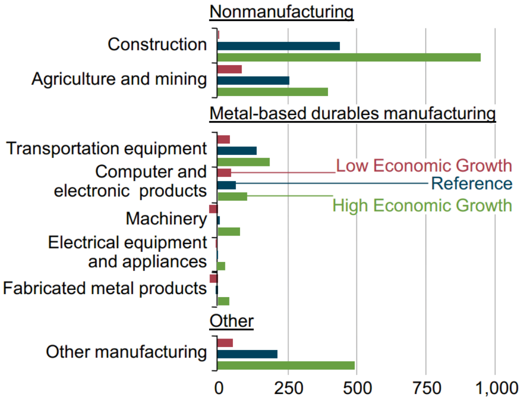


Figure 7. Changes in delivered energy for non-energy-intensive industries in three cases, 2010-2035 (trillion Btu). Delivered energy does not include losses during electrical generation and energy transmission.
Source: DOE, "AEO 2012," fig. 85, 82.

While sectoral energy consumption correlates with the value of shipments (that is, more production and sales leads to more energy use), there is also improved energy efficiency and productivity from both improved processes and changing material feedstock.[9] One illustration is the reference case for iron and steel: Shipments of steel increase about 23%, but energy use decreases 12% during the 2010 to 2035 period, primarily due to shifts from blast furnace-based primary steel production to greater use of electric arc furnaces using recycled products. Aluminum also shows growing shipments but reduced energy use due to increased recycling. Paper product energy productivity improvements are less pronounced due to projected increases in demand for more energy-intensive products such as paperboard. For low energy-intensity manufacturing, the projected improvements in energy productivity are marked. For instance, transportation equipment manufacturing energy use grows 37%, while value of shipments double, translating to 1.3% annual energy productivity improvements during 2010-2035.

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[8] *The AEO provides shipments but not value-added figures. Shipments is the total value of sales from a sector while value-added subtracts the value of purchased materials, supplies, energy, and contracted services, which provides a better basis for analyzing productivity of an economic sector or industry. Aggregating the value of manufacturing shipments results in significant duplication because the products of some industries are used as inputs to others. The U.S. Census Annual Survey of Manufactures states, "Estimates of the overall extent of this duplication indicate that the value of manufactured products exclusive of such duplication (the value of finished manufactures) tends to approximate two-thirds of the total value of products reported in the annual survey." U.S. Census Bureau, "Annual Survey."*

[9] *Feedstock refers to material inputs into manufacturing processes.*

Petroleum refining, which actually encompasses the broader category of liquid fuels, is the only exception to manufacturing energy productivity improvement due to modeled growth in coal- and biomass-based liquid fuel production, which is more energy intensive than petroleum-based liquid fuel processing. Further, increased refining of heavier and higher-sulfur crude oil would increase energy intensity as well.

Overall the AEO 2012 reference case projects roughly a one-third improvement in energy productivity for both manufacturing and the broader industrial sector by 2035. Interestingly, several alternative AEO 2012 cases that posit more favorable energy efficiency policy and technical scenarios yield little difference from the reference case. Table 1 illustrates projected manufacturing shipments, energy consumption, energy productivity (dollar value of shipments per 1000 Btu consumed), and percentage changes in energy productivity under four scenarios described in the table legend.

	2010	2011	2020	2025	2030	2035
Shipments* (billion 2005 dollars)						
Reference	4260	4459	5260	5745	6023	6285
High Tech**			5283	5785	6067	6328
Extended Policies***			5253	5752	6033	6302
$25 GHG****			5121	5576	5881	6126
Consumption (quadrillion Btu)						
Reference	25.76	26.32	26.45	27.44	27.80	28.21
High Tech			26.73	28.02	28.87	29.38
Extended Policies			26.42	27.41	27.80	28.13
$25 GHG			24.56	25.25	26.42	27.36
Energy Productivity (2005 dollars shipments per 1,000 Btu consumed)						
Reference	0.1653	0.1694	0.1988	0.2094	0.2167	0.2228
High Tech			0.1977	0.2065	0.2101	0.2154
Extended Policies			0.1988	0.2098	0.2170	0.2240
$25 GHG			0.2085	0.2208	0.2226	0.2239
Energy Productivity (% change from 2010)						
Reference		2.5	20.3	26.7	31.1	34.8
High Tech			19.6	24.9	27.1	30.3
Extended Policies			20.3	26.9	31.3	35.5
$25 GHG			26.1	33.6	34.7	35.5
Energy Productivity (% change from 2011)						
Reference			17.4	23.6	27.9	31.5
High Tech			16.7	21.9	24.0	27.1
Extended Policies			17.1	23.8	28.1	32.2
$25 GHG			23.1	30.3	31.4	32.2

Table 1. AEO 2012 Manufacturing Shipments, Energy Consumption, Energy Productivity under Four Case Scenarios

Source: Derived from AEO 2012, interactive table browser.
Note: For energy consumption, nonmanufacturing consumption was subtracted from total industrial consumption to derive manufacturing only consumption. Energy productivity is based on the value of shipments divided by thousands of Btu consumed.
** Shipments is the value of products sold by the sector.*
*** High Tech = Integrated high technology case includes earlier availability, lower cost, and higher efficiency for residential, commercial, industrial, and transportation technologies as well as lower cost renewable, nuclear, and fossil fuel energy supply technologies.*
**** Extended Policies = Extends various energy policies, except those for biofuels, that now have sunset provisions, assumes increased capacity limits on investment tax credits, and assumes implementation of additional and more stringent standards for residential and commercial equipment, building energy codes, and light-duty-vehicle fuel economy.*
***** $25 GHG = Scenario imposes a $25 per-ton carbon dioxide emissions fee throughout the economy starting in 2013, rising 5% per year based on real 2010 dollars through 2035.*

While the AEO 2012 and table 1 suggest that there is only modest scope for strong improvements in U.S. manufacturing energy productivity over the reference case, it should be noted that AEO projections are not predictions and that past AEO projections have changed markedly from year to year, depending on changes in economic growth, energy prices, policy adoption, and technological advances. As it is said, all models are wrong but some are useful. Also, as Niels Bohr and Yogi Berra reportedly said, prediction is very difficult, especially about the future.

Other analyses indicate significantly greater scope for potential industrial and manufacturing energy efficiency improvements. The National Research Council cited several studies that estimated potential economically attractive industrial sector energy savings of 14 to 22% (4.9-7.7 Q) in 2020, compared to the AEO 2008 reference case "business-as-usual" or BAU projections.[10] See table 2.

Industry	Energy use in Q			
	2007	2020 BAU projection	2030 BAU projection	Savings from BAU in 2020
Petroleum refining	4.39	6.07	7.27	0.3-3.28
Iron and steel	1.38	1.36	1.29	0.21-0.76
Cement	0.44	0.43	0.41	0.1-0.22
Bulk chemicals	6.85	6.08	5.60	0.19-1.1
Pulp and paper	2.15	2.31	2.49	0.14-0.85
Total, all industries (including those not shown above)				4.9-7.7 Q (14-22%)

Table 2. Energy Use in Industry and Estimated Savings in 2020 Due to Energy Efficiency Improvements

Source: National Research Council, America's Energy Future, table 4.10.
Note: Savings are based on reviews of studies for specific energy-using industries, both for combined heat and power (CHP) and for an industry as a whole. Savings shown are for cost-effective technologies that provide an internal rate of return of at least 10% or exceed a company's cost of capital by a risk premium. CHP accounts for 0.7-2.0 Q of the total estimated savings potential for 2020.

The American Council for an Energy-Efficient Economy examined the long-term potential for energy efficiency in the U.S. economy.[11] The study's analysis of industrial energy efficiency improvement potential considered two major scenarios, advanced and Phoenix, in addition to an Energy Information Administration-based reference case.

The advanced case projected an average industrial energy intensity, or energy productivity, improvement of 2% per year through 2050, about double the nearly 1% annual improvement in the reference case. The study notes that 2% annual energy intensity improvement is lower than what U.S. industry experienced during portions of the 1970s and 1980s, comports with what various leading manufacturing firms have achieved for over a decade (3M, Alcoa, Dow, and United Technologies Corp.), and was identified as a sustainable rate in a McKinsey study.[12] This scenario posits continued incremental improvements in product and process technologies and system optimization rather than major shifts in materials and products or radical changes in manufacturing technology.

The more aggressive Phoenix case assumes 2.75% annual energy intensity or productivity improvements through 2050, positing robust increases in research and development (R&D) by industry and government and tax policy enhancements favorable for investment in new production capital. The scenario considers the implementation of various transformative manufacturing technologies and significant shifts in materials available for producing final products. The ACEEE team noted that U.S. industry experienced such rates of efficiency improvements during portions of the 1980s and that transformative investment in the steel industry during the 1990s and 2000s achieved such gains.

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[10] *National Research Council, America's Energy Future, table 4.10.*

[11] *Laitner et al., "Long-Term Energy Efficiency"*

[12] *Ibid., citing Prindle, "From Shop Floor to Top Floor" and McKinsey & Co. "Unlocking Energy Efficiency."*

Figure 8 and table 3 illustrate ACEEE scenario projects for U.S. industrial energy intensity and consumption. Whether less or more optimistic energy productivity projections come to pass is, of course, highly uncertain and is subject to a wide range of exogenous and sometimes unpredictable factors. However, public policy and private sector decisions combine to help create the future. Policies and decisions affecting R&D; technology commercialization; capital investment; price and availability of energy and material resources; human capital and behavioral incentives; environmental sustainability; trade and commerce; and other issues will fashion the future of American manufacturing.

An examination of the crosscutting topics of investment, technology, human behavior, and government and governance as they relate to manufacturing energy productivity follows. This can help us illuminate paths forward to an energy efficient, environmentally sound, and economically prosperous future for American manufacturing.

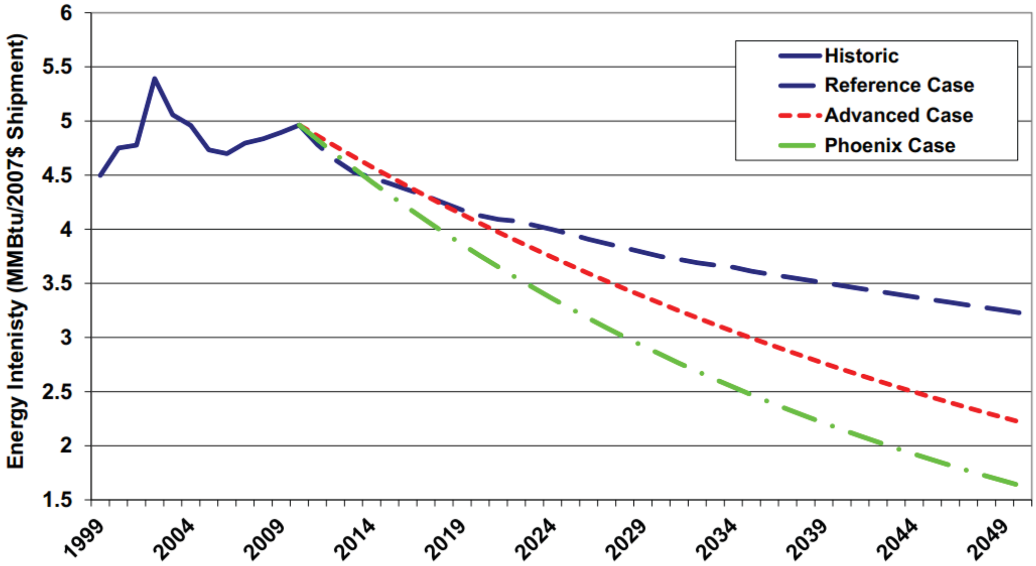

Figure 8. ACEEE projected industrial energy intensities for reference and policy cases. Projected curves are smooth averages but the study authors note that actual progress is likely to be "lumpy" due to economic cycles and varied timing of investments, technology introduction, and other factors.
Source: Laitner et al., "Long-Term Energy Efficiency," fig. 14.

