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Industrial Technologies Program Research Plan for Energy-Intensive Process Industries

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The Business of Innovation

Industrial Technologies Program Research Plan for Energy-Intensive Process Industries

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Summary

Energy security, environmental quality, and the need to reduce carbon-dioxide emissions drive the development of advanced technologies for energy-saving deployment across industry. In this plan, the Industrial Technologies Program (ITP) identifies the objectives of its cross-cutting strategy for conducting research in collaboration with industry and U.S. Department of Energy national laboratories to develop technologies that improve the efficiencies of energy-intensive process industries. Working with ITP staff, the national laboratories, and industry, Battelle Memorial Institute has generated this research plan to leverage the intellectual property resident within ITP, its industrial partners, and the national laboratories in order to accelerate the selection of efficient technologies that can be rapidly deployed in broad market areas.

The management and investment approach recommended in this technology research, development, and deployment (RD&D) plan is intended to help ITP obtain more impact from its investments. Specifically, the approach uses a technology maturation process built around ITP's strength in partnering with industry and a new patent-bundling methodology. Key elements include investment in a technology pathway that involves the maturation of existing technologies from the national laboratories and their industrial partners in 2008, followed by an aggressive schedule for demonstration and deployment in 2009 and beyond.

Key Strategic Elements

- ***Partnering and cost-sharing with industry***
- ***Leveraging the intellectual property and institutional knowledge of the national laboratories and their partners to accelerate deployment***
- ***Developing cross-cutting, manufacturing tech nologies using platforms that can be applied across a broad spectrum of markets.***

Technology investments fall under one of four technology platforms:

- **Industrial Reactions and Separations**—New technologies with improved energy intensity and process intensification capabilities will yield dramatic energy and cost savings in a wide range of industries from oil refineries, food processing, and chemical production to emerging industries, such as biorefiner-ies.

- **High-Temperature Processing**—Improvements for producing metals and non-metallic materials are expected to include deployment of lower-energy alternatives to conventional high-temperature processing technologies that cur-rently account for nearly 50% of industrial energy usage today.

- **Waste Heat Minimization and Recovery**—Technology advances will include the "Super Boiler" to reduce the overall energy demand and the contribution of steam generation to manufacturing; high-performance furnaces to permit the

domestic metals industry to resurge on the world market; and broadly applicable waste-heat-recovery technologies that contribute to industrial sustainability, reduced water usage, and a lower carbon footprint while saving energy.

- **Sustainable Manufacturing—** Technologies that enable the manufacture of components with multiple market applications will be investigated. New manufacturing options that reduce process steps or parts count (thereby reducing energy intensity through the manufacturing value chain) will be developed through the coupling of design options, materials combinations, and manufacturing technologies.

Deployment of the technologies developed under these platforms is expected to contribute to a 25% reduction in energy intensity and carbon emissions between now and 2017. Each of the technology platforms consists of several defined areas of technological focus that are expected to provide the framework for cost-shared projects supporting ITP's strategy. The individual projects that provide the highest value to industry stakeholders and the government within the overall technology development platforms will be selected for funding. Key deliverables are expected to include the following:

- new separation technology to allow for cost-competitive ethanol production
- alternatives to conventional energy-intensive conventional heat-soak treatment cycles used by the materials manufacturing industry, targeting a minimum reduction in energy of 20%
- light-weight, high-strength, corrosion-resistant materials or alloys for the automotive and aerospace industries that will increase fuel efficiency and decrease costs by at least 10%
- cost-competitive production methods for alternative energy devices, such as photovoltaics, that demonstrate a conversion efficiency of 30% (compared with today's efficiency of 10%)
- next-generation, ultra-high-efficiency Super Boiler technology that enables a 20% increase in energy efficiency over existing steam-generation systems
- near-net shape cold-forming and solid-state joining technologies for aluminum automobile power-train housing, requiring 40% less energy than conventional cast housings
- a new energy control and material recovery process that reduces energy and waste by 20% for a 200,000 vehicle take-out automobile paint line.

Although the plan lists deliverables such as these for each focus area, it is likely that the actual deliverables will evolve as the project planning progresses and detailed value propositions consistent with business planning and deployment for the technology are completed. Additionally, it is anticipated that many R&D projects will yield incremental improvements that will be quickly executed by industrial partners as the program proceeds.

Acknowledgments

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- Industrial Reactions and Separations: Seth Snyder, ANL; Ward TeGrotenhuis, PNNL; Dave DePaoli, ORNL; Brad Chadwell, Susan Rose, and Stephanie Flamberg, Battelle; Eric Petersen, INL
- High-Temperature Processing: Craig Blue, ORNL; Mike Watkins, PNNL; George Fenske, ANL; Glenda Holderbaum, Battelle
- Waste Heat Minimization and Recovery: Richard Doctor, ANL; Terry Hendricks, PNNL; Rod Osborne, Battelle.
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Introduction

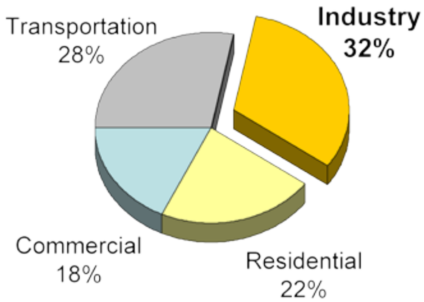


Figure 1. 2005 Energy Use Totaled 99.9 Quadrillion Btu (includes electricity losses)

The industrial sector accounts for approximately one third of energy usage in the United States (see Figure 1). In the area of energy-intensive processes in particular, the Industrial Technologies Program (ITP) seeks to improve energy efficiency and reduce carbon emissions across the most energy-consuming manufacturing processes by developing and promoting technologies common to many industries. ITP's approach is to increase efficiency, while applying the best energy management practices to help industry save energy, improve productivity, and stimulate growth.

Strategy and Purpose

In support of ITP, Battelle Memorial Institute worked with industry and the U.S. Department of Energy's (DOE's) national laboratories to generate this research plan for energy-intensive process industries. The plan identifies a market-transforming strategy for future ITP investments in collaborative development and improvement of current and next-generation energy-saving technologies.

This research plan builds upon ITP's very successful legacy of collaborative research, development, and demonstration (RD&D) projects that, by providing energy cost-saving technologies to industries, have reduced industrial energy intensity and enhanced environmental performance. It identifies advanced technologies whose development and deployment could dramatically affect U.S. industry's impact on national energy security, environmental quality, and climate change issues. The plan also begins to address the manufacturing technologies that will be needed to foster energy efficiency in emerging industries such as biorefineries and photovoltaics.

Technology-Based Platforms

ITP is refining its research and development (R&D) strategy to one with a technology-based approach, which consolidates R&D activities around specific technology platforms that are expected to provide large energy-saving benefits across industry while also meeting stakeholder's technological needs. The core R&D activities fall under one of four technology platforms that address the top energy-consuming industrial activities. Each of the technology platforms, in turn, encompasses three or four areas of technological focus for R&D supporting a core manufacturing process.

Four ITP Technology Platforms

- ***Industrial Reactions and Separations***
- ***High-Temperature Processing***
- ***Waste Heat Minimization and Recovery***
- ***Sustainable Manufacturing***

Deployment of the resulting technologies will contribute to a 25% reduction in energy usage and consequent carbon emissions reductions between now and 2017.

Key Strategic Elements

To help achieve the targeted reductions, three key strategic elements are integrated into this plan:

- partnering and cost-sharing with industry
- leveraging the intellectual property and institutional knowledge of the national laboratories to accelerate deployment
- developing cross-cutting, manufacturing technologies that can be applied across a broad spectrum of markets.

"Commercialization Councils" bundle IP and build cross-laboratory collaboration.

The use of a multi-laboratory "Commercialization Council" can provide a method for bundling intellectual property (IP) and building cross-laboratory teams that accelerate technology maturation. Under this approach, industry partners are an essential part of the process, providing funds and commercial expertise. Multi-laboratory cooperative research and development agreements (CRADAs) are set up to bring the right teams together. Analysis of the IP at the laboratories is integral to developing the strategy for technology maturation and deployment. Each of the areas of technological focus presented in this plan will undergo a process of reviewing patents for bundling and selecting the appropriate resources for moving forward. Cross-laboratory teams, which were created to generate this plan, are now in place to accomplish these goals.

Mining institutional resources shortens the path to market.

ITP's strong history of working with the national laboratories and industry is the foundation for this part of the strategy. A well-maintained body of IP and expertise developed from previous, and sizeable, investments already exists. Combining this IP source with information from each DOE national laboratory will result in a powerful foundation for commercialization. By mining existing institutional knowledge, experience, and technology based at the laboratories as well as partner universities and companies, other investments at the laboratories can be leveraged to support a shorter path to commercialization. Time to market is critical, and ongoing efforts to improve the execution of the projects that result from this IP analysis of the focus areas are intended to improve both industry's and the government's return on these investments.

Bundling IP and expertise in close partnership with the industry spectrum achieves wide market application.

This IP and expertise bundling, close partnership with a broad spectrum of industry, and improved project execution will ensure that these technologies achieve the second goal, namely, wide market application. Fundamental principles of technology transfer will provide right-to-practice in discrete market areas, thereby minimizing competitive issues. Using an approach built around technology maturation will fully leverage previous DOE investment to move quickly to demonstration and deployment.

Plan Contents and Organization

The following sections of the plan describe the energy challenges being faced, current market situation, derivation of the technology platforms, and ITP's project management approach. Descriptions of the technology platforms and focus areas and a list of participants in the ITP workshops conducted during the process of developing this plan are provided in Appendixes A and B, respectively.

Helping Industry Face the Energy Challenge

Over the past 28 years, ITP has supported more than 600 separate RD&D projects that have produced approximately 200 commercialized technologies. While the associated energy savings are impressive, industry has reaped even greater benefits from productivity improvements, reduced resource consumption, decreased emissions, and enhancements to product quality associated with these technological advances. In addition, many ITP-supported projects have significantly expanded basic knowledge about complex industrial processes and have laid the foundation for developing future energy-efficient technologies.

Savings from Successfully Commercialized ITP-Supported Technologies	
During 2005	402 trillion Btu, equivalent to about $4.44 billion
Cumulative ITP History	5.13 quadrillion Btu, equivalent to about $29.3 billion

ITP's primary role is to invest in high-risk, high-value RD&D that will reduce industrial energy intensity while stimulating economic productivity and growth. Because energy is a critical input for many of the nation's key manufacturing industries, reducing energy intensity also will reduce energy costs, cut emissions of greenhouse gases and other priority pollutants, and improve productivity per unit of output. As a Federal program, ITP invests in advanced technologies that are anticipated to produce dramatic energy and environmental benefits for the nation. Investments focus on technologies and practices that will provide clear public benefit, but have market barriers preventing adequate private-sector investment.

Strategies for Transforming the Way Industry Uses Energy

1. ***Accelerate adoption of proven technologies and practices.***
2. ***Deploy new technologies for industry-specific applications.***
3. ***Expand industrial opportunities for combined heat and power.***
4. ***Develop technologies for advanced energy conversion and processes under energy-intensive technology platforms.***

ITP is pursuing four primary objectives in support of the strategies to transform the way industry uses energy. These objectives are designed to overcome known barriers to energy efficiency, including the lack of specialized knowledge and expertise to identify and implement proven technologies, the operational risks of adopting new technologies that could upset vital 24/7 manufacturing operations, and the technical risks and high costs of pursuing cutting-edge technologies for next-generation processes. Because of the rich diversity of industrial processes, a portfolio of energy- and waste-saving technologies must be developed and deployed—some that will apply to all manufacturing facilities and some that will target specific energy-intensive processes that are the source of most industrial carbon emissions.

