TECHNOLOGY ROADMAP

ENERGY LOSS REDUCTION AND RECOVERY IN INDUSTRIAL ENERGY SYSTEMS

November 2004

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Energy Loss Reduction and Recovery in Industrial Energy Systems

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Office of Energy Efficiency and Renewable Energy
Industrial Technologies Program

Preface

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.

Industrial energy systems (e.g., boilers, process heaters, motor-driven equipment) 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 energy systems, ITP sponsored the *Energy Loss Reduction and Recovery in Energy Systems Roadmapping Workshop* in April 2004 in Baltimore, Maryland. This *Technology Roadmap* is based largely on the results of the workshop and additional industrial energy studies supported by ITP and EERE. It summarizes industry feedback on the top opportunities for R&D investments in energy systems, and the potential for national impacts on energy use and the environment.

This report is available for download at http://www.eere.energy.gov/industry/energy_systems/

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Overview

Role of Energy Systems

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 for compressors, fans, pumps, conveyors and other machine-driven equipment (see Figure 1). Some industrial facilities have on-site energy systems for the generation of electricity or cogeneration of electricity and steam for processes.

Industrial Energy Systems

- *Steam generation (boilers, central steam plants)*
- *Fired heaters (furnaces, dryers, calciners, melters, smelters)*
- *Refrigeration and cooling*
- *Machine driven equipment (compressors, pumps, fans, grinders, crushers, mixers, conveyors)*
- *Power generation (steam and gas turbines, cogeneration systems)*

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 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.

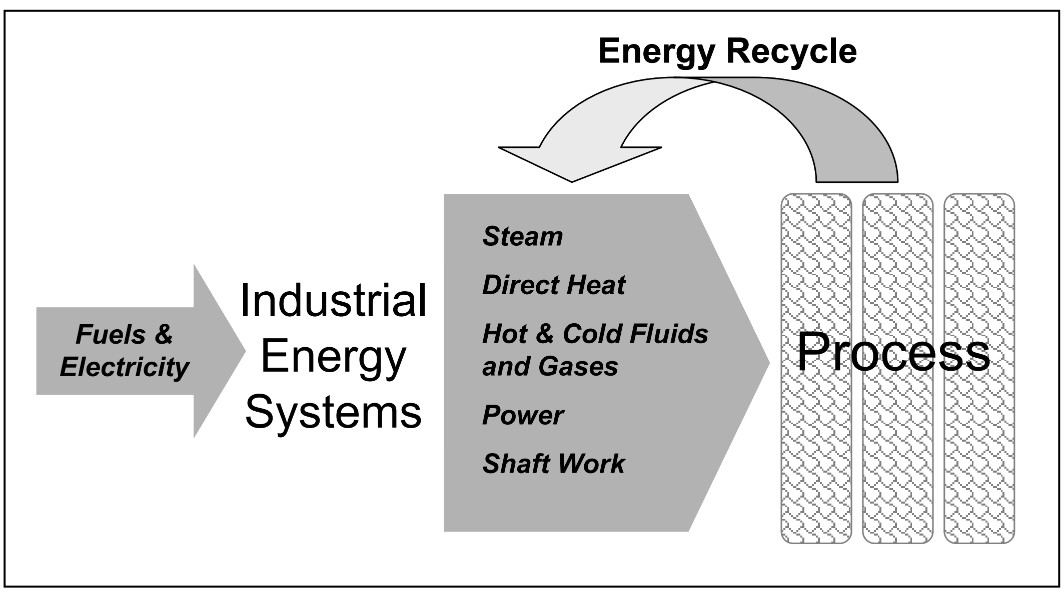


Figure 1. Function of Energy Systems in Manufacturing Processes

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. Some of the most important trends and challenges impacting future investments in more efficient energy systems are shown in Table 1.

Table 1 Trends and Challenges Impacting Development and Adoption of More Efficient Energy Systems

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

Energy Cost and Supply

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. Particularly hard-hit are those industries that depend on natural gas for both fuel and feedstock (e.g., ammonia manufacture, methane reforming) or rely largely on gas-fired boilers for steam. For decades energy users and producers have been moving toward cleaner gas-fired systems as an alternative to dirtier coal-fired systems, putting tremendous pressure on current natural gas supply and cost.

One solution is to import more liquefied natural gas (LNG). However, the volatility (and heating value) of imported LNG is variable and can impact energy system efficiency. With refineries operating at capacity, and cheaper costs for refining oil overseas, the trend towards imports of LNG, gasoline, and other fuels is expected to increase.

The increasing cost and decreasing reliability of the fuel and electricity supply is making industry take a closer, more critical look at energy efficiency projects as a solution for rising energy costs. For many industries, electricity reliability and quality will continue to be a challenge in the future as processing and control technologies become more sophisticated.

Business and Investment Climate

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.

The general health and economic outlook of the industry also has an impact on investment decisions, particularly those that are considered more risky. In today's business climate, corporate decision-makers are heavily influenced by economic trends as well as the need to keep stockholders satisfied.

Another issue is the lack of incentives to invest in energy efficiency for technology developers as well as end-users. However, as fuel prices rise and overseas competition puts pressure on U.S. manufacturers, energy efficiency projects could become more attractive.

Government and Regulations

Government policies and regulations can significantly impact the ability of U.S. industry to take on energy efficiency projects. In the environmental arena, continually changing regulations on pollutant emissions to air, land and water can create disincentives to technology development and deployment. Investments are often diverted to comply with regulations (pollution abatement and control) rather than prevention or reduction of emissions. In the petroleum refining industry, for example, domestic producers are faced with the challenge of meeting environmental regulations for process emissions, as well as creating transportation fuels that meet environmental regulations. The requirements for low sulfur fuels, for example, create the need for additional treating and upgrading of crude fractions, which requires more energy and generates more criteria pollutants. In some cases, efficiency improvements conflict with environmental compliance by creating more emissions or byproducts.

Climate change is an issue around which much uncertainty still exists. While there are currently no U.S. policies or regulations requiring mandatory reductions in greenhouse gases, they could be looming in the future. Carbon taxes or other greenhouse gas policies could emerge as a result and create further challenges for U.S. industry in balancing energy, economic, and environmental goals.

The regulation of energy can also create challenges and disincentives. Deregulation of electricity, for example, has contributed to electricity reliability and supply issues in some regions. In some states, regulations prevent industry from partnering with utilities to take advantage of co-location, cogeneration, or other alternative, more efficient energy options.

Public Awareness, Training, and Education

The availability of sufficient and good quality information to inform decision-makers is a common barrier to energy efficiency investments. The tendency is often to "buy cheap" rather than "buy right." The industrial community is often simply not aware of new technology and the potential benefits to be gained by exploring their use.

The information barrier can be impacted by development of better tools for assessing the benefits of energy projects and training programs at both the executive and plant level. Tools and information dissemination strategies are also needed to increase awareness of emerging technologies and the potential competitive advantages to be gained.

As energy costs rise, more manufacturing companies are beginning to place an increasing value on the systems approach to energy use in the plant as a means of cutting costs. There is an increasing trend in some companies to acquire energy experts or put together teams to find better energy solutions.

Energy Use and Losses in Energy Systems

The Energy Footprint

The energy footprint provides a blueprint of the energy flows within industry and individual industrial sectors. The energy footprint shown in Figure 1 details the energy flows for the 24.7 quadrillion Btus (quads) of energy use associated with U.S. manufacturing [EI 2004, EI 2003]. The total energy use shown in Figure 1 includes

- onsite energy losses, i.e., the energy that is lost in energy systems from equipment inefficiencies, thermodynamic operating limitations, during distribution of energy throughout the plant, and in the conversion of energy to useful work; and
- offsite losses, i.e., energy losses incurred offsite at the utilities providing the electricity and fuels that are purchased by the industrial sector. Offsite losses occur primarily in the generation and transmission of electricity (25 to 45% thermal efficiency is typical).

The energy losses occurring occur onsite in industrial facilities represent immediate targets for energy efficiency improvements. As shown in Figure 1, of the 24.7 quads of energy associated with manufacturing in 1998 [MECS 1998], approximately 5.5 quads are lost prior to reaching the process. An additional 20-50% of the energy finally delivered to processes can also be lost in the form of waste heat, flares, byproducts and other sources. These downstream losses, which have not been estimated for the footprint, are more complex and depend upon the nature of the process and specific site conditions. In general, energy losses can potentially be reduced by adoption of more efficient technology; better integration of heat sinks and sources within the plant; increased utilization of waste energy; and improved operating and maintenance practices.

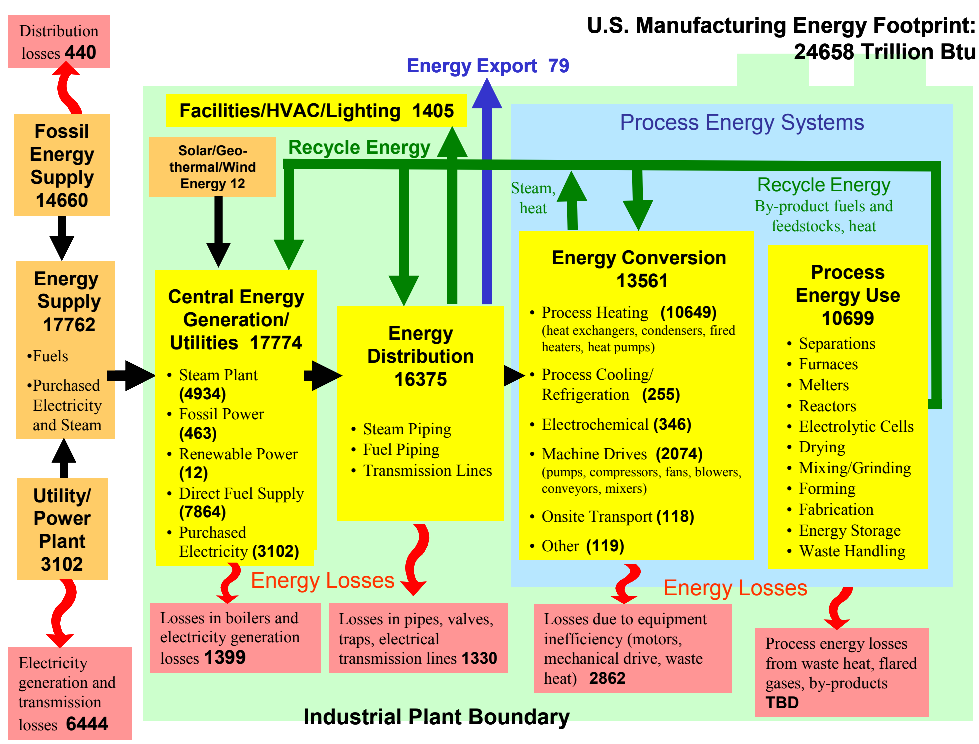


Figure 1. U.S. Manufacturing Energy Footprint, 1998 Energy Use [EI 2003]

Offsite losses are substantial, and add 6.9 quads to the energy associated with U.S. manufacturing. While these losses are incurred offsite, they can still be impacted by changes made within industrial facilities. For example, the use of onsite cogeneration systems allows industry to generate its own electricity more efficiently and with fewer energy losses than those associated with purchased electricity.

Energy Use and Loss in Industrial Sectors

Understanding the relative importance of energy systems among the different industrial sectors is key to identifying potential energy efficiency opportunities. Figure 2 compares the energy use and losses in energy systems (steam systems, fired systems, and motor drive) across sixteen industrial sectors. As Figure 2 illustrates, five industrial sectors account for over 80% of all the energy inputs to energy systems. These industries, which include 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. The energy losses associated with energy systems (generation, distribution, and conversion) in these five industries totals about 4.4 quadrillion Btus (quads), which is over 15% of the energy consumed by U.S. industry.

Sheer magnitude of energy use and losses in these five industries indicates that they 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.

The remainder of this report outlines the key opportunities for improving the efficiency of industrial energy systems. While emphasis is placed on the top energy users, the opportunities identified also encompass a number of other industries, notably cement, aluminum, and textiles.

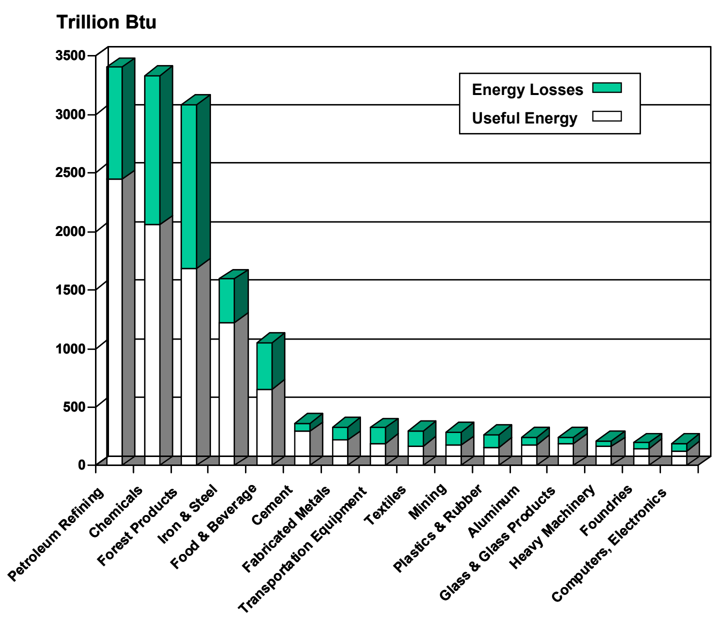


Figure 2. Energy Systems Energy Use and Onsite Losses (steam systems, fired systems and cooling, motor-drive) [EI 2004]

Fluid Heating and Boiling

Scope of Technology

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

Selected Examples of Industrial Fluid Heating and Boiling

- ***Petroleum Refining and Chemicals Manufacture*** *(steam generation, reactant heating, steam injection, steam stripping, distillation tower reboilers, condensers, air and fluid preheating and cooling, drying, pyrolysis, cryogenic cooling)*
- ***Forest Products*** *(steam generation, feedstock heating and processing, drying)*
- ***Food and Beverage*** *(steam generation, evaporation, sterilization, pasteurizing)*
- ***Textiles*** *(steam generation, drying, dyeing)*

Many similar energy systems are used for fluid heating, boiling and cooling in chemicals, petroleum refining, forest products, and to some extent in other major industries such as food processing and textiles. Some examples include boilers for generating steam; condensers; dryers; and direct-heat furnaces.

