Innovative Energy Systems Challenge

A Competition to Foster Innovation

Opportunities for Innovative Energy Systems in the U.S. Chemical Industry

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A Vision2020 Initiative

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Chemical Industry Vision2020
Technology Partnership (Vision2020)'s
Challenge Technical Committee

1. Overview

The Challenge seeks to stimulate investment in high-risk R&D that targets energy-savings opportunities that are not captured by best-available technology.

The Chemical Industry Vision2020 Technology Partnership[1] (Vision2020) seeks to accelerate innovation and technology development by leveraging financial and technical resources. In particular, the industry-led partnership encourages cooperative R&D on technologies that will advance the industry's progress toward a more sustainable energy future. In pursuit of this goal, the Vision2020 Partnership proposes to conduct an *Innovative Energy Systems Challenge* to stimulate R&D that will enhance the productivity of energy systems throughout the chemical industry. The Challenge specifically targets an often overlooked area of R&D: systems that are integrated with the chemical processing and energy supply systems within plant boundaries.

Chief technology officers (CTOs) and other industry leaders have determined that more efficient energy systems represent a top opportunity for saving energy in the U.S. chemical industry. Innovations in these systems could improve productivity, reduce costs, and increase energy efficiency in chemical plants worldwide. Collectively, inefficiencies in on-site and off-site energy generation, transmission, conversion, and distribution systems account for energy losses of more than 2.7 quadrillion Btu (quads) annually, which is nearly enough energy to meet the needs of every house and commercial building in California for one year.

Exhibit 1.1 shows the total heat and power energy supplied to all U.S. chemical plants for 1998. Of the 5.07 quads of primary source (fossil) energy consumed each year to supply heat and power, about 1.35 quads are lost at off-site electric power generation facilities and in fuel distribution systems. More than one quad is lost through inefficiencies in on-site energy generation, distribution, and conversion before the energy reaches the chemical processes. Vision2020 estimates that innovative energy systems could cost-effectively achieve a 30-percent reduction in these on- and off-site energy losses by 2020—an energy savings of more than 700 trillion Btu per year, valued today at about $2 to $3 billion. The Challenge is a major step toward realizing these potential savings.

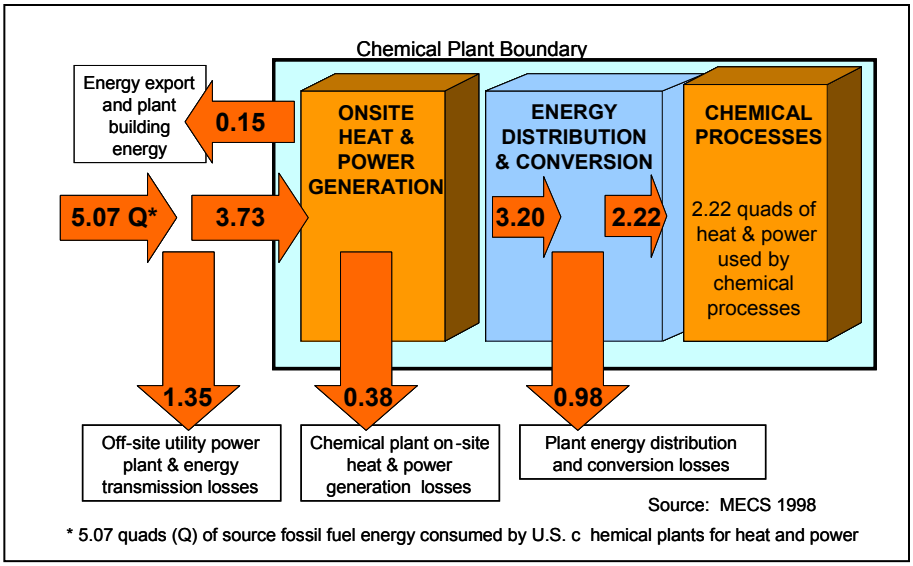


Exhibit 1.1 U.S. Chemical Industry Heat & Power Energy Requirements

[1] Vision2020 is led by the Vision2020 Steering Committee. For additional information, see www.ChemicalVision2020.org.