U.S. Manufacturing Facing Market Challenges

ITP's new strategy to develop and deploy cross-cutting technologies that can be used across a broad spectrum of industries is expected to provide greater flexibility in the application of technologies and increase the likelihood of their deployment in the face of dramatic changes in market and economic conditions. For example, the exponential growth of the industrial sectors within China and Korea is driving multi-national companies to invest in meeting foreign market needs using state-of-the-art technologies. The U.S. materials and process industries face intense competitive pressures. Strong cost competition from foreign producers and alternative materials, as well as shareholder expectations of near-term profits, are squeezing corporate expenditures. In today's global economy, U.S. firms often find themselves at a cost disadvantage for labor, materials, energy, and environmental compliance. Unable to significantly differentiate their product from foreign sources, and with reduced trade barriers, increased trade deficits have occurred for all of these industries, as listed in the table below. In addition, many products from the energy-intensive industries target similar markets; for example, steel, aluminum, glass, and plastics all target the food and beverage container market, as well as many automotive applications.

Industry	Total Trade ($B)		Trade Balance ($B)	
	1997	2004	1997	2004
Wood Products	$18.4	$27.4	$-7.4	$18.4
Paper	$29.3	$36.4	$-0.1	$-5.0
Petroleum	$20.2	$52.7	$-5.8	$-27.0
Chemicals	$118.7	$217.1	$19.5	$-0.5
Nonmetallic Minerals	$16.9	$23.4	$-4.1	$-9.6
Primary Metals	$56.8	$78.9	$-15.1	$-33.4
Total Manufacturing	$1,357.3	$1,940.6	$-130.6	$-487.4

To combat market pressures, companies have pursued strategies to cut costs and mitigate risks through mergers and acquisitions, leveraging R&D funds with private and public partners, globalizing and integrating R&D, and outsourcing technical components. For the United States to remain competitive, it must remain at the cutting edge by developing and deploying new technologies.

DOE Portfolio Analysis Shows the Importance of Industrial Technologies to Energy Productivity

Several cross-cutting analyses of DOE's Office of Energy Efficiency and Renewable Energy science and technology portfolio were recently conducted by an expert panel of national laboratory staff. The results confirmed that ITP plays a key role in the end-use segment of the energy market. Many industrial processes have a large impact on local and regional power generation because of the typically high energy requirements for manufacturing and process industries. And, while great strides have been made that have reduced the overall energy intensity of the industrial sector,

- **the panel concluded that efficiency improvements within the Industrial Technology Sector provide one of the approaches with the greatest leverage to reduce petroleum imports, and that energy efficiency also can provide immediate benefit.**

The panel also recognized that the manufacturing processing value chain taken as a whole is a significant contributor to the U.S. energy consumption profile; however,

- **reducing manufacturing process energy consumption has not been a significant focal point of the DOE portfolio in the recent past, so targeted investments could result in substantial short-term benefits as technologies are deployed.**

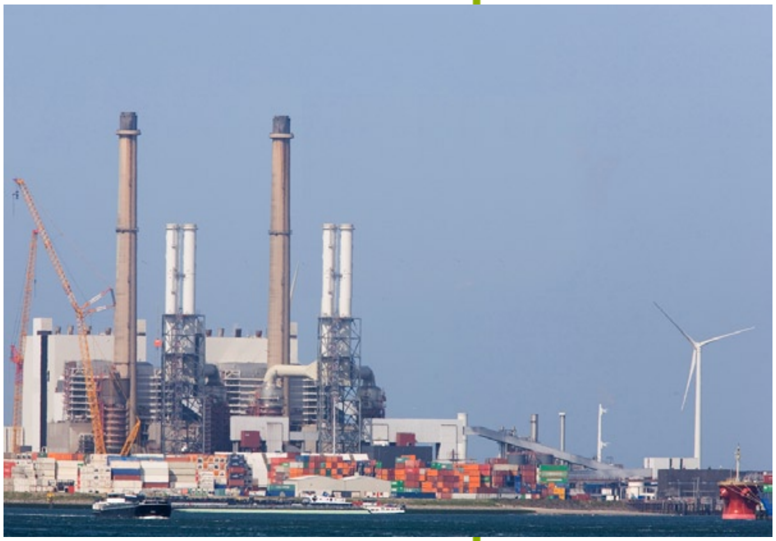
The panel recommended the development of advanced catalysts and membranes to replace distillation, provide more cost-effective uses of low-grade waste heat, and provide more efficient furnaces and ways to generate process heat. A qualitative risk profile was developed for each of these technologies for technical devel-opment as well as market deployment.

- **All of the technologies evaluated, both longer-term transformational and shorter-term incremental, were considered to be only low to moderate technical and deployment risks compared with the broad energy R&D portfolio.**

Beyond the energy savings and its cost-reduction benefit, CO_2 emissions are an ever-increasing concern for U.S. manufacturers and end-users. Based on the estimate that carbon capture and sequestration may place up to a 30% cost burden on many processes, the panel felt that

- **energy efficiency, with its concomitant CO_2 reduction, will play an even more prominent role as industry implements technologies to capture and dispose of CO_2 within specific process steps.**

Energy Efficiency and Climate Change



It is widely recognized that control of CO_2 emissions will become regulated in the United States in the very near future, probably within the next 3 to 5 years. While there is a sizeable ongoing debate about the strategic regulatory framework it will take, many industries are working today to understand the impact that control of CO_2 emissions will have on their businesses by considering various scenarios. Estimates vary by industry and process, but CO_2 capture and sequestration may impose a cost penalty as high as 30%. Higher energy conversion efficiencies can reduce carbon emissions for many industries and will therefore play an important role in reducing the cost penalty. Consequently, improved energy efficiency and carbon management will co-exist for many industries in the future.

The models developed by the Global Energy Technology Program (GTSP) at the Joint Global Change Research Institute, a Battelle-run institute at the University of Maryland, have put the impact of climate change in economic terms for the energy market, and particularly the end-use segment. The GTSP has shown that the loss of one-quarter of one percent per year in the rate of end-use energy intensity improvement would increase annual CO_2 emissions at the end of the century by 6 GtC/year, almost as much as the entire global emissions from fossil fuel in 1990. The economic impact of this is an additional $7 trillion (in 2005 dollars) compared to the reference case. Conversely, increasing the rate of end-use energy-intensity improvement by the same one-quarter of one percent annually saves $3 trillion. The GTSP considers end uses from all economic sectors, so while the exact contribution from industry is not quoted in this plan, it is still a very large number. Consequently, ITP's R&D accomplishments have the ability to significantly impact industrial CO_2 emissions.

Carbon management will track in parallel with energy-efficiency improvements.

Market Overview

As was already seen in Figure 1, the industrial sector accounts for approximately one-third of energy usage in the United States. This usage provides both opportunity and challenge to the U.S. economy. By significantly reducing its energy use per unit of gross domestic product through technology development, the United States can put itself in a strong competitive position relative to other nations. The challenge is to move aggressively forward with technology development in many industrial sectors that dedicate only a small percentage of revenues to R&D (see Figure 2).

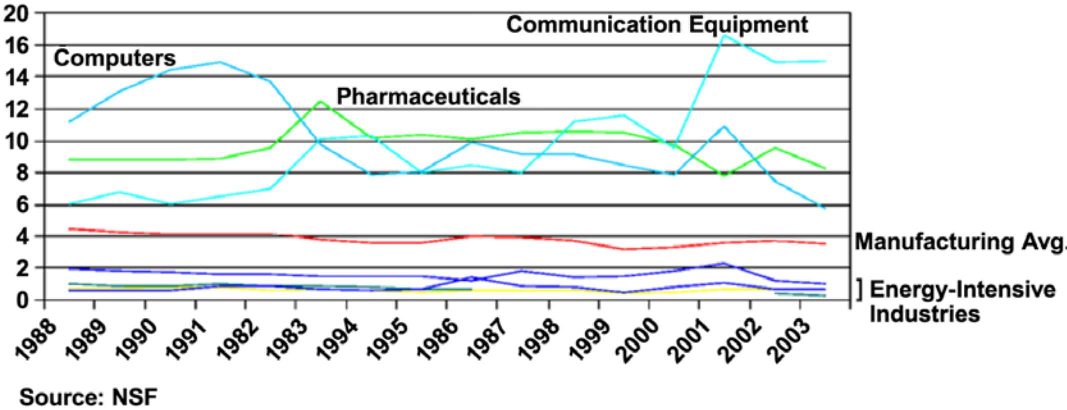


Figure 2. Research and Development Trends
(R&D expenditures as a percentage of total revenue)

Governments in other countries make significantly higher investments in the development of manufacturing technology than the United States. For example, Japan invested $337 million in the industrial sector in 2003, while the United States invested $75 million in 2005. Traditionally, the United States has had limited investments in the industrial sector and the funding has decreased over the last few years. However, budget increases can begin to address this shortfall. This research plan is meant to provide a clear picture of the opportunity to improve our competitive position by focusing on the industrial sector.

Defining the Technology Platforms

The significant value of organizing around platform themes that hold potential for cross-cutting benefits is clear. The business case for an investment is easier to justify when common results can be applied to multiple applications. For example, the results of ITP's existing cross-cutting programs (e.g., materials, combustion, and sensor developments) offer the potential for use in broader applications because leveraging the original investment makes development costs for new applications incremental.

Four cross-cutting technology R&D platforms are proposed for ITP based on the following:

- the results of a series of workshops involving key personnel from the national laboratories, Battelle, and industry
- an analysis of industrial energy end-use data by process
- a review of other already-discussed research results.

The issues of sustainability and water management were discussed during the workshops, but not addressed because they were judged to be beyond ITP's immediate mission. Additional refinement of platform and project descriptions, benefits, and metrics will be accomplished during fiscal year (FY) 2008.

To summarize the energy end-use data, process heating, steam generation, and machine drives are the largest contributors by a wide margin. This is shown in Table 1 (data summarized from the Manufacturing Energy Consumption Survey [MECS] 2002).

Cross-Cutting Benefits of Organizing Around Platform Themes

- ***The ability to serve a wider swath of U.S. industry and especially those that will continue U.S. global manufacturing leadership in energy and technology***
- ***Sharpened focus on manufacturing technologies***
- ***Maximum synergy among complemen tary technologies***
- ***Greater flexibility in launching new initiatives***
- ***More consistent, long-term R&D agenda versus discrete projects***
- ***Easier to communicate with ITP stakeholders***
- ***More responsive to the Program Performance and Accountability Framework requirements in ITP's Multi-Year Program Planning Process***
- ***Characterization of the carbon emissions reductions across multiple applications.***

Table 1. Estimated U.S. Manufacturing Energy Consumption by End-Use (2002)

End Use	Energy Use (10^{12} Btu)
Process Heating	5,870
Steam Generation	5,074
Machine Drive	2,553
Process Cooling	390
Electrochemical	390
Other Process Use	518
HVAC/Lighting	1,467
Total	**16,262**
Note: End-uses reported for 9,956 10^{12} Btu; the remaining 6,306 10^{12} Btu were distributed in the same ratio as the reported data.	