This technology roadmap focuses on the fluid heating, cooling and boiling systems that are widespread across the industrial sector. Improvements in these energy systems have the greatest potential to reduce energy use and impact multiple industries. While many industries use energy systems that are specifically tailored to process needs, they could still potentially benefit from advances made to more generic energy systems based on the same principles.

Major Sources of Energy Losses

Waste heat, in the form of 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. Steam at 200ºF, for example, has low energy content and is more difficult to economically recapture as an energy source than steam at 500ºF.

In pulp and paper manufacture, waste steam, hot water, exhaust gases, evaporation of spent liquors, and radiation heat losses are the primary source of energy losses from fluid heating and boiling. The two most energy intensive processes are paper drying and black liquor concentration (both evaporation processes). The processes contributing the most energy losses are 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 radiative heat losses from evaporators, dryers and other key processes.

R&D Priorities

A number of R&D priorities were identified to facilitate the recovery and reduction of energy losses from fluid heating, boiling and cooling processes in chemicals, petroleum refining, and forest products. Table 2 summarizes these priorities in order of importance.

As Table 2 illustrates, from an industry perspective the recovery of energy from waste heat is by far the top priority and represents the greatest opportunity for reducing energy use. This includes the recovery of energy from high and low quality heat present in waste gases and liquids. Energy system integration, or systems integration of plant energy sources, also emerged as a high priority, and 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. Longer-term opportunities are present 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).

A number of priority topics were identified for the technical areas shown in Table 2. These are outlined in more detail in Figures 3 to 8.

Table 2 Overview of Energy Systems Priorities for Fluid Heating and Boiling (number of priority votes)

Recovery of Energy from High and Low Quality Waste Heat (both gases and liquids) From Processes (19)	⇒	Energy recovery technologies such as 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.
Energy System Integration (10)	⇒	Balance of energy across the plant to integrate energy sources and sinks, development of pinch opportunity tools, part load cycling and load management
Energy Source Flexibility (6)	⇒	Tools for selecting alternative energy sources, modular energy systems (chillers, CHP), energy storage, heat-activated power, alternate fuel products, substitution of steam vs direct heat vs indirect heat vs CHP, steam for mechanical drives
Education and Best Practices (6)	⇒	Education and training at executive and plant level, increased awareness of new technology and tools for efficiency improvements
Separations to Enable Energy Recovery (5)	⇒	Cleanup of high temperature gases, energy efficient dehydration of liquid waste streams, thermal vs non-thermal separations, centrifugal distillation, , drying-heat activated heat pumps, separation of liquid and water from chemicals
Energy Export and Co-location (4)	⇒	Inventory of waste heat sources across industry, analysis of co-location opportunities, export of fuels from pulp and paper (gasification of black liquor, alternatives to Fischer-Tropsch for conversion of off-gases)
Improved Controls, Automation, and Robotics for Energy Optimization (1)	⇒	Advances to optimize control of combustion processes, energy flows

Figure 3. Priority Topic: Fluid Heating and Boiling Energy Recovery from Fluids and Gases

Description and Goals Significant amounts of energy are wasted annually in the form of waste heat and byproducts from industrial processes. New energy recovery technologies are needed to capture waste energy resources as well as store and transport waste energy. Technology development should encompass recovery of energy from both high and low quality sources of waste liquids and gases.

Key Performance Requirements

- Proven technology feasibility
- Demonstrated capability over low temperature (110-160ºF) and high temperature (400-1500ºF) ranges
- Validated economic feasibility

Challenges and Barriers

- Availability of materials for corrosive environments
- Obtaining usable energy from low temperature heat sources
- Economic feasibility

Potential R&D Topics

- Alternative energy recovery cycles (e.g., HRSG for alternate cycles – Kalina)
- Alternatives to shaft power using waste heat (e.g., biphase expanders)
- Waste heat pumping/thermally activated technologies for low temperatures (heat-activated heat pumps/refrigeration)
- Low-cost technologies to recover low-grade heat
- High-temperature heat recovery technologies
- Standardized designs for heat recovery equipment to establish commonality and reduce costs
- Innovative working fluids for low temperature applications
- Vacuum from low-grade waste heat (e.g., thermo-compressors)
- Corrosion-resistant materials and powder coatings for heat exchanger exhaust or corrosive gas recovery
- Hot filtration of corrosive gases
- Liquid or gas thermal engines that operate on less than 300ºF waste heat
- Waste heat boilers for corrosive stream heat recovery
- New heat exchanger geometries, techniques and equipment with higher heat transfer rates
- Heat recovery from difficult fluids (suspensions, contaminated or gummy streams)
- Innovative thermal storage and waste energy transport technology

Partnership Roles and Responsibilities

Cost Shared R&D – Government, industry, vendors

Screening and Testing, Experimental Validation – Technology suppliers, universities, Federal laboratories

R&D Lead – Technology suppliers, Federal laboratories

Validation – End-users participate

Risk

LOW — HIGH

Technical

High to moderate; extended R&D required for some concepts.

Commercial

Variable; dependent on payback, technical liability, variability of fuel prices, and system reliability.

Benefits

LOW — HIGH

Energy Savings

Innovation

Technology Non-Existent

Multiple Applications

Environment

Economics of Use

Development Timeline

2005	2010		2015	2020
Search and explore existing technologies; define industry opportunities	Apply technology to opportunities	Lab and beta-test concepts	Demonstrate and validate at pilot scale	

Figure 4. Priority Topic: Fluid Heating and Boiling Energy System Integration

Description and Goals There are many opportunities to reduce energy losses and optimize energy use by integrating energy sources and sinks throughout the plant. The object of energy integration will be to optimize plant-wide energy utilization by identifying and developing synergies in the energy use of process designs and operations. Integration and use of CHP will be a key facet of energy systems integration. While various tools are commercially available for system integration, there are some opportunities to expand and develop new tools (part load cycling, tariff calculation).

Key Performance Requirements

- Simple to use tools
- Motivates end users to pursue outside expertise for more in-depth cost and benefits analysis and system engineering as needed

Challenges and Barriers

- Diverse industrial processes and site-specific conditions
- Economies of scale of CHP technologies

Potential Tool Development

- Energy balances across plant to integrate energy and minimize cost of operation
- Pinch opportunity identification tools (integration of heat sources and sinks)
- Tool for tariff calculation to help minimize purchases from utilities
- Part load cycling and load management

Partnership Roles and Responsibilities

Industry – Helps design and beta test tools; provides input on practicality of CHP technologies.

Federal Laboratories, Universities – Develop technologies and tools.

Government – (Federal or State) facilitate development of tools; fund tool development; promote and distribute tools; fund integrated CHP technology development; validate technology.

Risk

LOW HIGH

Technical

Tools are low risk if widely used. CHP integrated systems are medium risk; interconnection issues exist.

Commercial

Tools are low risk if widely used.

Benefits

LOW HIGH

Energy Savings

Tool Development

Integrated CHP

Multiple Applications

Environment

Development Timeline

2005	2010	2015	2020
Tools to help manage part loads; better integrate heat sources and sinks; energy tariffs tools (2005-2007)	Tools will be opportunity finders/screeners and will optimize two or more unit operations through integration (2008-2012)	System integrated CHP will be identified and developed (2008-2012)	

Figure 5. Priority Topic: Fluid Heating and Boiling Energy Source Flexibility

Description and Goals There are opportunities to develop alternate energy systems to meet requirements for process heat and power, with potential reductions in energy use and losses. Examples include using steam rather than direct heating, or using microwaves instead of steam. In some cases, CHP may provide a direct source of power for equipment. The goal will be to identify and develop alternative energy systems that are economically viable and improve energy optimization within the plant.

Key Performance Requirements

- Cost effective when compared with conventional
- Environmentally compliant or improved environmental performance
- Adoption generates energy savings

Challenges and Barriers

- Regulatory uncertainties
- Energy price and supply uncertainties
- Infrastructure for some new fuels (e.g., biomass or other renewables)
- Utility restructuring uncertainty

Potential R&D Topics

- Comparison of alternatives – steam versus direct heat versus indirect heat versus CHP
- Steam applied to mechanical drives
- Microwaves versus steam or other energy sources
- Cold flushes on heat pumps
- Heat-activated power systems
- Small, cost-effective modular systems across the board (chillers, CHP, etc)
- Sensor systems to facilitate energy source flexibility
- Liquid fuel production/burner technology for waste fuels or byproducts (e.g., ethers, animal products, others)
- Alternative fuel products
- Tools and guidelines for selecting alternatives

Partnership Roles and Responsibilities

Technology Assessment – Government, industry Federal Laboratories, Universities.

Proof of Concept – Government, Industry, Federal Laboratories.

Demonstration – Industry and government.

Risk

LOW — HIGH

Technical

Low to high technical risk, depending on pathway.

Commercial

Moderate commercial risk once demonstrated.

Benefits

LOW — HIGH

Energy Savings

Innovation

Technology Non-Existent

Multiple Applications

Environment

Economics of Use

Development Timeline

2005	2010	2015	2020
Baseline study of producing alternative fuels, alternative power/energy cycles for targeted industries	Proof of promising concepts	Demonstration in selected industries	

Figure 6. Priority Topic: Fluid Heating and Boiling – Separations to Enable Energy Recovery: Cleanup of High Temperature Gases

Description and Goals Significant amounts of waste energy are available in the form of high temperature exhaust or byproduct gases from a variety of processes. In many cases, these gases contain corrosive materials and particulates, making them difficult to capture and recover as an energy resource. Research is needed to develop technology for continuously removing particulates and other contaminants from high temperature gases without having to cool them down, allowing energy recovery. Energy savings opportunities are substantial. In gasification, for example, there is the potential to save as much of 20% of energy output with hot gas recovery technology.

Key Performance Requirements

- Durability
- Cost-effectiveness
- Gas stream clean enough to fuel a combustion turbine

Challenges and Barriers

- Materials durability
- Fouling of equipment
- Reliability; eliminated or infrequent shutdowns
- Adequate gas/gas separations

Potential R&D Topics

- Innovative gas cleanup technologies to remove particulates (e.g., magnetic separation)
- Separation of volatile organics (VOCs) and other contaminants from waste gases
- Technology to dehydrate streams containing lignin and fiber

Partnership Roles and Responsibilities

Federal Laboratories/ Universities – Identify candidate gas streams and potential benefits of cleanup/recovery.

Federal Laboratories/Industry – Develop prototype technology.

Federal Laboratories/Suppliers – Demonstration of technology.

Suppliers – Commercialization.

Risk

LOW — **HIGH**

Technical

High technical risk, extended R&D.

Commercial

High commercial risk.

Benefits

LOW — **HIGH**

Energy Savings

Innovation

Technology Non-Existent

Multiple Applications

Environment

Development Timeline

2005	2010	2015	2020
Identification of candidate technologies; exploration of new concepts.		Demonstration in selected industries	

Figure 7. Priority Topic: Fluid Heating and Boiling – Separations To Enable Energy Recovery: Energy Efficient Dehydration of Liquid Waste Streams

Description and Goals There are numerous opportunities in industry to recover energy from liquid waste streams. However, in many cases these waste streams contain significant amounts of water that must be separated before energy recovery can be effected. The cost of separation can be prohibitive, resulting in lost opportunities for capturing an energy resource. Research is needed to develop cost-effective and energy efficient technology for dehydrating the water from potentially useful liquid waste streams.

Key Performance Requirements

- Cost-effective drying performance
- High level of dehydration with high cost savings

Challenges and Barriers

- Materials durability
- Fouling
- Alternative uses and valuations for dehydrated streams

Potential R&D Topics

- Separation of liquid streams and water from chemicals
- Cleanup of waste water
- Evaporation technology for cleanup of liquid streams

Partnership Roles and Responsibilities

Federal Laboratories/ Universities – Identify candidate streams and potential benefits of total dehydration.

Federal Laboratories/Industry – Develop prototype technology.

Federal Laboratories/Industry/ Suppliers – Demonstration of technology.

Suppliers – Commercialization.

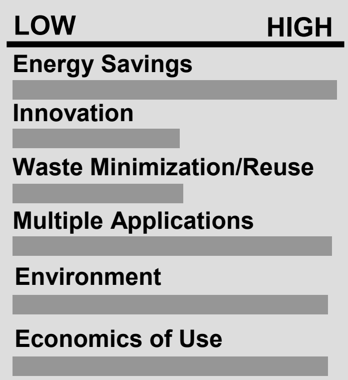
Risk

High risk of non-adoption as alternative; demonstrated reliability required.