2. Energy Saving Opportunities in Chemical Plant Processes and Energy Supply Systems

Overview of Energy Savings Opportunities

Manufacture of chemicals from raw materials is an energy-intensive process. A significant amount of energy is lost through inefficiencies inherent in current energy systems. About 1,345 trillion Btu (27%) of the 5,074 trillion Btu produced for the industry is lost even before it reaches the plant due to inefficiencies in the generation and transmission of purchased electricity and the distribution of fuel. Another 1,363 trillion Btu (27%) or more is lost through inefficiencies in on-site generation, distribution, and conversion. Total losses exceeding 2,708 trillion Btu represent a significant opportunity for innovative energy systems.

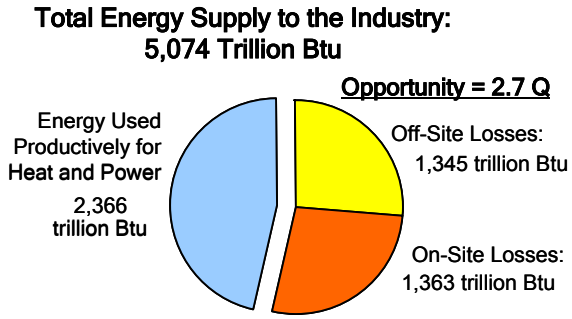
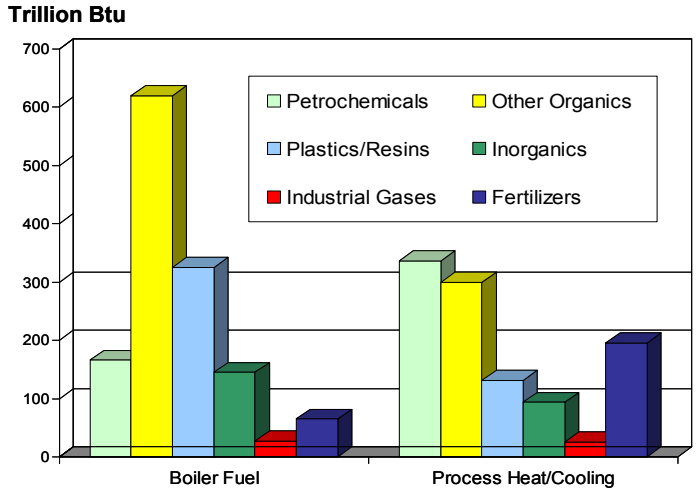
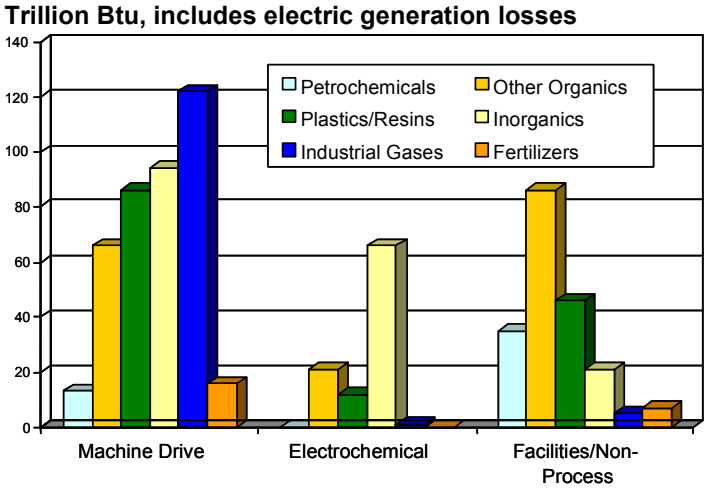


Exhibit 2.1 Losses Represent Savings Opportunity



Each year about 3,729 trillion Btu (3.7 quads) are actually delivered to or purchased by U.S. chemical plants for process heat and power [*Manufacturing Energy Consumption Survey (MECS 1998)*, U.S. DOE]. The largest share of that process energy, about 2,800 trillion Btu or roughly 75 percent, is used in boilers and for heating and cooling (see Exhibit 2.2). About 25 trillion Btu of this is exported off-site as electricity.

◀ **Exhibit 2.2 The U.S. chemical industry's boilers and process heating and cooling systems use 2,800 trillion Btu annually (MECS 1998).**



The remaining 930 trillion Btu of power, natural gas, fuel oil, and LPG is used for machine drive, as in pumps, fans, compressors, conveyors, and mixers; electrochemical processes; on-site transport; and facilities and other non-process equipment, such as for lighting and HVAC systems (see Exhibit 2.3).