According to Table 1, roughly 75% of total manufacturing energy use is attributed to the top three end-uses. The further breakdowns for each of these by process and component are shown in Figures 3 through 5. From the figures, we can see that a significant amount of energy is dedicated to drying and water removal. Other high-energy usage areas include fractionation and stripping, typically by distillation. Reactions occurring in refineries and other chemical processes, such as hydrogenation, reforming, and cracking, comprise approximately 22% of the energy used by industry. This area of technological focus will be addressed under the Industrial Reactions and Separations platform.

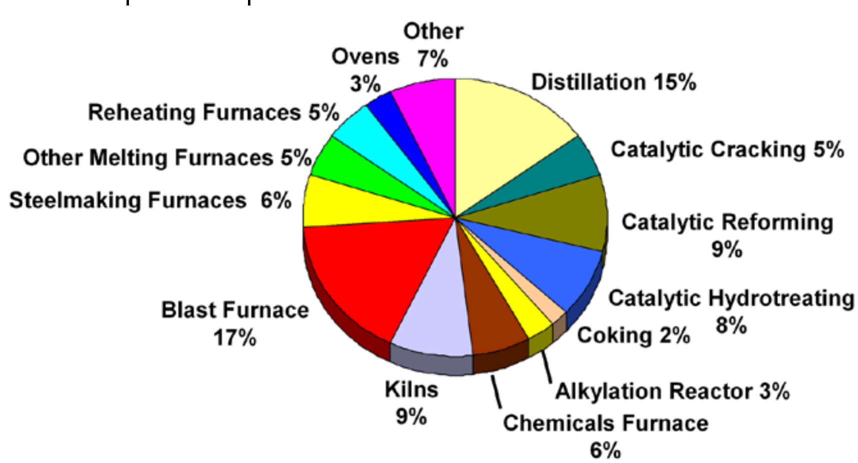


Figure 3. U.S. Manufacturing Energy Use by Process Heating Equipment (2002)

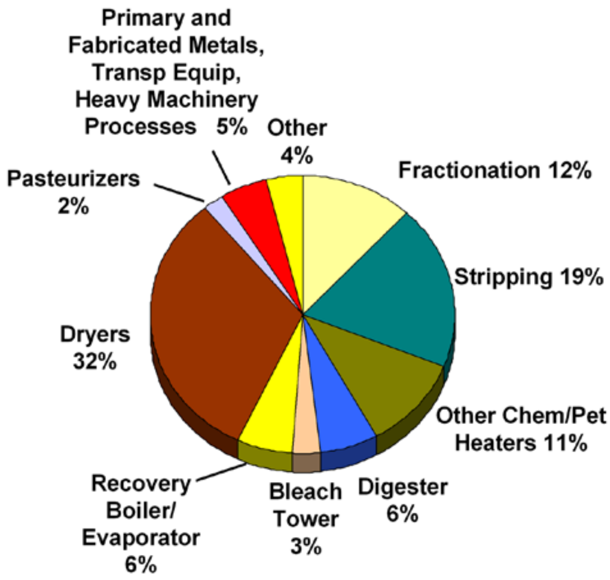


Figure 4. U.S. Manufacturing Steam Use by Equipment Type (2002)

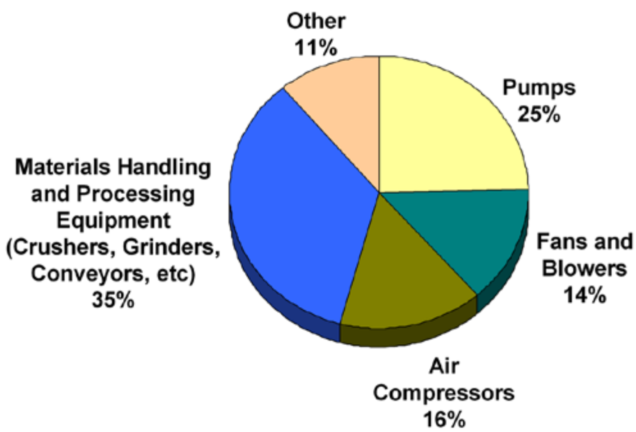


Figure 5. U.S. Manufacturing Use by Motor-Driven Equipment (2002)

After reviewing this information, the ITP mission, and industry priorities, a number of themes emerged, which provided the basis of the recommended technology platforms. Each of these is extremely complex, which necessarily results in the platform concept. Overlaying the technology platforms are the environmental benefits that also result from reduced energy intensity and therefore reduced CO_2 emissions.

Theme	Technology Platform
• Process industries use economies of scale to compete. • With large capital investments, most innovations are incremental and provide some competitive advantage. • Process industries require novel and transformational innovations to remain competitive and strengthen global positions.	Industrial Reactions and Separations
• High-temperature industrial processes require large energy inputs to meet required product specifications; therefore, incremental efficiency improvements can have a large impact. • Transformational processes that produce the same product at lower, but still elevated, temperatures, also will have a large impact because of the energy costs of increasing the temperature of the process system.	High-Temperature Processing
• Industry relies on steam and process heat in a variety of ways, so significant energy costs from its generation are part of the ultimate product cost. • At present not all of that energy can be economically used before it is released, so capturing and using more will make processes more energy efficient.	Waste Heat Minimization and Recovery
• The additive energy costs that result from each step in the manufacturing supply chain are a large fraction of final product cost. • Improved yields (less waste) per unit energy cost throughout the supply chain will have significant impact at the overall system level as well as at the manufactured component level.	Sustainable Manufacturing

Some overlap among the platforms is almost by design given the high-level organization described. However, some general criteria can be used to decide how to place a project in a particular category. It should be noted that it is not as important to get a project in one category or another as it is to select high-priority projects and implement the results. As an example, industrial separations are often high-temperature processes. If the technology needed is dictated by temperature requirements, it can be placed under the High-Temperature Processing platform. If, on the other hand, the separation process itself is the issue, the technology can be placed under the Industrial Reactions and Separations platform. Some judgment was exercised in making these choices, but our goal was to make sure the right technologies are supported in some way. The platforms are described in more detail in Appendix A.

Estimates of the potential benefits of each platform will be estimated using ITP's Government Performance and Results Act (GPRA) process. This process uses energy and market data to project potential energy, economic, and environmental benefits resulting from RD&D of ITP-supported technologies. GPRA analysis input and results related to this plan will be provided as they become available.

Technology Platforms and Focus Areas

Under this plan, core research and development in energy-intensive processes falls under one of four technology platforms, which represent the top energy-consuming industrial activities.

Focus on Energy Efficiency

Industrial Reactions and Separations

Develop technologies for efficient reaction and separation processes

- Advanced Water Removal
- Advanced Gas Separations
- Hybrid Distillation
- Energy-Intensive Conversion Processes

High-Temperature Processing

Develop efficient high-temperature technologies for producing metals and non-metallic minerals

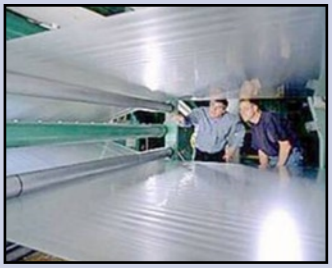
- Lower-Energy, High-Temperature Materials Processing
- New Materials Development
- Materials Processing for Enabling Emerging Industries

Waste Heat Minimization and Recovery

Develop high-efficiency steam generation and combustion technologies and improved energy recovery technologies

- Super Boiler
- Ultra-High Efficiency Furnace
- Waste Heat Recovery Systems

Sustainable Manufacturing



Develop advanced materials and technologies for making higher-quality products more efficiently and productively

- Net and Near-Net Design and Manfacturing
- Engineered Functional Materials and Coatings
- Advanced Forming, Joining, and Assembly
- Integrated, Predictive Manfacturing and and Plant Operations

Table 2 summarizes the project energy savings from the associated areas of technological focus under each technology platform. The platform purpose, strategic value, and overall objectives, for R&D investment are described below. The specific technology focus areas are described in detail in Appendix A.

Table 2. Technology Platforms and Projected Energy Savings from Associated Focus Areas

Technology Platform	Description	Current R&D Stage[(a)]	Key Milestones	2030 Projected Savings (Range in TBtu)	Carbon Dioxide Reduction ($MMTCO_2$/yr)
Industrial Reactions and Separations — *Technologies to reduce energy usage in reactions and separations*					
Advanced Water Removal	Advancing non-thermal water-removal technologies	3-4	**2008** Complete steam cycle washer field test. **2012** Demonstrate advanced water management technologies in pre-treatment, conversion, and product recovery processes.	500	35
Advanced Gas Separations	Leveraging membrane and adsorption technologies for gas separation.	2-3	**2009** Identify cost-effective methods to increase surface area per unit volume of membrane. **2012** Develop new membrane materials with improved robustness and selectivity.	60	5
Hybrid Distillation	Developing unit operations that combine distillation with other technologies	3	**2008** Select hybrid systems for concept development and complete field testing of predictive model. **2012** Scale up a hybrid distillation system.	240	20
Energy-Intensive Conversion Processes	Discovering new catalysts and reaction processes to improve the yield of most energy-intensive processes	2-3	**2009** Demonstrate, at lab scale, new catalysts, microreactor, reactor, and separation systems. **2015** Demonstrate new manufacturing process strategies at the pilot scale for olefin, chlor-alkali, ammonia, and chemical pulp production.	200	15
Subtotal				**1000**	**75**
High-Temperature Processing — *New materials, material processing, and process monitoring technologies to increase energy efficiency during high-temperature processing and enable emerging industries*					
Lower-Energy, High-Temperature Materials Processing	Developing high-power yet lower-energy transient thermal and non-thermal processing to provide drastic gains in energy efficiencies relative to today's long heat-soak technologies	2-3	**2008-2010** Assess excitation sources to determine best options. **2015-2020** Commercialize best technologies for large-scale production and deployment.	150	10
New Materials Development	Using modern materials science to develop nanostructure enhanced alloys, advanced steels, self-healing surface films, and complex shaped titanium and magnesium engineering components	2	**2008-2010** Identify new materials systems that have potential to extend service life and increase efficiency. **2015** Commercialize new materials for large-scale production and deployment.	150	10
Materials Processing for Enabling Emerging Industries	Addressing the critical barrier of low-cost manufacturing to enable co-processing of materials with drastically different melting points by developing high-power processing over large areas on low-temperature substrates in non-vacuum environments and developing sensors and controls	2	**2008-2010** Develop new low-cost manufacturing processes to heat treat materials on low-cost organic substrates. **2015** Commercialize successful technologies for large-scale production and deployment, targeting a threefold increase in energy efficiency.	100	10
Subtotal				**400**	**30**