Commercial

High commercial risk.

Benefits



Development Timeline

2005	2010	2015	2020
Screening of existing technology; determine value of improvement; identify alternative routes.	Design lab scale concepts.	Demonstrate pilot scale technology.	

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

Scope of Technology

Melting, smelting, metal heating, agglomeration and calcining represent a broad category of heating technologies used across many industrial sectors, particularly 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 palletizing 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. Calcining kilns represent some of the largest, hottest pieces of equipment used in U.S. manufacturing.

Selected Examples of Melting, Smelting, Metal Heating, Agglomeration, and Calcining

- ***Iron and Steel*** *(agglomeration, ironmaking, steelmaking, reheating, annealing)*
- ***Aluminum*** *(alumina calcination, scrap melting, smelting, preheating, annealing)*
- ***Metal Casting*** *(melting)*
- ***Glassmaking*** *(melting)*
- ***Transportation Equipment, Heavy Machinery, Fabricated Metals*** *(metal heating, paint drying, curing)*
- ***Cement and Forest Products*** *(calcining)*

Many similar energy systems are used for melting in the steel, aluminum, and metal casting industries, and to some extent in the glass, fabricated metals, and other industries. Some examples include electric melting furnaces, gas-fired melting furnaces, gas-fired reheating and annealing furnaces, and cupola furnaces.

This technology roadmap focuses on the melting and metal heating systems that are widespread across the industrial sector, and are of particular importance to iron and steelmaking, aluminum, glass, metal casting, and cement. Improvements in these energy systems have the greatest potential to reduce energy use and impact multiple industries.

Major Sources of Energy Losses

In metal melting and heating, 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. 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.

Major sources of losses from calcining processes are exhaust gases (evaporated water, combustion gases, carbon dioxide from calcinations) and radiation and convection heat losses. Agglomeration produces energy losses through heat transfer mechanisms and exhaust gases.

R&D Priorities

A number of R&D priorities were identified to reduce energy losses in the various processes commonly used in the manufacture of metals and non-metals. Table 3 summarizes these priorities in order of importance.

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, and by devising more innovative uses of energy sources.

From the technical areas shown in Table 3, a number of priority topics were identified for future research and development. These are outlined in more detail in Figures 8 to 11.

Table 3 Overview of Energy Systems Priorities for Metals and Non-Metallic Minerals (number of priority votes)

Recovery of Waste Heat from Exit Gases (10)	⇒ Enhanced energy recovery through robust, simple designs, secondary heating, integrated heating and recovery systems, corrosion-tolerant technology, and others.
Improved Process Heating for Glass and Metals Melting, Calcining, Refining, Heating, and Annealing (8)	⇒ Technologies to reduce energy losses, including higher temperature air preheat, improved thermal transfer, cascade heating, batch to continuous processes, hybrid heating, and others.
Improved Sensors, Controls Automation and Robotics for Heat Reduction Process Optimization (6)	⇒ Technologies to minimize energy and cost while meeting product specifications, such as remote measurement of temperature and pressure, direct measurement of product parameters, predictive models, automated process heaters, and others.
Improved Heat Transfer Systems for Heating Liquids and Gases (5)	⇒ Technologies to enhance heat transfer such as better channeling of heat and improved transport efficiency; innovative technologies such as modular or compact heating systems.
Waste Heat Reduction and Recovery for Drying (3)	⇒ Improved drying technologies such as infrared and others for paint drying, curing, and other operations.
Waste Heat Recovery for Quenching and Cooling (2)	⇒ Technologies for recovering heat from quenching and cooling of metals, glass, and other high temperature materials (molten and solid metals)
Heat Recovery From Combustible Gases (2)	⇒ Technology for utilization of combustible byproduct gases; could include gas cleanup technology for corrosive, contaminated gases.
Waste Heat Recovery From Lower Quality Liquids and Steam (2)	⇒ Enhanced heat recovery from lower quality hot fluid sources.
Improved Controls, Automation, and Robotics (1)	⇒ Controls and other technology to optimize heat reduction and energy use in melting, smelting, metal heating and other process heating operations.
Waste Heat Recovery From Calcining (other than flue gases)	⇒ Recovery of heat from lime calcining, cement calcining

Figure 8. Priority Topic: Metals/Non-Metallic Minerals Improved Process Heating

Description and Goals Process heating accounts for a substantial amount of energy use in the metals and non-metallic mineral industries, and in many cases represents a large share of production costs. The competitiveness of these industries can be increased by optimizing productivity and minimizing the energy intensity of process heating systems. Energy intensity is defined as specific energy use, or "Btu/lb of material processed"; productivity includes inputs, reliability, maintenance, and product output. The goal is to improve the thermal efficiency of the process heating "box" and maximize heat transfer (not necessarily reduce waste heat).

Key Performance Requirements

- Faster, more effective heating
- Environmentally compliant
- Cost-effective

Challenges and Barriers

- Mostly application specific
- Thermodynamic limitations
- Cost and risk of innovation

Potential R&D Topics

- Preheating of air to higher levels
- Improved thermal transfer of the process
- Improved productivity through reduction in product waste, improved heat transfer (faster heating, faster throughput), and optimized production schedules and practices
- Cascade heating techniques
- Switching from batch to continuous furnace where applicable
- Rapid heat transfer to and within material for heat treating
- Rapid heating and melting technologies
- Combined heat and power
- Hybrid heating
- Process heaters that meet emission requirements without compromising cost, productivity, and energy use

Risk

LOW — HIGH

Technical

Application-specific. Some required extended R&D.

Commercial

Application-specific.

Benefits

LOW — HIGH

Energy Savings

Innovation

Multiple Applications

Environment

Economics of Use

Development Timeline

2005	2010	2015	2020
Rapid heating, hybrid heating, CHP, preheat of air to higher temperatures.	Improved thermal transfer designs.	Cascade heating, batch to continuous, rapid heat transfer to and within material, rapid melting.	

Figure 9. Priority Topic: Metals/Non-Metallic Minerals Recovery of Waste Heat From Exit Gases

Description and Goals Exit gases from processes used to manufacture metals and other materials often have substantial embodied energy, but cannot be cost-effectively captured as an energy source for a variety of reasons. Research is needed to develop new methods and technologies for economically recovering waste heat from exit gases, including those that are corrosive or laden with contaminants.

Key Performance Requirements

- Robust, simple designs for waste heat recovery
- Materials with acceptable thermal properties and corrosion-resistance
- Acceptable system configuration
- Maintainable, resistant to fouling

Challenges and Barriers

- Adequate materials (e.g., corrosion-resistant)
- Defining industry needs
- Understanding which technologies are the best fit for various applications
- Cost-effective materials and designs

Potential R&D Topics

- Cost-effective, corrosion-resistant material systems
- Enhanced heating system to improve quality and utility of exit gases (e.g., secondary heating; may include heating exit gases to make them more “friendly” [e.g., destroy certain chemical species)
- Integration of heating and heat recovery systems (including transport of energy)
- Definition of exclusive industry needs
- Feedback (temperature, back pressure, residue) systems to convey what performance would be without recovery so that performance with recovery can be optimized
- System design update
- Benchmarking and comparison of various technologies to determine “best use” of recovered heat
- Understanding environmental compatibility of the recovery system (e.g., toxic substances, contaminants)

Risk

LOW — HIGH

Technical

Possible product quality impacts; need for environmental compliance.

Commercial

Economic viability must be proven.

Benefits

LOW — HIGH

Energy Savings

Innovation

Multiple Applications

Environment

Development Timeline

2005	2010	2015	2020
Concept development; benchmarking; definition of needs.	Design lab scale concepts.	Demonstrate pilot scale technology.	

Figure 10. Priority Topic: Metals/Non-Metallic Minerals Improved Sensors, Controls, Automation, and Robotics

Description and Goals Research is needed to develop improved sensors and controls for process optimization. The goal is to meet product specifications while minimizing energy use and cost, and ultimately achieving reductions in heat requirements. Automation and robotics could also play a role in energy optimization in some industrial processes.

Key Performance Requirements

- Application-specific
- Remote and online capabilities
- Broad, direct measurement capabilities
- Maintenance of product quality

Challenges and Barriers

- Application-specific
- Severe operating environments (temperature, pressure)
- Corrosive environments

Potential R&D Topics

- Sensors for remote measurement of temperature and pressure in harsh environments
- Direct measurement of product specification parameters (composition, temperature, mechanical properties, physical properties)
- Predictive models for on-line control
- Instrumentation (instantaneous energy sensor) that enhances operator awareness of process heater operation
- Simple instrumentation to help operators optimize process operations more effectively
- Fully automated process heater (intermediate results will enable development of valuable new technologies)
- Automatic emission control system for emission reduction
- Continued wireless development

Risk

LOW — HIGH

Technical

Application-specific; some extended R&D could be required.

Commercial

Application-specific; typically low cost for retrofit.

Benefits

LOW — HIGH

Energy Savings

Innovation

Multiple Applications

Environment

Development Timeline

2005	2010	2015	2020
Remote measurements in harsh environments; wireless development; instant energy sensors.	Direct measurement of product specs.	Predictive models for online control; fully automated process heaters; automatic emission controls.	

Figure 11. Priority Topic: Metals/Non-Metallic Minerals Improved Heat Transfer Systems

Description and Goals Research is needed to develop improved heat transfer systems for heating of liquids and gases in metals and non-metallic minerals manufacturing. Improvements are possible in a wide range of technical areas, from better heat transfer mechanisms to innovative equipment and working fluids.

Key Performance Requirements

- More cost-effective heat transfer
- Innovation (modularity, compactness, other design enhancements
- Optimization of energy inputs

Challenges and Barriers

- Lack of complete, comprehensive knowledge of process fundamentals
- Effective integration of sources and sinks
- Achieving energy transport efficiency
- Cost-effective materials and designs

Potential R&D Topics

- Effective integration (e.g., different heating methods, different heat sources, how integration affects heat transfer design)
- Compactness (e.g. small versus large heat exchanger; convection versus radiation)
- Thermal responses of fluids and associated chemistries
- Better channeling of heat transfer
- Transport efficiency (engineering to enable cost-effective transporting of heat from one place to another)
- Stabilization of working fluids (e.g., thermal and chemical effects, such as algae in water or the impact of the rate of heat input on particles in fluids such as lubricants or other chemicals)
- Modeling mass and heat transfer
- Feedback for more effective control of heating processes
- Benchmarking and comparison of different heat transfer methods
- Modular systems for heat transfer (modular design may be more effective than centralized units)
- Compact heat transfer systems (more efficient)

Risk

LOW — HIGH

Technical

Inadequate knowledge of process fundamentals.

Commercial

Potential commercial impact on business.

Benefits

LOW — HIGH

Energy Savings

Improved Product Quality

Multiple Applications

Economics of Use

Development Timeline

2005	2010	2015	2020
Concept selection and exploration; benchmarking.	Lab and pilot scale development.	Technology demonstration and validation.	

Top Twenty Opportunities

A list of top opportunities was developed based on inputs obtained at the Energy Loss and Reduction Workshop and previous studies conducted [EI 2003, EI 2004, USCHPA 2001]. These opportunities are illustrated along with the associated energy savings in Table 4.

Table 4 Top Twenty R&D Opportunities (Trillion Btu)

#	Opportunity Area	Industries Analyzed	Pre-Process Energy Savings	Post-Process Energy Savings	Total Energy & Cost (million $) Savings
1	**Waste heat recovery** from gases and liquids in chemicals, petroleum, and forest products, including hot gas cleanup and dehydration of liquid waste streams	chemicals, petroleum, forest products	0	828	828 ($2210 MM)
2	**Combined heat and power systems**	forest products, chemicals, food, metals, machinery	634	0	634 ($2000 MM)
3	**Advanced industrial boilers**	chemicals, forest products, petroleum, steel and food processing	400	0	400 ($1090 MM)
4	**Heat recovery from drying processes**	chemicals, forest products, food processing	160	217	377 ($1240 MM)
5	**Steam best practices** (improved generation, distribution and recovery), not including advanced boilers	all manufacturing	310	0	310 ($850 MM)
6	**Pump system optimization** in electric motor-driven systems	All manufacturing	*302 (98)	0	*302 (98) ($1370 MM)
7	**Energy system integration**	chemicals, petroleum, forest products, iron and steel, food, aluminum	110	150	260 ($860 MM)
8	**Improved process heating/heat transfer systems for chemicals and petroleum industries** (improved heat exchangers, new materials, improved heat transport)	petroleum, chemicals	121	139	260 ($860 MM)
9	**Energy efficient motors and improved rewind practices**	all manufacturing	*258 (84)	0	*258 (84) ($1175 MM)
10	**Waste heat recovery** from gases in metals and non-metallic minerals manufacture (excluding calcining), including hot gas cleanup	iron and steel, cement	0	235	235 ($1133 MM)
11	**Energy source flexibility** (heat-activated power generation, waste steam for mechanical drives, indirect vs direct heat vs steam)	chemicals, petroleum, forest products, iron and steel	119	75	194 ($1100 MM)
12	**Improved sensors, controls, automation, robotics**	chemicals, petroleum, forest products, iron and steel, food, cement, aluminum	39	152	191 ($630 MM)
13	**Improved process heating/heat transfer for metals melting, heating, annealing** (cascade heating, batch to continuous, better heat channeling, modular systems)	iron and steel, metal casting, aluminum	63	127	190 ($915 MM)
14	**Compressed air system optimization** in motor-driven systems	all manufacturing	*163 (53)	0	*163 (53) ($740 MM)
15	**Optimized materials processing** (grinding, mixing, crushing)	all manufacturing	*145 (47)	0	*145 (47) ($660 MM)
16	**Energy recovery from byproduct gases**	petroleum, iron and steel	0	132	132 ($750 MM)
17	**Energy export and co-location** (fuels from pulp mills, forest biorefineries, co-location of energy sources/sinks)	forest products	0	105	105 ($580 MM)
18	**Waste heat recovery from calcining** (not flue gases)	cement, forest products	11	63	74 ($159 MM)
19	**Heat recovery from metal quenching/cooling processes**	iron and steel	0	57	57 ($275 MM)
20	**Advanced process cooling and refrigeration**	Food processing, chemicals, petroleum and forest products	*57 (15)	0	*47 (15) ($212 MM)
TOTALS			**2889**	**2280**	**5162 ($18,357 MM)**

*Includes losses incurred during offsite generation and transmission of electricity, based on conversion factor of 10500 Btu/kWh. Number in parenthesis does not include losses.