◀ **Exhibit 2.3 The industry uses another 930 trillion Btu for machine drive, other process equipment, plant facilities, and non-process use (MECS 1998).**

The energy supply chain begins with the electricity, steam, natural gas, liquefied petroleum gases, coal, and petroleum products supplied to a chemical plant from off-site utilities. Once energy reaches the plant (indicated by green area in Exhibit 2.4), it flows either to a *central energy generation/ utility* system (e.g., steam plant, power generation, cogeneration) or is *distributed* immediately for use as direct- fueled process heat/energy.

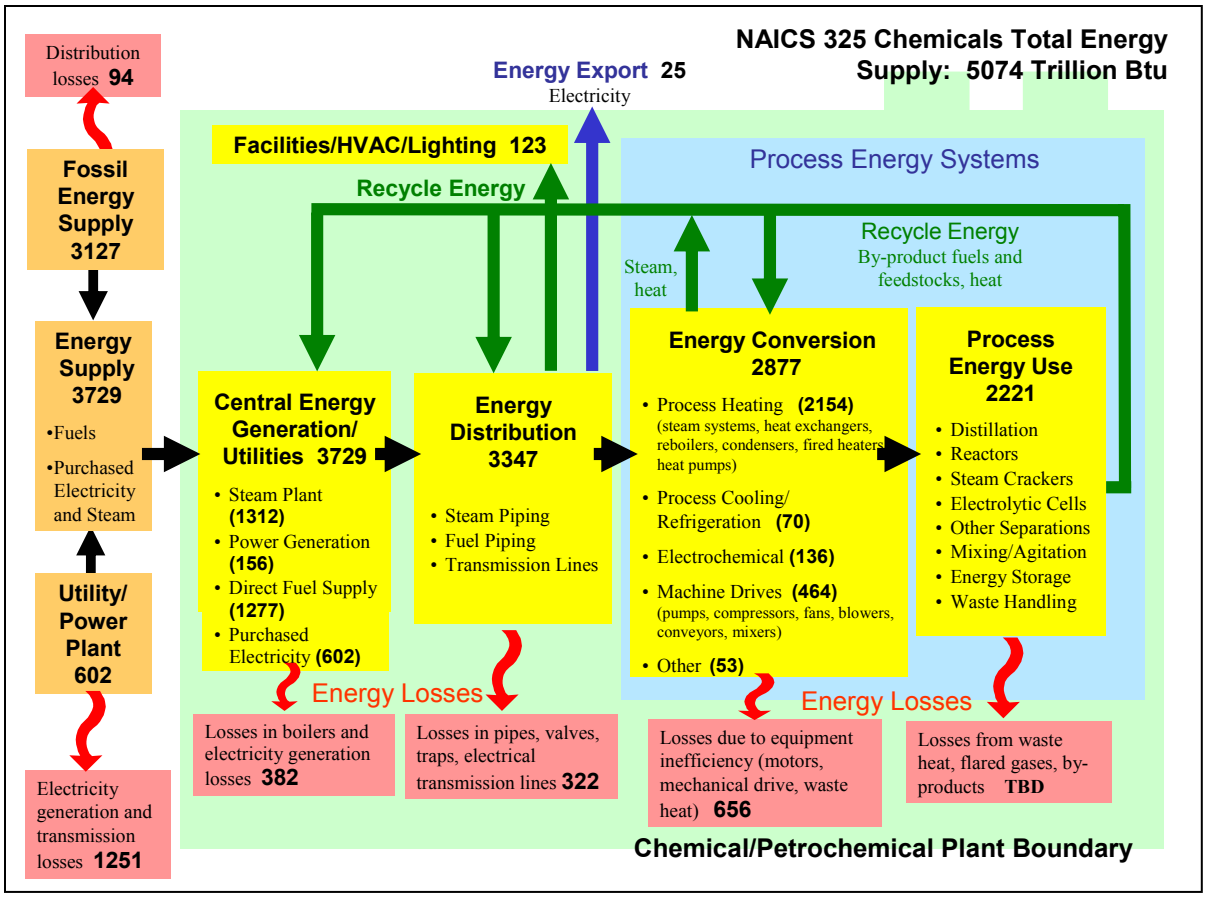


Exhibit 2.4 Energy Is Lost from Off-site and On-site Integrated Energy Systems in the U.S. Chemical Industry (values in trillion Btu) [1998 MECS]

Process energy (see blue area of Exhibit 2.4) is often routed to *energy conversion* equipment that is generally integrated with specific processes (e.g., reboilers on distillation columns, ethylene steam cracking furnaces, boilers). The converted energy is then sent for use in *processes* and unit operations, where it drives chemical reactions, produces heat in cracking furnaces, fractionates and separates product streams, and produces final products.