Technology Platform	Description	Current R&D Stage[(a)]	Key Milestones	2030 Projected Savings (Range in TBtu)	Carbon Dioxide Reduction ($MMTCO_2$/yr)
Waste Energy Minimization and Recovery — *Technologies to improve steam boilers and furnaces and reduce fuel demands using waste heat recovery*					
Super Boiler	Developing technologies to produce steam with high efficiency, reliability, and lower costs with first-generation Super Boilers showing 20% increases in steam generation efficiency and occupying substantially reduced footprints relative to installed boilers	3	**2008** Install first-generation Super Boiler. **2010** Install a second-generation Super Boiler at a national laboratory for demonstration and monitoring. **2015** Make second-generation commercial package available for purchase.	350	20
Ultra-High-Efficiency Furnace	Improving furnace technologies initially targeted for advanced aluminum and steel furnace applications	2	**2009** Complete design of a prototype furnace. **2013** Initiate field test of ultra-high-efficiency furnace at an industrial site. **2015** Install the first commercial-scale furnace.	90	5
Waste Heat Recovery Systems	Recovering heat now lost to the environment to apply as useful process energy and electricity	2	**2010** Develop and demonstrate a heat recovery system installed at an appropriate site. **2015** Develop a compact, light-weight, high-temperature (>700ºC) heat-to-electricity demonstration unit.	260	25
Subtotal				**700**	**50**
Sustainable Manufacturing — *Advances in materials and technologies for making higher-quality products more-efficiently and productively*					
Net and Near-Net Design and Manufacturing	Advancing casting, rolling, forging, powder metallurgy, and other forming techniques	3-4	**2008** Develop concepts for reduced energy, near-net shape manufacturing technologies. **2012** Demonstrate tool-less free-form manufacture of net-shape high-integrity aluminum chassis.	140	10
Engineered Functional Materials and Coatings	Developing tailored structures, coatings, and composites for enhanced robustness and degradation resistance in severe-service industrial operations	2-3	**2008–2010** Develop concepts for engineered functional materials and coating processes. **2015** Integrate advanced engineered functional material and coating technologies into the manufacturing sector.	100	10
Advanced Forming, Joining, and Assembly	Developing techniques to improve industry's ability to achieve economical structures.	3	**2008** Identify concepts for reduced energy forming, joining, and assembly technologies. **2012** Demonstrate integrated process control and non-destructive materials characterization.	75	5
Integrated, Predictive Manufacturing and Plant Operations	Designing control strategies using sensor and feedback systems to reduce down-time, waste, energy usage, and improve quality.	2	**2010** Develop predictive interferential process control algorithms and control models. **2015** Demonstrate integration and intelligent control of multiple non-destructive evaluation.	130	10
Subtotal				**445**	**35**
Grand Total				**2545**	**190**

(a) R&D stage numbers reflect the commercialization track stages under the Stage Gate™ methodology described under Focusing on Commercial Deployment.

Industrial Reactions and Separations

Develop and implement advanced reaction and separation rocesses for the benefit of U.S. industrial competitiveness nd energy security.

This platform targets development and demonstration of dvanced technologies for energy-intensive reactions and eparations processes, focusing on accelerated, economic evelopment of technologies for production of fuels, hemicals, and materials from renewable sources, which will ncreasingly form the basis of the 21st century economy.

Value Proposition

ns and separations will improve energy intensity in process industries, with separations being most critical in processes that involve water removal and/or require conventional distillation. Distillation alone accounts for about 15% of U.S. manufacturing energy use. Process industries penetrate virtually all aspects of the economy. Although improvements to individual installations won't necessarily offer enormous energy savings, cross-cutting improvements to separations processes across multiple industries aggregate to one of the largest opportunities for saving energy. In addition to developing efficient new reactions and separations processes, this platform will investigate the use of alternative and renewable feedstocks for the chemicals, petroleum, and other process industries. Unlike traditional processes, renewable energy sources represent an emerging market for both new process capital and conversion of existing plants in rapidly growing products. ITP's investment will be vital to the success of DOE's "20 in 10" mandate and will provide the backbone for deployment.

Enhancing energy intensity and process intensification through improved reactions and separations will

- contribute to the EPACT 2005 goal of reducing energy intensity by 2.5% per year by 2017 by increasing energy efficiency 15 to 40% in targeted processes
- enable the deployment of renewable and alternative feedstocks to meet the "20 in 10" mandate of displacing 20% of U.S. oil and gas
- enable zero-discharge water use.

Targeted Outcomes (2030)

Energy Savings: 1000 trillion Btu/yr

CO_2 Reduction: 75 $MMTCO_2$/yr

Energy Cost Reduction: $2 billion/yr

Water Savings: 30 billion gal/day

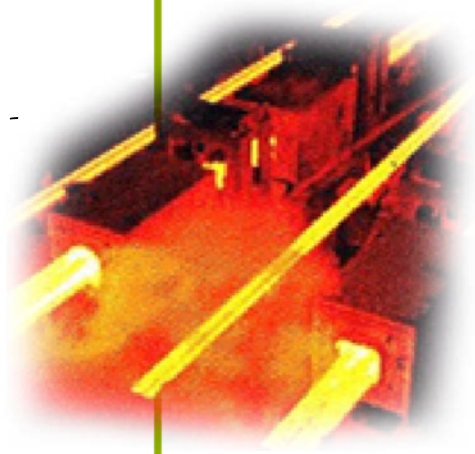
Focus Areas

The areas of technological focus for R&D investment under this platform include the following:

- Advanced Water Removal
- Advanced Gas Separations
- Hybrid Distillation
- Energy-Intensive Conversion Processes.

Key Stakeholders	
• Chemical and petrochemical industry • Biorefineries, agri-processers, bioenergy	• Forest products • Food processors

High-Temperature Processing



Develop and deploy improved technologies for processing (at elevated tem raw materials and intermediate products that rely on the alteration of th - physical and chemical properties of materials to achieve product specifica in existing and emerging industries.

This platform targets
- reducing wasted energy in melting
- reducing energy consumption for heat treating
- reducing energy consumption in primary materials production, such as steelmaking
- breakthroughs in non-vacuum processing that enable emerging industries such as photovoltaics, solid-state lighting, and flexible electr

Value Proposition

The overarching objectives of the cross-cutting high-temperature processing platform is to significantly increase the efficiencies of existing energy-intensive high-temperature processes; develop advanced materials and breakthrough technologies to significantly reduce energy intensity and greenhouse gas emissions; and develop new low-energy processes and products for emerging industries. Investments under this platform will reduce energy consumption and carbon emissions by
- deploying lower-energy alternatives to conventional high-temperature processing technologies that currently account for nearly 50% of industrial energy usage
- developing and implementing sophisticated transient thermal processing techniques to enable the manufacture of new energy devices that currently cannot be processed using conventional global high-temperature processes because of materials limitations.

Focus Areas

The focus areas identified align with the need to reduce energy intensity and increase the energy efficiency associated with high-temperature manufacturing operations. In addition, to support longer-term environmental and global competitiveness objectives, new technologies that rely on non-carbon-based fuels must be developed. The technology areas for R&D investment under this platform include
- Lower-Energy, High-Temperature Materials Processing
- New Materials Development
- Materials Processing for Enabling Emerging Industries.

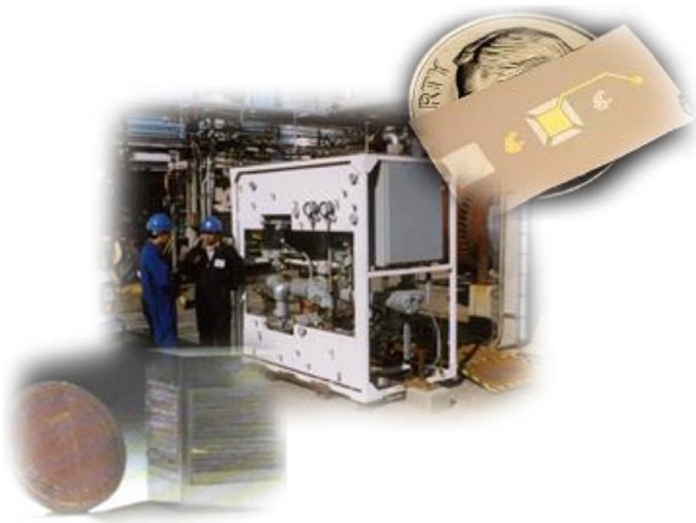
Key Stakeholders	
• Metal manufacturers • Glass and ceramic manufacturers	• Metal casting industry • Photovoltaics and battery industries

Targeted Outcomes (2030)

Energy Savings: 400 trillion Btu/yr

CO_2 Reduction: 30 $MMTCO_2$/yr

Energy Cost Reduction: $2 billion/yr



Waste Heat Minimization and Recovery

ields per unit energy for the material manufacturing ss industries by improving overall energy efficiencies he use of advanced combustion and heat-recovery

form targets waste heat recovery, including d heat and power systems, combustion, gy-efficiency improvements for industrial and boilers.

Investments in waste heat minimization and recovery will improve energy efficiency by

- developing and deploying cost-effective heat-recovery systems and advanced heat-transfer fluids such as nano-fluids, considering the wide range of waste heat process issues (e.g., temperature, composition, energy content, and accessibility)
- developing and deploying cost-effective, energy-efficient industrial combustion technologies and systems, such as those used in process steam boilers and industrial furnaces
- reducing energy and material inputs and emission outputs, including carbon, by the use of these improved systems
- implementing computational (fluid dynamic, thermodynamic, multi-physics, and/or system dynamics and controls) support to target the most appropriate implementation of waste heat recovery and combustion system improvements.

Focus Areas

Improving the market for new high-efficiency steam boilers and furnace concepts requires developing cost-effective waste heat minimization technologies and capitalizing on opportunities to reduce fuel demands using waste heat recovery. This includes the development of advanced heat-transfer and energy conversion materials, coatings, systems, and testing; novel heat-transfer technologies, including the application of micro-channel heat exchangers and nano-fluids; technologies that reduce fouling; component- and system-level computational modeling and simulation; and advanced system validation. Areas of technological focus include

- Super Boiler
- Ultra-High-Efficiency Furnace
- Waste Heat Recovery Systems

Targeted Outcomes (2030)

Energy Savings: 700 trillion Btu/yr

CO_2 Reduction: 50 $MMTCO_2$/yr

Energy Cost Reduction: $2.8 billion/yr

Water Savings: 1.7 trillion gal/yr

Key Stakeholders	
• Glass, aluminum, petrochemical, chemical, forest product industries • Food processors • Energy, steel, specialty metals, refining	• Process and manufacturing equipment producers • Biorefineries • Alternate energy sector

Sustainable Manufacturing

Improve yields per unit energy cost for multiple elements of the manufacturing supply chain and reduce waste and/or improve energy efficiency, while demonstrating air- and water-neutral production methodologies.

This platform targets
- sustainable integrated manufacturing technologies
- regenerable and recyclable materials and pr
- advanced process control, automation, and infrastructure development.

Value Proposition

Investments in sustainable manufacturing will improve energy efficiency by developing and deploying technologies that enable the manufacture of components that have multiple market applications; and by coupling various design options, materials combinations, and manufacturing technologies to reduce process steps or parts count to remove energy intensity from the supply chain at the systems level and to ensure a competitive, sustainable U.S. manufacturing capability.

Focus Areas

Sustainable manufacturing focus areas are aligned with the need to address the efficient use of energy and sustainable energy resources in the processing of energy-intensive materials and components; the desire to increase the use of sustainable, renewable, and recyclable materials in the manufacture of energy-intensive products; and the identification of technology opportunities that exist with the global integration of intelligent design, process control, fabrication and assembly, and real-time product control. The technology areas for R&D investment under this platform include the following:

- Net and Near-Net Design and Manufacturing
- Engineered Functional Materials and Coatings
- Advanced Forming, Joining, and Assembly
- Integrated, Predictive Manufacturing and Plant Operations.

