Technology Roadmap for Energy Loss Reduction and Recovery: Top Twenty Opportunities

James Quinn, U.S. Department of Energy
Joan Pellegrino, Energetics, Incorporated

ABSTRACT

A workshop was held in April 2004 to bring together industry representatives interested in reducing and/or recovering energy lost in manufacturing processes. The objective of the workshop was to gain industry consensus on critical needs for new energy systems, and to identify and prioritize the greatest areas of opportunity for reducing energy losses. Participants from chemicals, petroleum refining, pulp and paper, iron and steel, aluminum, and cement industries, along with representatives from equipment manufacturers and national laboratories, met and discussed priorities for advanced technologies. The primary focus was on energy systems technology used in steam systems (advanced boilers, burners), fired systems (furnaces, heaters, calciners, reboilers), onsite power generation, and related systems (e.g., controls, automation).

The results of the meeting have been summarized in the ***Technology Roadmap for Energy Loss Reduction and Recovery (Technology Roadmap)***. This paper presents the main points of this ***Technology Roadmap***, describes the process used for the preceding workshop, and outlines the top twenty energy savings opportunities that were identified. In the aggregate, these opportunities are substantial, totaling over 5 quads (quadrillion Btus) of energy and $19 billion in potentially avoided energy costs. While many of the opportunity areas contain R&D components, some are more near-term opportunities that involve best practices or optimization of equipment.

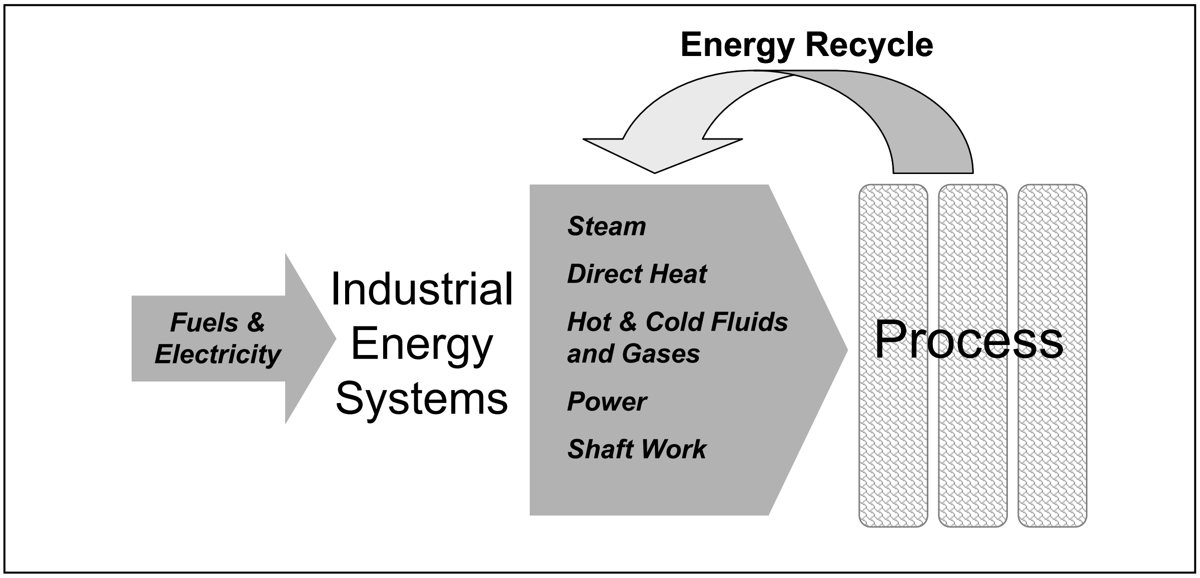
Introduction

Energy systems are an integral and critical component of U.S. industry. They provide the process heating, cooling and power needed for conversion of raw materials and fabrication of final products. Industrial energy systems channel fuels and power into a variety of energy sources such as steam, direct heat, hot fluids and gases, and shaft power. These energy systems encompass a wide range of equipment, including boilers, furnaces, dryers, calciners, melters, smelters, coolers, and machine-driven equipment such as compressors, pumps, fans, grinders, crushers and mixers. In addition, some industrial facilities use on-site energy systems for the generation of electricity or cogeneration of electricity and steam for process heating.