	2010 Actual Data	2050			Change from 2050 Reference Case	
		Reference Case	Advanced Case	Phoenix Case	Advanced Case	Phoenix Case
Industrial Sector						
Delivered Energy						
Electricity	3.2	3.4	2.3	2.3	-33%	-33%
Other Fuels	20.6	25.9	17.4	12.3	-33%	-53%
Subtotal Delivered	23.8	29.2	19.6	14.5	-33%	-50%
Electricity Losses	6.1	4.0	1.6	1.7	-60%	-59%
Total Primary Energy	29.9	33.2	21.3	16.2	-36%	-51%

Table 3. ACEEE End-Use and Primary Industrial Energy Consumption in Quads for Reference and Energy Efficiency Scenarios (energy consumption in Q)
Source: Laitner et al., "Long-Term Energy Efficiency," table 12.

INVESTMENT

In theory, firms should be willing to pursue all profitable investments. However, in reality, manufacturers and businesses face capital constraints and prioritize their investments according to anticipated payback or rate of return as well as other factors such as the fit with company strategy and perceived risks and uncertainty. Because energy savings can be uncertain and savings realized can be negated if an energy-efficiency measure adversely affects production, a risk premium may be applied to an investment decision. The nature of a proposed investment (R&D, new production, improving existing production, training and education, and other forms) may vary considerably depending on corporate culture, company objectives, product lifecycle stage, and motivations of individual decision makers.

RATES OF RETURN AND INVESTMENT PRIORITY

Key drivers of industrial energy efficiency investments are the financial return demanded and risks tolerated by different classes of investors. Table 4 summarizes the investment expectations for three broad sectors.

Sector	Simple Payback (years)	Return-on-investment (annual %)
Government	7-30	3-10
Investors	3-7	10-25
Industry	1-3	25-100

Table 4. Illustrative Investment Requirements by Sector
Source: Citigroup, Inc. 2012.

Government: Governments address both immediate and longer-term problems of society. They have a relatively low discount rate for investments or spending, which translates to longer-term expectations for payback. The threshold payback for government energy efficiency investments can be ten years or longer. For other programs, governments may look forward 20-30 years for investments in health care, poverty reduction, transportation, and so on. In effect, governments will invest for a 3-10% annual return on investment (ROI).[13]

Investors: Investors run the gamut from venture capitalists seeking very high returns by tripling or quintupling their money in 3-5 years, to the other extreme of pension funds that have an appetite for 40-year loans, to hydroelectric projects and other long-lived assets. Investors relevant to industrial energy efficiency projects tend to seek a 3-7 year payback period, implying 10-20% annual ROI.

Industry: Manufacturing companies and other industrial firms have a number of financial targets and guideposts. Return on assets and return on capital employed (ROCE) are among the most important indicators of the profitability of the firm's capital investments. They also serve as guides for future investments. Return on capital employed is determined by dividing earnings before interest and taxes (EBIT) by capital employed, plus short-term loans, minus intangible assets [ROCE = EBIT ÷ (capital employed + short-term loans – intangible assets)]. This ratio should exceed the cost of borrowing. Internal investment opportunities are compared against this measure with, typically, only the highest-returning, lowest-risk projects receiving funding. A second major driver is earnings per share (EPS), which is the profit measure tracked by capital market investors. Pressure for quarterly earnings and growth causes companies to favor investments that yield a rapid return so as to be reflected in EPS as soon as possible. Thus, as shown in table 4, generally industrial firms impose very high hurdle rates for funding internal projects.

As an illustration pertinent to manufacturing energy productivity, researchers at Resources for the Future performed a study on adoption of energy efficiency measures by companies provided with energy audits by university-based Industrial Assessment Centers (IAC). The study found that most plants required measures to offer a payback in less than 15 months, corresponding to an 80% or higher annual rate of return.[14] About half of IAC-recommended measures were rejected mainly for not meeting economic return criteria.

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[13] *The Department of Energy currently uses a real discount rate of 3% and nominal rate of 3.9% for performing lifecycle cost analyses of federal facility energy efficiency, renewable energy, and water conservation capital investment projects. Rushing, Kneifel, and Lippiatt, "Energy Price Indices."*

[14] *Anderson and Newell, "Information Programs."*

Recognition of the differing return requirements of different sectors suggests that it may take less incentive to move financial investors, say, investors in energy service companies,[15] into industrial energy efficiency projects than to entice the industrial firms themselves. However, risk must also be considered. A large industrial company, most familiar with its own facilities and processes, may consider certain energy efficiency investments to be low to moderate risks. Yet a third-party investor might consider those investments a large risk due to less familiarity with processes, facilities, and corporate plans and objectives. An energy service company with industrial process knowledge could fill this gap if it is well equipped to identify best practices, understand implementation requirements, and quantify risks and benefits.

Further, ROI hurdle rates and companies' relative priorities for business expansion, capital replacement, and cost-reducing investments will vary across a business cycle and may vary by industrial sector. Companies invest differently in a boom period than in a recession. Policies and incentives should be sensitive to business cycle factors. For example, programs that encourage and support manufacturers investing in energy efficiency during downtimes would create jobs during sluggish periods of economic activity and increase the competitiveness of the plant after the downturn. Also, according to a Harvard Business Review study, firms that combine improving operational efficiency and investing in marketing, R&D, and new assets are most likely to survive a recession.[16]

Firms may also prioritize investment options based on criteria beyond risk adjusted rate of return estimates. Some investments may be mandatory if the firm wants to keep the facility operating, including requirements to meet environmental, health, and safety rules.[17] Companies may prioritize profit-center, growth-oriented investments in expanding production or selling new product over cost-center investments in reducing costs, including energy costs.[18] This type of investment decision making can be colored by accounting and accountability at the facility. If energy costs are measured and charged back to production units and product lines, there may be more incentive for production managers to invest in energy cost reductions than if they are treated as an overhead cost handled by another unit without attribution to specific production lines. Further, whether energy savings are, at least partially, retained by the plant or business unit or they flow back to corporate headquarters can affect the ardor with which plant management will pursue energy investments.

ENERGY IS JUST ONE FACTOR

One challenge to the pursuit of manufacturing energy productivity improvements is that for most manufacturing industries, energy accounts for a small fraction of production costs. A U.S. Environmental Protection Agency (U.S. EPA) report found for 2002 that for all industries examined, energy costs amounted to only 3.7 cents per dollar of value added and 1.8 cents per dollar of shipments. However, energy accounted for over 20 cents per dollar of value added for several energy intensive industries (petroleum refining, cement, iron and steel, and aluminum) and was above average for several others (pulp and paper, 8.8 cents; metal casting, 8.0 cents; metal finishing, 6.7 cents; chemicals, 5.4 cents; and wood products, 4.7 cents). In contrast, energy accounted for 1.1 cents per dollar value added for motor vehicle manufacturing.[19]

We might expect industries with small profit margins and in which products compete mostly on price (e.g., commodity goods) to be more concerned about reducing energy costs of production than higher profit margin, less commoditized sectors where differentiated product features and services may be the major bases for competition. In many cases energy efficiency gains are a co-benefit of investments undertaken to enhance productivity and/or product quality—energy is just one of multiple factors driving investment decisions.

Energy productivity can grow as part of a broader modernization, transformation, or restructuring of manufacturing. The modernization or replacement of old capital stock can simultaneously improve productivity and competitiveness, product quality, and energy and environmental performance. For example, the share of American iron and steel production based on scrap-using electric arc furnace (EAF) mini-mill steelmaking has grown and is expected to continue to grow relative to integrated steelmaking using blast furnaces and basic oxygen furnaces to turn iron ore, coal, coke, and other ingredients into steel. The recovery of energy imbedded in scrap iron and steel and avoidance of coking saves much energy. Further, even integrated steel mills are adopting technologies used by mini-mills and are adopting alternative technologies, such as direct reduction iron-making (DRI) that uses natural gas rather than coal-derived coke as a reductant.[20]

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[15] *Typically under energy service performance contracts, energy service companies identify and evaluate savings opportunities, calculate projected cash flows from specific savings opportunities, and provide capital for the required investments. The funding is supported by a bond which is paid back over time from energy savings.*

[16] *Gulati, Nohria,* and *Wohlgezogen, "Roaring Out of Recession."*

[17] *However, there can be opportunities for energy-efficiency measures to reduce or supplant the need for additional end-of-pipe pollution controls and, thus, reduce environmental compliance costs.*

[18] *National Research Council, America's Energy Future, 188.*

[19] *EPA, "Energy Trends in Selected Manufacturing," table 9, 2-16.*

[20] *EPA, "Energy Trends in Selected Manufacturing," 3-53; "Nucor Breaks Ground. "*

Another example of capital stock modernization providing significant energy productivity improvement is industrial boilers. An Energy and Environmental Analysis, Inc. report, "Characterization of the U.S. Industrial/Commercial Boiler Population," notes that such boilers consume as much as 37% of all non-electric energy at industrial facilities, equating to 6,500 trillion Btu annually.[21] The largest source of fuel for industrial boilers is by-products and wastes such as gases from oil, chemicals, and primary metals processing and wood waste in the paper and forest products industries. These, provide 3,249 trillion Btu annually.[22] The next largest industrial boiler fuel and the largest purchased fuel is natural gas, making up 2,100 trillion Btu of annual energy consumption. Combined, by-product and waste fuels and natural gas account for over 80% of the fuel consumed by boilers in the industrial sector.[23] Many industrial boilers are decades' old, with efficiencies of less than 60%. If these boilers can be replaced by fully condensing boiler technology, efficiencies of over 90% can be achieved. While smaller (less than 10 million Btu per hour) boilers have fully condensing options on the market, R&D is needed to bring this technology to larger boilers.[24] Also, upgrading noncondensing boiler systems to CHP offers significant efficiency gains.

Investment in new and revamped facilities also allows opportunities to rethink production processes and design. An Interface, Inc. carpeting facility developed in China during the late 1990s provides an example.[25] The plant designers rethought plant layout and piping for circulating hot fluids used in the process by designing the piping layout prior to deciding equipment location rather than vice versa, and opting for wider pipes but smaller pumps. This reduced friction and, thus, power and energy needed to circulate fluids in the plant. A system conventionally designed to require 95 horsepower of pumping power could, instead, operate with 13 horsepower. Capital and energy costs were reduced compared to conventional design. Further, as compared to conventional design, less space was needed, construction and maintenance was easier, and performance was improved.

Whether restructuring and reviving existing industries, expanding operations, or developing new industries and radically different manufacturing techniques (for instance, additive manufacturing), new manufacturing investment can bring increased manufacturing energy use from industrial expansion but at higher rates of energy productivity.

The rapid growth in domestic natural gas and associated liquids supply and concomitant moderation of energy prices is a boon to American manufacturing. It may be reversing offshoring, the practice of sending processes abroad, in some industries. One example is that of a Nucor iron and steel facility being built in Louisiana, which will use the natural gas-using DRI process. Interestingly, several years earlier, Nucor purchased an iron-reduction plant in Louisiana, disassembled it, and rebuilt the plant in Trinidad and Tobago.[26] Other examples include Dow's decision to reactivate a closed ethylene cracker facility in Louisiana and build a new one in Texas and Shell's plans to build a chemical facility in Pittsburgh.[27] However, the benefits of moderate energy prices also reduce incentives for energy productivity investments.

POLICY INFLUENCES

The general investment climate as well as that of manufacturing energy productivity can also be influenced by laws and regulations. In the case of tax policies, the cost of fuel and purchased power is expensed, while capital investments, such as for energy productivity improvements, depreciate over time. Depreciation schedules can have important impacts on project economics and can affect the timing and composition of new investment or replacement of old capital. For instance, while backup generators depreciate over 3 years, CHP facilities depreciate over 20 years, which can affect the relative economics of installing CHP.[28] Similar energy-consuming equipment can have differing depreciation schedules based on the classification of the industry using the equipment.[29] Another tax policy impact on investment is the R&D tax credit (formally the Research and Experimentation tax credit) that provides a credit for expansion of R&D investment.[30] This credit was allowed to expire at the end of 2011.