Key Stakeholders	
• Metal-forming/cutting and heat-treating industries • Metals processing, forming, and component suppliers • Transportation manufacturing	• Fabricated consumer product industry • Process and manufacturing equipment producers • Mining, chemical, petroleum, agriculture, pulp and paper

Targeted Outcomes (2030)

Energy Savings: 445 trillion Btu/yr

CO_2 Reduction: 35 $MMTCO_2$/yr

Energy Cost Reduction: 1.8 billion/yr

Focusing on Commercial Deployment

ITP's rigorous technology management process contributes to the success of its R&D program. The Program's approach relies on the Stage Gate™ methodology (a registered trademark of R.G. Cooper & Associates)—a phased project development approach that produces fact-based funding decisions based on a set of defined evaluation criteria for five commercialization track stages. The approach provides consistent program and project management guidelines; characterizes projects in terms of scope, quality, performance, and program integration; evaluates and monitors project progress against milestones; assesses the viability of technology commercialization; and guides decisions on project funding (e.g., go forward, stop, hold, return).

Under the Stage Gate model, funding commitments for projects are initially low, increasing as work progresses and confidence in a successful outcome rises. Early focus is placed on exploring the most uncertain and risky technical elements to minimize spending over the long term. Conducting a thorough analysis of the potential for the technology and its expected economics in the initial stages provides important information for making judgments about the project along the way. The expectation is that projects with serious technical or other issues will be identified in the initial stages, thereby enabling greater investment in the projects that have the greatest probability for success.

Most of the areas of technological focus in this plan are in Stage 2 (Concept Definition). However, because ITP has several ongoing projects that are mature and appear to warrant moving forward to deployment, there will be projects that will continue with demonstrations and will be funded under that budget category. Given that new R&D activities will rely more on the national laboratories, it is important to note that the laboratories function primarily in the first three stages, but can work with industrial partners to support Stage 4 in certain cases.

By leveraging IP, expertise, and infrastructure across the laboratories, projects are expected to move quickly from Stage 2 to development and maturation (Stages 3 and 4). This accelerated

Commercialization Track Stages

***Stage 1** – Preliminary Investigation and Analysis: scoping studies to identify research topics; technical and market assessments; idea generation.*

***Stage 2** – Concept Definition: early stage research to explore and define a technical concept or to answer a specific technical question; laboratory-scale research.*

***Stage 3** – Concept Development: develop ment and testing of a prototype technology or process; development of models and infor mational databases; predictive modeling or simulation of process or equipment perfor mance; evaluation of scalability and end-user acceptability; demonstration of concept feasibility at the prototype or bench scale.*

***Stage 4** – Technology Development and Infor mation Validation: pilot-scale development of technology or process; technology field test and validation of economic potential; verifica tion and documentation of information.*

***Stage 5** – Information Dissemination and Commercialization: all activities necessary for information delivery and commercial launch (production scale technology manufacture and installation; development of market infrastructure; demonstrated com mercial operation).*

development can only occur with early and consistent involvement of the industrial partners from Stage 2 through Stage 4—with the latter being where industry takes the lead. Also critical to the success of the technology deployment will be the licensing guidelines that provide industry access to any and all IP relevant to commercialization in specific market areas. An industrial advisory group will formulate these guidelines with help from ITP and the national laboratories, so that all industrial partners will be aware of the terms for licensing.

Appendix A — Focus Areas

Technology focus areas for R&D investment are described under the following technology platforms.

Industrial Reactions and Separations

Advanced Water Removal

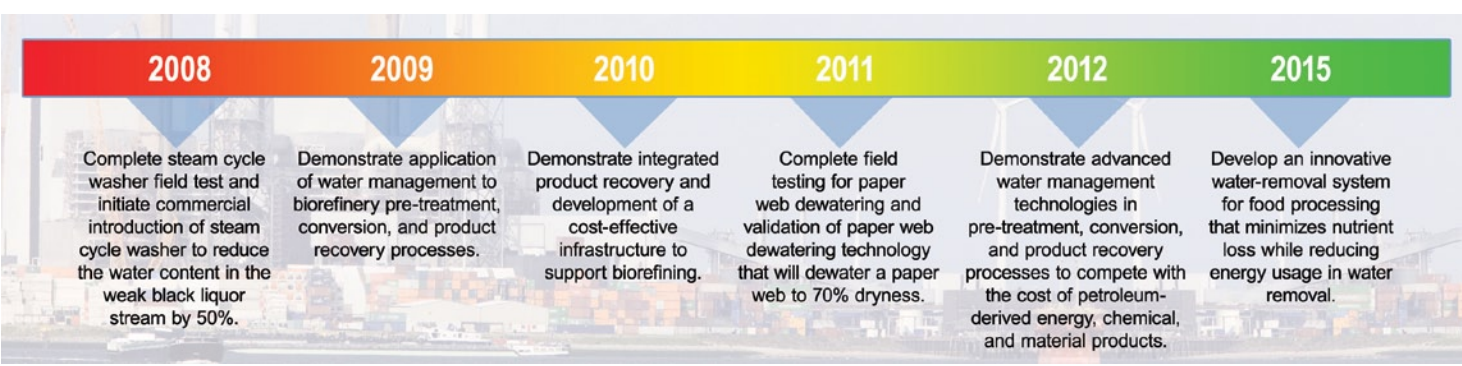
This focus area will develop non-thermal water-removal technologies that will reduce the energy requirements for water removal in high-volume process industries and emerging biorefineries.

Objectives	Major Challenges to Achieving Objective(s)
• Substantially reduce energy use in drying and concentration processes. • Produce large-volume fuels, chemicals, and materials from renewable feedstocks at prices that compete with petroleum feedstocks by improving water management. • Continue working on high-efficiency methods of dewatering (e.g., multi-port dryer, steam cycle washer for unbleached pulp), including energy- and water-recovery technologies.	• Economic attractiveness of the new technologies • Applicability of new processes to different types of processes and/or paper grades or biomass types • Regulatory (environmental) concerns for new technology implementation • Technology acceptance in mature industries • The dependence of biorefinery competitiveness on efficient water management from pre-treatment to conversion to recovery of products from dilute fermentation broths.

Technology Pathways and Metrics
• Develop a high-consistency pulp washer that reduces the water content in the weak black liquor stream by 50% (by 2008). • Develop a non-evaporative technology that dewaters a paper web to 70% dryness (by 2011). • Advance thermal technologies to recover and recycle heat and water (by 2015).

Developing non-thermal water-removal technologies and higher-efficiency thermal processes will reduce the energy requirements for water-removal or dewatering—a common, often energy-intensive function in many industrial manufacturing processes. The energy consumed by steam-driven evaporation processes in some industries is on the order of 1,000 TBtu/yr. In some large-scale production cases, evaporation potentially could be replaced by alternative technologies for a total estimated energy savings of over 100 TBtu/yr. Incorporating water recovery and reuse in dewatering technologies will reduce the consumption of increasingly scarce water resources, and breakthrough dewatering technologies (membranes, advanced filtration techniques, electrolysis, and crystallization) will dramatically lower energy consumption, improve energy intensity, and reduce the capital cost of equipment. Alternative and renewable feedstocks will play a role in achieving the "20 in 10" mandate. Biorefineries, including traditional pulp and paper industry, grain and oil seed processors, and emerging biomass processors of agricultural residues and energy crops, will produce multiple products (fuels, chemicals, and materials) in distributed models. Water management of dilute products will be essential for the industry to become economically competitive.

Key Milestones/Deliverables



Advanced Gas Separations

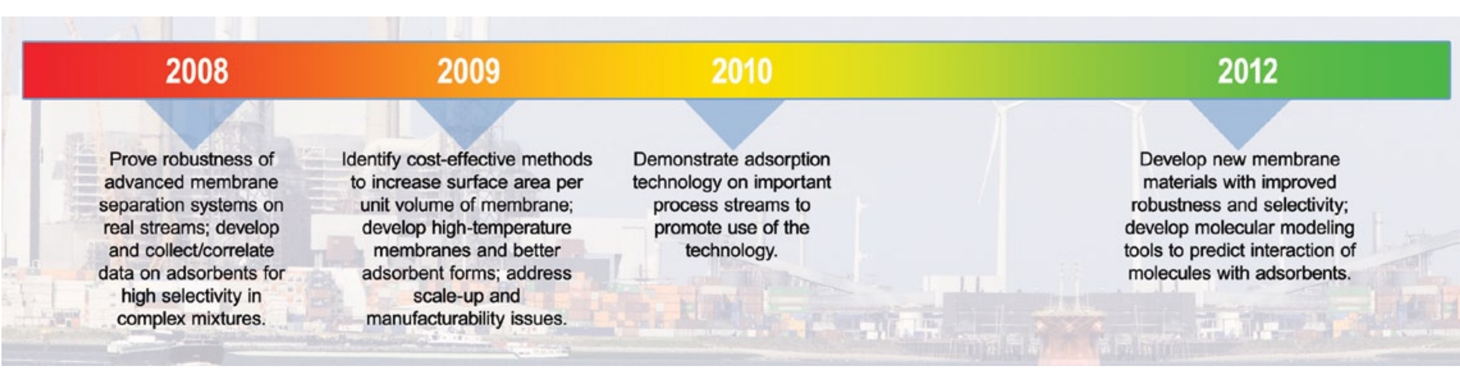
This focus area seeks to make major advances in membrane and adsorption technologies for oxygen/nitrogen separations and H_2, CO_2, and CO separations to increase energy efficiency through reduced energy consumption, simplified gas production processes, increased productivity, and lower greenhouse gas emissions.

Objectives	Major Challenges to Achieving Objective(s)
• Develop lower-energy, advanced gas separation technologies that improve gas separation efficiency by 30% without increasing CO_2 capture and compression electricity costs for new power plants by more than 20%.	• Gas separation technologies for the chemical, petroleum, manufacturing, and renewable fuel industries need to be more economically competitive before large-scale implementation of non-thermal separation technologies can be achieved. • Current technologies are expensive, but capital has already been invested in these established technologies.

Technology Pathways and Metrics
• Develop and demonstrate robust, efficient membrane separation systems that operate on real process streams, effectively integrate with other processes, and are capable of operating in harsh high-temperature environments. • Investigate novel material concepts for dilute streams; develop scaleable, low-cost manufacturing techniques; identify step-change technologies that create surface areas; and develop process simulation packages for membranes (by 2015). • Develop adsorbents for high selectivity in complex mixtures; integrate materials research and process development; correlate equilibrium and kinetics adsorbent data; develop improved adsorbent forms and geometries; reduce manufacturing costs; and demonstrate adsorption technology on important process streams (2010). • Develop switchable adsorbents using non-thermal desorption energy; improved high-performance conductors; non-conventional ways to desorb adsorbed molecules; process design tools to allow technology comparisons; non-conventional adsorbents (e.g., micelles, liquid crystals, enzymes, colloids); and molecular modeling tools to predict interaction of molecules with adsorbent surfaces (by 2015).[1]
1 Vision 2020: 2000 Separations Roadmap Published by the Center for Waste Reduction Technologies of the American Institute of Chemical Engineers in cooperation with DOE. http://www1.eere.energy.gov/industry/chemicals/pdfs/separations_roadmap.pdf

Advanced gas separations potentially could have game-changing impact on energy production and consumption in chemical, petroleum, manufacturing, and pulp and paper industries if existing air-fueled furnaces could be replaced economically with oxygen-fueled or oxygen-enriched furnaces. This will require vastly more energy-efficient oxygen/nitrogen separation than is achievable with current cryogenic technologies. The viability of numerous energy production and conversion applications—including alternative thermochemical processes for production fuels and chemicals, carbon capture, and hydrogen use—also depends critically on energy-efficient means of H_2, CO_2, and CO separations.