All manufacturing processes rely to some degree on energy systems. In the very energy-intensive basic industries, such as chemicals, petroleum refining, iron and steelmaking, and pulp and paper, energy systems are the backbone of the manufacturing process and crucial to profitability and competitiveness. For these industries, changes in the efficiency and environmental performance of critical energy systems can significantly impact the cost of production.

The role of energy systems in the manufacturing plant is depicted in Figure 1. This figure illustrates the strong inter-dependence of industrial processes on the effective conversion of energy to work, most of which is accomplished in industrial energy systems.

Figure 1. Role of Industrial Energy Systems in the Manufacturing Plant



Source: DOE 2004

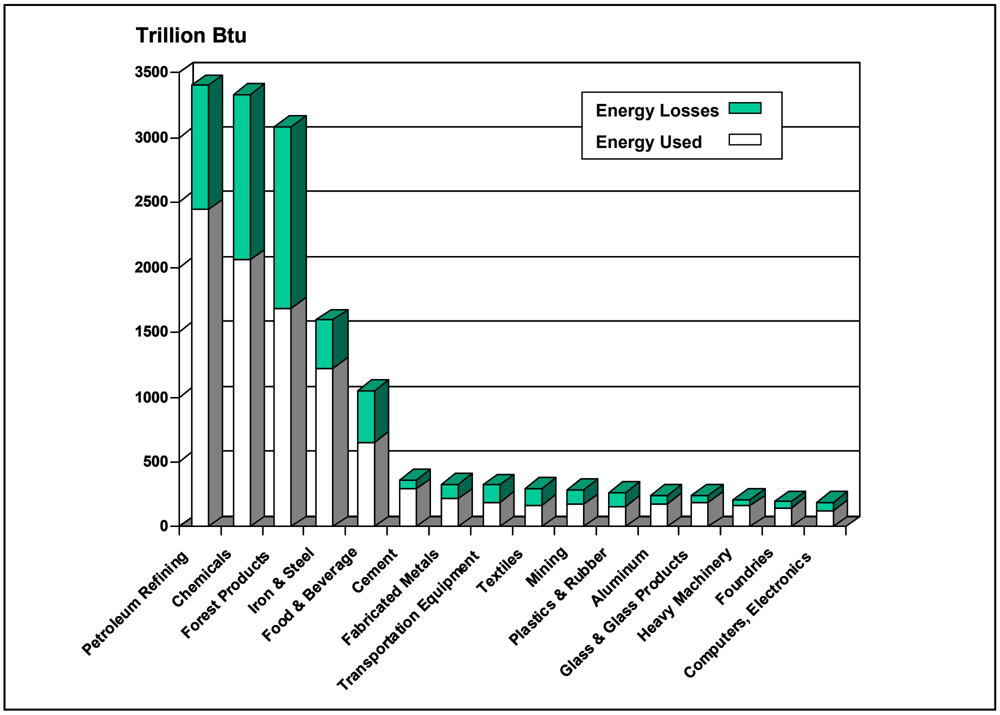
Energy Use and Losses in Industrial Energy Systems

Energy used in industrial energy systems (steam systems, fired systems, and motor drives) in manufacturing and mining amounted to about 16 quadrillions Btu (quads) of energy in 1998 (Pellegrino et al. 2004), or about 87% of total energy use. Figure 2 compares the energy use and losses in energy systems across sixteen industrial sectors. As Figure 2 illustrates, five industrial sectors account for over 80% of all the energy used in energy systems. These industries, petroleum refining, chemicals, forest products, iron and steel, and food and beverage, are similar in that they are all large users of steam systems as well as fired systems such as furnaces and dryers.

Not all of the energy delivered to industry is used productively. Large amounts of energy are lost in onsite energy systems prior to delivery to processes during generation, distribution, and conversion of energy – about 5.5 quads. Another 6.4 quads of lost energy is associated with electricity purchased by industry from offsite utilities. The energy losses associated with energy systems in the five top energy-consuming industries totals about 4.4 quadrillion Btus (quads), which is over 15% of the total annual energy consumed by U.S. industry. The magnitude of energy use and losses indicates that these industries are prime targets for energy efficient improvements.

In addition, due to the cross-cutting nature of energy systems, energy efficiency improvements made in these top five energy consumers can be replicated in many other industries. Textiles and transportation equipment, for example, are relatively large steam users and could take advantage of cross-cutting steam system improvements. Cement, mining, aluminum and glass manufacture rely heavily on fired systems, and could potentially benefit from advances in drying, melting, calcining, or smelting technology.