There are suggestions that the Clean Air Act's New Source Review program and grandfathering of existing plants may impede modification of and investment in facilities, including efficiency-enhancing investments, by owners concerned about triggering lengthy permitting processes and more stringent and expensive air pollution abatement requirements.[31]

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[21] *Energy and Environmental Analysis, "Characterization of the U.S. Industrial/Commercial Boiler," ES-4.*

[22] *Ibid.*

[23] *Ibid.*

[24] *Energy and Environmental Analysis, "Characterization of the U.S. Industrial/Commercial Boiler."*

[25] *Chan-Lizardo et al., "Big Pipes, Small Pumps."*

[26] *"Nucor Breaks Ground."*

[27] *"Points of Light."*

[28] *National Research Council, Real Prospects for Energy Efficiency, Sec. 4.5.*

[29] *Sachs et al., "Depreciation."*

[30] *26 USC §41 Credit for Increasing Research Activities*

[31] *National Research Council, Real Prospects for Energy Efficiency, Sec. 4.5; EPA, "Energy Trends in Selected Manufacturing," ES-4.*

Utility rate structures and governance—which for investor-owned utilities are highly regulated by state utility commissions—also affect the investment environment for energy-efficiency measures, including at manufacturing facilities. Some have identified rate structures, interconnection requirements, and other processes as constraining industrial CHP.[32] However, some states and regions increasingly recognize that energy efficiency, CHP, distributed generation, and demand response can be valuable components of managing the costs of delivered energy and supporting a more resilient electric grid.[33] In parts of the Northeast and Midwest, energy efficiency and demand response can participate in the PJM and independent system operator (ISO)-New England electric capacity markets.[34] Demand response and new rate approaches provide Southern Company with the equivalent of 2,200 GW of generation capacity.[35] Various states have initiated statewide efforts to streamline interconnection procedures and standards for CHP and distributed generation.

Many states recognize that utilities are uniquely positioned, because of their customer relationships, to offer end-use energy efficiency programs and information programs. Various states provide incentives for utilities to offer energy efficiency programs. One method that has been implemented in over twenty states is some form of rate decoupling or related rate design approaches to make distribution utilities financially indifferent to reduced volumes sold due to energy efficiency and conservation.[36] Other incentives that support utility investment in energy efficiency include shared savings mechanisms, return on equity adders, and performance target bonuses.[37]

Numerous states have energy efficiency resource standards (EERS), requirements for utilities to pursue “all cost-effective energy efficiency,” and other financial incentives or regulatory requirements for pursuit of energy efficiency by utilities or, sometimes, by third parties (such as Efficiency Vermont, Efficiency Maine, and the District of Columbia’s Sustainable Energy Utility). These can provide ratepayer-funded investments for industrial energy-efficiency technical assistance and upgrades. However, utility energy-efficiency programs usually have to meet benefit-cost ratio criteria and annual evaluation cycles that may favor investment in more quickly implemented and more homogeneous residential and commercial efficiency measures (e.g., lighting upgrades, high efficiency appliance subsidies, home weatherization, and retrofits) over industrial plant-specific long-lived capital investments.

Despite the existence of various utility energy efficiency programs and their achievement of significant energy savings, the potential is for much greater gains, including in the industrial sector. Various states like New York have had energy-efficiency-potential studies performed and have initiated formal proceedings to promote greater deployment of energy-efficiency resources.[38]

The inclusion of CHP and waste heat recovery in EERS and in state (and, prospectively, federal) renewable, alternative, or clean electricity standards, sometimes called renewable portfolio standards or alternative energy portfolio standards, can also support industrial energy efficiency. However, there are concerns that CHP could crowd out other energy efficiency and renewable energy opportunities in such standards.[39]

A barrier to utility ratepayer-financed industrial energy-efficiency programs is the perception by some manufacturing firms that they may be required, via their utility bills, to subsidize improvements by their competitors. To address this concern, some states allow industrial facilities to opt out of utility energy-efficiency programs and the need to pay into such programs via their utility bills. These companies may or may not be required to make equivalent self-directed energy efficiency investments.[40]

Finally, investment decisions depend greatly on uncertainties and perceived risks—market, economic, technical, regulatory, trade environment, and so on. This is pertinent to industrial R&D, whether it is for energy or otherwise, which may be amenable to risk mitigation through tax credits, industry consortia, and public–private collaborations of various sorts. However uncertainty and risk also apply to investment decisions for both existing and emerging technologies and techniques. Risk and uncertainty cannot be eliminated and is inherent to economic decision making and part of capitalist competition. However, as will be discussed later in the technology and human behavior sections, demonstration and validation activities and technical assistance/manufacturing extension can help disseminate technologies and techniques to enhance energy productivity, economic development, and environmental performance.

[32] *National Research Council, Real Prospects for Energy Efficiency, Sec. 4.4.1.*

[33] *New York State Energy Research and Development Authority, “Contribution of CHP.”*

[34] *PJM, “Reliability Pricing Model”; ISO-New England, “Forward Capacity Market.”*

[35] *Shiver, Kenneth, Southern Co., personal communication, August 3, 2012.*

[36] *Alliance to Save Energy, “Utility Rate Decoupling.”*

[37] *National Action Plan for Energy Efficiency, “Aligning Utility Incentives,”3.*

[38] *Optimal Energy et al., “Energy Efficiency and Renewable Energy.”*

[39] *Opalka, “Ohio May Include CHP.”*

[40] *Chittim, “Follow the Leaders.”*

TECHNOLOGY

POTENTIAL AND OPPORTUNITY

The potential for improving manufacturing energy productivity is very large. Several DOE sector-based studies explored theoretical minimum energy intensities or maximum energy productivities that could be realized for several energy-intensive manufacturing sectors. These are illustrated in table 5.

Sector	2010 energy intensity*	DOE theoretical minimum*	Percent decrease	2010 energy productivity**	DOE theoretical maximum energy productivity**	Percent increase
Cement	54.7	20.3	63	0.018	0.049	172
Iron & steel	26.8	13.6	49	0.037	0.074	100
Aluminum	23.8	4.5	81	0.042	0.222	429
Chemicals	15.3	1.8	88	0.065	0.556	755
Pulp & paper	14.0	7.9	44	0.071	0.127	79

*Table 5. Energy intensity and energy productivity improvement potential for selected U.S. manufacturing industries, 2010.Source: Derived from Lovins and Rocky Mountain Institute 2011, Fig. 4.8, p. 146, based on DOE reports.Note: * = 1,000 Btu/2009 $ shipments; ** = 2009 $ shipments/1,000 Btu*

While there are numerous practical constraints to reaching theoretically possible manufacturing energy productivity, much progress is achievable. The Annual Energy Outlook reference and various alternative case scenarios project significant improvements (roughly one-quarter to one-third by 2030 or 2035) in U.S. manufacturing energy productivity due, in part, to structural changes in industry and shifts in feedstock materials but also to energy efficiency improvements of manufacturing processes and operations. Other studies (such as those noted by the National Research Council and conducted by ACEEE and the Rocky Mountain Institute) identify large efficiency improvement opportunities and scenarios. And there is a library of case studies, ranging from facility housekeeping measures to the introduction of significantly and even radically new production technology pointing to great energy productivity opportunities.

There are numerous crosscutting processes and technologies where advances offer very high potential for manufacturing energy productivity gains. Among these are sensors, controls, and associated energy management software; motor and drive systems; process heating; compressed air; CHP (sometimes referred to as cogeneration); and waste heat recovery. Here we discuss the last two as illustrations of energy productivity potential.

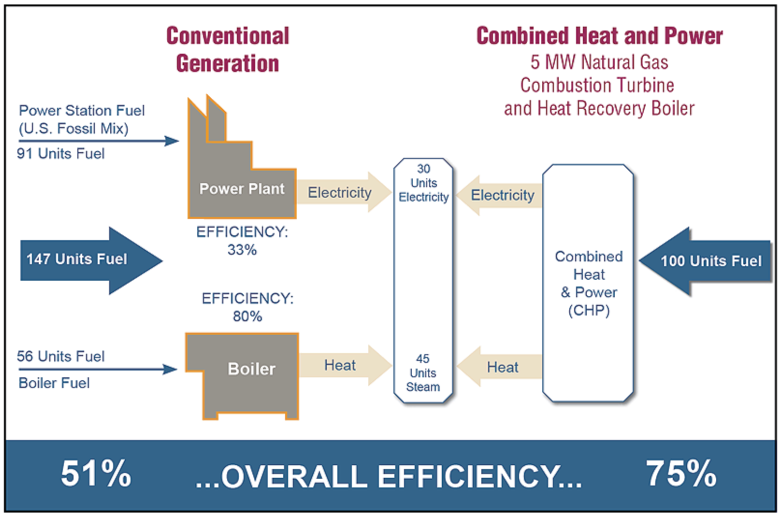

Figure 9. Comparison of CHP and separate heat and power efficiencies. Source: EPA, Combined Heat and Power Partnership.

While conventional thermal electric power plants discard about two-thirds of the energy value in fuel as waste heat, CHP plants capture both electric power and useful thermal energy from the same unit of fuel burnt. Figure 9 illustrates how CHP can deliver much higher efficiencies than separate heat and power, for example purchasing offsite utility power plus using an onsite boiler or furnace for heat. In the separate heat and power case, 154 units of energy in fuel are needed to deliver 75 units (30 of electricity and 45 of heat) for the plant's processes, yielding 49% energy efficiency. In contrast, in the CHP case 100 units of fuel energy deliver 75 units to the process, yielding 75% efficiency.

According to a study prepared for Oak Ridge National Laboratory, the United States has a substantial base of CHP and a still larger potential. In 2006 about 85 gigawatts (GW) of CHP capacity amounted to about 9% of U.S. generating capacity. It provided 505 million MWh of electricity or more than 12% of U.S. generation.[41] This translates to 1.9 Q of avoided fuel consumption. The great majority of CHP installations are at industrial facilities as shown in Figure 10.

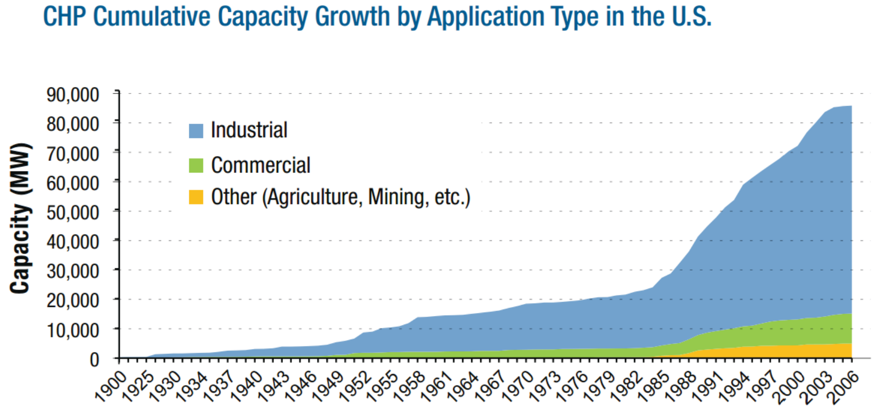

Figure 10. CHP cumulative capacity growth by application type in the United States.
Source: Shipley et al., "Combined Heat and Power," v.

The study suggested that it is feasible for CHP in industrial, commercial, and other sectors to expand to garner 20% of U.S. generation capacity by 2030 and to save 5.3 Q of fuel annually. Combined heat and power not only offers improved efficiency and concomitant fuel cost savings, but also reduces pollution emissions and provides energy reliability benefits.[42]

A DOE study reported that for many manufacturing processes, 20-50% of energy consumed is lost as waste heat in exhaust gases and liquids and from conduction, convection, and radiation from hot surfaces of equipment, materials, and products.[43] There can be significant opportunities to beneficially capture waste heat. These can amount to 10-50% improvements in energy efficiency for furnaces. Economizers, recuperators, regenerators, heat recovery steam generators, and other equipment can recover thermal energy to preheat fluids and materials, provide process or domestic hot water, and to generate electricity. Table 6 provides examples of waste heat sources and uses. While significant waste heat recovery is already done, 5-13 Q per year of heat from manufacturing processes is still lost.