Key Milestones/Deliverables



Industrial Reactions and Separations

Hybrid Distillation

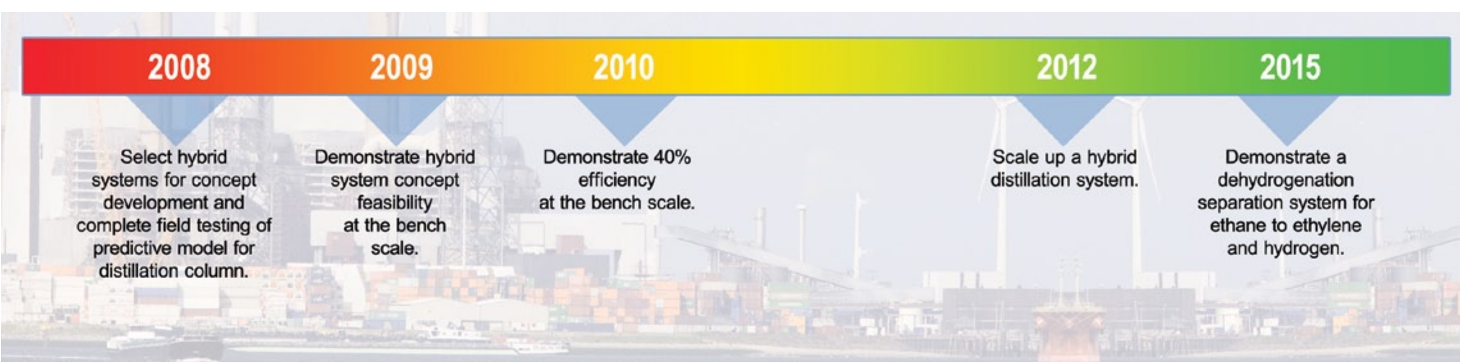
This focus area will develop unit operations that combine distillation with other technologies to improve the separation efficiency of distillation systems and combined reaction-separation systems.

Objectives	Major Challenges to Achieving Objective(s)
• Develop lower-energy hybrid distillation technologies that improve the separation efficiency of distillation systems by 40%.	• The thermal efficiencies of existing distillation systems are very low. • The physical behavior of process streams within a distillation column is not well understood.

Technology Pathways and Metrics
• Demonstrate development of better predictive modeling tools, visualization and imaging methods for distillation, optimization of separation technologies for use with distillation, and hybrid distillation systems to demonstrate a >20% increase in efficiency for selected distillation operations (by 2010). • Optimize multiple column configurations and adapt computational models to hybrid systems for plant-specific evaluation of commercial-scale systems to achieve greater separation efficiencies (by 2015).

Distillation consumes 2,400 TBtu/yr, representing over 10% of the energy consumed by the entire manufacturing sector. The thermal energy efficiency of a commercial distillation column is low, typically less than 10%. Significant energy savings on the order of 240 TBtu/yr could realistically be achieved if high-energy-intensity separation technologies like distillation were replaced with low-energy-intensity alternatives or by hybrid systems in specific applications. Hybrid distillation systems couple distillation with more efficient separation technologies to reduce the separation required by the distillation column. Hybridizing distillation is more technically and economically feasible than replacing distillation columns with alternative separation technologies. Additional savings in separation energy can be achieved through the addition of new membrane systems for enriching oxygen feed to furnaces and reformers (5 TBtu/yr savings) and by recovering hydrogen gas from petroleum flare gas if improved membranes were available (3 TBtu/yr).

Key Milestones/Deliverables



Energy-Intensive Conversion Processes

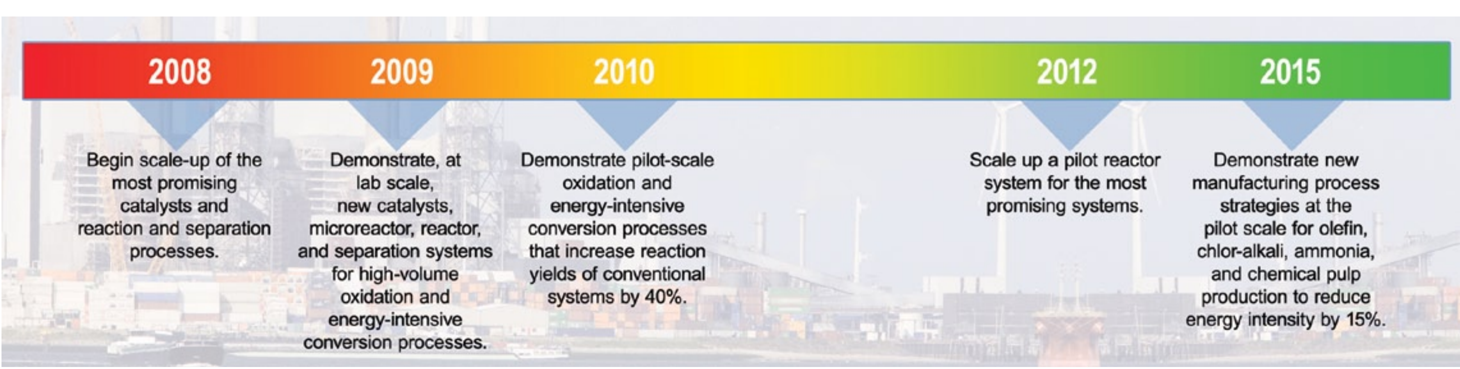
This focus area will develop new catalysts, reaction processes, and purification processes to improve the yield of the most energy-intensive conversion processes, including oxidations.

Objectives	Major Challenges to Achieving Objective(s)
• Develop new catalysts, reaction processes, and separation processes that increase oxidation yield by 40%. • Reduce the energy intensity for olefin, chlor-alkali, ammonia, and chemical pulp production by 15% and develop related manufacturing process strategies.	• Advances in oxidation reaction yields depend on improved catalyst selectivity and conversion during the production of many major chemicals. • Inherently poor catalyst properties (stability, longevity, durability, cost, and performance) • Limiting homogeneous gas-phase oxidation • Applicability and acceptance of new processes and use of alternative feedstocks

Technology Pathways and Metrics
Develop and demonstrate • new, more selective catalysts that improve reaction conversions and minimize secondary reactions • alternative reaction media to improve reaction conversions • integrated catalyst, media, and reactor designs for new oxidation processes • application of novel separation technologies that enhance product purification, solvent recovery, and dehydration Anticipated total recoverable energy for the existing processes is estimated at 98 TBtu/yr for ethylene oxide, 55 TBtu/yr for terephthalic acid, and 25 TBtu/yr for phenol. Assuming an energy savings of 25%, a total of ~44 TBtu/yr of energy savings could be realized across all three processes (by 2015).

Oxidation reaction conversions are low (10 to 15%) due to poor catalytic selectivity and reaction conditions. Catalysis may reduce energy intensity in industrial processing by reducing the temperature and time required for conversion. Improved yield and selectivity of reactions result in reduced energy consumption in downstream separation and purification of products. Revolutionary breakthroughs are needed to develop new classes of catalysts that surpass current limits in selectivity and activity. For example: microporous catalysts with improved internal diffusion where diffusion limitations may result in lower overall reaction rates and poor selectivity; and process intensification concepts such as microchannel reactors that have enhanced heat and mass transfer may enable improved yield of desired products and allow the use of more expensive catalysts because of higher productivity. New catalyst classes will accelerate industrial development of product specific catalysts outside the scope of ITP. In addition to oxidation reactions, this focus area will develop new reaction and separation technologies for the production of olefins such as ethylene and propylene, chloralkali production (chlorine and caustic soda), ammonia production, and chemical pulp production—processes that consume over 1.5 quads of energy and depend on old technology.

Key Milestones/Deliverables



High-Temperature Processing

Lower-Energy, High-Temperature Material Processing

This focus area will address the steps required to develop high-power yet lower-energy transient thermal processing to enable significant reductions in energy demands associated with conventional heat-soak treatment cycles practiced by industry.

Objectives	Major Challenges to Achieving Objective(s)
• Increase energy efficiency of industrial processes required to manufacture high-temperature materials by >25% and develop new processes based on alternate fuels and energy sources.	• Manufacturing infrastructure changes and cost requirements for implementing alternate technologies at large scale • Reducing manufacturing costs and processing time
Technology Pathways and Metrics	
• Develop and pilot test new lower-energy, high-temperature transient processing methods, including those that could use alternate fuels in industrial processes, resulting in a minimum of 20% reduction in energy use (by 2012). • Commercialize and implement new technologies for use in industrial processes (by 2017).	

Heat treating presently accounts for energy use of more than 500 TBtu/yr at a cost of nearly $20 billion. Numerous advanced processes are being developed that could potentially provide the same or greater level of performance as current high-temperature processes but at much lower temperatures and with potentially large energy savings. These benefits can only be realized through the development of detailed understanding of the effects of thermal transients on final material properties. Effective adaptation of these technologies will be accelerated by the use of advanced thermo-physical modeling techniques and new methods for integrated process monitoring and controls. Examples of excitation sources that potentially could be used to achieve high throughput at significantly lower overall energy inputs include magnetic field, laser, radiant, e-beam, ultrasonic, infrared, microwave, induction processing, and hybrid excitations. Technology developments will focus on developing shorter manufacturing cycles through transient processing coupled with materials process models, and developing new manufacturing processes using alternate fuels and energy types.

Key Milestones/Deliverables

New Materials Developments

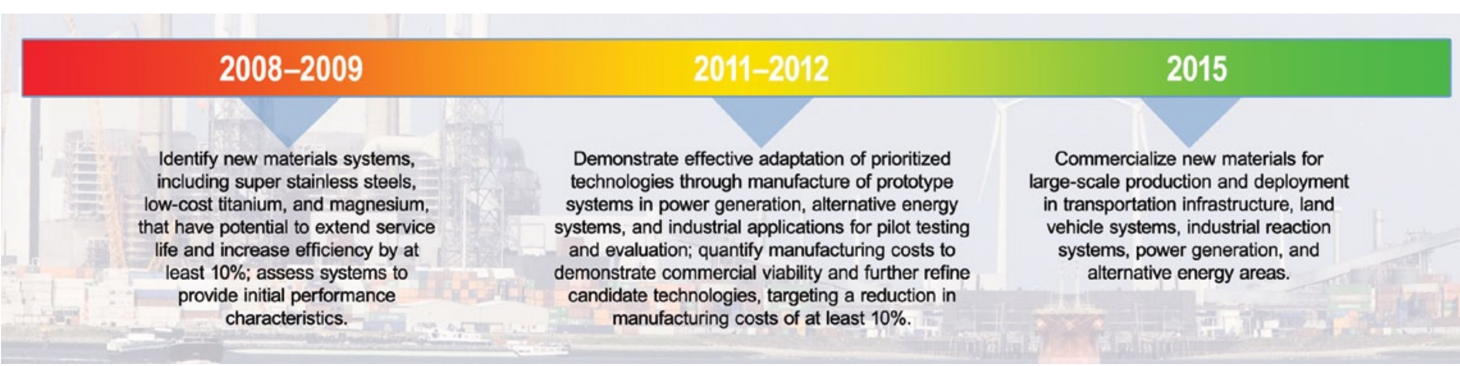
This focus area will address the steps required to enhance the performance of advanced steels, alloys, and other materials through changes in compositions and prescribed thermal mechanical processing.