Figure 2. Industrial Energy Systems Energy Use and Losses (Boilers, Fired Systems, Cooling, and Motor-Drive)



Source: DOE 2004 Technology Roadmap

Background: Energy Systems Technology Roadmap Workshop

The diverse and widespread use of energy systems across industrial sectors creates numerous opportunities for energy efficiency improvements with potentially broad national impacts. The challenge is to focus on the industries and processes where the greatest potential energy benefits are to be gained.

Within the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), the Industrial Technologies Program (ITP) forms partnerships with industry to improve energy efficiency and environmental performance. The primary role of ITP is to invest in high-risk technology research and development (R&D) with the potential to reduce industrial energy use while stimulating economic productivity and growth.

As discussed earlier, industrial energy systems consume substantial amounts of energy and represent an important investment area for ITP. To help guide R&D decision-making and gain industry insights on the top opportunities for improved industrial energy systems, ITP sponsored the ***Energy Loss Reduction and Recovery in Energy Systems Technology Roadmap Workshop*** in April 2004 in Baltimore, Maryland.

Representatives from major energy-intensive industrial sectors were invited to participate in the ***Energy Systems Technology Roadmap Workshop***. These included participants from chemicals, petroleum refining, pulp and paper, iron and steel, aluminum, mining, foundries, and cement, as well as manufacturers who supply equipment to these industries.

The workshop kicked off with a presentation of potential opportunity areas for energy loss reduction, based on the preliminary results of a recent study (Pellegrino et al. 2004). The development of opportunities was based on a number of criteria, as shown in Table 1. Participants were asked to review the opportunities and provide feedback, which would then be incorporated in refining the opportunity areas (presented later in this paper).

Table 1. Opportunity Selection Criteria

Criteria Area	Description
Energy	Magnitude of potential energy savings for combined individual and multiple-industry applications
Applicability	Applicability across more multiple industries
Priority	Identified by industry as a priority in visions, roadmaps
Economics	High potential for reducing costs
Markets	Feasibility and industry acceptance of technology
Environment	Environmental soundness, or potential for reducing environmental impacts

The meeting was originally organized along three major breakout topics, shown below. However, calcining was ultimately combined with the melting group to better accommodate the expertise represented by industry participants, and the last category was dropped.

- Fluid Heating and Boiling (focus on chemicals, petroleum refining, pulp and paper, textiles, food processing)
- Melting, Smelting, Metal Heating, and Agglomeration (focus on iron and steel, aluminum, foundries)
- Calcining, Forming, and Fabrication (focus on cement calcining, plastics)

Participants in each breakout session were asked to discuss 1) the trends and challenges that could impact the development and adoption of advanced energy systems technologies; 2) the major sources of wasted energy in their industries; 3) the energy system research areas they felt would have the most impact on energy losses; and 4) potential research topics and technology options for capturing energy loss opportunities and reducing energy use in energy systems. These discussions resulted in a series of prioritized mid- to long-term R&D topics in each of the breakout areas, along with a list of more near-term options for reducing energy losses.

The ***Technology Roadmap for Energy Loss Reduction and Recovery*** (available on-line at www.eere.energy.gov/energy_systems/) is based largely on the results of the workshop. Further refinements of the opportunity areas were conducted after the workshop, utilizing feedback obtained from industry participants. The remainder of this paper summarizes industry feedback on top opportunities and priorities for R&D investments in energy systems, and provides some insights about the potential for national impacts on energy use and the environment.

Trends and Challenges Impacting Energy Systems

In the industrial sector, the decision to invest in more energy efficient technology is driven by many competing factors. Some factors are internal, such as those relating to the company's corporate investment philosophy, and are influenced by stockholders, business decisions, and the economic climate. Other factors are external, such as Federal policies and regulations, and are mostly beyond the company's realm of influence or control. Selected important trends and challenges impacting investments in more efficient energy systems are shown in Table 2.

The volatility in energy supply and price has been growing steadily and is viewed by industry as a significant challenge for the future. The cost of natural gas is having a serious impact on all industries that are dependent on natural gas, especially on those where natural gas constitutes 60 to 70% of energy supply.

One of the primary challenges to investing in energy efficiency projects is managing the technical and economic risk, particularly when fuel prices are volatile and paybacks are uncertain. Return on investment is a determining factor and is influenced by the size of the initial investment and potentially recurring costs associated with projects. In most companies, funds for energy efficiency projects compete with product development, where returns are much more predictable.