WASTE HEAT SOURCES	USES FOR WASTE HEAT
» **Combustion Exhausts** Glass melting furnace Cement kiln Fume incinerator Aluminum reverberatory furnace Boiler » **Process off-gases** Steel electric arc furnace Air compressors Internal combustion engines » **Conductive, convective, and radiative losses from equipment:** Hall-Héroult cells[a] » **Conductive, convective, and radiative losses from heated products:** Hot cokes Blast furnace slags[a]	» **Combustion air preheating** » **Boiler feedwater preheating** » **Load preheating** » **Power generation** » **Steam generation for use in:** power generation mechanical power process steam » **Space heating** » **Water preheating** » **Transder to liquid or gaseous process steams**

a. Not currently recoverable with existing technology

Table 6. Examples of Waste Heat Sources and Uses
Source: DOE, "Waste Heat Recovery: Technology and Opportunities in U.S. Industry," table 1, p. 2.

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[41] *Shipley et al., "Combined Heat and Power," 12.*

[42] *The ORNL study offers the case of an Entenmanns bakery (Bayshore, N.Y.) that operated a CHP system and "didn't miss a beat" during the Northeast-Midwest blackout in the summer of 2003. Shipley et al., "Combined Heat and Power," 16.*

[43] *DOE, "Waste Heat Recovery," 3.*

Both economic and technical constraints impede better utilization of waste-heat resources, including first cost and payback periods; economy of scale effects; limited options for low-temperature heat use; site and application-specific constraints; and in some cases, corrosion, fouling, and chemical reactivity of exhaust streams. Waste heat recovery can be advanced by both increasing the use of off-the-shelf technologies in currently cost-effective applications and developing innovations to broaden the feasibility and benefits of waste-heat recovery.

INNOVATION, COMMERCIALIZATION AND PRODUCT LIFECYCLE

Advances in manufacturing energy productivity will depend on innovation, commercialization of innovations, and the diffusion of innovations into widespread practice.

Innovation is the act of developing and putting into use new products and processes. It can include totally new products and processes for new applications, new products and processes for existing applications, or the use of existing products and processes in novel ways. It is more than invention. It can take place through formal R&D or be a tweak to shop-floor practices. It can derive from scientific research or it can arise from customer or line worker insights. It can be the hardware of technology, materials, and physical products or it can be new organizational or management approaches.[44]

Commercialization is an attempt to profit from innovation. It is a business decision based on judgments about future returns on investment in product design and development, manufacturing, and marketing. Often commercialization means scaling up from prototype or small-scale application to larger-scale production and application. It often entails creation of marketing and distribution channels and after-service capabilities.

Diffusion of innovation is the spread of innovations. It can occur through regular market channels as products, technologies, and services are commercialized and sold, and through peer-to-peer professional exchanges. Education and training can also be the medium through which innovation spreads. And technical assistance—such as through agricultural and, apropos this paper, manufacturing extension services—can also play important roles.

Technological improvements important for raising energy productivity range from modest incremental changes in existing processes to radical changes in materials and processes. The application of information and communications technologies, including sensors; software offering modeling and simulation capabilities; and process controls often offer great improvements in energy and material efficiency, product quality, and productivity while reducing waste and pollution by allowing more precise control of production processes.

The characteristics of industrial innovation tend to vary with the maturity of the product. (See table 7.) Often in the early stages of a major technology, there are significantly different approaches that compete largely on functional performance. Think of competing steam-, gasoline-, and electric-powered early automobiles or of competing incompatible computer architectures among early personal computers. As a product enters the growth phase, typically the industry settles on a smaller number of standard offerings, competition becomes more sensitive to cost, and often profit margins decrease. Businesses seek to improve and differentiate their products through new features and components, including services, while also decreasing manufacturing costs. Finally, as a product becomes commodity-like, competition focuses on cost reduction, such as reducing energy costs, along with some enhancements in quality.[45]

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[44] *U.S. Congress, Office of Technology Assessment, "Innovation and Commercialization."*

[45] *Ibid., 48-49.*

Characteristics	Introductory Stage	Growth Stage	Mature Stage
Predominant type of innovation	Frequent major changes in products	Major process changes required by rising volume	Incremental for product and process, with cumulative improvement in productivity and quality
Competitive emphasis	Functional product performance	Product variation	Cost reduction
Stimulus for innovation	Information on users' needs and users' technical inputs	Opportunities created by internal technical capability.	Pressure to reduce cost and improve quality
Product line	Diverse, often including custom designs.	Includes at least one product design stable enough to have significant production volume	Mostly undifferentiated, standard parts
Production processes	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital intensive, and rigid; cost of change is high
Equipment	General purpose, requiring highly skilled labor	Some subprocesses automated, creating islands of automation	Special purpose, mostly automatic with labor tasks mainly monitoring and controlling
Materials	Inputs limited to generally available materials.	Specialized materials may be demanded by some suppliers	Specialized materials will be demanded; if not available, vertical integration will be extensive
Plant	Small-scale, located near user or source of technology	General purpose with specialized sections	Large-scale, highly specific to particular products

Table 7. Characteristics of Innovation in Different Phases of Industrial Development
Source: Abernathy and Utterback, "Patterns of Industrial Innovation."

While the product or technology innovation lifecycle generally follows the stages described above, there can be significant and even disruptive technological changes. They can be changes in the product itself (e.g., transition from piston to jet aircraft engines; vacuum tubes to transistors to integrated circuits; aluminum to composite aircraft parts; and, prospectively, internal combustion to electric drive autos) or in manufacturing processes (e.g., electroplating to vapor deposition and related processes for metal finishing; petroleum-based to bio-based chemical synthesis; rise of direct-reduction iron making; and emerging additive manufacturing approaches).

What this means for energy productivity of manufacturing is that there can be a wide range of improvement opportunities that differ across sectors based on market characteristics and industrial structure. Also the likely innovators, whether entrepreneurial startups or entrenched incumbent firms, also vary. Further, energy efficiency is only one of many motivations for and perhaps only a modest consideration in R&D, commercialization, and capital investment decision making. Labor and capital productivity; production volume; variety of product and service offerings; quality; environmental, health, and safety compliance; cost and reliability of energy and nonenergy inputs; and other factors impinge on profitability and competitiveness.t

Several case examples follow to illustrate a range of technological opportunities to improve manufacturing energy productivity—plant-level measures, a significantly new process, change from central to site-of-use chemical production, and a new material applicable to a broad array of industries.

CASE STUDIES

» Delta Faucet Co. Reduces Energy and Chemical Use for Degreasing

The machining department at Delta Faucet's Jackson, Tenn. plant operated seven degreasing tanks to clean faucet components. The tanks contained a coolant and washing compound heated to either 165°F or 185°F using natural gas as the fuel. In January 2003 the plant switched to an alternative coolant and replaced the washing agent with water. Degreased parts were much cleaner, showing one-tenth as much oil and grease as previously found. Plant personnel experimented with reducing tank temperatures and settled on room temperature for five tanks and 85°F for the remaining two, while maintaining a high level of cleanliness of the processed parts. Delta Faucet estimated annual savings of 2.8 billion Btu or over 99% of natural gas consumption for heating the tanks as well as $2,000 per month in reduced chemical costs.[46]

» Mesabi Nugget, LLC Commercializes New Iron Production Process

Mesabi Nugget commercialized a technology based on Kobe Steel's ITmk3 process for making high-purity iron from low-grade taconite ore. The process combines reduction and melting into a single-step process that saves 30% of the energy that would be required in conventional blast furnace iron making. The iron nugget product is comparable in quality to pig iron, but was expected to cost about half as much. The nuggets are suitable for use in electric arc furnace steelmaking operations, further reducing energy and emissions relative to traditional basic oxygen furnace based steelmaking.[47]

» Microchannel Reactor for Onsite Hydrogen Peroxide Production

Hydrogen peroxide (H_2O_2) is used in a variety of applications, including the pulp and paper industry, chemical synthesis, water purification, and health care. Conventionally H_2O_2 is centrally produced at high concentration then transported to customers who dilute it prior to storage and use. Standard H_2O_2 production technology is not suited to site-of-use production because of flammability and explosion hazard and corrosion and contamination concerns.

Stevens Institute of Technology and FMC Technology developed a microchannel reactor that enables users to produce on-site as-needed quantities and concentrations of H_2O_2. The technology has the potential to save 5 trillion Btu of steam and 3 trillion Btu of electricity annually at the production stage (not including transport and storage savings), which could trim 30% of production and transportation costs in a $1-billion-per-year industry. Safety and user productivity gains are also expected.[48]

» Aspen Aerogels Thermal Insulation Technology Applicable to Broad Range of Industries

With DOE support, Aspen Aerogels demonstrated the use of silica aerogels for steam system, duct, vessel, and other industrial insulation applications. Silica aerogels exhibit extremely low thermal conductivity allowing 50-80% less material to be used to achieve equivalent performance of other insulation types. The materials resist moisture and water vapor incursion and offer robust performance in harsh environments. The firm says that its product can accommodate complex geometries and can be installed more quickly than some alternative insulation materials.[49]

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[46] *Tennessee Department of Environment & Conservation, "Turn down the heat."*

[47] *DOE, "2008 Industrial Technologies Report," 51-52.*

[48] *DOE, "2008 Industrial Technologies Report," 55-56.*

[49] *DOE, "2008 Industrial Technologies Report," 57-58; Aspen Aerogel, "Case Studies."*

SCOPE AND TARGETS FOR MANUFACTURING ENERGY PRODUCTIVITY

In thinking about potential targets for advancing manufacturing energy productivity, we can distinguish between two major approaches. One is to focus on crosscutting technologies or practices applicable to a broad array of sectors. Among these are steam systems, process heating, motors and pumps, compressed air systems, sensors and process controls, and continuous energy improvement methodologies such as energy management systems (EnMS). The other approach is to look at industry-specific processes such as glassmaking, aluminum smelting, semiconductor production, and manufacture of particular pharmaceuticals. There is a continuum; some processes are more or less widely employed than others are, for example distillation, painting, refrigeration, machining. Opportunities for new technology R&D and for diffusion of existing technologies, techniques, and best practices through training and technical assistance exist across the continuum.

It is also important to look at manufacturing systems holistically to consider energy, economic, and other impacts beyond the factory floor and past a particular industry sector to the economy as a whole.

Consider the role of materials in the energy equation. If an assessment of a process or a plant's energy efficiency or productivity is based solely on energy in the form of fuels and electricity consumed, it will miss the energy embodied in materials, including water, that are used and, perhaps, wasted by the process or plant. Projected energy productivity gains in the aluminum and iron and steel industries derive in large part from anticipated growth in use of recycled stock. Reuse and recycling of paper, metals, plastics, glass, solvents, water, and other materials present very large savings of energy that would otherwise be needed to produce and process new materials. Figure 11 notes energy savings per ton recycled of selected materials. Beneficial use of byproducts, "downcycling" (recycling of a material into a lower value use), and energy recovery from wastes also represent large energy resources. However, avoiding wastes, residues, and scrap in the first place is best for material and energy productivity as well as for environmental performance.

As an illustration, a printed circuit board manufacturer that implements technology to extend plating bath life might, from a narrow perspective, be viewed as having lower energy efficiency or productivity than a plant that more readily discards used baths. This is because of the electricity needed to operate the bath life extension apparatus.[50] However, a broader view considering energy implications of reduced chemical and water consumption, avoided waste disposal, and, perhaps, recycling of recovered residues would likely find the plant employing bath life extension to be more energy productive.