Some chemical processes are exothermic (energy producers) and can therefore generate energy in the form of steam, waste heat, fuel gases, or by-products. This excess energy is recovered and recycled back into the plant whenever possible.

Energy losses occur all along the energy supply and distribution system (see red arrows in Exhibit 2.4). Energy is lost in power generation and steam systems, both off-site at the utility and on-site within the plant boundaries, due to equipment inefficiency and mechanical and thermal limitations. Energy is lost in distribution and transmission systems carrying energy to the plant and within the plant boundaries.

Losses also occur in energy conversion systems where efficiencies are thermally or mechanically limited by equipment material and design (e.g., heat exchangers, process heaters, pumps, motors, etc.). In some cases, heat-generating processes are not optimally located near heat sinks, and it may be economically impractical to recover the excess energy. With some batch processes, energy is lost during off-peak times simply because it cannot be stored.

Energy is lost from processes whenever waste heat is not recovered and when waste by-products with fuel value are not utilized. The energy value of recovered heat and by-products can be considerable. In 1998, the U.S. chemical industry used about 748 trillion Btu of by-product energy (e.g., light off-gases, heavy by-product oils and tars)—equivalent to about 20 percent of all energy used by the industry for heat and power. Although comprehensive current estimates of total waste heat releases from the industry are unavailable, older studies put these at about 2,000 trillion Btu annually.

From the off-site utility to the end of the chemical process, about 46 percent of the energy supplied to a chemical plant (~2,708 trillion Btu) is lost, and about 50 percent of those energy losses occur inside the plant boundary. There are significant opportunities to reduce the energy consumed as well as the energy lost in both central and process-integrated energy systems.

In many cases, thermal and mechanical inefficiencies of energy systems lead to significant energy losses—losses that could be reduced through advances in technology as well as improved energy management practices. For example, since the simple-cycle efficiencies of combustion turbines used for power generation are relatively low (25 to 35 percent), overall thermal efficiency can be greatly improved by upgrading to cogeneration systems. Advanced materials can also enable turbines to operate at higher temperatures and achieve higher generating efficiencies. Installing advanced turbines or cogeneration systems at the plant can eliminate transmission losses associated with purchased electricity. Technology that matches heat and power requirements to the process, utilizes waste heat, reuses waste by-product fuel, or optimizes location of heat sources and sinks can also have a significant impact. These innovative energy systems, which are the focus of this Challenge, are critical to realizing energy savings and reducing production costs.

From the off-site utility to the end of the chemical process, about 46 percent of the energy supplied to a chemical plant is lost before it is used by the process. About 19 percent of the energy losses occur inside the plant boundary.

Individual chemical companies have limited resources for the type of high-risk R&D required to develop innovative energy systems. Cost-shared public-private funding could help fill this R&D gap. Federal programs that have traditionally provided cost-shared funding to develop more efficient technologies for U.S. manufacturing are in the Office of Energy Efficiency and Renewable Energy (EERE) within the U.S. Department of Energy. Specifically, the DOE Distributed Energy Program (www.eere.energy.gov/der) supports research, development, and technology transfer activities for cleaner and more fuel efficient electric power and thermal energy devices for on-site, customer-side applications such as industrial gas turbines, microturbines, reciprocating engines, and integrated energy systems; the Industrial Technologies Program (ITP) (www.eere.energy.gov/industry/) provides cost-shared assistance to promote R&D for energy conversion and process energy use; and the ITP BestPractices program (www. eere.energy.gov/ bestpractices/) provides tools and technical assistance to help plants improve energy management practices and save energy in the near-term (see Exhibit 2.5).