Table 2. Trends and Challenges Impacting Development and Adoption of More Efficient Energy Systems

Category	Trend or Challenge
Energy Cost and Supply	• Price volatility for natural gas, fuel and electricity • Decades of movement toward gas-fired versus coal-fired electricity • Variable volatility (heating value) of liquefied natural gas (LNG) imports • Maxed-out capacity in refineries (increasing imports) • Lower cost of refining oil overseas • Growing issues with energy reliability and quality • Interest in "green products" and fuel substitutes (renewable fuels)
Business and Investment Climate	• Technical and economic risk (uncertain return on investment) associated with efficiency projects • Lack of incentives for development and use of new technology • General industry outlook and health • Lack of R&D investments in efficiency (continuing emphasis on products) • Understanding solution economics • Greater competition from overseas manufacturers
Government and Regulations	• Election cycles and impacts on R&D priorities • Continually changing regulations, particularly for environment and power • Potential for carbon taxes, carbon trading, other climate change policies • Inability to form partnerships between industries and utilities (partly due to regulation) • Conflict between energy efficiency and environmental compliance • Limited federal funding opportunities for "supporting industries" such as heat treating, versus large materials industries (steel, chemicals)
Education, Training and Public Awareness	• Under-education of industry – "buy right" versus "buy cheap" • Increasing use of system-wide analysts, energy experts and teams to optimize plant energy use in some industries • Inadequate industry awareness of new technology

Source: DOE 2004

Technology Priorities for Reducing Energy Losses

The workshop provided input on major sources of energy losses and the R&D priorities for reducing or recovering energy losses for two major topical areas: 1) fluid heating and boiling, and 2) melting, smelting, metal heating, agglomeration, and calcining.

Fluid Heating and Boiling

Fluid heating and boiling is a critical component of many energy intensive processes used in the manufacture of chemicals, refined petroleum products, forest products, food and beverage, and textiles. Fluid heating and boiling systems include fired systems such as furnaces, evaporators, dryers, condensers, and other direct-fueled systems, as well as steam generators (mostly boilers, although a small amount of steam is produced with electric elements). Heat exchangers, steam injectors, and other auxiliary equipment are also integral components of fluid heating and boiling. Energy systems for cooling of fluids include cooling towers and ponds, heat exchangers, cryogenic equipment, chillers, and other equipment.

Major sources of energy losses. Waste heat embodied in hot gases or fluids is the primary source of losses from fluid heating and boiling. In petroleum refineries, for example, contaminated waste steam from fractionating and stripping processes is a major source of waste heat. In both refineries and chemical manufacturing, waste gases from boilers, furnaces, vents, flares, and coolers, represent a large source of waste heat. The energy content of these waste heat sources depends primarily on temperature.

In pulp and paper manufacture, waste steam, hot water, exhaust gases, evaporation of spent liquors, and radiation heat losses are the primary energy losses from fluid heating and boiling. The greatest energy losses are from paper drying, evaporation, pulping, chemical recovery and bleaching. These processes are all heavily dependent on steam as an energy source. In the food processing industry, significant energy is lost in wet corn milling and sugar processing from fluid heating and boiling. Most of the waste energy is in the form of waste steam, exhaust gases, and heat losses from evaporators, dryers and other processes.

Research and development (R&D). R&D priorities for reducing and recovering energy losses from fluid heating, boiling and cooling processes in chemicals, petroleum refining, and forest products are shown in Table 3, listed in order of importance. These include near-, mid-, and long-term R&D priorities, as well as technology options that could be achieved more readily in the near term with existing or currently emerging technology and best practices.

Based on input from industry participants, the recovery of energy from waste heat is by far the top priority and represents the greatest opportunity for reducing energy loss targets. This includes the recovery of energy from high or low quality heat present in waste gases and liquids. Longer-term research could reduce energy losses through energy source flexibility, which is essentially exploring alternatives to the way energy sources are currently used (e.g., direct heat versus steam, steam for mechanical drives, waste fuels or renewables).

Energy system integration, or systems integration of plant energy sources represents a more near-term opportunity to reduce energy losses. Commercial technologies are already available for energy integration, and limited R&D investments (e.g., for tool development) would be needed to capture this opportunity.