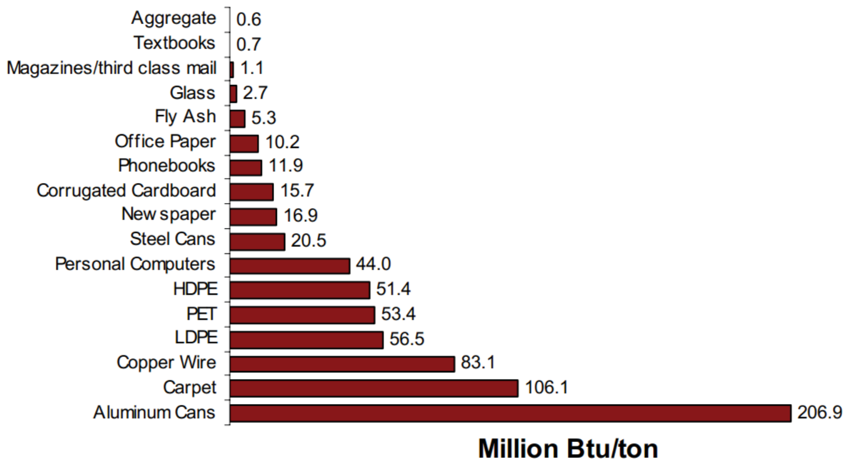

Figure 11. Energy savings per ton of material recycled. Savings comparisons are as compared to landfilling. Source: Choate, et al. 2005, Exhibit 1.

Another caution against construing energy productivity too narrowly is that the production of a more energy-intensive product or material can sometimes yield greater savings on a lifecycle basis as compared to a previous or alternative product or material. It is possible that it takes more energy per dollar of shipment, and is certainly so per unit of product, to produce a compact fluorescent light bulb (CFL) than an equivalent incandescent light bulb, but CFLs use far less energy than do incandescent bulbs. As another example, a holistic energy productivity or efficiency assessment comparing steel, aluminum, titanium, and composite alternatives for aircraft or automotive applications should consider weight and, thus, fuel economy impacts on the vehicles in which they will be used rather than only the Btu used per pound or dollar of product made at the factory.

This holistic approach of changing the choice of components used to make a product or of vendors from whom components are purchased in order to reduce nationwide energy use offers large potential savings. Such savings have never been evaluated on a nationwide basis, so they are an additional efficiency resource available. While not in broad use, consideration of supply-chain energy is used by some leading American companies to achieve significant savings in energy and cost.

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[50] *Nunno and Freeman, "Minimizing Plating Bath Wastes."*

RESEARCH AND DEVELOPMENT

A major impediment to achieving the promise of energy efficiency and productivity improvements is the chronic underinvestment in end-use energy technology and a somewhat discontinuous system of industrial R&D support in the United States compared to competing nations, such as Japan.

Both the public and private sectors have critical roles in supporting R&D. About two-thirds of U.S. R&D is funded by business and a bit over a quarter by government, with about 6% by academia and nonprofit organizations.[51] Government R&D support, through direct funding and via subsidies and incentives such as tax credits for business R&D, is economically justified because companies cannot fully appropriate the returns on such investment; that is, knowledge spillover will also benefit competitors.[52] Thus, industry tends to underinvest in R&D. In the energy field, externality costs of environmental impact and broader energy reliability and security matters also affect the rationale for public support of R&D.

According to the National Science Board's Science and Engineering Indicators 2010, the average R&D-to-sales ratio of all U.S. industry varied between 3.2% and 3.5% in the period 2003-2007. Excluding the six R&D-intensive industries (computers and electronics, chemicals, aerospace and defense, R&D services, and automotive), the average R&D-to-sales ratio is 1.4%.[53] (Industrial R&D for energy efficiency in manufacturing could not be determined from these data.) The U.S. corporate R&D tax credit was allowed to expire at the end of 2011.

R&D magazine estimated that industrial R&D in the energy sector would amount to $6.7 billion for 2012 in the United States and $17.9 billion globally.[54] The figures include R&D by utilities, manufacturers, and technology firms. It covers the spectrum of energy activities from production and generation through power transmission and distribution, including smart grid, to energy efficiency. Because of the breadth of these activities, it is difficult to make conclusions specifically about manufacturing energy productivity R&D. *R&D* also estimated that U.S. investor-owned utilities invest between 1.5-2.2% of net income on R&D activities, though it is likely that a very small fraction of that is for industrial energy end use. As compared to other innovation-based sectors of the economy and to the significance of energy industry to the national economy, the amounts are modest.

The Electric Power Research Institute, an organization of the electric utility industry, was estimated to have a total 2012 R&D budget of $279 million, of which almost $59 million is for Power Delivery & Utilization, a sector that includes transmission, distribution, grid operations, and related areas as well as energy end use.[55] These amounts are tiny fractions of the over $350 billion spent on electricity in the United States in 2009, of which $60 billion was spent by industrial customers.[56] For natural gas utilities, the end-use efficiency budget for the Gas Technology Institute in 2011 was $21 million. This is down from about $100 million per year in 1992, the high point of natural gas industry R&D.[57]

In the public realm, the major supporter of applied U.S. energy efficiency R&D is the DOE Energy Efficiency and Renewable Energy Office (EERE). EERE operates the Advanced Manufacturing Office, which was appropriated $96 million for FY 2010 and had an enacted funding level of $116 million for FY 2012. However, those Advanced Manufacturing Office budgets support various technical assistance, training, and outreach activities as well as R&D.[58] Other parts of DOE (such as the Advanced Research Projects Agency-Energy) and other federal agencies may also fund some pertinent R&D.

The National Science Foundation supports several programs that cooperate closely with industry, including Engineering Research Centers, Industry/University Cooperative Research Centers, and Partnerships for Innovations programs. These, some of which may have relevance to manufacturing energy productivity, garner less than 2% of the National Science Foundation budget.[59] Also the National Institute for Standards and Technology created an Advanced Manufacturing Technology Consortium, which was budgeted $12.3 million for 2011.[60]

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[51] *National Science Board, Science and Engineering Indicators 2010, chapter 4.*

[52] *Patents and other intellectual property protections are also pertinent.*

[53] *National Science Board, Science and Engineering Indicators 2010, chapter 4.*

[54] *Grueber and Studt, "2012 Global R&D Funding Forecast."*

[55] *Ibid.*

[56] *DOE, "Annual Energy Review,", table 3.6.*

[57] *Edelstein, Ron (Gas Technology Institute). 2012. Personal communication. August 3*

[58] *Alliance to Save Energy, "FY 2013 Federal Energy Efficiency."*

[59] *Ezell, "Revitalizing U.S. Manufacturing."*

[60] *Ibid.*

In comparison, Japan's New Energy and Industrial Technology Development Organization is the country's largest public R&D management organization. It coordinates technology development activities in collaboration with the industrial, academic, and governmental sectors, and undertakes technology development and demonstration projects pertinent to energy and global environmental problems and to enhancing Japanese industrial competitiveness.

The New Energy and Industrial Technology Development Organization fiscal year 2011 budget was about $1.7 billion. That included about $875 million for clean energy, which includes energy efficiency, and about $49 million for new manufacturing and robotics national projects. It also included $241 million for "Practical Application and Commercialization Promotion Activities" and $114 million for "Energy Conservation Introduction and Dissemination Activities" in the industrial and buildings sectors.[61] The New Energy and Industrial Technology Development Organization offers direct financial support for introducing and deploying clean energy technologies to bridge initial market development gaps. In addition to programs such as this, Japanese utilities also fund dedicated research facilities for industrial customers, such as the Industrial Gas Utilization R&D Center operated by the Osaka Gas Company.

As previously discussed, technological innovation is more than R&D (and may occur without formal R&D). It requires commercialization and deployment to be useful. Though partly discussed above, the roles of technical assistance and demonstration and validation activities are covered later in this paper.

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[61] *Total budget noted in the text above does not include about $276 million for Kyoto Protocol mechanism-related activities. New Energy and Industrial Technology Development Organization, "Profile of NEDO."*

HUMAN BEHAVIOR

Human behavior is influenced by many factors in very complex ways and is the purview of several scientific disciplines. Here we discuss three major factors that affect decisions to develop and deploy energy productivity improvements in industry: (1) motivation and management, (2) knowledge, skills, and training, and (3) perceptions of risks and benefits. These factors interrelate and some of the discussion here overlaps with other sections of the report because human behavior mediates investment and technical decision making and interacts with government and governance issues discussed in later sections.

MOTIVATION AND MANAGEMENT

Individual employees and managers may be driven to pursue energy efficiency based on personal interests and passions to save energy, protect the environment, or achieve other societal or even moral objectives. However, corporate or organizational structures and procedures can either propel or impede the motivation for identifying and implementing energy productivity improvements.

Companies can be biased in favor of investments that increase production and product offerings over cost savings options that have the same or better financial returns. We can expect that managers and line personnel may be more motivated to pursue energy efficiency if energy costs are charged to their production units and, thus, to their financial performance than if such costs were charged to a separate overhead function. Also recognition and reward for energy savings ideas can motivate energy saving innovations on the shop floor and in corporate halls. The question, “Are there incentives for staff and management to save energy?” leads to related questions:

» Are managers better rewarded for getting a product out the door than they are for reducing energy and other costs?

» Does the company or organization seek to integrate energy management into core management processes or is it treated as a separate, ancillary function?

» Is there a policy and culture of continuous improvement, and does that apply to energy management?

» Does the company value energy and environmental performance as part of its image and reputation?

» Does the company take energy productivity into account when planning new production facilities and processes?

» Are facility managers, product managers, and production staff accountable for energy and related costs? Is management of such costs part of performance evaluations?

» Do facilities retain at least part of the money realized from saving energy or do savings revert to the corporate treasury?

» Does the company or organization operate an incentive program that recognizes and rewards individuals and teams for their energy productivity ideas and efforts?

These questions are familiar to those who have studied or enacted management systems focused on advancing quality and environmental performance in past years. In the 1980s, a quality movement arose in the United States and elsewhere, particularly following the rapid rise of highly competitive, high-quality automobiles, electronics, and other products from Japan. Companies developed programs to raise quality by engaging and incentivizing employees, customers, and suppliers; integrating quality considerations into core decision making, rather than leaving such issues to separate quality-assurance/quality-control functions; and instituting a culture of continual improvement with an objective of zero defects. The International Organization of Standardization (ISO) 9000 set of standards is perhaps the most widely recognized formal quality management system.

Subsequently, efforts to go “beyond compliance”, to perform better than regulations require; engage employees, supply chains, and other stakeholders; and achieve continual improvement in the environmental realm led to development of environmental management systems, including the ISO 14000 series of standards. Now, ISO has published the ISO 50001 Energy Management Standard for energy management systems (EnMS). Early implementation is underway in the United States with support of the DOE-sponsored Superior Energy Performance (SEP) certification program.

Table 8 lists early participants in SEP that have achieved certification.

Name of Facility	Energy Performance Improvement*	Year of Certification
SEP PLATINUM		
» Volvo Trucks, NA: Dublin, VA	25.8%	2012
» Dow Chemical COmpany, manufacturing plant: Texas City, TX	17.1%	2011
» 3M Canada Company: Brockville, Ontario, Canada	15.2%	2012
SEP GOLD		
» Cook Composites and Polymers Co.: Houston, TX	14.9%	2010
» Allsteel: Mascatine, IA	10.2%	2012
SEP SILVER		
» Dow Chemical Company, energy systems plant: Texas City, TX	8.1%	2011
» Owens Corning: Waxahachie, TX	9.6%	2010
» Nissan, NA: Smyrna, TN	7.2%	2012
» Freescale Semiconductor Inc.: Oak Hill, TX	6.5%	2010

Table 8. SEP Certified Facilities
Source: U.S. Council for Energy-Efficient Manufacturing.
** Energy Performance imporvements were achieved over a period of two to three years.*

Whether or not adopted through a formal EnMS, successful cases of companies, manufacturing and nonmanufacturing, integrating energy efficiency into their organizations commonly feature the “seven habits” identified in a report prepared for the Center for Climate and Energy Solution (formerly the Pew Center on Global Climate Change). These key features are shown in Table 9.