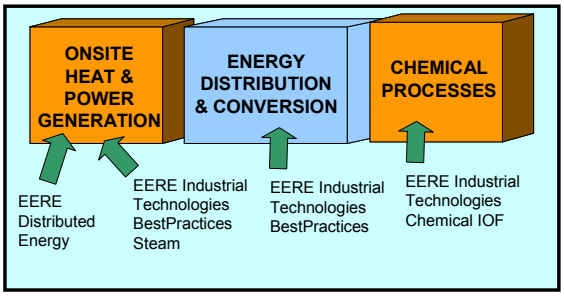


Exhibit 2.5 Traditional R&D Funding Areas by DOE Program

3. Industry's Priority Needs for On-site Technologies

Priority Needs for the Chemical Industry

Annual energy losses in excess of 2.3 quads represent a significant opportunity for energy savings in U.S. chemical manufacture. Realizing the potential energy savings will require improved energy management plus advances in a number of critical technologies. As shown in Exhibit 3.1, a wide range of development work is needed in the areas of power and steam generation, heat integration and energy management, and heat transfer and energy recovery.

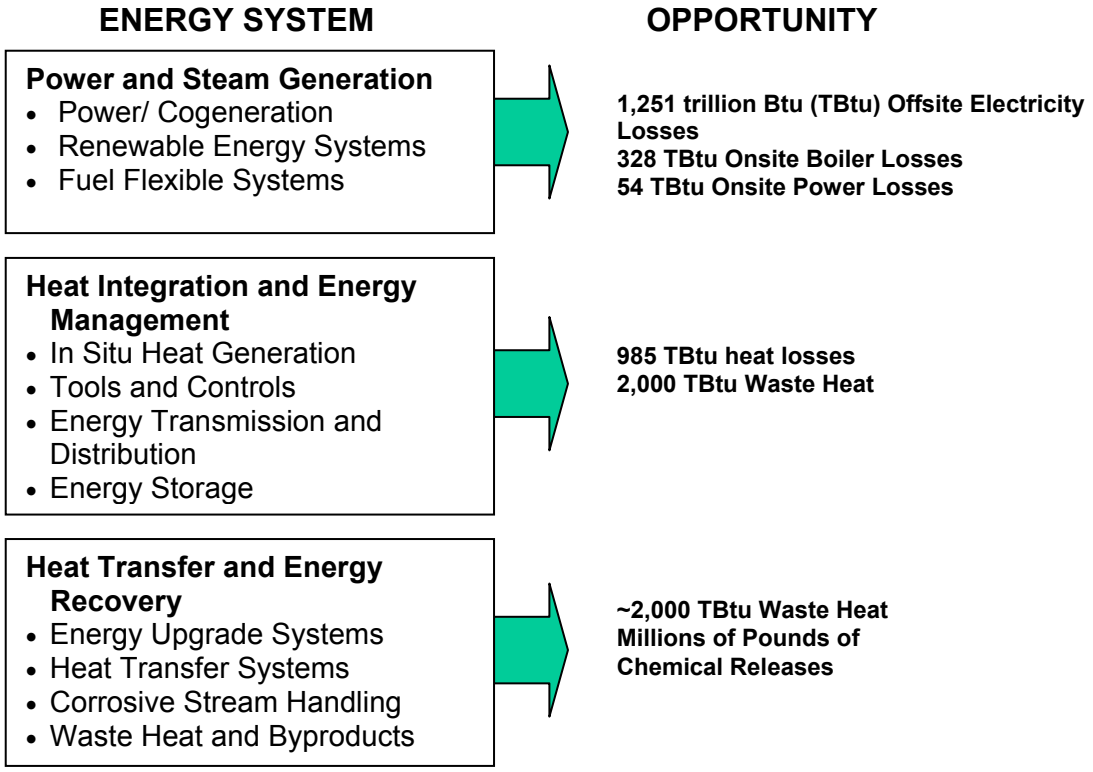


Exhibit 3.1 R&D in Integrated Energy Systems Could Yield Substantial Energy Savings

If even 10 percent of the energy losses (our opportunity for greater efficiency) listed in the right-hand column above were eliminated, the industry could save 230 trillion Btu annually.

Power and Steam Generation includes boilers, turbines, and auxiliary equipment for producing electrical power and process steam, as well as associated energy supply distribution systems (transmission lines and steam pipes). Some of these systems are integrated with processes, while others are part of central plant utilities. Exhibit 3.2 illustrates the preliminary needs identified for this area. Primary opportunities for new energy systems include increasing efficiency in power generation, reducing losses associated with power generators and steam boilers, developing alternative power systems, using renewable energy or other fuel sources, and increasing fuel flexibility.