Table 3. Energy Systems Priorities for Fluid Heating and Boiling

Topic (# of Votes)	R&D/Technical Need	Technology Options
Recovery of Energy from High and Low Quality Waste Heat (both gases and liquids) From Processes (19)	Technologies capable of operating over low temperature (110-160°F) and high temperature (400-1500°F) ranges	Alternative energy cycles, thermal storage, alternatives to shaft power using waste heat, working fluids for low grade heat recovery, heat activated heat pumps and refrigeration, improved thermal transport, corrosive stream heat recovery, corrosion-resistant materials, energy storage.
Energy System Integration (10)	Ability to balance energy across the plant to integrate energy sources and sinks	Pinch opportunity identification tools, part load cycling and load management methods. User-friendly tools to handle diverse industrial processes and site-specific conditions. Expansion of existing tools and development of new tools.
Energy Source Flexibility (6)	Alternate, cost-effective energy systems to supply process heat and power that are more energy efficient and environmentally sound.	Tools for selecting alternative energy sources, development of modular energy systems (chillers, CHP), energy storage, heat-activated power, alternate fuel products, substitution of steam vs direct heat, indirect heat vs CHP, using steam for mechanical drives.
Education and Best Practices (6)	Increased awareness of new technology and tools for efficiency improvements.	Education and training at executive and plant level to justify energy efficiency projects and promote benefits of investment in new energy technology.
Separations to Enable Energy Recovery (5)	Technology to enable the difficult separations required in some energy recovery schemes.	Cleanup of high temperature gases, energy efficient dehydration of liquid waste streams, thermal versus non-thermal separations, centrifugal distillation, drying-heat activated heat pumps, and separation of volatile organics, contaminants, lignin and fiber from waste streams.
Energy Export and Co-location (4)	Export of fuels and electricity from pulp and paper and other industries. Co-location of plants producing energy with those requiring energy.	Diverse technologies promoting energy export and co-location: inventory of waste heat sources across industry; analysis of U.S. co-location opportunities; gasification of black liquor to produce fuels and power; alternatives to Fischer-Tropsch for conversion of synthesis gas.
Improved Controls, Automation, and Robotics for Energy Optimization (1)	Research to optimize control and automate combustion processes and energy flow throughout the plant,	Remote sensing and control, global control networks, burner sensing and control, other control or automation systems to optimize energy use.

Source: DOE 2004.

Melting, Smelting, Metal Heating, Agglomeration, and Calcining (Metals and Non-Metallic Minerals)

Melting, smelting, metal heating, agglomeration and calcining represent a broad category of heating technologies used across many industrial sectors, particularly in metals and mining. Melting is integral to the production of steel and secondary aluminum, while smelting is at the core of primary aluminum production. Agglomeration processes such as sintering and pelletizing use heat to convert powdery ores into larger pieces that are more easily handled. Calcining (conversion of calcium carbonate to calcium oxide) is used to process ores and clays, in cement and limestone manufacturing, in chemical recovery in Kraft pulping (lime mud calcining), and for various other processes.

Major sources of energy losses in metals and non-metallic minerals processes. The primary sources of losses in fired systems are hot gases (both contaminated and clean), warm water, and hot products that must be cooled or quenched. In iron and steelmaking, for example, energy is lost when hot products such as coke, annealed metal, molten iron, hot slabs, and process gases are cooled or quenched. Smelting, which produces molten metal, generates energy losses in the form of furnace exit gases. Metal heating and heat treating is accomplished in various types of furnaces and generates losses through exit gases and radiative heat transfer. Agglomeration produces energy losses through heat transfer mechanisms and exhaust gases.

Major sources of losses from calcining processes are exhaust gases (evaporated water, combustion gases, carbon dioxide from calcinations) and radiation and convection heat losses. Energy losses from the very large kilns used in cement manufacture can be substantial.

Research and development (R&D) priorities for metals and non-metallic minerals processes. R&D priorities were identified to reduce energy losses in the various processes commonly used in the manufacture of metals and non-metals, and are shown in Table 4. All of the priorities shown in Table 4 have a significant research component, although some near-term opportunities using modifications to existing technologies are included.

The highest priority was given to recovery of waste heat from exhaust gases from various furnaces, kilns, melters, smelters, and other metal or non-metallic minerals processing equipment. The second highest priority was to take an alternative approach – that of reducing or mitigating energy losses by improving the systems that convert energy to useful work (e.g., process heaters, fired systems, melters, smelters), and by devising more innovative uses of energy sources. Other priority technology pathways for reducing losses included the development of better sensor and control systems, and advanced technologies that would allow enhanced heat transfer for systems needed to heat liquids and gases.