The pre-process energy savings shown in Table 4 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 consumption. No attempt has been made to predict increases in the energy use baseline over time.

The potential impacts of reducing energy losses are substantial. As shown in Table 4, the top twenty opportunities represent over 5 quads of energy (total energy savings), or about 22% of the total energy (including offsite electricity generation and transmission losses) used by the manufacturing sector in 1998

Table 5 Cross-Industry Technology Matrix

	1. Waste heat recovery/ gases and liquids/chemicals, petroleum, forest products	2. Combined heat and power	3. Advanced industrial boilers	4. Heat recovery from drying	5. Steam best practices	6. Pump system optimization	7. Energy system integration	8. Improved process heating/ heat transfer/ chemicals, petroleum	9. Efficient motors/rewind practices	10. Waste heat recovery/ gases/ metals and minerals	11. Energy source flexibility	12. Improved sensors, controls	13. Improved process heating/heat transfer/ metals melting, heating	14. Compressed air optimization	15. Optimized materials processing	16. Energy recovery/ byproduct gas	17. Energy export and co-location	18. Waste heat recovery/calcining	19. Heat recovery/metal quenching/ cooling	20. Advanced process cooling/ refrigeration
Petroleum Refining	■	■	■		■	■	■	■	■		■	■		■	■	■	■			■
Chemicals	■	■	■	■	■	■	■	■	■		■	■		■	■	■	■			■
Forest Products	■	■	■	■	■	■	■	■	■		■	■		■	■	■	■	■		
Iron and Steel		■	■		■	■	■		■	■	■	■	■		■	■	■		■	
Food and Beverage	■	■	■	■	■	■	■	■	■		■	■		■	■		■			■
Cement				■		■	■		■		■	■			■			■		
Heavy Machinery		■	■		■	■	■		■		■	■	■				■		■	
Mining						■	■		■		■	■			■				■	
Textiles	■	■	■		■	■	■	■	■		■	■		■			■			
Transportation Equipment		■	■		■	■	■		■		■	■	■				■		■	
Aluminum & Alumina						■	■		■	■	■	■	■		■				■	
Foundries						■	■		■	■	■	■	■		■				■	
Plastics & Rubbers	■	■	■		■	■	■	■	■		■	■		■			■			
Glass & Glass Products						■	■		■	■	■	■	■		■					
Fabricated Metals						■	■		■	■	■	■	■						■	
Computers, Electronics, Appliances						■	■		■		■	■								

Note: Shading indicates opportunity is applicable to that industry.

[MECS 1998, EI 2003]. The costs associated with energy use in the industrial sector provide another perspective. According to the MECS, the manufacturing sector spent about $80 billion in energy in 1998, and that number has been rapidly rising as fuel and electricity prices increase. Total potential cost savings shown in Table 4 are over $19 billion, or about 24% of 1998 energy expenditures in manufacturing.

The opportunities in Table 4 are based on a relatively small subset of the manufacturing sector (the top energy consumers). Due to their crosscutting nature, however, the potential 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. Table 5 illustrates the cross-industry applications for the opportunities identified in Table 4.

Energy savings for most of the top twenty opportunities were estimated based on two separate analyses conducted over the last year [EI 2003, EI 2004], and on the national roadmap for combined heat and power (CHP) and other CHP estimates [USCHPA 2001, ACEEE 1999]. 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 dependent on the specific application and industry. The complete estimation methodology for the top twenty topics can be found in the energy loss opportunities analysis, slated for publication in November 2004 [EI 2004]. A brief description of the scope and assumptions behind each opportunity is given below. Additional details are provided in the Appendix.

Opportunity 1 includes energy savings from **waste heat recovery from gases and liquids** (both high and low quality energy) in chemicals, petroleum refineries, and the forest products industry. Enabling separations, such as hot gas cleanup and the dehydration of liquid waste streams are included as R&D areas, as are supporting R&D such as corrosion-resistant materials and innovative working fluids. Waste heat recovery and separations were identified as priority topics and are described in more detail in Figures 3, 6, and 7 (Fluid Heating, Boiling and Cooling chapter). Technology R&D areas include innovative energy recovery cycles, waste heat pumping, thermally activated technologies, new heat recovery techniques, and improved energy transport and storage.

Opportunity 2 represents the potential savings possible from the increased use of **combined heat and power (CHP)** systems in the industrial sector, specifically in the forest products, chemicals, metals, and machinery industries. Savings are based on potential adoption of 54 GW of new CHP capacity by 2020, or double predicted additions for 2010. Total estimated potential is 88 GW [USCHPA 2001, ACEEE 1999]. Savings were estimated by calculating the reduction in losses achieved in going from a heat rate of 10,500 Btu/kWh to the more efficient heat rate of 4500 Btu/kWh, made possible through cogeneration of heat and power.

Opportunity 3 includes the adoption of **more efficient boilers**, such as the "Super Boiler" now under development, as well as other boiler innovations. While many industry steam users could benefit from advanced boilers, most of the impact will be achieved in the heavy steam-using industries such as chemicals, forest products, petroleum refining, food processing, and textiles. Savings are based on an energy and environmental analysis of new boiler technologies [EI 2004a].

Opportunity 4 represents energy savings from the recovery of waste heat from relatively inefficient **drying processes** in a number of industries, including chemicals, forest products, and food processing. Improvements are possible in processes such as paper drying, concentration, evaporation, and other processes where water is removed [EI 2004]. While savings are not included, this opportunity would also encompass process operations such as paint drying and curing, which are used in assembly and fabrication industries such as heavy machinery, fabricated metals, and transportation equipment.

Opportunity 5 includes application of **steam best operating and maintenance practices** to steam generation, distribution and recovery systems (excluding development of advanced boilers). Savings are based on a 5% reduction in steam energy inputs across the entire manufacturing sector.

Opportunities 6, 9, 14, and15 involve the optimization of **motor-driven systems** such as pumps, compressors, and materials processors (grinders, mixers, crushers, sizers), as well as upgrading motors and improving rewind practices [Xenergy 1998]. Motor-driven systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand in the plant translates into less electricity generated at utilities, along with the associated large generation and transmission losses. [Note: The efficiency of electricity generation at utilities ranges from 25-45%.]

Opportunity 7 represents energy savings from **energy system integration**, which involves a diversity of methods for integrating energy sources and sinks, integration of energy requirements to minimize the cost of operations, and part-load cycling and load management. This area was identified as a priority topic and is outlined in more detail in Figure 4 (Fluid Heating, Boiling and Cooling chapter). Energy savings are based on a 3% reduction in pre- and post-process energy losses in six energy-intensive industries (petroleum, chemicals, forest products, iron and steel, food processing, and aluminum).

Opportunity 8 covers potential improvements to **process heaters (fired systems) and heat transfer systems** in the non-metal industries, specifically chemicals and petroleum. This includes improved materials, innovative heat exchanger designs and geometries, better heat transport, and other process heating enhancements. Savings are based on a 5% reduction in pre- and post-process losses in fired systems in the two industries analyzed.

Opportunity 10 involves the **recovery of waste heat** from gases generated in **metals and non-metallic minerals** manufacturing (excluding calcining, which is covered in Opportunity 18). Supporting technologies such as hot gas cleanup and corrosion-resistant materials would be included. Savings are based on a prior analysis [EI 2004] of iron and steel and cement. This area was identified as a priority topic and is outlined in more detail in Figure 9 (Melting chapter).

Opportunity 11 covers **energy source flexibility**, which is essentially finding new or alternative ways to provide the energy required for manufacturing processes. Technology options range from innovations such a microwaves or heat-activated power, to the substitution of steam for direct heat or vice versa. This area was identified as a priority topic and is discussed in more detail in Figure 5 (Fluid Heating, Boiling and Cooling chapter). Savings are based on a prior analysis [EI 2004] and an assumption of 10% of pre-process losses in selected industries.

Opportunity 12 is a broad category for optimizing energy through the use of **improved sensors, controls, automation and robotics**. Savings are based on 5% of end-of-process losses in five selected industries, and 1% of pre-process losses in the same five industries (shown in Table 4). This area was identified as a priority topic and is outlined in more detail in Figure 10.

Opportunity 13 covers potential improvements to **process heaters (fired systems) and heat transfer systems** in the metal and non-metallic mineral industries (analogous to Opportunity 8 for chemicals and petroleum). This includes improved materials, innovative heat exchanger designs and geometries, better heat transport, and other process heating enhancements. This area was identified as a priority topic and is discussed in more detail in Figure 8 (Melting chapter). Savings are based on a 5-10% reduction in pre- and post-process losses in fired systems in the industries analyzed (see Table 4).

Opportunity 16 involves the recovery of energy from **combustible byproduct gases** in various industries, notably petroleum refining and iron and steel. Savings are based on a prior analysis [EI 2004] of these two industries. Technology options might include gas separation and recovery and gas cleanup.

Opportunity 17 looks at the potential for **exporting energy** from pulp mills and biorefineries, including fuels produced by Fischer-Tropsch synthesis of gases from black liquor gasification. This topic also covers co-location of facilities to optimize energy resources (e.g., location of large excess steam producer near heavy steam user). While some estimates project potential wood-based fuels at 160 trillion Btu annually, this estimate uses a more conservation figure (about 100 trillion Btu annually) based on wood resource estimates. Opportunities for co-location have not been estimated, but could be substantial.

Opportunity 18 involves the recovery of waste heat from **calcining**, specifically lime mud reburning in the pulp and paper industry, and cement calcining. Flue gases are not considered, as these are covered under Opportunity 10. Savings are based on a prior analysis [EI 2004].

Opportunity 19 represents energy savings from recouping heat lost in the **quenching and cooling of metals**. Savings are based on a prior analysis [EI 2004] for iron and steel, although they could be much higher if other metal producing, casting and fabricating industries were considered.

Opportunity 20 covers **advanced cooling and refrigeration** processes, specifically in the chemicals and food processing industries. Savings are based on a 20% reduction in electricity requirements for motor-driven refrigeration systems in these industries [Xenergy 1998]. Additional savings would be possible through improvements in other cooling systems (non-electric).

Table 6 Opportunity Energy Savings Summarized by Broad Categories

Category	Combined Savings (Trillion Btu)
Waste Heat and Energy Recovery (Opportunities 1,4,10,16-19)	1808
Improvements to Boilers, Fired Systems, Process Heaters and Cooling (Opportunities 3,8,13,20)	897
Energy System Integration and Best Practices (Opportunities 5-7,9,14-15)	1438
Energy Source Flexibility and Combined Heat and Power (Opportunities 2, 11)	828
Sensors, Controls, Automation (Opportunity 12)	191
Total	5162

Potential energy savings represented by the above opportunities are summarized in Table 6 according to broader categories that group similar approaches across different industries. Combined savings for waste heat and energy recovery are the largest at nearly 1.8 quads (more mid- to long-term opportunities). Substantial savings are also possible (nearly 1.5 quads) for more near-term options such as energy integration and optimization of equipment such as pumps, compressors and steam systems.

Not all the opportunities shown in Table 6 will require R&D. The more near-term opportunities, such as optimization of motor systems and energy systems integration, could be achieved with little or no research investment, as some technology and tools are already available.

Path Forward

Some important industry needs and potential energy savings opportunities have been identified for industrial energy systems. While some of these opportunities can be achieved in the near-term with existing technology, others will require longer-term, higher risk research, development and demonstration. How this research is supported, conducted and implemented will play a key role in moving forward toward reducing and recovering lost energy opportunities.