Objectives	Major Challenges to Achieving Objective(s)
• Enable development and use of key materials and alloys that will lead to enhanced and more efficient processes, result in decreased environmental impact for their production and use, and decrease operational costs by at least 10% for each.	• Reliability, safety, and cost effectiveness of newly developed materials

Technology Pathways and Metrics
• Develop, pilot test, and commercialize new super stainless steel and titanium materials systems in commercial applications that demonstrate a minimum of 10% reduction in energy use during their production and in end-use applications (by 2012). • Develop and commercialize super stainless steel and titanium materials and expand applications, demonstrating a minimum of 20% reduction in energy use in their production and end-use application (by 2017).

New super stainless steels exhibit comparable cost and creep resistance to state-of-the-art advanced austenitic stainless steels, but have the potential for significantly higher operating temperatures and durability under highly aggressive oxidizing conditions (up to 800 to 900°C) at a fraction of the cost. They represent an entirely new class of heat-resistant alloys, because no alumina-forming, iron-based alloys suitable for structural use above ~600°C exist. In addition, new opportunities and processing challenges, such as fabrication, joining, and forming, are evolving in the production of advanced steels, as well as titanium and magnesium, which are coming to the forefront industrially. These advanced materials are required to be corrosion-resistant, materials-compatible, and of light weight and high strength, driven primarily by the need for fuel efficiency in the aerospace and automotive industries. The need for titanium is projected to potentially triple by 2015, and the automotive sector has identified magnesium as a key material in meeting its fuel efficiency goals.

Key Milestones/Deliverables



High-Temperature Processing

Materials Processing for Enabling Emerging Industries

This focus area will address the steps required to enable high-efficiency production of emerging materials.

Objectives	Major Challenges to Achieving Objective(s)
• Enable the cost-competitive production and better performance of emerging alternative energy technologies, such as photovoltaics, by developing non-vacuum-based processing methods suitable for the material substrates needed for these devices.	• Controlling defects to enhance performance • Reducing manufacturing costs and time • Co-processing of materials with dramatically different melting points • Enabling large-scale implementation of new technologies
Technology Pathways and Metrics	
• Successfully demonstrate non-vacuum-based process heating technologies that show increased production rates and increased conversion efficiencies by up to a factor of three (by 2012). • Introduce new materials processing technologies in production plants (by 2012).	

Strategic, evolving industries, including photovoltaics, batteries, solid-state lighting, and thin-film transistors, present new energy-sensitive, high-throughput processing challenges. A critical barrier to the implementation of these advanced products is the need for low-cost manufacturing that enables the co-processing of materials with dramatically different melting points, often in non-vacuum type processes. Overcoming this barrier will require high-temperature processing over broad areas on low-temperature, inexpensive substrates, reel-to-reel non-vacuum processing, and advanced sensors and controls.

Key Milestones/Deliverables

Super Boiler

This focus area will develop technologies to produce steam with high efficiency, reliability, and lower costs with first-generation Super Boilers showing 20% increases in steam generation efficiency over the existing equipment and occupying substantially reduced footprints relative to installed boilers.

Objectives	Major Challenges to Achieving Objective(s)
• Achieve a fuel-to-steam efficiency of 94% or higher (20% increase over existing equipment). • Decrease NOx 2 ppm and CO emissions to <10 ppm. • Decrease VOC emissions to below 1 ppmv. • Improve flue gas water recovery up to 60%.	• The need to reduce emissions while increasing efficiency at the same time • Expanding ultra-low-emissions design from natural gas to other fuels • Higher capital for newer, more efficient boilers • Aversion to novel designs • Difficulty in transferring advanced burners developed for one boiler to another boiler • The belief that capitalized equipment is uneconomical to replace even as superior products come to the market

Technology Pathways and Metrics
• Combine a suite of advanced technologies into a cost-effective, integrated package, including stage-intercooled combustion with internal recirculation, micro-channel heat transfer, flue gas heat/water-recovery, and smart control systems to meet targets (by 2011).

Steam accounts for over 30% of total U.S. manufacturing energy consumption. Eighty percent of the more than 33,000 large industrial boilers used by the U.S. manufacturing sector were purchased prior to 1978, with the largest share being purchased in the 1960s. These boilers will require replacement, and current state-of-the-art boilers offer only slight improvements over these units. However, current boiler users are very reluctant to commit financial capital to unproven or novel technology. Industry needs a boiler with an unconventional geometry that incorporates an advanced combustor design and heat/water-recovery system, and is compact, highly efficient, lower in emissions, and has multi-fuel capability. First-generation Super Boilers already integrate several novel technologies to achieve extraordinarily low emissions of NOx <5 ppmv, helping end-users comply with stringent emissions regulations. Second-generation Super Boilers will extend these performance benefits to high-temperature and high-pressure steam generation.

Key Milestones/Deliverables

Waste Heat Recovery and Minimization

Ultra-High-Efficiency Furnace

This focus area will develop improved furnace technologies initially targeted for advanced aluminum and steel furnace applications.

Objectives	Major Challenges to Achieving Objective(s)
Develop ultra-efficient heating and melting technologies with a reduced footprint by • lowering the cost barriers and increasing furnace efficiency • reducing furnace size and weight • improving furnace performance with advanced materials, sensors, and controls.	• Industry concerns about added process complexity with advanced furnaces • Cost-effective methods that will show acceptable capital recovery • The belief that it is uneconomical to recover the waste heat for power generation and that risks associated with system reliability may not justify improved energy efficiency of the process unit

Technology Pathways and Metrics
• Conduct R&D to combine a suite of advanced furnace technologies into a cost-effective integrated package that will be deployed over 3 years in a series of industrial demonstrations (by 2015).

Current industrial furnaces are characterized by low efficiency and significant physical size and weight. This focus area targets the development of a new competitive approach to heating and melting that combines advanced heat-transfer measurement, improved materials, closed-loop control systems, and paradigm-changing technologies (such as electrochemical heat treating and microwave heating) to increase furnace efficiency by at least 10%. Examples include: breakthrough technology to replace a three-step operation in the steel industry with a one-step iron-making production process using an advanced hearth; and a radically new aluminum production concept using isothermal melting, which could reduce energy input by 28%, generate no in-plant emissions, lower capital and operating costs, require a third of the floor space of a conventional system, and facilitate point-of-use production. In 5 to 10 years, barriers will be lowered for blast furnaces, specialty metals furnaces, metal casting, chemicals, and glass industries. The development of cost-competitive technologies to improve furnace performance will concentrate on advanced materials and coatings to protect against corrosive environments; advanced heat-transfer technologies; and novel designs to optimize heat-transfer performance while minimizing fouling and degradation in system performance. Other activities will include component- and system-level computational modeling and simulation and investigations of stable, reliable high-temperature thermal interface materials.

Key Milestones/Deliverables

Waste Heat Recovery Systems

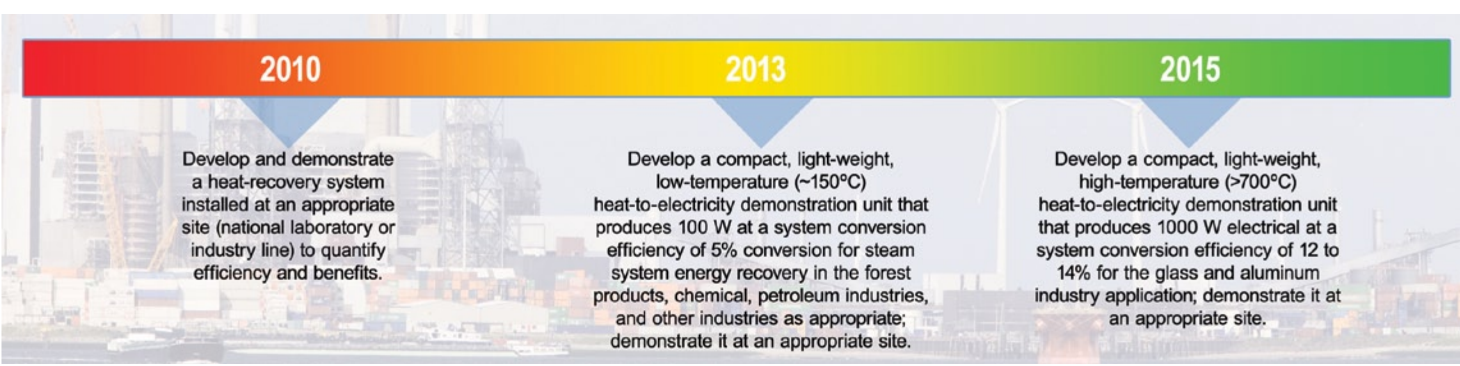
This focus area will develop and demonstrate cost-competitive technologies to recover process waste heat for application in the industrial sector.

Objectives	Major Challenges to Achieving Objective(s)
• Lower the cost barriers and address concerns about lower process availability for near-term applications of waste heat. • Lower the barriers to the economic use of waste heat to generate premium electric power in the longer term.	• Industry concerns about added process complexity with waste heat recovery • The lack of compact, light-weight, cost-effective materials, components, and systems to convert high-temperature waste heat to high-value electricity an order of magnitude lower than benchmark technology • The harsh operating environment • The belief that it is uneconomical to recover waste heat for power generation and that risks associated with system reliability may not justify improved energy efficiency of the process unit.

Technology Pathways and Metrics
• Combine a suite of advanced waste-heat recovery technologies into a cost-effective integrated package that will be deployed over 4 years in a series of industrial demonstrations (by 2009). • Deploy novel waste heat to electricity technologies in a series of industrial demonstrations (by 2012).

Industry needs a new competitive approach to meeting process cooling needs while using waste heat as a resource. Process waste heat is often discharged to the atmosphere via air-cooled and water-cooled heat exchangers, or as combustion products or hot gases. Because so much energy is lost in current heat-exchange equipment, this focus area will concentrate on advanced materials, coatings, heat-transfer technologies, and novel designs to optimize heat-transfer performance. These advances must minimize fouling and degradation in system performance that lead to costly losses from plant downtime. Initially, advanced thermoelectric systems and organic Rankine cycle systems for energy recovery will be targeted because these technologies have shown the most scientific and engineering promise. Heat-exchange equipment will be optimized with the process design under varying conditions.

Key Milestones/Deliverables



Sustainable Manufacturing

Net and Near-Net Design and Manufacturing

This focus area will address the steps required to develop net and near-net shape manufacturing technologies deployed within highly integrated design, process control, and intelligent manufacturing operation, and product control capabilities that will be representative of next-generation, energy-efficient, and sustainable manufacturing.

Objectives	Major Challenges to Achieving Objective(s)
• Develop integrated design, process development, tooling fabrication, and component-forming technologies that reduce process energy input by >20% and increase material yields in forming operations by >10%.	• The lack of energy-efficient, high-yield net and near-net shape materials processing and manufacturing technologies that fully integrate design, development, and real-time control in a sustainable environment hurts U.S. manufacturing efficiency and competitiveness • The U.S. manufacturing sector cannot be sustainable without making significant advances in the integration of intelligent manufacturing tools and controls into efficient net and near-net shape manufacturing technologies.

Technology Pathways and Metrics
• Develop and demonstrate a minimum of three (3) reduced-energy net and near-net shape metal fabrication and forming technologies that integrate design, process control, and real-time product properties and performance monitoring, resulting in a minimum 10% material yield improvement (by 2010). • Demonstrate net and near-net shape manufacturing integration of sustainable materials and plant operations to validate >20% energy input reduction for selected metal-forming and manufacturing operations (by 2015).