Some heat transfer and heat recovery priorities identified for metals and non-metallic minerals have potential cross-over with the technology options discussed in fluid heating and boiling. These include recovery of energy from combustible gases, waste heat reduction and recovery in drying processes, and waste heat recovery from lower quality liquids and steam.

Summary of Energy Loss Reduction and Recovery Opportunities

A list of top twenty opportunities (shown in Table 5) was developed based on inputs obtained at the Energy Loss and Reduction Workshop and using other industrial energy studies. Energy savings for most of the top twenty opportunities were estimated based on two separate analyses conducted over the last year (Pellegrino et al. 2004, Pellegrino et al. 2003), and on the national roadmap for combined heat and power (CHP) and other CHP estimates (USCHPA 2001). Estimated energy savings for motor-driven systems were taken from a motor market assessment and opportunities analysis (Xenergy 1998). Cost savings are based on a distribution of electricity, natural gas, petroleum, coal and byproduct fuels, and are application-dependent.

Energy and Cost Savings

The pre-process energy savings shown in Table 5 represent areas where energy losses occurring prior to the process can be reduced or mitigated, i.e., losses occurring in energy generation and distribution outside or within the plant boundary, and during the conversion of energy to useful work. Post-process energy savings indicate opportunities occurring at the end of the process, i.e., energy present in exhaust gases, exiting water or effluent streams, evaporative losses to the air, energy present in combustion gases or byproduct gases, or energy wasted through radiative heat losses. Both pre- and post-process energy savings for each opportunity represent potential energy savings for one year, based on current energy use.

Table 4. Energy Systems Priorities for Melting, Smelting, Metal Heating, Agglomeration, and Calcining (Metals and Non-Metallic Minerals)

Topic (# of votes)	R&D/Technical Need	Technology Options
Recovery of Waste Heat from Exit Gases (10)	Cost-effective recovery of energy from exit gases in metals and non-metallic minerals manufacturing processes	Secondary heating, integrated heating and recovery systems, corrosion-tolerant technology, materials with high thermal performance and corrosion-resistance.
Improved Process Heating for Glass and Metals Melting, Calcining, Refining, Heating, and Annealing (8)	Reduction of energy losses via improved thermal efficiency and heat transfer	Higher temperature air preheat, improved thermal transfer, cascade heating, switching from batch to continuous processes, hybrid heating, rapid heating and melting technologies, combined heat and power, optimized production schedules and practices.
Improved Sensors, Controls Automation and Robotics for Heat Reduction Process Optimization (6)	Cost-effective sensors/controls to minimize energy and cost while meeting product specifications	Remote measurement of temperature and pressure, direct measurement of product parameters, predictive models, automated process heaters, instantaneous energy sensors, automated emission control systems, and wireless technologies.
Improved Heat Transfer Systems for Heating Liquids and Gases (5)	Enhanced heat transfer of liquids and gases in metals and non-metallic mineral processing systems	Better channeling of heat and improved transport efficiency, and modular or compact heating systems. Fundamental studies on thermal responses of fluids and associated chemistries, modeling of mass and heat transfer, and stabilization of working fluids.
Waste Heat Reduction and Recovery for Drying (3)	Improved drying technologies for paper-making paint drying, curing, and other processes	Infrared, direct-fired drying, alternative fuel dryers, air heat recovery, mechanical vapor recompression, and advanced heat pumps
Waste Heat Recovery for Quenching and Cooling (2)	Quenching and cooling of metals, glass, and other high temperature materials (molten and solid metals)	Utilization of flue gases from reheat furnaces, coke oven batteries, and continuous annealing; thermo-electric systems for medium temperature clean flue products.
Heat Recovery From Combustible Gases (2)	Technology for utilization of combustible byproduct gases currently vented or incinerated (CO-rich gases from electric arc furnace, gases from catalytic cracker catalyst reburning)	Separating/concentrating combustible components of gases, hot gas cleanup, materials for corrosive environments, innovative burners.
Waste Heat Recovery From Lower Quality Liquids and Steam (2)	Enhanced heat recovery from lower quality hot fluid sources present in metals and non-metallic minerals processes (steam and other liquids)	New working fluids, heat-activated heat pumps

Source: DOE 2004.