1. EFFICIENCY IS A CORE STRATEGY
» Efficiency is an integral part of coproate strategic planning and risk assessment and is not just another cost management issue or sustainability "hoop" to jump through. » Efficiency is an ongoing part of the organization's aspirations and metrics for itself.
2. LEADERSHIP AND ORGANIZATIONAL SUPPORT IS REAL AND SUSTAINED
» At least one full-time staff member is accountable for energy performance. » Corporate energy management leadership interacts with teams in all business units. » Energy performance results affects individuals’ performance reviews and career advancement plans. » Energy efficiency is part of the company’s culture and core operations. » Employees are empowered and rewarded for energy innovation.

Table continued on the next page

3. THE COMPANY HAS SMART EFFICENCY GOALS

» Goals are organization-wide.
» Goals are translated into operating/business unit goals.
» Goals are specific enough to be measured.
» Goals have specific target dates.
» Goals are linked to action plans in all business units.
» Goals are updated and strengthened over time.

4. THE STRATEGY RELIES ON A ROBUST TRACKING & MEASUREMENT SYSTEM

» The system collects data regularly from all business units.
» The data is normalized and baselined.
» Data collection and reporting is as granular as possible.
» The system tracks performance against goals in a regular reporting cycle.
» Performance data is visible to senior management in a form they can understand and act upon.
» Energy performance data is shared internally and externally.
» The system is linked to a commitment to continuous improvement.

5. THE ORGANIZATION PUTS SUBSTANTIAL EFFORTS INTO EFFICIENCY

» The energy manager/team has adequate operating resources.
» Business leaders find capital to fund projects.
» Companies invest in human capital.

6. THE ENERGY EFFICIENCY STRATEGY SHOWS DEMONSTRATED RESULTS

» The company has met or beat its energy performance goal.
» Successful energy innovators are rewarded and recognized.
» Resources are sustained over a multi-year period.

7. THE COMPANY EFFECTIVELY COMMUNICATES EFFICIENCY RESULTS

» An internal communications plan raises awareness and engages employees.
» Successes are communicated externally.

Table 9. The Seven Habits of Highly Efficient Companies
Source: Prindle, Table ES-1, p. vi.

The Dow Chemical Company offers a strong example of a manufacturing firm that has integrated energy efficiency into its culture. The company's Louisiana Division implemented energy contests in 1981 that offered capital to winning energy efficiency submissions leading to high-return efficiency successes. The approach, started as a bottom-up effort in one part of the company, garnered top management support, was modified and extended across the company, and grew to include the Waste Reduction Always Pays (WRAP) program to reduce pollution and wastes.[62] The company's EnMS includes strong top-management commitment; aggressive and clear publically stated energy goals; effective organizational structures with cross-functional teams and clear lines of accountability; rigorous measurement, tracking, and reporting systems; strong communications to internal and outside stakeholders; and rewards to individuals and business units for energy efficiency innovations.[63] The company's manufacturing energy intensity, measured in Btu per pound of product, has improved more than 40% since 1990, saving the company a cumulative $24 billion and 5,200 trillion Btu.[64] This is roughly equivalent to 5% of annual U.S. energy use. Dow is now in the process of adopting the new ISO 50001 standard and is a participant in the DOE SEP certification program.[65]

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[62] *Baker, "Dow Chemical Company."*

[63] *Prindle, "From Shop Floor to Top Floor," 84.*

[64] *Dow Chemical Co.*

[65] *For more on Superior Energy Performance, see* [http://www.superiorenergyperformance.net/.](http://www.superiorenergyperformance.net/)

KNOWLEDGE, SKILLS, AND TRAINING

Productivity improvements—energy or otherwise, in manufacturing and elsewhere—are a function of human as well as physical capital. Energy productivity advances will depend on the knowledge, skills, and training of management, technical staff such as specialist energy managers, and production personnel to develop and implement improvements and operate existing processes efficiently. There is a need for energy and process expertise both in-house at companies and facilities as well as for outside consultants and technical assistance providers.

Although, as noted previously, there are various crosscutting manufacturing technologies (e.g., boilers and steam systems, motor systems), there are many industry-specific processes. This means that while commercially available training, credentials, and service providers exist for some energy systems like boiler tune-ups and steam system maintenance, they are not readily available for others. The limited pool of expertise impedes opportunities for energy service companies to provide to manufacturing industry the types of energy efficiency services that they provide in the commercial and institutional buildings sector. It also means that manufacturing extension, utility technical assistance staff, and similar assistance providers often lack in-depth understanding of client processes, thus constraining the advice they can effectively provide their clients.

Insufficient company energy expertise may not only constrain energy performance in existing operations and opportunities for in-house improvements, it can also limit the ability to assess advice from outside, including advice from vendors with an interest in making a sale and of technical assistance providers who, as noted, may be viewed as being insufficiently expert.

This leads to challenges of risk and reward perception in the face of uncertainty.

PERCEPTIONS OF RISKS AND BENEFITS

Manufacturers have to make decisions in the face of uncertainty all the time. What will demand be? What will be the costs of my inputs, including energy? What are my competitors doing? Will regulations change and will I be affected? And so forth.

Energy efficiency investment decisions are not only accompanied by questions about what costs may be of different fuels and energy supply options, but also by incomplete, uncertain, and perhaps untrusted information on the performance of energy efficiency options. Can I trust the equipment vendor who wants to make a sale or the technical assistance advice of an outsider? Whether suggested by in-house or outside sources, is the new or modified technology, equipment, or practice cost effective? Is it reliable? How will it affect productivity and product quality? Is it compatible with current operations or will it disrupt them? If it does not work as well as expected, how much cost or damage will my business suffer?

Everett Rogers described variables that affect the rate of adoption of innovations.[66] Among these are perceived advantage, compatibility, complexity, trialability, and observability. Potential adopters of new technologies are often skeptical of performance claims made by vendors and assistance providers, and they are also concerned about compatibility with existing processes, products, skill sets, and business relationships and practices. Will a new technology or practice require refurbishing equipment or retraining staff? Will there be downtime or other disruptions to operations, and at what cost? Will well-established relationships with suppliers and customers be affected? Potential adopters may also be uncomfortable if a new approach appears complex.

Trialability and observability are important for resolving questions of relative advantage and compatibility of the proposed technology or practice. Being able to try the new approach on a portion of a production line or facility allows the potential user to mitigate risks of disrupting large parts of its operations for something that may not deliver the expected benefits. Observability, meaning the ability for others to discern the results, is also important for diffusing techniques. Seeing a technology or practice work at one plant or in a demonstration facility can give confidence that it will work at the observer's own facility.

These factors have implications for disseminating energy-productivity improvements in manufacturing. Federal and state agencies and vendors provide various fact sheets, case studies, tool kits, decision software, and other products to help promote energy-efficient manufacturing (or, in the case of vendors, to market their products and services). Information exchanges, mentoring, on-site energy assessments, technology demonstration and validation activities, and on-site technology trials are approaches available to reduce the uncertainty and risk of trying new technologies and techniques, whether related to energy productivity improvements or manufacturing improvements generally.

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[66] Rogers, *Diffusion of Innovations*, chapter 6.

A study from the allied field of pollution and waste reduction illustrates the relative effectiveness of different approaches toward technology diffusion. The Illinois Waste Management and Resource Center (WMRC, now the Illinois Sustainable Technology Center) examined impacts of several forms of outreach it employed in the 1990s to further the use of available but poorly deployed technologies for reducing wastes in the metal finishing industry.[67] The study noted that such technologies as conductivity controls, evaporators, ion exchange, and reverse osmosis had been commercially available for years and shown to be technically and economically beneficial in numerous contexts but had a market penetration rate at the time of around 10%.

WMRC found that awareness information (e.g., discussions, literature) alone had little effect on technology adoption. Potential users tended to require deeper how-to assistance such as on-site demonstrations and trials of technologies before deciding to adopt new technology. The how-to assistance allowed companies to become more familiar and comfortable with technologies, particularly when trials were done with their own parts and chemical baths. This addressed both the trialability and observability traits identified by Rogers. The WMRC study observed the importance of vendors. In one case a chemical vendor worked with WMRC to resolve compatibility questions, leading that vendor to identify a market opportunity and become an advocate for the pollution-preventing technology. Yet in another case, a vendor saw the technology as a threat to its sales and actively discouraged adoption by falsely claiming incompatibilities.

It is the job of vendors, not public agencies, to sell new technologies, products, and services. Vendors are vital to advancing energy productivity and other manufacturing performance advances. For vendors, demonstrations and trials can assuage skepticism about technology performance. Also, vendors providing third-party verifications of technology performance can reduce uncertainty about their offerings.[68] . In some cases electric and natural gas utilities operate centers to demonstrate, sometimes with clients' parts, commercially available energy productivity technologies.

CASE STUDY

» Alabama Power and Georgia Power Technology Application Centers

Alabama Power and Georgia Power, subsidiaries of Southern Company, operate Technology Application Centers (TACs) located in Birmingham, Ala. and Atlanta, Ga. as demonstration facilities to help industrial customers reduce production costs, improve energy efficiency, increase productivity, improve product quality, and address environmental concerns. The TACs focus on a variety of technologies, such as infrared heating, induction heating, ultraviolet curing, waste-heat recovery, compressed-air systems, advanced lighting, and comfort heat technologies. They demonstrate the application of these technologies to such processes as powder coating, curing, drying operations, burn-off operations, energy cost reduction, and many others. The TACs assist customers with problem solving and demonstrate manufacturing applications using customers' parts and products. They also provide technical assistance, manufacturing process evaluations and materials analyses to help improve production processes.

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[67] *Lindsey, "Key Factors for Promoting."*

[68] *The EPA operates the Environmental Technology Verification (ETV) program to provide third-party validation services in a number of environmental technology categories. The Department of Defense operates the Environmental Security Technology Certification Program (ESTCP) that demonstrates and validates environmental and energy technologies that address defense environmental needs. Some of the technologies verified by the programs are pertinent to manufacturing. Several other verification programs have operated at federal and state levels and abroad, some of which are focused on particular environmental technology categories.*

GOVERNMENT AND GOVERNANCE

Government and, more broadly, governance—which can include private sector policies, management systems, industry standards, and professional norms—have been referred to numerous times in the previous sections. They directly and indirectly, and advertently and inadvertently, influence investment and management decisions in industry, including those related to energy and energy productivity.

Government's role in U.S. society, including policies on energy, environmental protection, technology development, and industrial competitiveness is subject to vociferous debate. But that is nothing new.[69]

The list of pertinent government (federal, state, and local) policy topics is long—R&D, technology demonstration and validation, technical assistance, voluntary programs, tax provisions, intellectual property, antitrust, environmental regulations, land use and facility siting, utility ratemaking and regulation, public procurement, education and training, and others. This section centers on several of these that are most germane to advancing manufacturing energy productivity.

TAX POLICIES AND DEPRECIATION RULES

Significant improvements in energy productivity can arise from replacing old capital stock with new, more efficient technologies and equipment. The 2012 Annual Energy Outlook and others' projections link energy intensity and productivity improvements to new capital investment. Making depreciation schedules and other tax provisions more favorable to new capital investment could enhance energy productivity while expanding overall industrial competitiveness. Tax credits for new plant and equipment should also be considered.

Depreciation schedules for individual types of equipment can impede investment in the most energy efficient options. For instance, as noted previously, back-up generators, a seldom-used asset, depreciate over 3 years while a CHP system that delivers ongoing energy efficiency and reliability benefits has a 20-year depreciation schedule. Sometimes the same or similar equipment have different depreciation schedules based on the industrial sector in which the equipment is installed, rather than on engineering-based estimates of the actual life of the asset. If recovery periods are too long, they may encourage continued operation of out-of-date equipment and discourage replacement with new more efficient equipment.[70]

That tax and accounting standards treat fuel and purchased energy as expenses, while energy-savings capital investments must be capitalized and depreciated over time, may insert a bias against energy productivity investments.[71]

Renewal of the corporate R&D tax credit and prospective strengthening of R&D tax incentives could support increased industrial technology innovation, including advances favorable for energy productivity.