Small-scale, energy-efficient power generation systems are one approach for increasing the flexibility of power supply as well as energy efficiency. Cogeneration and tri-generation are other viable options for reducing energy losses and overall fuel requirements. Renewable energy sources can provide diversity in energy supply with lower environmental burden. The typically higher capital costs of renewable

Exhibit 3.2. Technology Needs for Power and Steam Generation		
Technology Area	**Options**	**Energy Opportunity Area**
Improved on-site power generation and cogeneration	• Modular systems, low-cost miniaturized energy systems, microturbines, small-scale cogeneration (with efficiency and reliability comparable to large-scale equipment) • Energy systems where heat and power generation can be disassociated while maintaining high efficiencies • In-situ mechanical energy generation to drive motors and compressed air systems • Direct conversion of chemical to electrical energy • Co-production of chemicals and electricity (e.g., generating power in a fuel cell while creating a chemical reaction needed for the process) • Tri-generation (heat, power, and cooling)	• Net demand for electricity: 733 Current on-site cogeneration and conventional turbines: 156 trillion Btu (46 billion kWh) • Losses associated with purchased electricity: 1,251 trillion Btu/yr • Fuel for on-site boilers: 1,721 trillion Btu; total steam system losses of 748 trillion Btu • Losses due to power generation equipment inefficiencies: 54 trillion Btu (thermal and mechanical) • Current power generation using renewables for chemical processes: 1 tenth of 1 percent • Natural gas use in boilers: 1,299 trillion Btu • Natural gas use in process heaters: 1,041 trillion Btu
Cost-effective solar/renewable energy technologies	• Conversion of solar energy to electricity • Wind turbines • Biomass gasification • Co-firing of biomass with fossil fuels in boilers	
Fuel-flexible energy systems	• New technologies to improve fuel flexibility and diversity (e.g., multi-fuel burners)	

technologies will need to be reduced, however, to make them more attractive for process heating and power applications in chemical plants. Fuel flexibility is another key approach to reducing costs, mitigating vulnerability to fluctuations in fuel prices, and improving efficiency (e.g., dual-fired boilers). As shown in Exhibit 3.3, the current mix of fuels used in boilers and process heaters is dominated by natural gas, which has shown considerable price volatility in the past few years. Technologies that enable fuel flexibility could permit switching to alternative fuels (LPG, oil) as needed in response to price fluctuations. New systems would need to be environmentally sound and account for changes in emissions due to fuel switching.

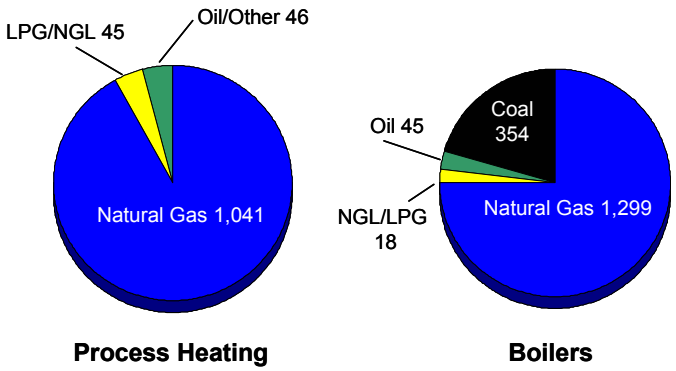


Exhibit 3.3 Fuel Flexible Systems Could Enable Fuel Switching During Periods of Price Volatility[MECS 1998] Trillion Btu [Does not include electricity inputs].

Heat Integration and Management includes the logistics of integrating plant-wide heat sources and sinks, adoption of best energy practices (e.g., insulation, controls, maintenance), and effective use of energy storage systems. Preliminary needs identified for heat integration and energy management practices are shown in Exhibit 3.4. Locating heat sources properly, improving control of heat system performance, and energy storage are all options for improving heat integration and reducing energy losses. Although these improvements are more incremental than those based on advances in technology, they can make a significant contribution to overall plant energy efficiency. Energy storage is an important area for improved energy management. Batch processes, for example, can waste generated energy when they are not operating. Effective energy storage could make more efficient use of the energy produced when processes are not operating, or store energy produced at off-peak times for later use.