The potential impacts of reducing energy losses are substantial. As shown in Table 5, the top twenty opportunities represent over 5 quads (quadrillion Btus) of energy (total energy savings), or about 22% of total energy (including offsite electricity generation and transmission losses) used by the manufacturing sector in 1998 (DOE 2001). Energy costs associated with energy use in the industrial sector are also substantial. The manufacturing sector spent about $80 billion in energy in 1998, and that number has been rapidly rising as fuel and electricity prices increase (DOE 2001). Total potential cost savings shown in Table 5 are over $18 billion, or about 24% of 1998 energy expenditures in manufacturing.

Not all the opportunities shown in Table 5 will require R&D. More near-term opportunities, such as optimization of motor systems and energy integration, could be achieved with little or no research investment. These could be realized through information transfer, technical assistance, technology demonstration, software tools, and other technology transfer mechanisms. Other opportunities, such as waste heat recovery, combined heat and power, and energy source flexibility will require a mix of R&D and modification of existing technology. Technology advances in energy systems are already underway in a number of areas. For example, one DOE-supported project is developing and demonstrating a new generation of process heaters for petroleum and chemicals production. This enhanced heat recovery, low emissions system could potentially save 84 trillion Btu per year (DOE 2003).

The opportunities in Table 5 are based on a relatively small subset of the manufacturing sector (the top energy consumers). Due to their crosscutting nature, technology developments in many cases could be applied to a host of other industries. Improved heat transfer systems, for example, could be applied to many types of heat exchange systems; new boilers could be adopted in any steam-using industry; and machine-drive optimization could be applied in nearly every industry.

Conclusions

Energy systems are critical to U.S. manufacturing. Every manufacturing sector relies on energy systems to provide the process heating, cooling and power needed to create final products from raw materials. While considerable emphasis is often placed on improving the efficiency of industrial processes, most energy use can be attributed to energy systems – about 16 quads. As a result, they represent substantial opportunities for energy improvements.

Not all of the energy delivered to industry is used productively. Large amounts of energy are lost in onsite energy systems prior to delivery to processes during generation, distribution, and conversion of energy – about 5.5 quads. Another 6.4 quads of lost energy is associated with electricity purchased by industry from offsite utilities. In addition, 20-50% of energy (2-5 quads) may be lost downstream of processing in flares and exhaust streams.

Overall five industries – chemicals, petroleum refining, pulp and paper, iron and steel, and food processing – account for 4.4 quads of industrial plant energy losses. These industries rely heavily on energy systems and represent the greatest potential targets for efficiency improvements. While these industries are major targets, there are many opportunities to improve efficiency in other industries that use energy systems. Technological advances to generic energy systems – and the resulting energy and cost savings benefits – could potentially be replicated across manufacturing. Textiles and transportation equipment, for example, are heavy steam users; cement, mining and glass rely heavily on fired heaters.

The volatility in the price of energy is currently driving energy investment decisions. However, a host of challenges in energy supply, business climate, regulations and public demands will also affect industry investment. For example, uncertain return on investment for efficiency projects, and continuing emphasis on funding new product development both inhibit investment in more efficient energy systems.

As illustrated in Table 5, the top twenty opportunities identified span the energy-intensive industries and provide substantial pre-process (2.9 quads) and post-process (2.3 quads) energy savings. When all top twenty opportunities are considered, the potential energy savings are significant – over 5 quads valued at about $19 billion in avoided energy costs. These opportunities are based on prior energy analysis, and input from industry experts who provided direction on R&D and technical needs and potential technology options (Pellegrino et al. 2004, DOE 2004).

Table 5. Top Twenty Opportunities for Energy Savings (Trillion Btu)