A more fundamental issue in tax policy and its relation to energy is that the American tax system relies more on taxing desirable activities (investment, savings, and income) rather than such things as pollution and waste that impose costs (negative externalities) to society at large. A move to tax "bads" rather than "goods" can have a significant effect on the attraction of energy productivity investment.

PROMOTING ENERGY MANAGEMENT SYSTEMS (ENMS) AND CONTINUOUS IMPROVEMENT

Corporate/organizational management policies and procedures are critical to providing motivation for energy productivity advances. Companies that engage and provide incentives to employees and managers as well as customers, suppliers, and other stakeholders can identify profitable opportunities to reduce costs, improve quality, and enhance product offerings.

The ISO series of management standards for quality, environmental, and, now, energy management (ISO 50001) promote several

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[69] *Alexander Hamilton, in his Report on Manufactures, advocated policies to promote American manufacturing, including moderate tariffs to provide limited protection to young American industry and to supply revenues for government, infrastructure investment, and subsidies to industry. Thomas Jefferson and James Madison were, at least initially, among Hamilton's opponents.*

[70] *Sachs et al., "Depreciation."*

[71] *National Research Council, Real Prospects for Energy Efficiency, Sec. 4.5.*

factors: incorporation of those factors into core corporate decision-making; commitment by top management; employee and stakeholder engagement; clear and quantified goals, metrics, and documentation; favorable management and accountability structures; and a culture of continual improvement.

Such management systems are matters of corporate and organizational governance, rather than of government policy. However, the DOE Superior Energy Performance program offers at least one way to promote EnMS. Technical assistance, peer exchanges, and other voluntary means can also allow government to help promote EnMS. In previous years EPA and state environmental agencies helped raise awareness of and promoted environmental-management programs. Prior to that, the U.S. Department of Commerce's National Institute for Standards and Technology (NIST) helped advance quality management systems through such means as the Baldrige Program and the Malcolm Baldrige National Quality Award.[72]

Further, EnMS can be encouraged through supply-chain relationships. Quality and environmental management system adoption grew as major firms and governments started to prefer or even require pertinent certifications from their suppliers. Government procurement preferences could strengthen incentives for EnMS adoption.

TECHNOLOGY DEVELOPMENT AND DIFFUSION

Government and the private sector both have roles to play in technology development and diffusion. Direct government support of R&D is most justified for basic and generic research where firms' R&D investments are most likely to yield knowledge that spills over to benefit rival companies as well. Further, government missions such as defense and externality costs, including environmental impacts and energy security vulnerabilities, also justify direct government involvement.

Beyond direct funding, federal and state governments can, and sometimes do, support public–private R&D consortia and collaboration, provide R&D tax incentives, and offer other incentives and facilitation of pertinent R&D.

Demonstration and validation of emerging technologies and techniques are also important for translating the fruits of R&D into real world deployment. There can be a government role to support and incentivize such activities. At times government can provide test beds for demonstration and validation activities. The DOE Advanced Manufacturing Office is establishing its first manufacturing demonstration facility at Oak Ridge National Laboratory.[73] The Department of Defense Environmental Security Technology Certification Program (ESTCP) performs demonstration and validation activities for environmental technologies needed to support defense missions.[74] Most technologies validated by ESTCP are outside the energy area and address such topics as waste management, site remediation and pollution prevention and control, and some of the energy-related projects concern nonmanufacturing activities. However there is opportunity for demonstrating energy productivity manufacturing technologies in the defense manufacturing base and in depot-level maintenance operations.

Large manufacturing energy productivity improvements are available from off-the-shelf technologies and techniques and through incremental shop-floor modifications. Manufacturing extension is an important avenue for accelerating the diffusion of productivity- and competitiveness-advancing approaches to businesses.

The main U.S. manufacturing technical assistance program is the Hollings Manufacturing Extension Partnership program (MEP) administered by NIST. It is a cost-shared program with one-third federal funding (about $100 million) matched by state and local governments and recipient company funding.[75] The program focuses on small and medium-sized enterprises (SMEs). Studies indicate that every federal dollar provided to MEP yields $32 of economic benefit and that one manufacturing job is retained for each $1,570 of federal investment.[76] In comparison, the Japanese government funds its analogous program, Kohsetsuhi Centers, at $2 billion annually while the similar United Kingdom Technology Strategy Board is funded at nearly $390 million annually. As a proportion of GDP and compared to U.S. federal funding of MEP, these Japanese and British programs are funded at a 54 and 20 times higher level.[77] Canadian and German SME manufacturing programs are also funded at an order of magnitude or higher rates than is MEP on a per dollar GDP basis.[78]

[72] *"About Us."*

[73] *DOE, "Manufacturing Demonstration Facilities."*

[74] *Marqusee, "Military Installations and Energy Technology Innovation."*

[75] *Ezell, "Revitalizing U.S. Manufacturing."*

[76] *National Institute of Standards and Technology, "Manufacturing Extension Partnership."*

[77] *Ezell and Atkinson, "National Manufacturing Strategy."*

[78] *Ezell, "Revitalizing U.S. Manufacturing."*

There are other technical-assistance resources for American manufacturers, some focused on energy and some not. The DOE Advanced Manufacturing Office supports 24 university-based Industrial Assessment Centers (IAC) that offers SME manufacturers energy audits and advice provided by engineering faculty and students.[79] The IAC garner about $4 million of federal funding annually.[80] The DOE also supports eight regional Clean Energy Applications Centers (CEACs) that offer technical assistance, education and outreach, and market assessments to promote CHP, waste heat recovery, and district energy applications.[81] The CEACs are gearing up to provide focused technical assistance to boiler operators that will be affected by new hazardous air pollutant rules to help promote efficiency and competitiveness improvements along with environmental compliance; a pilot program in partnership with state agencies operates in Ohio. In addition, the EPA has several outreach and recognition programs, such as Energy Star for Industry and the CHP Partnership that provide some support and information resources for manufacturers.

Also, there are networks of state and local economic development, pollution prevention, and small-business environmental-assistance programs that perform outreach and technical assistance to manufacturing businesses. These programs vary widely in resources, capabilities, and expertise.

The NIST MEP, DOE, and EPA collaborate with the Departments of Labor and Agriculture and the Small Business Administration, state and local agencies, Small Business Development Centers, community organizations, and other bodies to provide technical assistance related to energy and environmental sustainability and lean manufacturing through the E3: Economy, Energy and the Environment collaborative. E3 focuses on SME manufacturers and their communities and helps coordinate technical assistance provision.[82]

While non-governmental, some electric and natural gas utilities provide technical assistance to manufacturing customers. For instance, the Alabama Power and Georgia Power Technical Applications Centers collaborate with regional IAC that provide energy audits and advice in their service territories.

Beyond the E3 program, it is not clear to what extent, if any, these various programs coordinate or collaborate with each other, leading to disjointed provision of services to manufacturing. It is also not clear if these various programs heed principles of technology diffusion and the lessons exemplified in the Illinois Waste Management and Resource Center study described earlier.

ALIGNING UTILITY INCENTIVES WITH INDUSTRIAL ENERGY EFFICIENCY

Electric and natural gas utilities play an important in supporting energy efficiency in manufacturing and generally. Energy utilities are highly regulated. Their motivation and ability to support energy efficiency is highly dependent on the legal and regulatory framework in which they operate, including how utility commissions determine rates; criteria for allowable investments; and incentives or mandates to pursue energy efficiency and renewable energy.

A summary of factors affecting energy utility relationships with manufacturing and industrial energy productivity follows.

» Various states have altered rate designs, including enacting decoupling and related approaches, to allow utilities to be financially indifferent to distribution volumes that may be affected by energy efficiency programs.

» New rate approaches in some states and organized independent system operator (ISO) markets recognize the value of demand resources such as energy efficiency, CHP and distributed generation, and demand response for meeting energy demand and supporting power quality and reliability.

» However, some have identified rate structures, interconnection procedures, and other processes as impeding industrial CHP. [83]

» Various states have enacted energy efficiency resource standards, renewable or alternative electricity standards that include energy efficiency, requirements for utilities to procure “all cost-effective energy efficiency,” and financial incentives to either promote or require energy savings. Some of these programs are administered by utilities, while others are run by state agencies or contracted third parties.

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[79] *DOE, “Industrial Assessment Centers.”*

[80] *Alliance to Save Energy, “FY 2013 Federal Energy Efficiency.”*

[81] *DOE, “Clean Energy Application Centers.”*

[82] *E3: Economy, Energy and the Environment, “About E3.”*

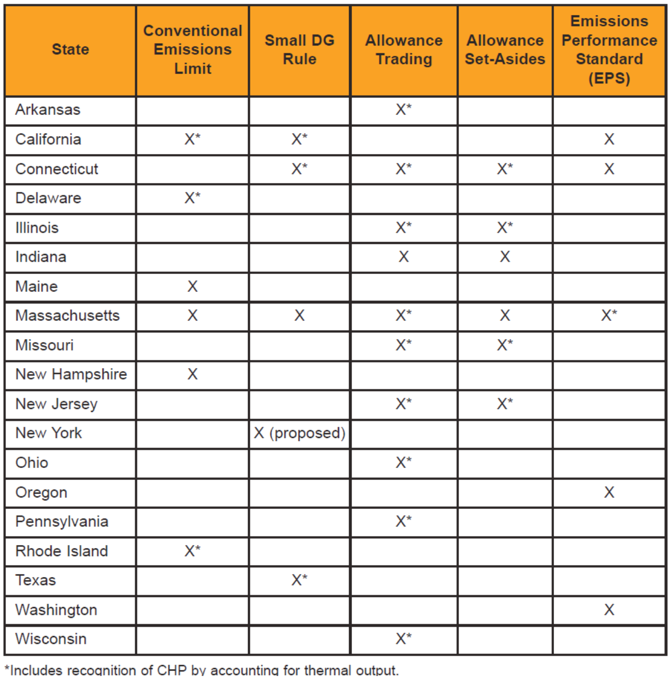
[83] *Shipley et al., “Combined Heat and Power,” 8.*

- Efficiency program metrics and schedules sometimes are perceived to favor residential and commercial measures over some larger and longer payback industrial-efficiency measures.
- Industrial utility customers might oppose ratepayer utility-efficiency programs that can benefit competing companies. Some states allow companies to opt out of such programs and might require firms to make equivalent self-directed energy efficiency investments, though such alternatives investments may not be verified.[84]
- Inclusion of CHP and waste heat recovery in energy efficiency resource standards and renewable electricity standards could enhance industrial efficiency, though there are concerns that inclusion could come at the expense of other efficiency and renewable energy options. Also, utility rules and rate structures can be designed to encourage utility support of CHP and other distributed energy assets to encourage energy efficiency.
- Some utilities have supported energy-productivity technical assistance.
- Utility support for end-use efficiency R&D, including through the Electric Power Research Institute and Gas Technology Institute, are miniscule relative to revenues.
- The centrality of electric and natural gas utilities to energy delivery, their strong customer relationships, and their administration of efficiency programs in many states make them vital to advancing manufacturing-energy productivity and energy efficiency generally. Continued attention to utility governance and regulation is deserved.

ENVIRONMENTAL REGULATIONS AND POLICIES

Environmental regulations and policies can better recognize energy-efficiency as a means to improve environmental quality, including in air quality planning and regulation. Environmental regulations can be made more innovation friendly and conducive to energy efficiency as an environmental compliance strategy if they are well designed.

The EPA and state environmental agencies increasingly recognize energy efficiency as a pollution-prevention approach and a means to reduce environmental compliance costs.[85] A growing number of air pollution rules promulgated under the Clean Air Act incorporate output-based standards that define allowable pollution levels per unit of useful output (electricity, useful heat, or manufactured product) rather than on the basis of input fuel. This provides additional incentive and some compliance flexibility for improving production efficiency as a means to help achieve regulatory compliance.[86] Also, several rules for electric-generating units provide a thermal credit for recovery of useful heat, giving some regulatory incentive for CHP and waste-heat recovery approaches. A number of states have enacted output-based standards, some with thermal recovery credits, which can encourage CHP applications. See Table 10.