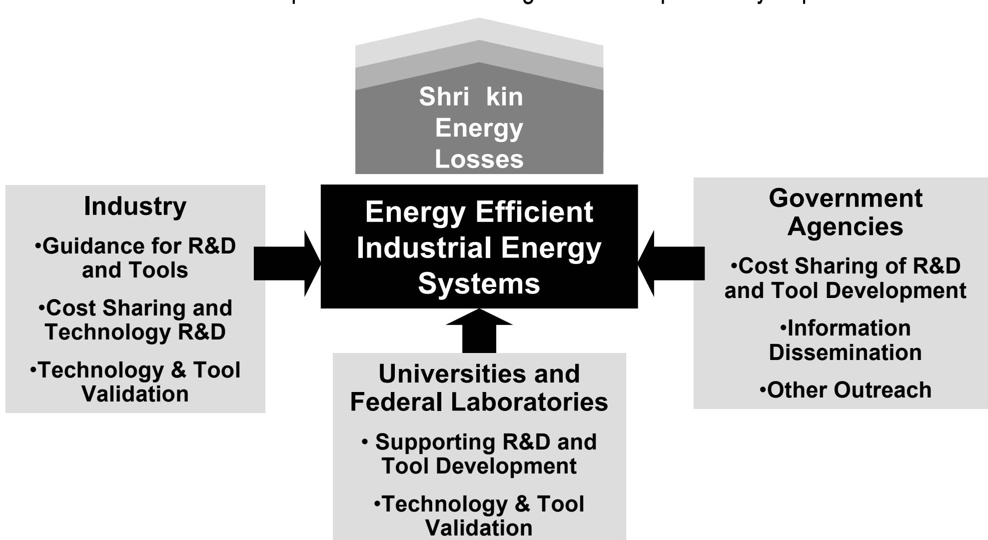
Roles of Industry and Government

The path forward to taking advantage of potential energy savings will be paved with a combination of fundamental and applied research efforts, supported and leveraged by both industry and government. More near-term research, for example, such as tool development and energy system integration, can be accomplished through government-industry collaborations where national laboratories and universities develop tools, and industry beta tests and provides feedback. Priorities for government-industry collaborations should be developed to take full advantage of synergies between industries that are specifically mentioned in the top twenty, as well as other basic and supporting industries that could benefit from new energy systems technologies.

More fundamental studies should be conducted in universities and national laboratories, with industry and government cost-sharing and providing guidance and technical direction. These efforts are critical to support future technology development and ensure the economic and technical viability of new concepts. Research, for example, to enhance heat transfer designs or to develop and test new working fluids, will be essential for improving the overall efficiency of process heaters and to enable the use of low quality waste heat sources.

Technology development, especially where application-specific, should be industry-led and, if precompetitive, Federally cost-shared. Consortia of industrial partners may be a viable approach for technologies that will have multiple-industry applications. In some cases, multiple-partner collaborations may be required that involve universities, national laboratories, and industry suppliers as well as end-users.

Demonstration will be a key facet of new technology development and implementation, and must take place at the industrial facility. Validation of performance, particularly for radically new systems, will be essential to promote commercialization and widespread use of technologies that are previously unproven.



Conclusions

There are significant opportunities for reducing energy losses and energy demand through the use of improved industrial energy systems. The top twenty opportunities outlined here represent over 5 quads of energy use and over $18 billion in energy expenditures that could potentially be avoided. Some of the opportunities listed represent relatively near-term targets achievable in the next five years (steam best practices, pump and compressed air optimization, energy system integration). These near-term targets will not require R&D, but might require increased plant awareness, promotion of energy best practices, better justification of energy efficiency projects, new tools and training. The remainder will be achieved through a combination of near-, mid- and long-term activities, not all of which are R&D. Opportunity 2, for example, which advocates the increased use of combined heat and power, does not necessarily require research. It will, however, require incentives (e.g., financial, permitting, other) for industry to invest as well as a better understanding of the benefits of using onsite power.

Some of the most worthwhile opportunities exist in the recovery of waste energy from fluids and gases in a diversity of industries from petroleum refining to metals manufacture. Drying is another energy-intensive process that generates substantial amounts of wasted energy, and could benefit from energy recovery as well as the exploration of alternative energy sources. The potential combined impacts from waste heat and energy recovery are nearly 1.7 quads of energy annually. Most of these opportunities require research and development, and could be achieved in the mid- to longer-term time frame.

Research to improve both boiler systems and fired systems (process heaters) represents an important opportunity to reduce energy losses. While some incremental improvements can be achieved, R&D could lead to innovations that substantially increase the efficiency of process heaters and heat transfer systems. Combined energy savings for these categories are nearly 900 trillion Btus annually.

In the near term, energy system integration and best practices can have a significant impact on energy losses. Tools to integrate energy sources and sinks and assist industries in improving operating and maintenance practices will help to achieve these near term opportunities. Improving the efficiency of motor-driven systems is another near-term opportunity that has the potential to make an impact across the manufacturing sector. The combined energy loss reductions for these areas total nearly 1.5 quads annually.

There are near- to long-term opportunities for increased use of CHP in industrial facilities. Combined heat and power represents a means of reducing energy losses both on-site and off-site. By displacing purchased electricity with more efficiently generated onsite energy, industry meets its energy needs more effectively and reduces its bottom line.

Effectively communicating information about new technologies and energy loss reductions will be essential to raise industrial awareness of the potential benefits and to help justify efficiency projects to corporate managers. Education and training in energy systems optimization are key components, and will help to promote industrial investment in energy efficiency.

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Appendix
Top Twenty Descriptions

1	Waste heat recovery from gases and liquids in chemicals, petroleum, and forest products
2	Combined heat and power systems
3	Advanced industrial boilers
4	Heat recovery from drying processes
5	Steam best practices
6	Pump system optimization
7	Energy system integration
8	Improved process heating/heat transfer systems for chemicals and petroleum industries
9	Energy efficient motors and improved rewind practices
10	Waste heat recovery from gases in metals and non-metallic minerals manufacture
11	Energy source flexibility
12	Improved sensors, controls, automation, robotics
13	Improved process heating/heat transfer for metals melting, heating, annealing
14	Compressed air system optimization
15	Optimized materials processing
16	Energy recovery from byproduct gases
17	Energy export and co-location
18	Waste heat recovery from calcining
19	Heat recovery from metal quenching/cooling processes
20	Advanced process cooling and refrigeration

Opportunity 1 Waste Heat Recovery From Gases and Liquids in Chemicals, Petroleum, and Forest Products

This opportunity area encompasses energy savings possible from waste heat recovery from gases and liquids (both high and low quality energy) in chemicals, petroleum refineries, and the forest products industry. Waste heat sources include waste steam (possibly contaminated), exhaust and flue gases, flares, hot water and radiation heat losses. The energy potential in these sources is considerable; energy content in waste streams above 75°F has been conservatively estimated to be nearly 7 quads.

Priority technology R&D areas include innovative energy recovery cycles, alternatives to shaft power, waste heat pumping and thermally activated technologies for low temperatures, waste heat boilers recovering corrosive heat streams, heat recovery from contaminated fluids, new heat recovery techniques, and improved energy transport and storage. Enabling R&D areas include separations such as hot gas cleanup and the dehydration of liquid waste streams, development of corrosion-resistant materials, innovative heat exchanger geometries, and development of innovative working fluids.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**0**		
Post-Process	**828**	**TOTAL**	**$2,210**
TOTAL	**828**		

Methodology

Potential heat recovery from gases and liquids in **chemicals manufacture** was calculated for five chemical chains based on average waste heat recovery potentials found in common practice, which range from 2.5-10%, with most values around 5-10% (see Table 1.1). Waste heat recovery potentials were applied to energy use in these chains to yield energy savings of 114 Tbtu. This accounts for about 7.8% of energy used by these chains for steam and fired systems (114/1456 Tbtu). However, these chains only represent 42% of total energy use (3451 Tbtu) in chemicals manufacture for steam and fired systems. To capture the savings represented by the other 58% of energy use, the energy savings rate of 7.8% was applied to the remaining energy (1995 Tbtu) to estimate additional potential savings from waste heat recovery of 156 Tbtu. Combined energy savings are 270 Tbtu.

Potential heat recovery in **petroleum refineries** was calculated separately for steam and fired systems. For fired systems, average efficiencies of 75-80% were applied to energy used in major unit operations to estimate potential energy losses (see Table 1.2 below). It was then assumed that between 20-45% of those losses could be captured, depending upon the process. This yielded energy savings of 357 Tbtu. For steam systems, an average efficiency of 40-55% was assumed for steam-using operations, with 20% recovery of the potential losses, except for atmospheric distillation, where a recovery value of 40% was applied (see Table 1-2). Energy savings using this approach came to 136 Tbtu. Combined savings for petroleum refining in this category amount to 493 Tbtu.

Potential heat recovery in the **forest products** industry was calculated for four major processes utilizing steam and fired systems (see Table 1.3). Average efficiencies of 40-45% were applied to energy use in these processes, followed by a potential10-25% recovery of energy losses in the form of waste energy from gases or liquids. Total energy savings from the four processes amount to 64 Tbtu. Combined energy savings for all three industries of 827.5 Tbtu are shown in Table 1.4.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% coal ($1.50/MMBtu) and 5% electricity ($0.0477/kWh). The remainder is assumed to be mostly waste fuels – no cost assigned). Boiler fuel mix is taken from the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Chemicals: *Energy and Environmental Profile of the U.S. Chemical Industry*, Energetics, Inc. 2000. *John Zinc Combustion Handbook*; Personal communication with Dr. Richard Martin, Aztec Engineering, 2004 and Arvind Thedki, E3M, Inc., 2004.

Petroleum: *Steam Systems Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries*, Resource Dynamics Corp. 2000; *Improving Steam Systems Performance, A Sourcebook for Industry,* U.S. DOE; *Energy and Environmental Profile of the U.S. Petroleum Refining Industry*, Energetics, Inc. 1998; Personal communication with Dr. Richard Martin, Aztec Engineering, 2004 and Arvind Thedki, E3M, Inc., 2004.

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Opportunity 1 Waste Heat Recovery From Gases and Liquids in Chemicals, Petroleum, and Forest Products: Supporting Data Tables

Table 1.1 Chemicals Manufacture	Energy Savings 10^12 Btu
The Ethylene Chain	**25.6**
Ethylene	18.63
Polyethlene - 1997	0.41
Poly Vinyl Chloride	0.70
Ethylene Oxide	0.44
Ethylene Glycol	0.43
Polystyrene	4.88
The Propylene Chain	**4.42**
Propylene	3.19
Polypropylene - 1997	0.13
Propylene Oxide - 1997	0.41
Acrylonitrile	0.27
Acrylic Acid	0.84
Acrylic Fiber	0.43
The BTX Chain (Benzene, Toluene, Xylene)	**36.32**
BTX	23.42
Benzene	0.31
Ethylbenzene	0.95
Styrene	8.24
Polystyrene	1.03
Cumene	0.20
Terephthalic Acid	0.59
Nylon 6.6	0.56
Nylon 6	0.20
Agricultural Chemicals – Fertilizers	**32.80**
Urea	0.22
Phosphoric Acid (furnace Process)	0.48
Ammonia	31.90
The Chlor-Alkali Industry	**15.31**
Caustic Soda (Chlorine/Sodium Hydroxide)	7.58
Soda Ash (Sodium Carbonate)	7.73
Total Five Chains	**115.34**
Estimated Additional Savings	**156**
TOTAL Industry	**271.34**

Table 1.2 Petroleum Fired Systems	Energy Savings 10^12 Btu
Atmospheric Distillation	96.24
Vacuum Distillation	29.85
Solvent Deasphalting	2.6
Delayed Coking	7
Fluid Coking	1.42
Flexcoking	1.34
Visbreaking	0.26
Fluid Catalytic Cracking	20
Catalytic Reforming	47.04
Alkylation	29.8
Ethers Manufacture	3.34
Isomerization	4
Catalytic Hydrotreating	70.25
Catalytic Hydrocracking	24.7
Lube Oil Mfg	19.16
	357.0
Petroleum Steam Systems	
Atmospheric Distillation	60
Vacuum Distillation	11
Fluid Catalytic Cracking	0
Catalytic Hydrocracking	4
Catalytic Hydrotreating	25
Catalytic Reforming	14
Alkylation	17
Isomers	5
	136.0
Total Petroleum Refining	**493.0**

Table 1.3 Forest Products Steam Systems	Energy Savings 10^12 Btu
Kraft Pulping	22
Semi Chem Pulping	2
Chemical Recovery	17
Lime Reburning	**23**
Total Forest Products	**64**

Table 1.4 Combined Energy Savings	Energy Savings 10^12 Btu
Chemicals	271.34
Petroleum	493
Forest Products	64
TOTAL All Industries	**828.34**

Opportunity 2 Combined Heat and Power

This opportunity area encompasses potential energy savings accruing from the increased use of combined heat and power (CHP, or cogeneration) systems in the industrial sector. Cogeneration systems produce both electricity and steam, which increases the thermal efficiency of the system when compared with utility power generating systems (from thermal efficiency of about 30-40% to as much as 75% or more for cogeneration). Energy savings accrue from a reduction in the energy losses associated with power generation inefficiencies. Net electricity generated by the manufacturing sector in 1998 amounted to nearly 500 Tbtu, with 428 Tbtu generated through cogenerating systems. Total purchased electricity for manufacturing amounted to 3.1 quads in 1998; the generation and transmission losses associated with manufacturing purchases were over 6.4 quads for that year. Onsite power generation currently accounts for only about 14% of manufacturing electricity demand.