The processing of raw materials into finished products typically results in significant material losses. For example, as much as 30% of starting material mass must be removed in the casting and finishing of an automotive cylinder head, and in other industries these losses are much greater. Removed material that does not remain with the finished product contains significant embedded energy that requires additional energy for recycle and reuse. Existing forming and manufacturing processes also require the design and fabrication of complex tooling, which has limited life and again contains significant embedded energy. Although investments have been made in a number of free-form fabrication technologies for tool-less near-net shape forming, these approaches have often fallen short of achieving the expected energy efficiency, material sustainability, and cost goals.

Key Milestones/Deliverables

Engineered Functional Materials and Coatings

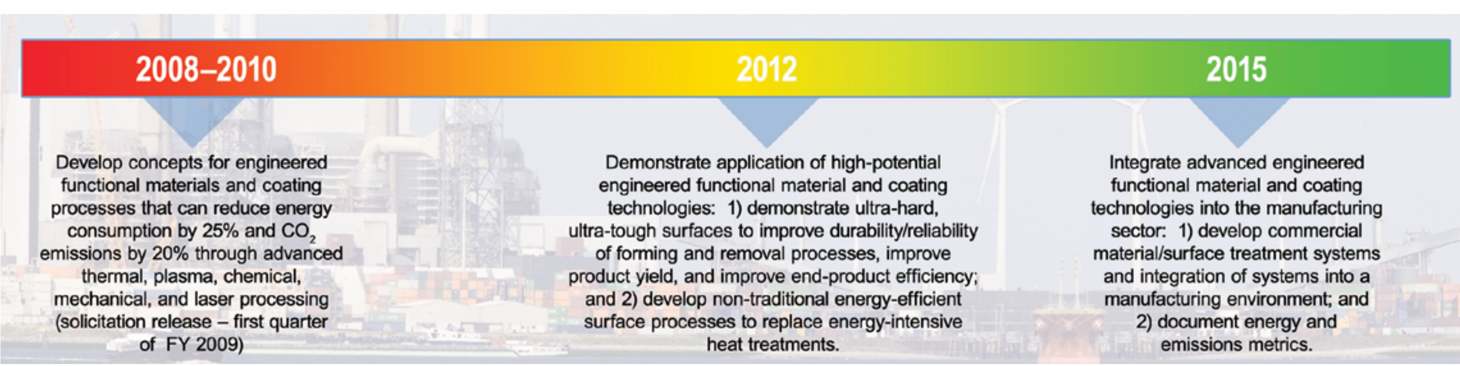
This focus area will address the development and deployment of materials and coating technologies that enhance energy efficiency, reduce environmental impact, and improve sustainability of manufacturing processes; replace energy-intensive processes; or improve the energy efficiency of end-products.

Objectives	Major Challenges to Achieving Objective(s)
• Develop, evaluate, and deploy engineered functional materials and surfaces to improve energy efficiency, productivity, and sustainability of manufacturing process equipment, and improve end-product performance. • Reduce parasitic energy losses in manufacturing. • Enable development and deployment of low-emission technologies to reduce carbon intensity by 15%.	• Evolving end-product performance requirements driving demand for advanced functional materials and surfaces and low-cost, energy-efficient manufacturing processes • Integration of sustainable, robust, energy-efficient manufacturing processes into the U.S. manufacturing infrastructure requires implementation of "green" engineering practices, and non-traditional, innovative technologies. • Integration of non-homogenous materials into a functional component/process

Technology Pathways and Metrics
• Develop near- and long-term thermal, mechanical, chemical, and electrical performance targets for high energy-consuming manufacturing process equipment and end-use sector products (by 2010). • Develop and demonstrate improved and/or alternative manufacturing processes that reduce energy consumption by 25% and emissions of CO_2 by 20% through implementation of advanced materials and engineered surfaces (thermal/chemical, mechanical, laser, and/or vapor deposition processes) (by 2015).

Fabrication and manufacturing of finished products typically require processes that consume large quantities of energy. Improving the efficiency of manufacturing processes through the application of functional materials and coatings can produce significant energy savings and reduce emissions dramatically. The challenge is to identify processes that provide end-products with the desired bulk (e.g., strength and fatigue life) and surface (e.g., friction, wear, corrosion, and thermal) properties. Recent developments in the fields of advanced high-strength steels, light-weight materials, and advanced surface modification technologies (e.g., hard coatings, thermal processing, mechanical and laser processing/alloying, etc.) provide new opportunities to develop sustainable, energy-efficient manufacturing processes and end-products.

Key Milestones/Deliverables



Sustainable Manufacturing

Advanced Forming, Joining, and Assembly

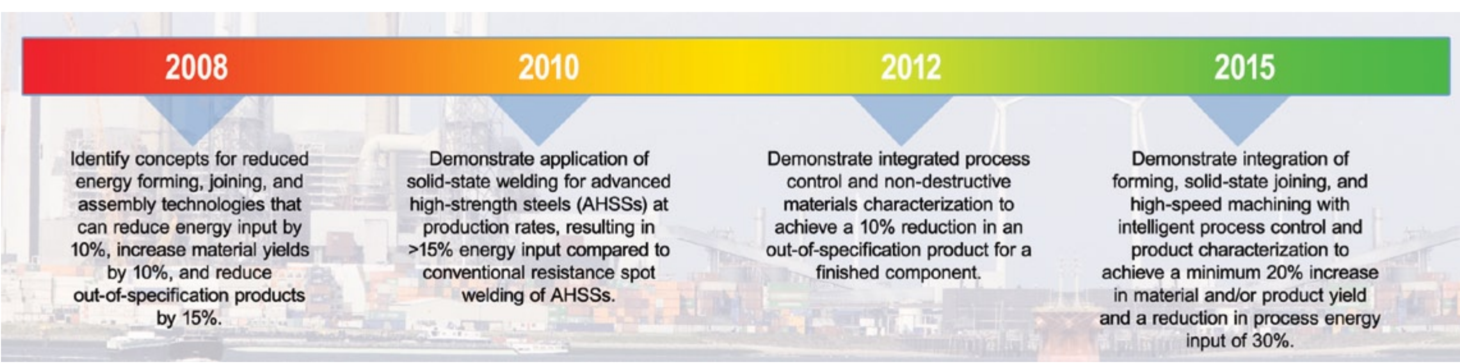
This focus area integrates design, process control, and intelligent manufacturing into forming, joining, and assembly operations for increased efficiency and competitiveness.

Objectives	Major Challenges to Achieving Objective(s)
• Develop lower-energy, forming, joining, and assembly technologies that are integrated with design, material handling, and process control, resulting in a reduction of manufacturing process energy input of >25%.	• Lack of energy-efficient, high-yield materials forming, joining, and assembly technologies that fully integrate design, development, and real-time control • Insufficient integration of intelligent manufacturing tools and controls for efficient forming, joining, and assembly technologies

Technology Pathways and Metrics
• Develop and demonstrate a minimum of three (3) reduced-energy advanced forming technologies that integrate design, process control, and real-time product properties and performance monitoring, resulting in a minimum 10% material yield improvement (by 2010). • Demonstrate sustainable manufacturing integration of advanced forming and joining technologies into industrial plant operations to validate >20% energy input reduction for selected metal-forming and manufacturing operations (by 2015).

Existing joining and assembly technologies involve high-energy heating, melting, and machining operations that result in large energy inputs, degraded product properties, and material losses. Emerging non-traditional warm and cold-forming technologies, solid-state joining, parts consolidation through advanced forming and assembly technologies, and integrated process and product control can derive reduced industrial energy use and increased manufacturing competitiveness.

Key Milestones/Deliverables



Integrated Predictive Manufacturing and Plant Operations

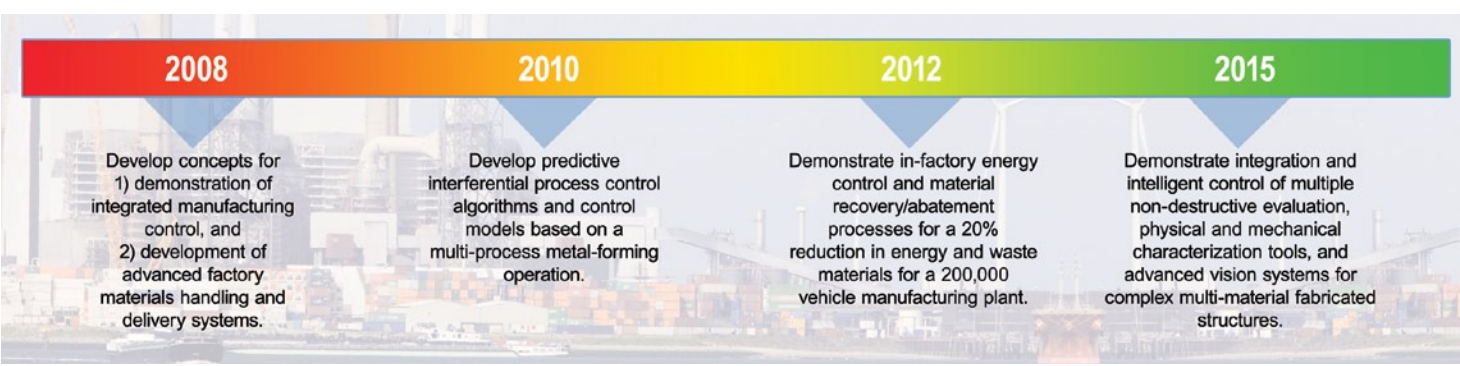
This focus area will integrate predictive and intelligent design, material processing, physical and mechanical property sensing, and real-time process control and feedback into a sustainable manufacturing environment. It focuses on eliminating product losses, product optimization, energy-efficient handling and transportation of materials, and sustainable and energy-efficient plant operations.

Objectives	Major Challenges to Achieving Objective(s)
• Develop and deploy fully integrated and predictive manufacturing processes and operational systems that eliminate product deviation, provide real-time control of product quality and performance, and enhance the use of sustainable materials and plant operations, resulting in manufacturing process energy reductions of >20%.	• Lack of high-level predictive process and manufacturing control, integration of materials handling and management strategies, and real-time control of product quality and performance • Insufficient integration of intelligent manufacturing tools and controls for efficient and sustainable materials handling and plant operations

Technology Pathways and Metrics
• Develop and demonstrate integrated non-destructive and real-time product and process control tools that will reduce manufacturing material and product rejection rates by >15% (by 2012). • Demonstrate real-time predictive control tools for energy-efficient materials processing and handling resulting in an overall manufacturing and plant energy reduction of >20% for a high-volume automotive vehicle paint line (by 2012).

The processing of raw materials into finished products requires significant net energy input in the individual processing, manufacturing, and assembly steps, and in the handling and transportation of materials, semi-finished components, and assembled products. In addition, operation of plant systems that directly support the manufacture and material handling operations requires significant energy input and contributes to the overall cost of manufacturing operations. The integration of product design, processing, and manufacturing with efficient, high-yield, plant operations offers the opportunity to reduce the energy content of manufactured products, enhance real-time control and monitoring of product quality and performance, and provide the basis for efficient and sustainable material handling, transportation, and plant operations.

Key Milestones/Deliverables



Appendix B — Workshop Participants

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