Exhibit 3.4. Heat Integration and Energy Management Practices

Technology Area	Options	Energy Opportunity Area
In-situ heat generation	• Heat generation physically close to where heat is consumed	• Plant-wide energy used for heat and power: 3,400 trillion Btu • Energy lost in on-site transmission and distribution systems: 323 trillion Btu
Tools and controls to optimize heat and energy flow	• New and improved heat optimization tools, including pinch analysis • Control systems to improve and optimize heat and energy flow	
Energy-efficient environmental controls	• NOx controls for application in boiler systems	
On-site energy transmission and distribution systems	• Low-cost insulation materials • Better distribution system controls and sensors	
Storage systems for thermal, chemical, and mechanical energy	• Thermal storage for energy produced from continuously-operating equipment • Electrolytic processes • Exothermic batch processes • Processes producing excess fluid energy • Light to electrical energy conversion processes	

Heat Transfer and Energy Recovery involves heat transfer systems as well as the effective use of waste heat and by-products generated in the plant, and is closely integrated with process energy systems. Exhibit 3.5 illustrates the preliminary needs identified for improved heat transfer and energy recovery technology. An estimated 2,000 trillion Btu currently exits from chemical plants every year in the form of waste heat (see Exhibit 3.6), with a large amount in the form of lower-quality steam. While recovery of some of the lower-valued waste heat is thermodynamically limited, there are still considerable opportunities to recapture waste energy content from these streams. Waste heat streams in the temperature range of 130°C, for example, contain energy that could be used in some chemical plant processes. One barrier to using these streams is the equipment corrosion that can occur if the waste stream condenses. Typically, the cost of generating heat from waste products can be less than the cost to generate heat from natural gas, making it an attractive option.

Fouling of heat exchange equipment is another serious problem that leads to excessive energy use as well as equipment maintenance and down time. New technology is needed to mitigate the effects of fouling, and to predict and prevent fouling conditions.

Waste by-products may not be utilized and/or not economical to recover. Many times these waste by-products are flared or incinerated rather than re-utilized. Valuable chemical products/by-products are also released through fugitive and point-source emissions. While there is no comprehensive source on the potential for recovery of fuel and feedstock energy from by-product gases and chemical releases, the

opportunity is considerable. A 1990 study [*Industrial Waste Gas Assessment*, RCG/Hagler, Bailly, Inc. 1990) estimated chemical process releases of just two chemicals (toluene and ammonia) to be 10 million pounds per year and 100 million pounds per year, respectively. A market study conducted in 1991 [U.S. Industrial Market Study] indicated a potential 20 trillion Btu of energy savings in about seven chemical processes: ethylene, urea, BTX, chlorine/caustic soda, phosphate fertilizer/phosphoric acid, synthetic rubber, and viscose rayon.

Exhibit 3.5. Heat Transfer and Energy Recovery Technology Needs

Technology Area	Options	Energy Opportunity Area
Energy transport and heat upgrade	• Technologies already available (e.g., industrial heat pumps) to economically upgrade waste heat to useable process heat • New and enhanced technologies to cost-effectively upgrade and transport	• 2,000 trillion Btu of waste heat exiting chemical plants • More than 20 trillion Btu of energy savings per year of chemical releases with fuel energy and feedstock value
Heat transfer without heat degradation	• New systems to improve the efficiency of heat transfer equipment	
More robust handling of "dirty" or corrosive process streams	• Improved processes and materials for heat transfer equipment to reduce the effects of fouling • Equipment to improve heat exchange in fouling environments	
Better utilization of waste products and emissions with fuel or feedstock value	• New technologies to capture waste fuel gas or fugitive and point-source emissions for fuel use • Waste heat chillers, absorption heat pumps for energy and product recovery • New, efficient waste heat recovery systems • Fuel cells driven by waste gases • Co-location of plants to utilize by-products of multiple companies through integrated recovery	
Waste heat recovery below 130°C	• Waste heat chillers, absorption heat pumps for energy recovery • New technologies to recover the heat and minimize potential corrosion problems • Power generation from low-grade waste heat	

Exhibit 3.6. Waste Heat Losses in the Chemical Industry (Trillion Btu/Yr)

	<150°F	150-300°F	300-600°F	>600°F	Total
Flue gas			350	60	410
Gas cooling and gas-liquid condensation	20	700	300	10	1030
Liquid products and effluents	120	190			310
Solid products and effluents		10		20	30
Radiative/convective/conduction heat losses					200
Engine exhaust			10	10	20
Total heat releases					2000

Source: *Characterization of Industrial Process Waste Heat and Input Heat Streams*, PNNL, May 1984.