While any power-consuming industry can potentially install onsite cogeneration units, the industry must be able to use or export the steam that is produced. In addition, if the industry produces excess electricity, it can be exported to the local grid (if permitted by local regulation), providing an additional revenue stream to offset energy costs. While this opportunity specifically targets the forest products, chemicals, food, metals, and machinery industries, other steam-using industries such as textiles manufacture are potential but smaller targets for increased use of CHP. Advanced cogeneration technologies include systems made more efficient through advances in turbine designs (microturbines, reciprocating gas turbines) or other innovations (e.g., advanced materials). Such technologies can also provide "trigeneration" capability, i.e., generation of power, heating and cooling.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**634**	**TOTAL**	**$2,000**
Post-Process	**0**		
TOTAL	**634**		

Methodology

Energy savings are based on the potential adoption of 56 GW of new CHP capacity by 2020 (total predicted potential capacity is 88 GW). These additions were assumed to be installed in four industries: pulp and paper (26 GW), chemicals (9 GW), food (8 GW), machinery (6 GW), and metals (7 GW). Energy consumption was estimated by first calculating the energy required to produce electricity at the heat rate of 10,500 Btu/kWh (typical of purchased electricity generated at utilities) and at the more efficient heat rate of 4500 Btu/kWh (typical for cogeneration facilities). Energy savings were then determined by calculating the reduction in energy losses achieved by producing electricity at the more efficient heat rate. Energy loss reductions are taken offsite, at the utility that would have been producing the purchased power. New capacity was assumed to be operating at 67% of capacity, or about 5900 hours per year, which yields an estimated 106 billion kWh. Fuel required by the utility to produce 106 billion kWh was estimated to be about 1110 Tbtu (750 Tbtu losses); for the industrial cogenerator, the same amount of kWh would require 476 Tbtu (115 Tbtu losses). The reduction in losses (and the potential opportunity for energy savings) was calculated to be 635 Tbtu.

For simplicity, cost savings are based on a fuel mix of 40% natural gas ($5.65/MMBtu) and 60% coal ($1.50/MMBtu). Average fuel prices were taken from the EIA Monthly Energy Review June 2004, and EIA Petroleum Marketing Monthly June 2004.

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Manufacturing Energy Consumption Survey, 1998, Energy Information Administration, U.S. Department of Energy, 2001.

Opportunity 2 Combined Heat and Power Systems: Supporting Data Tables

Table 2.1 Industrial Onsite Power Generation				
	Onsite Electricity			
Industry	Million kWh	Trillion Btu	% of Electricity Demand	Future Potential for CHP (MegaWatts)
Pulp & Paper	55,000	188	37	26,198
Cement	560	2	4	204
Steel	5,275	18	10	6,941 (primary metals)
Chemicals	45,721	156	21	9,440
Petroleum Refining	15,240	52	30	6,789 (refining plus coal products)
Food	6,155	21	8	8,086

Sources:

CHP Market Assessment, Onsite Sycom Energy Corporation, for the U.S. Department of Energy, 2000.

Hendrick G. van Oss, *Cement 2001*, U.S. Geological Survey.

Opportunity 3 Advanced Industrial Boilers

This opportunity area encompasses the development and adoption of more efficient boilers, such as the "Super Boiler" now under development, and other revolutionary boiler and combustion system innovations. While many industry steam users could benefit from advanced boilers, most of the impact will be achieved in the heavy steam-using industries such as chemicals, forest products, petroleum refining, food processing, and textiles.

About 6 quads of energy are currently consumed in industrial boilers every year (manufacturing and mining). Based on 80% conversion efficiency (an average value – some boilers have efficiencies as low as 60%, depending on age and fuel type), the energy losses associated with conversion of water to steam in boilers is about 1.2 quads annually.

The conversion efficiency of industrial boilers can be improved by boiler innovations such as high intensity heat transfer, high efficiency, low emission burners, smart control systems, efficient preheating, flame radiation and other enhancements. The Super Boiler technology, for example, combines a number of innovations in one system to achieve optimum efficiency.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**400**		
Post-Process	**0**	**TOTAL**	**$1,090**
TOTAL	**400**		

Methodology

Energy savings are based on an energy and environmental analysis performed for the Super Boiler technology using the ITP Impacts Projection Model, and extrapolated to larger market segments. This analytical model projects energy benefits for a span of 30 years, based on escalation of current markets, selected market penetration curves, and user inputs of energy impacts relative to conventional technology. A conservative scenario for the Super Boiler was assumed to be a potential accessible market of 35%, with 70% of that market penetrated by 2025. This scenario yields a projected energy savings of about 200TBtu in 2025 (see Table 3.1).

Since Super Boiler technology is assumed to impact a limited market segment (about ½ of industrial boilers of 10 MMBtu/h capacity or larger, and about 40% of total firing capacity of these boilers), it was assumed that similar results could be achieved with other technology advances in at least 80% of the total boiler market. Extrapolating results to this larger market yielded roughly an additional 200 TBtu of potential energy savings by 2025. Total energy savings were thus assumed to be about 400 TBtu, based on long-term market penetration of advanced boiler systems over 20 years (see Table 3.2).

For simplicity, cost savings are based on a fuel mix of 41% natural gas ($5.65/MMBtu), 12% coal ($1.50/MMBtu), 5% fuel oils ($4.7/MMBtu) and 42% other (mostly waste fuels – no cost assigned). Boiler fuel mix is taken from the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004, and EIA Petroleum Marketing Monthly June 2004.

References

Engineering and Economic Analysis Tool: "Super Boilers", Energetics, Inc. for the U.S. Department of Energy, Government Performance Reporting Act (GPRA) FY 2006 submissions, June 2004.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc. and E3M, Inc. for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, U.S. Department of Energy, 2001.

Opportunity 3 Advanced Industrial Boilers: Supporting Data Tables

Table 3.1 Potential Energy Impacts Based Solely on Super Boiler Technology

Impact By Year	2010	2015	2020	2025
ANNUAL SAVINGS				
Energy Metrics				
Total primary energy displaced (trillion Btu)	3.57	30.12	130.03	186.86
Direct electricity displaced (billion kWh)	0.00	0.00	0.00	0.00
Direct natural gas displaced (bcf)	3.48	29.33	126.61	181.94
Direct petroleum displaced (million barrels)	0.00	0.00	0.00	0.00
Direct coal displaced (million short tons)	0.00	0.00	0.00	0.00

Table 3.2 Potential Energy Impacts Based on 80% of Boiler Population

Impact By Year	2010	2015	2020	2025
ANNUAL SAVINGS				
Energy Metrics				
Total primary energy displaced (trillion Btu)	8.17	68.85	297.22	427.10
Direct electricity displaced (billion kWh)	0.00	0.00	0.00	0.00
Direct natural gas displaced (bcf)	7.95	67.04	289.40	415.87
Direct petroleum displaced (million barrels)	0.00	0.00	0.00	0.00
Direct coal displaced (million short tons)	0.00	0.00	0.00	0.00

Opportunity 4 Heat Recovery From Drying Processes

This opportunity represents energy savings from the recovery of waste heat from relatively inefficient drying processes in a number of industries, including chemicals, forest products, and food processing. Improvements are possible in processes such as paper drying, concentration, evaporation, and other processes where water is removed. This opportunity would also encompass process operations such as paint drying and curing, which are used in assembly and fabrication industries such as heavy machinery, fabricated metals, and transportation equipment.

Energy used for drying processes in just two industries (pulp and paper and food processing) is over 1 quad annually, and most drying processes are inherently inefficient. Technologies for energy recovery could potentially include direct-fired dryers, alternative-fuel dryers, air heat recovery, mechanical vapor recompression, and advanced heat pumps. Heat could potentially be recovered from exhaust or flue gases and saturated vapors that are vented to the atmosphere.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**160**	
Post-Process	**217**	**TOTAL $1,240**
TOTAL	**377**	

Methodology

Energy savings are derived from pre-process and post-process drying operations in the chemicals, forest products and food processing industries. Pre-process drying losses are based on 10% recovery of steam losses in steam-driven drying systems in these three industries, which encompass losses from generation, distribution and conversion of steam to useful work. Post-process drying heat recovery is based on 5-15% recovery of heat downstream of the drying process, with the bulk of energy loss recovery coming from paper drying and food processing (see Table 4.1).

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on the fuels used for process heating according to the 1998 MECS. Drying is not specifically separated out in the MECS and better estimates of fuel distribution for drying are only available for some industries. Drying systems can be direct-fuel fired, steam-driven, or powered by electricity. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunity Analysis, Energetics, Inc. and E3M, Incorporated, for the U.S. Department of Energy, November 2004.

Table 4.1 Potential Energy Recovery in Drying Processes

Sector	Energy Savings 10^12 Btu
Chemicals	
Ammonia Phosphate	0.23
Superphosphates	0.06
	0.29
Forest Products	
Pulp Drying	3
Paper Drying	138
	141
Food Processing	**76**
TOTAL	**217.29**

Opportunity 5 Steam Best Practices

This opportunity area covers the application of best operating and maintenance practices to steam generation, distribution and recovery systems (excluding development of advanced boilers) prior to steam delivery to the process. Significant energy is lost throughout steam systems during generation, distribution, and conversion of steam to useful work . Overall, these losses have been estimated to be as much as 55% of the energy inputs to steam systems.

Current fuel inputs to steam systems amount to over 6 quads annually. Losses associated with steam systems, from generation to distribution and conversion, amount to over 2.8 quads, representing a significant opportunity for efficiency improvement.

Best practices includes a combination of improved maintenance and upkeep (e.g., leaks in pipes, traps, vents); increased use of energy management tools to optimize steam system operation (vent steam, condensate recovery, combustion efficiency, steam distribution, feed water heat exchange); and incremental equipment improvements (e.g., insulation).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**310**	
Post-Process	**0**	**TOTAL $850**
TOTAL	**310**	

Methodology

Energy savings are based on a 5% reduction in energy inputs to steam systems across the entire manufacturing and mining sector.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh), 10% coal ($1.50/MMBtu) and 39% other (mostly waste fuels – no cost assigned). This is based on boiler fuel inputs according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc. and E3M, Inc for the U.S. Department of Energy, November 2004.

Table 5.1 Industry Ranked by Steam Use

Sector	Steam Use Tbtu	Steam Use Rank
Forest Products	2442	1
Chemicals	1645	2
Petroleum Refining	1061	3
Food & Beverage	610	4
Textiles	132	5
Transportation Equipment	112	6
Iron & Steel Mills	96	7
Plastics & Rubber	81	8
Computers, Electronics	53	9
Alumina & Aluminum	41	10
Fabricated Metals	35	11
Heavy Machinery	25	12
Foundries	22	13
Glass & Glass Products	5	14
Mining	4	15
Cement	1	16

Opportunity 6 Pump System Optimization

This opportunity area involves the optimization of motor-driven pump systems that are used throughout the industrial sector. Pumps are inherently inefficient (about 40% of energy inputs are lost in conversion), and are often improperly sized or utilized. Pump system optimization can be achieved, for example, by identifying systems that are inefficiently configured for the application (e.g., continuous pumping for batch operations, over-sized), upgrading old or high-maintenance systems, and identifying damaged pumps.

Optimization of pumping systems can have significant energy impacts. These systems currently account for about 25% of motor drive energy use in the manufacturing sector, or about 600 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Most pump systems are driven by electricity, which is primarily purchased from outside utilities. Consequently, pump systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for pumping in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**302* (98)**	
Post-Process	**0**	**TOTAL $2,000**
TOTAL	**302* (98)**	

Methodology

Energy savings are based on energy reduction potentials derived in a recent survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity (see Table 6.1), and amounts to 98 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for pumping, assuming all pumping systems were power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 204 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

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

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Opportunity 6 Pump System Optimization: Supporting Data Tables

Table 6.1 Estimated Energy Savings for Pumping Systems		
	Billion KiloWatt-Hours	**Trillion Btu (Net)**
Mid-Range Energy Savings	28.7	97.9
High-Range Energy Savings	38.4	131.0

Source:

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

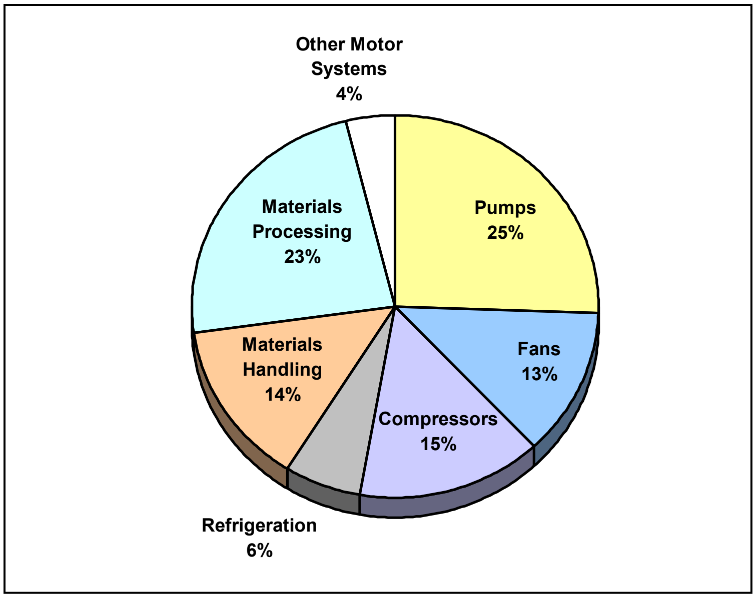


Figure 6.1 Motor Systems Energy Use By Equipment Type

Opportunity 7 Energy System Integration

This opportunity area encompasses energy savings from energy system integration, which involves a diversity of methods for integrating energy sources and sinks, integration of energy requirements to minimize the cost of operations, and part-load cycling and load management. The objective is to optimize plant-wide energy utilization by identifying and developing synergies among energy flows in process design and operation. Heat integration and CHP are key facets of energy systems integration. Technologies to promote and implement energy system integration would include tools to perform energy balances across the plant to integrate energy use and cost; pinch opportunity identification tools; tariff calculators to assist in minimizing purchases from utilities; and tools to more effectively deal with part-load cycling and load management. Tools should be user-friendly, and motivate end-users to pursue outside expertise for in-depth cost and benefits analysis and systems engineering. A challenge will be to develop tools that are suitable for a diverse industrial sector.