#	Opportunity Area	Industries Analyzed	Pre-Process Energy Savings	Post-Process Energy Savings	Total Energy Savings	Total Cost (million $)
1	**Waste heat recovery** from gases and liquids	chemicals, petroleum, forest products	0	830	830	$2,200
2	**Combined heat and power systems**	forest products, chemicals, food, metals, machinery	630	0	630	$2,000
3	**Advanced industrial boilers**	chemicals, forest products, petroleum, steel, food processing	400	0	400	$1,100
4	**Heat recovery from drying**	chemicals, forest products, food	160	220	380	$1,200
5	***Steam best practices** not including advanced boilers*	*all manufacturing*	*310*	*0*	*310*	*$850*
6	***Pump system optimization***	*all manufacturing*	**300 (100)*	*0*	**300 (100)*	*$1,400*
7	***Energy system integration***	*chemicals, petroleum, forest products, steel, food, aluminum*	*110*	*150*	*260*	*$860*
8	**Improved process heating/heat transfer systems**	petroleum, chemicals	120	140	260	$860
9	***Energy efficient motors and improved rewind***	*all manufacturing*	**260 (80)*	*0*	**260 (80)*	*$1,200*
10	**Waste heat recovery** from gases in metals, minerals	iron and steel, cement	0	240	240	$1,100
11	**Energy source flexibility**	chemicals, petroleum, forest products, steel	120	80	200	$1,100
12	**Improved sensors, controls, automation, robotics**	chemicals, petroleum, forest products, iron/steel, food, cement, aluminum	40	150	190	$630
13	**Improved process heating for metals, minerals**	iron and steel, metal casting, aluminum	60	130	190	$900
14	***Compressed air system optimization***	*all manufacturing*	**160 (50)*	*0*	**160 (50)*	*$740*
15	***Optimized materials processing***	*all manufacturing*	**150 (50)*	*0*	**150 (50)*	*$660*
16	**Energy recovery from byproduct gases**	petroleum, iron and steel	0	130	130	$750
17	**Energy export and co-location**	forest products	0	100	100	$580
18	**Waste heat recovery from calcining** (not flue gases)	cement, forest products	10	60	70	$160
19	**Heat recovery from metal quenching/ cooling processes**	iron and steel	0	60	60	$280
20	**Advanced process cooling and refrigeration**	food processing, chemicals, petroleum and forest products	*60 (20)	0	*60 (20)	$210
TOTAL FOR TOP TWENTY			**2,900**	**2,300**	**5,200**	**$18,800**

*Includes losses incurred during offsite generation and transmission of electricity, based on conversion factor of 10500 Btu/kWh. Number in parenthesis does not include offsite losses.
Italics indicate opportunities that are near-term and mostly achieved through implementation of best energy management practices.

Sources: DOE 2004, Pellegrino et al. 2004

The top twenty opportunities are comprised of a mix of near- and long-term efforts requiring variable levels of research and development. Waste heat recovery from fluids and gases, for example, could be achieved in part in the near-term through the modification of existing technology, such as heat pumps, while more challenging cases will require long-term R&D for entirely new technology, materials of construction, and so forth.

Other near-term opportunities, such as optimization of equipment through best practices, could be realized through information dissemination, technical assistance and technology demonstration programs, software tools, and other technology transfer mechanisms. Tools are already available, for example, for the optimization of pumps, compressors, and other motor-driven systems.

The potential energy savings from advanced energy savings has been shown to be substantial. To realize these opportunities will require the combined efforts of industry, government, and academia, such as those put forth in the development of this Technology Roadmap. Two important components will be effectively communicating information about new technology and the potential benefits, and justifying investment in energy efficiency projects.

References

Pellegrino, Joan, Nancy Margolis, Melanie Miller, Mauricio Justiniano, and Arvind Thedki. 2004. *Energy Use, Loss and Opportunities Analysis: U.S. Manufacturing and Mining.* Energetics, Inc. and E3M, Inc. for the U.S. Department of Energy, Industrial Technology Programs.

[DOE] U.S. Department of Energy. November 2004. *Technology Roadmap: Energy Loss Reduction and Recovery in Industrial Energy Systems.* www.eere.energy.gov/energy_systems

Pellegrino, Joan, Nancy Margolis, Melanie Miller, and Mauricio Justiniano. 2003. *Energy Footprint Series: U.S. Manufacturing and Mining.* Energetics, Incorporated, Columbia, Maryland, for the U.S. Department of Energy, Industrial Technology Programs.

[DOE] U.S. Department of Energy. October 2003. "High-Efficiency, Ultra-Low-Emission Integrated Process Heater System." Active Project Factsheet. http://www.eere.energy.gov/industry/combustion/pdfs/processheatersystem.pdf

[DOE] U.S. Department of Energy, Energy Information Administration. 2001. *Manufacturing Energy Consumption Survey 1998.* www.eia.doe.gov/mecs/

[USCHPA] U.S. Combined Heat and Power Association, U.S. Department of Energy and U.S. Environmental Protection Agency. 2001. *National CHP Roadmap.*

Xenergy, Inc. *U.S. Industrial Motor System Market Opportunities Assessment.* 1998. Conducted for the U.S. Department of Energy and Oak Ridge National Laboratory.