State	Conventional Emissions Limit	Small DG Rule	Allowance Trading	Allowance Set-Asides	Emissions Performance Standard (EPS)
Arkansas			X*		
California	X*	X*			X
Connecticut		X*	X*	X*	X
Delaware	X*				
Illinois			X*	X*	
Indiana			X	X	
Maine	X				
Massachusetts	X	X	X*	X	X*
Missouri			X*	X*	
New Hampshire	X				
New Jersey			X*	X*	
New York		X (proposed)			
Ohio			X*		
Oregon					X
Pennsylvania			X*		
Rhode Island	X*				
Texas		X*			
Washington					X
Wisconsin			X*		

*Includes recognition of CHP by accounting for thermal output.

Table 10. State Output-Based Environmental Regulations
Source: EPA 2011a, Table 2.
Note: The table notes several forms of air quality regulations and management mechanisms in which states have incorporated output-based standards and also where thermal credit for CHP is recognized.

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[84] *Chittim, "Follow the Leaders."*

[85] *Among various examples, prominence of energy efficiency in greenhouse gas Best Available Control Technology guidance; inclusion of integrated planning model (IPM) analyses of demand-side energy efficiency measures in the Notice of Proposed Rulemaking for the Mercury and Air Toxics Standard in the National Emission Standards for Hazardous Air Pollutants From Coal- and Oil-Fired Electric Utility Steam Generating Units, 76 FR 24976; EPA recognition and support for energy efficiency nitrogen oxide (NO_x) allowance set-asides; inclusion of energy-efficiency provisions in the recently issued area and major source "boiler MACTs"; and EPA support for ENERGY STAR, the State Energy Efficiency Action Network (and its predecessor, National Action Plan for Energy Efficiency), and the CHP Partnership.*

[86] *EPA, "Output-Based Environmental Regulations."*

Further, though less directly applicable to manufacturing facilities, the EPA is trying to revive approaches to allow states and tribes to credit end-use energy efficiency and renewable energy programs and policies in their air quality plans (State and Tribal Implementation Plans).[87] This could encourage states to implement or enhance energy-efficiency programs. Also, in its potential future regulations for existing power plant greenhouse gas emissions, EPA could allow credit for reduced utilization (and thus lower emissions) resulting from end-use efficiency, including at industrial and manufacturing facilities.

The EPA is also collaborating with DOE and states in providing technical assistance to help industry enhance efficiency and environmental performance and compliance. For instance, the EPA helps support a pilot project in Ohio in which the DOE-supported Midwestern Clean Energy Applications Center is offering assistance to large boiler operators on options available for complying with new hazardous air pollutant rules, including the economic and operational feasibility of various efficiency upgrades. Also the EPA's CHP Partnership, Energy Star for Business, and other voluntary programs can help simultaneously advance energy efficiency and environmental performance in industry.

Finally, regulatory delay, which has many causes, can slow capital investment. It is difficult to make decisions on expensive and long-lived capital assets when the schedule and form of future regulations or legislation, environmental or otherwise, have yet to be finalized.

This summary covers only a few aspects of a few government and governance issues that seem likely to significantly affect manufacturing energy productivity. However, other issues may turn out to be important too, including trade, intellectual property, antitrust, education, and other policies.

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[87] *EPA, "***Roadmap for Incorporating Energy***."*

CONCLUSION

There are large opportunities for improving the energy productivity of American manufacturing. The 2012 Annual Energy Outlook base case projections are for manufacturing energy productivity improvements of roughly one-third by 2035, but others project greater improvements.

Productivity gains are projected to arise both from changing industrial structure as the share and mix of production changes over time and from energy-efficiency advances for particular processes and technologies.

Material productivity, including water productivity, is integral to manufacturing energy productivity. Reducing waste and increasing reuse, recycling, and the beneficial use of otherwise wasted materials can enhance energy productivity. However, shifts to lower grade feedstock (such as lower grade ores and heavier oils for refining) could increase the energy required per unit of manufactured product.

Materials also feature in considering lifecycle energy impacts of products. A more energy-intensive product, such as a specialty alloy or composite material, can yield great energy savings in its use, for example in aircraft and vehicles, over a less energy-intensive conventional material, or it can substitute for a greater amount of a less energy-intensive material that would otherwise need to be made. Also a more energy-intensive process can provide net energy benefits if materials savings and avoided wastes are considered. Analysts are cautioned to look holistically, beyond factory fence lines when considering energy impacts. A wider analysis can identify additional large energy savings opportunities.

There is large scope for wider application of existing best practices, processes, and technologies. Innovation opportunities range from shop floor and facility-level modifications to the fruits of formal R&D. Both incremental changes to existing approaches and radical technological changes offer promise. So, policies for the creation and diffusion of more efficient technologies and practices, including R&D incentives and more robust technical assistance services are pertinent.

Although energy efficiency is often cost effective and the lowest cost energy resource, various factors impede manufacturing energy-productivity advances. One is the relative cost of energy in manufacturing. While there are some highly energy-intense industries, such as aluminum, cement, chemicals, iron and steel, and pulp and paper, energy accounts for only a small portion of production costs for most manufacturing sectors and thus may not garner strong attention. Further, industrial firms demand very high rates of returns for investment projects. They often prefer growth-oriented investments in expanded production and product offerings over cost-savings projects, including energy savings, that deliver similar or even higher returns.

In many cases energy is just one of multiple factors in investment decisions. Broader objectives of manufacturing modernization, productivity, and quality improvement usually drive capital investments. However, consideration of energy efficiency in this larger context can open up opportunities not previously considered. While energy-productivity improvement can often be just a co-benefit, its subsidiary status allows it to ride on the shoulders of these broader goals. The restructuring of the American steel industry over the last two decades, leading to greater use of recycled feedstock and more efficient processes is a notable example. Tax policies and depreciation schedules that encourage rather than discourage capital investment can advance energy productivity objectives. Also, there can be tax and depreciation approaches that focus on energy efficiency.

Corporate management structures and processes are important for creating motivation and incentives for energy efficiency. The most successful corporate programs have top management commitment; clear lines of accountability and supporting management structures; strong and clear commitments married to rigorous metrics and reporting; effective communications and stakeholder engagement; and rewards to individual and team contributors. Building on earlier development of quality and environmental-management systems are energy-management systems, including the newly developed ISO 50001 standard promoted by the DOE Superior Energy Performance program and a growing number of consultants. Such standards seek to integrate energy into corporate decision making, advance best practices, and inculcate a continual improvement ethos. Further, a growing number of companies view environmental sustainability—including energy management—and corporate social responsibility as important to their reputations and their financial performance.

Knowledge, skills, and training are vital for improving manufacturing competitiveness as well as for improving energy management. Enhanced skills and training would benefit production managers and line workers as well as specialized industrial energy managers. Outside the manufacturing firm, increased industrial experience and knowledge would enhance the abilities of consultants, extension agents, vendors, and others who interact with and support manufacturing industry.

Utilities can play an important role in partnering with industry to advance manufacturing energy productivity if they have proper incentives. Some states and utilities have adopted rate structures that diminish or remove the throughput bias that otherwise incentivizes utilities to sell more energy. Many states have adopted energy efficiency resource standards, "all cost-effective energy-efficiency" procurement rules, and other measures that either promote or compel utilities to administer energy efficiency programs, including those pertinent to manufacturing. Some utilities have partnered with Industrial Assessment Centers and economic development bodies to work with industry to help them improve productivity and competitiveness. Some also operate centers to assess and demonstrate relevant technologies. However, there are also cases where rate structures, interconnection procedures, and other processes impede industry from implementing CHP. Utility ratemaking and regulation will remain important topics in considering industrial energy-productivity policy options.

Environmental regulations can propel or impede energy-productivity investment. Some features of the Clean Air Act, such as the grandfathering of existing plants, may inhibit capital modifications and improvements. Yet, EPA and state regulators increasingly recognize energy efficiency as a pollution prevention technique and a means to reduce compliance costs. Recent rulemakings and guidance for state air-quality planning seek to better recognize and credit energy efficiency for its beneficial air-quality impacts.

Table 11 summarizes opportunities for and barriers to enhancing the energy productivity of the U.S. manufacturing sector.

OPPORTUNITIES	BARRIERS
» Large potential to expand use of currently available best practices and technologies » Large potential for new, more efficient technologies and processes » Advances in information technologies and intelligent manufacturing to improve process control and efficiency » Energy productivity is often a co-benefit of capital modernization and investments made to enhance productivity and quality » Energy is a large part of production costs for several large industries and should receive strong management attention » Energy efficiency is often the lowest cost energy resource (i.e., often cheaper to save than to buy energy) » Large scope for recovery of waste heat and materials and for CHP » Energy-management systems to integrate energy in corporate decision making, motivate employees and stakeholders to pursue efficiency, and inculcate continual improvement ethos » Utility rate structures, incentives, and regulations can, if well crafted, promote utility-industry partnerships for advancing energy productivity » Utility and grid operators increasingly value demand-side resources, including energy efficiency, demand response, and CHP » Increasing recognition of energy efficiency as a means to improve environmental quality, including in air quality planning and regulation	» High investment hurdle rate in industry (i.e., require high ROI rates and short payback periods) » High first cost of various efficiency measures » Bias favoring growth (increase production or product offerings) over cost reduction (including energy saving) investments » Tax and depreciation rules that discourage capital investment » Energy is a small portion of production costs for many manufacturing industries so may not garner strong management attention » Shortage of skilled, qualified energy managers and analysts » Modest levels of R&D for industrial energy productivity » Manufacturing extension and technical services are modestly supported and limited in scope » Diverse utility rate structures, incentives, and regulations have varied, inconsistent impacts on manufacturing energy efficiency across the states » Clean Air Act grandfathering and New Source Review may impede some investments to modify or replace old, less efficient capital » Externality costs (environmental and social costs) are not fully reflected in energy prices » Moderate natural gas prices (in the U.S.), while a boon to industrial consumers, may reduce attention to energy savings opportunities » Macroeconomic uncertainties and weak economy

Table 11. Opportunities and Barriers of Improving Manufacturing Energy Productivity

The topics discussed in this paper are complex and not without some controversy, particularly regarding policy and government's role. We have only scratched the surface of a large multidisciplinary topic spanning engineering, economics, business, risk perception and management, technology diffusion, and law and regulation.

APPENDIX A: LIST OF ACRONYMS

ACNEEP – Alliance to Save Energy's Commission on National Energy Efficiency Policy

AEO – Annual Energy Outlook

Btu – British Thermal Unit

CEAC – Clean Energy Applications Centers

CFL – Compact Fluorescent Light Bulb

CHP – Combined Heat and Power

DOE – Department of Energy

DRI – Direct Reduction Iron-making

E3 – Economy, Energy and the Environment collaborative

EAF – Electric Arc Furnace

EBIT – Earnings before Interest and Taxes

EERS – Energy Efficiency Resource Standard

EERE – Energy Efficiency and Renewable Energy Office

EnMS –Energy Management Systems

EPA – Environmental Protection Agency

EPS – Earnings per Share

ETV – Environmental Technology Verification

ESTCP – Environmental Security Technology Certification Program

GDP – Gross Domestic Product

GW - Gigawatts

H_2O_2 – Hydrogen Peroxide

IAC – Industrial Assessment Center

IAO – Independent System Operator

ISO – International Organization of Standardization

MEP – Manufacturing Extension Partnership

NIST – National Institute for Standards and Technology

NSR – New Source Review

Q/Quad – Quadrillion

R&D – Research and Development

ROCE – Return on Assets and Return on Capital Employed

ROI – Return on Investment

SEP – Superior Energy Performance

SMEs – Small and Medium-sized Enterprises

TACs – Technology Application Centers

WMRC – Waste Management and Resource Center

WRAP – Waste Reduction Always Plays

APPENDIX B: LIST OF FIGURES

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