This opportunity potentially impacts all energy inputs used for heat and power in the manufacturing sector, which amount to nearly 18 quads each year. The total pre-process energy losses (generation, distribution, and conversion) associated with manufacturing equal about 5.9 quads annually.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**110**	
Post-Process	**150**	**TOTAL $860**
TOTAL	**260**	

Methodology

Energy savings are first based on a reduction in pre-process energy losses in steam systems, power generation, and process heating (fired systems) for six industrial sectors: petroleum refining, chemicals, forest products, iron and steel, food processing, and aluminum manufacture. This includes generation, distribution, and conversion (pre-process) losses. A conservative across-the-board reduction of 3% was assumed to be achievable due to the implementation of enhanced energy system integration, which yielded energy savings of 110 TBtu.

Post-process loss reductions were estimated to be 2% of steam and other fuels delivered to processes (2% of about 7.5 quads) in five industries (all the above, excluding aluminum). These reductions amounted to 150 Tbtu.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for steam and process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Table 7.1 Pre-Process Losses Considered for Energy Systems Integration

	Steam System Losses*	Fired System Distribution Losses	Fired System Conversion Losses	Total Pre-Process Losses
Petroleum Refining	484	68	312	864
Chemicals	748	38	172	958
Forest Products	1143	30	7	1180
Iron and Steel	44	42	199	285
Food Processing	277	10	40	327
Aluminum	19	5	30	54

Opportunity 8 Improved Process Heating/Heat Transfer Systems in Non-Metals Industries

This opportunity area encompasses potential improvements to process heaters (i.e., fired systems) and supporting heat transfer systems (boilers excluded) in the non-metal industries, specifically chemicals and petroleum. Typical fired systems in these industries include pyrolysis furnaces, preheat furnaces, evaporators, kettle boilers (reboilers) and others. Energy expended in fired systems in these two industries currently amounts to 3.4 quads annually.

Technologies might include improved materials, innovative heat exchanger designs and geometries, better heat transport configurations, predictive heat exchanger design, and other process heating enhancements. While the opportunity is evaluated specifically for two industries, advances in process heating and heat transfer systems could be extended to numerous other non-metal sectors, such as food processing, forest products, textiles, and plastics and rubber.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**121**		
Post-Process	**139**	**TOTAL**	**$860**
TOTAL	**260**		

Methodology

Pre-process energy savings are based on a 25% reduction in pre-process energy conversion losses only in fired systems in the two industries analyzed (see Table 8.1). Post-process losses are based on a 5% reduction in the final energy delivered to fired systems in these two industries (taking into account generation, distribution and conversion losses.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 8.1 Pre-Process Losses and Energy Delivered to Fired Systems (TBtu)

	Generation Losses	Distribution Losses	Conversion Losses	Total Pre-Process Losses	Delivered to Process
Petroleum Refining	0	68	312	380	1776
Chemicals	0	38	172	210	997

Opportunity 9 Energy Efficient Motors and Rewind Practices

This opportunity area involves the adoption of high efficiency motor systems and improving motor rewind practices. Every industrial sector makes use of motor-driven equipment, and in many cases the efficiency of motor use can be enhanced by upgrading the motor (e.g., variable speed drives, high efficiency motor) or through rewinding. Motor-driven equipment currently accounts for over 2.3 quads of energy use throughout manufacturing and mining.

Motors represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing motor electricity demand translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**258* (84)**	
Post-Process	**0**	**TOTAL $1,175**
TOTAL	**258* (84)**	

Methodology

Energy savings are based on energy reduction potentials derived in a recent survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity and amounts to 84 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with the reduced purchased electricity for more energy efficient motors, assuming all are power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 174 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

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

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Opportunity 10 Waste Heat Recovery From Gases In Metals and Non-Metallic Minerals Manufacture

This opportunity involves the recovery of waste heat from gases generated in metals and non-metallic minerals manufacturing (excluding calcining, which is covered in Opportunity 18). Exit gases from processes used to manufacture metals and other materials often have substantial embodied energy, but cannot be cost-effectively captured as an energy source. New technologies are needed to recover waste heat from exit gases, especially those that are corrosive or laden with contaminants.

Technologies could include enhanced heating system to improve quality and utility of exit gases (secondary heating, destruction of selected chemical species), integration of heating and heat recovery (including transport), and feedback systems to optimize performance. Supporting technologies such as hot gas cleanup and corrosion-resistant materials are also included. While the energy savings for this opportunity have been determined only for iron and steel and cement, these technologies could potentially be extended to a number of industries, such as lime and soda ash manufacture, coal gasification, and others where hot contaminated, or corrosive gases are an issue.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**235**	**TOTAL $1,230**
TOTAL	**235**	

Methodology

Savings are based on a recent analysis of iron and steel and cement (see Table 10.1). This analysis assumes an average percent of waste heat recovery that could be possible (10-20%), based on consultation with various industry experts. A percentage of the flue gases from cement calcining are included here. Because of potential overlaps, the remaining potential energy savings for cement calcining are covered under opportunities specific to calcining (Opportunity 18).

For simplicity, cost savings are based on a fuel mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu). Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Table 10.1 Recovery of Waste Heat from Exit Gases from Metals/Non-Metallics

	Energy Savings 10^12 Btu
Iron and Steel	
Coke Making	4
BF Iron Making	97
EAF Steelmaking	59
Tunnel Furnace	4
Slab Reheat Furnace	31
Subtotal	**195**
Cement	
Calcining Flue Gases	**40**
TOTAL	**235**

Opportunity 11 Energy Source Flexibility

This opportunity area encompasses covers energy source flexibility, which is defined as finding new or alternative sources to meet energy requirements for manufacturing processes. Alternatives should be more energy efficient and cost-effective when compared with conventional technology, and should be environmentally sound or exhibit improved environmental performance. In some cases emerging or existing technology can be reconfigured to provide alternatives; in other cases, research, development and demonstration of entirely new concepts will be required.

Energy source flexibility can impact a significant portion of energy use. Total manufacturing energy consumption for steam generation and fired systems currently amounts to nearly 14 quads annually.

Technology options include innovations such as microwaves or heat-activated power; the substitution of steam for direct heat or vice versa; CHP as a direct power source; small, cost-effective modular energy systems (e.g., chillers); steam applied directly to mechanical drives; and alternative-fuel-fired systems (e.g., advanced burners for combustion of animal products, ethers, other waste fuels).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**119**	
Post-Process	**75**	**TOTAL $655**
TOTAL	**194**	

Methodology

Pre-process energy savings are based on a reduction of 5% of steam system pre-process losses in major steam using industries (petroleum refining, chemicals and forest products), and amount to 119 Tbtu. The baseline steam losses for these industries are 484 Tbtu, 748 Tbtu, and 1143 Tbtu, respectively. Post-process energy savings (downstream of the process) are based on a prior analysis (see Table 11.1) that encompasses four industries – chemicals, petroleum refining, forest products, and iron and steel. In ammonia sulfate, manufacture, for example, savings were estimated to be 0.34 Tbtu, based on typical conversion efficiencies and replacement of steam with an alternative energy source. Details of this analysis can be found in the *Energy Use, Loss and Opportunities Analysis*, cited below.

Cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh), 5% coal ($1.50/MMBtu) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices are from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 11.1 Potential Energy Recovery Achieved Through Energy Source Flexibility: Post-Process

	Energy Savings 10^12 Btu
Chemicals	
Nitric Acid Mfg	0.18
Ammonia Sulfate	0.34
Subtotal	0.52
Petroleum	
Delayed Coking	7
Forest Products	
Bleaching	14
Iron and Steel	53
TOTAL	**74.52**

Opportunity 12 Improved Sensors, Controls, and Automation

This opportunity area is a broad category for optimizing energy through the use of improved sensors, controls, and automation. Research is needed to develop improved sensors and controls for process optimization. The goal is to meet product specifications while minimizing energy use and cost, and ultimately achieve reductions in energy requirements. Automation and robotics could also play a role in energy optimization in some industrial processes.

Technologies include remote measurement of temperature and pressure in harsh environments, direct measurement of product specification parameters, and predictive models for on-line controls. Effective optimization of process heater operations and innovations that enable automation of process heaters are also represented in this category, including those that better control or reduce environmental emissions (e.g., NOX).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**39**	
Post-Process	**152**	**TOTAL $630**
TOTAL	**191**	

Methodology

Pre-process energy savings are based on a reduction of 1% of pre-process losses in chemicals, petroleum, forest products, iron and steel, food, foundries, aluminum and cement (see Table 12-1.)

End-of-process energy savings are based on a recent study which identified losses and target opportunities for six selected industries (chemicals, petroleum, iron and steel, forest products, food processing, and cement (see reference below, Energetics 2004). The savings are based on a 5% reduction in the identified losses, assumed to be achieved through improved sensor and control systems and ultimate optimization of steam and fired systems.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices are from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysi, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 12.1 Pre-Process Losses Considered for Improved Sensors and Controls

	Steam System Losses*	Fired System Distribution Losses	Fired System Conversion Losses	Total Pre-Process Losses
Petroleum Refining	484	68	312	864
Chemicals	748	38	172	958
Forest Products	1143	30	7	1180
Iron and Steel	44	42	199	285
Food Processing	277	10	40	327
Cement	0.4	9	44	53
Aluminum	19	5	30	54
Foundries	10	4	22	36

*Includes steam generation, transport through distribution systems, and pre-process conversion to useful work.

Opportunity 13 Improved Process Heating/Heat Transfer for Metals Melting, Heating and Annealing

This opportunity area covers potential improvements to process heaters (fired systems) and heat transfer systems in the metal and non-metallic mineral industries (analogous to Opportunity 8 for chemicals and petroleum). Process heating systems represent a large share of energy use and production costs in the metals and non-metallic minerals industries (nearly 2 quads in iron and steel, aluminum, foundries, and fabricated metals). The competitiveness of these industries could be enhanced by optimizing productivity (inputs, reliability, maintenance, product output) and minimizing the energy intensity (Btu/lb of material processed) of process heating systems. The overall goal is to improve thermal efficiency and maximize heat transfer (not necessarily reduce waste heat).

Technology options include innovative heat exchanger designs and geometries, better heat transfer (faster heating, faster throughput), improved productivity via reduction in product waste, cascade heating techniques, switching from batch to continuous furnace operation, rapid heat treating, metal heating, and melting technologies, hybrid heating systems, and other process heating enhancements.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**63**	
Post-Process	**127**	**TOTAL $915**
TOTAL	**190**	

Methodology

Pre-process energy savings are based on 25% reduction in pre-process energy conversion losses in fired systems in three industries – iron and steel, aluminum, and metalcasting (based on a previous energy footprint analysis – see references). Post-process energy savings are based on a 5-10% reduction in post-process losses in fired systems in the industries analyzed (see Table 13.1).

For simplicity, cost savings are based on a fuel mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Footprints, Energetics, Inc for the U.S. Department of Energy, November 2003.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 13.1 Potential Energy Savings for Fired Systems

	Conversion Losses	Pre-Process Potential Savings (25%)	Energy Delivered to Process	Post-Process Potential Savings (5-10%)
Iron and Steel	199	50	1131	113
Aluminum	29	7	272	14
Foundries	22	6	125	-
TOTAL	250	63	1403	127

Opportunity 14 Compressed Air System Optimization

This opportunity area involves the optimization of motor-driven compressed air systems. Compressors are inherently inefficient (about 80-90% of energy inputs are lost in conversion to useful work). Compressor system optimization can be achieved, for example, by identifying systems that are leaking, poorly configured for the end-use, and by reducing system air pressure or reducing run times.

Optimization of compressed air systems can have significant energy impacts. These systems currently account for about 15-16% of motor drive energy use in the manufacturing sector, or over 300 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Compressors are driven by electricity, which is primarily purchased from outside utilities. Consequently, compressor systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for compressors in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**163* (53)**	
Post-Process	**0**	**TOTAL $740**
TOTAL	**163* (53)**	

Methodology

Energy savings are based on energy reduction potentials derived in a recent survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity (see Table 14.1), and amounts to 53 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for compressors. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 110 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

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

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Table 14.1 Estimated Energy Savings for Compressed Air Systems

	Billion KiloWatt-Hours	Trillion Btu (Net)
Mid-Range Energy Savings	15.5	52.9
High-Range Energy Savings	20.0	68.2

Opportunity 15 Optimized Materials Processing

This opportunity area involves the optimization of motor-driven material processing systems (e.g., mixers, grinders, crushers) that are used throughout the industrial sector. These systems are very inefficient in the conversion of energy to usable work (as much as 80-90% of energy inputs are lost in conversion). Optimization of these systems could be achieved through innovations in equipment, better integration of equipment and end-use, implementation of continuous versus batch operations, upgrading old or high-maintenance systems, and identifying damaged systems.

Optimization of materials processing systems can have significant energy impacts. These systems currently account for about 25% of motor drive energy use in the manufacturing sector, or about 600 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Most materials processing systems are driven by electricity, which is primarily purchased from outside utilities. Consequently, these systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for such systems in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**145* (47)**	
Post-Process	**0**	**TOTAL $660**
TOTAL	**145* (47)**	

Methodology

Energy savings are based on a reduction of 15% of current equipment conversion losses (473 TBtu) attributed to materials processing systems in the U.S. manufacturing sector. These losses were estimated in a recent study (Energetics 2004, below).

Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for these systems, assuming all pumping systems were power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which were calculated to be 102 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Opportunity 16 Energy Recovery From Byproduct Gases

This opportunity area involves the recovery of energy from combustible byproduct gases in various industries, notably petroleum refining and iron and steel. Byproduct gases may contain components (e.g., methane, propane, light hydrocarbons, carbon monoxide) with significant fuel value but are not economically recoverable with today's technology. For example, components may be very dilute, making recovery technically and economically difficult.

Data is lacking on the true energy potential for this area, although sources indicate that millions of pounds of combustible chemicals are lost in byproduct streams annually. Some of the technology options for capturing the energy potential of these byproducts include novel techniques for separating or concentrating combustible components, hot gas cleanup technology, materials for corrosive environments, and innovative burners. Examples of sources include CO-rich gases from the electric arc furnace in steelmaking, and gases from fluid catalytic cracker catalyst reburning.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**132**	**TOTAL $750**
TOTAL	**132**	

Methodology

Savings are based on a recent analysis (Energetics 2004, below, and Table 16.1) for petroleum refining and iron and steel. Sources in petroleum refining are the feed fired heater and catalyst regenerator on the fluid catalytic cracker (average efficiency about 75%). As the prior study significantly underreports losses of combustible gases, it was also assumed that another 5% of the energy delivered to fired systems after pre-process losses (1776 TBtu) could be recouped as a combustible gas, or about 89 TBtu. Combined energy savings for petroleum refining are 112 TBtu.

The electric arc furnace is the primary source of combustible gases in iron and steel. Average efficiency of the furnace was assumed to be about 56%.

Cost savings are based entirely on natural gas at $5.65/MMBtu, assuming this would be the primary fuel replaced. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 16.1 Energy Savings Potentials for Recovery of Combustible Gases

Sector	Energy Savings 10^12 Btu
Petroleum	
Fluid Catalytic Cracking	23
Other Offgases	89
	112
Iron and Steel	
EAF Steelmaking	**20**
TOTAL	**132**

Opportunity 17 Energy Export and Co-Location

This opportunity area looks at the potential for exporting energy from pulp mills and other plants, such as fuels produced by Fischer-Tropsch synthesis of synthetic gases from black liquor gasification. This topic also covers co-location of plants to optimize energy resources (e.g., location of large excess steam producer near heavy steam user).

Fuels such as renewable ethanol could supplement current petroleum-based fuels and reduce our dependence on foreign oil. Pulp mill wastes and forestry residues, as well as primary forestry resources could serve as the feedstock for renewable fuels and chemicals. Such resources are considerable (see Figure 17.1). Co-location of plants provides energy optimization by linking waste energy with potential users. It also provides opportunities to increase the use of on-site combined heat and power (CHP).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**105**	**TOTAL $580**
TOTAL	**105**	

Methodology

While some estimates project potential wood-based fuels at 1 quad annually, this estimate uses a more conservative estimate based on current mill waste and forestry residues (see Figure 17.1). The estimated conversion factor for wood resources to ethanol is 72.8 gallons ethanol/dry ton of material. Based on this conversion factor, an energy content of 3.539 MMBtu/bbl for ethanol, and 86 dry tons of wood-based materials available for conversion, energy potential was calculated to be about 105 trillion Btu. These savings represent the petroleum feedstock that would be supplemented with ethanol. Opportunities for co-location were not estimated, but could be substantial.

Other studies [Agenda 2020 Presentation 2004, below] have indicated that if 100% of pulp mills were converted to forestry biorefineries, as much as 1.9 billion gallons of ethanol could be produced annually (about 160 TBtu). For this analysis the more conservative number of 105 TBtu was chosen.

Cost savings are based entirely on cost of petroleum products at $5.80/MMBtu, assuming this would be the primary fuel replaced. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

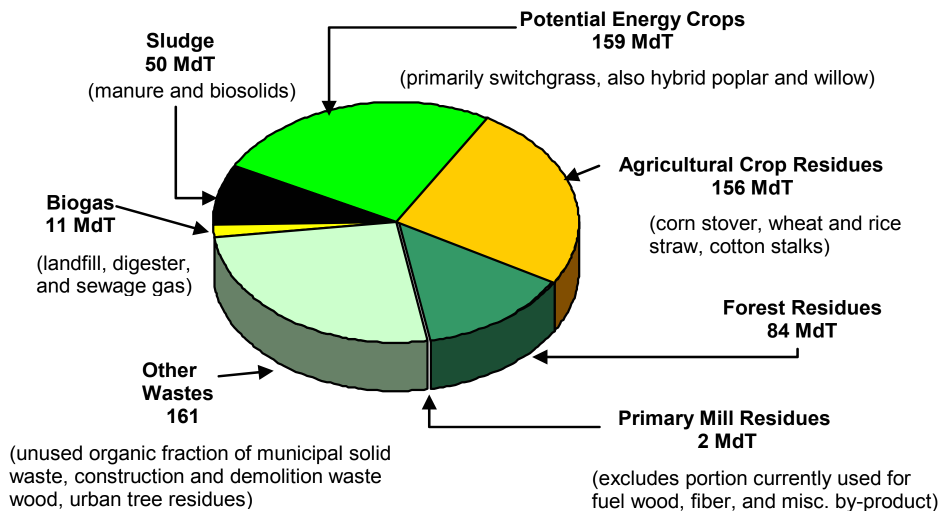
References

Industrial Bioproducts: Today and Tomorrow, Energetics, Inc for the U.S. Department of Energy, Biomass Program, March 2004.

Aden et al, *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*, National Renewable Energy Laboratory, Golden, Colorado (NREL/TP-510-32438), June 2002.

B.A. Thorp, "The Forest Biorefinery: A Partial View," Presentation on behalf of Agenda 2020, June 2004; data also to appear in September and October issues of Paper Age.

Opportunity 17 Energy Export and Co-Location: Supporting Data Tables



Total Feedstocks Available: 623 Million dry Tons (MdT) per year

Figure 17.1 Biomass Resources Available for Fuels and Chemical Feedstocks

Opportunity 18 Waste Heat Recovery From Calcining

This opportunity area involves the recovery of waste heat from calcining, specifically lime mud reburning in the pulp and paper industry, and cement calcining. Flue gases from cement calcining are not considered, as these are covered under Opportunity 10, Waste Heat Recovery From Metals and Non-Metallic Minerals. Calcining in these two industries amounts to about 0.5 quads of energy use annually.

In cement manufacture, technology options include recovery of heat in evaporated water, dust, clinker cooling, and from radiative and convective heat losses. In pulp and paper making, the efficiency of the lime kiln used for reburning is very low (30-40%) and could be improved by increasing heat transfer between lime mud and combustion gases, and using heat recovery for better preheating of combustion air and lime mud.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**11**	**TOTAL $159**
Post-Process	**63**	
TOTAL	**74**	

Methodology

Pre-process energy savings are based on a 25% reduction in pre-process equipment conversion losses (25% of 44 TBtu). Post-process energy savings are based on a recent analysis (Energetics 2004, below) that examines opportunities for reducing energy losses in a number of industries, including cement and forest products. The assumptions and results are shown in Tables 18.1 and 18.2. About 50% of recoverable losses (40 TBtu) in cement calcining are assumed to be flue gases and are included under Opportunity 10. All potentially recoverable losses from lime mud reburning are considered here.

Cost savings are based on a mix of 30% natural gas ($5.65/MMBtu), 30% coal ($1.50/MMBtu), and 40% waste fuels (no cost assigned), according to approximate fuel distribution for process heating in the 1998 MECs (see references below) for process heating in iron and steel. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Opportunity 18 Waste Heat Recovery From Calcining : Supporting Data Tables

Table 18.1 FOREST PRODUCTS: FIRED SYSTEMS Roll Up Analysis

Process/ Unit Operation	Equipment Used	2001 U.S. Production 10^6 Short Tons/year	Energy Intensity (10^6 Btu/ston pulp)	Total Energy Use (10^12 Btu/yr)	Average Energy Loss (10^12 Btu/yr)	Energy Loss Recovery or Reduction Category						Improvement Potential (%)						Savings Tbtu/year
												Best Practices		Technology				
						Waste Heat Reduction	Waste Heat Recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	Existing Potential	*Future* New Potential	Commercially Available Technology & Equipment	Commercially Available *Alternative* Equipment	* *Future** R&D for New Technology & Equipment	**Future** R&D for Alternative Process	
Lime Mud Calcining	Lime Kiln	52	2.00	103	65		X	X	X				X	15		20		23
TOTAL				**103**	**65**													**23**

Assumptions: Efficiency improvements are based on recovery of kiln waste heat, reducing kiln heat losses, and reduction in heat needed for lime mud dissociation. Energy use is consistent with 1998 MECS fuels used in fired systems (166 TBtu), and with the LBL study, which indicates about 3-4% of energy use is attributed to lime burning (115 TBtu).

Table 18.2 CEMENT MANUFACTURING: FIRED SYSTEMS Roll Up Analysis

Process/ Unit Operation	Equipment Used	2002 U.S. Production Short Tons/year	Energy Intensity (10^6 Btu/ton clinker)	Total Energy Use (10^12 Btu/yr)	Average Energy Loss (10^12 Btu/yr)	Energy Loss Recovery or Reduction Category						Improvement Potential (%)						Savings Tbtu/year
												Best Practices		Technology				
						Waste heat reduction	Waste heat recovery	Energy Source Flexibility	Controls, Automation,	CHP (fired and other)	Motors & Drives	Existing Potential	*Future** New Potential	Commercially Available Technology & Equipment	Commercially Available *Alternative* Equipment	* *Future** R&D for New Technology & Equipment	**Future** R&D for Alternative Process	
Wet Process Long Kiln	Rotary kiln	24,647,428	6.00	148	104	X	X	X	X		X	X	X	25		25		52
Dry Process Long Kiln	Rotary kiln with heat recovery	46,450,922	4.50	209	100	X	X	X	X	X	X	X	X	10		15		25
Dry Process Preheater Kiln	Rotary kiln with preheat towers	11,849,725	3.80	45	14			X	X	X	X		X	11				2
Dry Process Precalciner Kiln	Rotary kiln with precalciner units	11,849,725	3.30	39	11			X	X	X	X		X	11				1
TOTAL				**441**	**230**													**80**

Assumptions: Efficiency improvements are based on reduction in kiln heat loss, conversion of wet kilns to semi-wet, better clinker cooling systems, high efficiency motors, optimized combustion system, heat recovery for cogeneration, increased use of preheaters and precalciners, and other heat recovery schemes.

Opportunity 19 Heat Recovery From Metal Quenching/Cooling

This opportunity area represents energy savings from recouping heat lost in the quenching and cooling of metals. These processes lose significant energy in the form of evaporated water that is vented to the atmosphere, energy embodied in medium- to low-temperature steam and cooling water. Capturing this waste heat is often not technically or economically feasible with today's technologies.

Technology options would efficiently recover heat from quenching and cooling of metals, glass and other high temperature materials (both molten and solid metals). This includes technology to utilize combustion products of flue gases from reheat furnaces, coke oven batteries, and continuous annealing. Innovations such as thermo-electric systems for medium temperature, clean flue products or cooling air are desirable.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**57**	**TOTAL $275**
TOTAL	**57**	

Methodology

Savings are based on a recent analysis (Energetics 2004, below) for iron and steel, although they could be much higher if other metal producing, casting and fabricating industries were considered. Results of the analysis are shown in Table 19.1, indicating the specific processes covered.

Cost savings are based a mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu), based on the approximate fuel distribution in the 1998 MECs (see references below) for process heating in iron and steel. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 19.1 Potential Energy Savings From Quenching/Cooling of Metals

Sector	Energy Savings 10^12 Btu
Iron and Steel	
Ingot	11
Continuous casting	8
Slab Reheat	20
Cleaning/Annealing	18
TOTAL	**57**

Opportunity 20 Advanced Process Cooling and Refrigeration

This opportunity area covers advances in cooling and refrigeration processes, specifically in the chemicals and food processing industries. Cooling and refrigeration accounts for over 200 trillion Btu of energy use in the manufacturing sector every year. A large portion of current technology is motor-driven. Although not one of the largest users of energy, refrigeration systems can be very energy-intensive (e.g., cryogenic chemical separations).

Technology options include innovative or alternative approaches to cooling, process redesign to eliminate the need for energy-intensive cooling units, and system optimization.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	***47(15)**	
Post-Process	**0**	**TOTAL $212**
TOTAL	***47(15)**	

Methodology

Pre-process savings are based on a 20% reduction in electricity requirements for motor-driven refrigeration in these industries as sited in a recent study (Xenergy 1998). Energy use for refrigeration in these industries was based on the Xenergy study and a study utilizing MECs data (see references below, and Table 20.1). Additional savings would be possible through improvements in other cooling systems (non-motor-driven), although these were not estimated for this study.

Cost savings are based entirely on the avoided use of electricity ($0.0477/kWh). Savings are counted only for the electricity saved by the industry user – not the losses avoided at the utility generator. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

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*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Table 20.1 Potential Energy Savings for Advanced Refrigeration Systems

Sector	Energy Use for Motor-Driven Refrigeration, Tbtu (with losses)	Potential Savings (Tbtu)
Chemicals	111	22
Food Processing	123	25
TOTAL	**234**	**47**