1.4 INDUSTRY

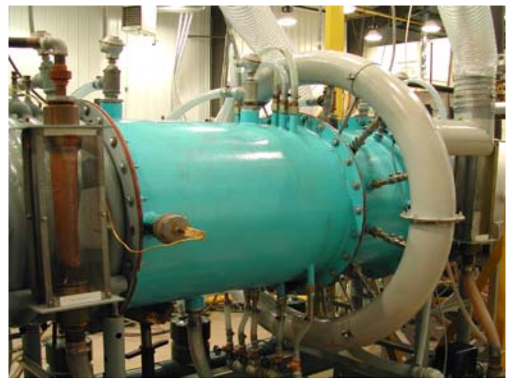
1.4.1 ENERGY CONVERSION AND UTILIZATION

Technology Description

Energy conversion and use account for a large share of carbon emissions from the industrial sector. An integrated systems approach to energy conversion and utilization incorporating the best technologies could significantly reduce greenhouse gas (GHG) emissions and improve industrial competitiveness. Many opportunities exist for improving the efficiency of energy generation, including advanced combustion technologies (burners, boilers), gasification technologies, and innovative energy delivery and conversion systems. Energy utilization gains can also be achieved through the increased adoption of existing technology for cogeneration of power and heat, referred to as combined heat and power (CHP), which provides higher thermal efficiency than purchased electricity. In addition, opportunities exist to reduce energy use and GHG emissions through economic recovery and use of both high- and low-level waste heat.

System Concepts

- The industrial sector could significantly reduce GHG emissions by improving energy utilization efficiency; gasifying waste materials to create useful fuels and materials; and using high-efficiency cogeneration technologies with lower-associated GHG emissions.
- Modern design techniques, advanced technology, and an integrated systems approach to mill or plant design could maximize the use of waste heat streams that are not currently recovered and reused.



A revolutionary super boiler now under development should substantially reduce energy use and carbon emissions throughout industry.

Representative Technologies

- Energy conversion technologies include high-efficiency burners and boilers; advanced steam cycles; innovative energy-conversion systems; and gasification of in-plant process streams, wastes, biomass, or combinations of these fuels. As an example of DOE-supported technology, ITP is working with the Gas Technology Institute and other industry partners to develop a revolutionary super boiler that could save more than a hundred trillion Btu of energy annually and reduce emissions (see inset).
- Energy utilization technologies include on-site combined heat and power systems, waste heat-recovery systems, advanced heat-exchanger designs, and innovative furnace technology (e.g., isothermal melting).

Technology Status/Applications

- Technologies with higher efficiencies have been demonstrated in several applications, but have not been uniformly adopted by industry.
- Energy-generation technologies currently used by industry typically have thermal efficiencies ranging from 25% to 55%; the next generation of energy-generation technologies promises substantially higher thermal efficiencies, perhaps ranging from 45% to 80%. This efficiency improvement would significantly reduce the amount of fuel required for industrial heat and power, thus reducing GHG emissions. Additionally, aggressive development and deployment of on-site generation technologies could reduce transmission and distribution losses, which average approximately 7%.
- Use of in-plant wastes and residues from production processes to generate energy is a promising area for reducing energy intensity and GHG emissions. RD&D is needed to increase the use and cost-effectiveness of technologies such as gasification.

Current Research, Development, and Demonstration
RD&D Goals • The overall research program goal in this area is to contribute to a 20% reduction in the energy intensity (energy per unit of industrial output, as compared to 2002) of energy-intensive industries by 2020. • By 2006, demonstrate a greater than 94 percent efficiency; and, by 2010, the packaged boilers will be commercially available with thermal efficiencies of 10%-12% higher than conventional technology. • By 2008, in the pulp and paper industry, demonstrate high-efficiency pulping technology that redirects green liquor to pretreat pulp and reduce lime kiln load and digester energy intensity. • By 2011, demonstrate isothermal melting technology – which could improve efficiency significantly in the aluminum, steel, glass, and metal-casting industries. **RD&D Challenges** • Entirely new technologies and increased understanding of thermal processes will be needed to facilitate development of advanced systems for improved energy recovery. • Technical advances are required in gasification technology to make it economical, particularly for gas clean-up, construction materials, and conversion to viable chemical products. **RD&D Activities** • DOE is developing and demonstrating advanced, high-efficiency combustion systems, advanced furnace designs, waste heat-utilization technologies, and gasification technologies. • RD&D activities related to this pathway are sponsored by DOE, the Environmental Protection Agency, and other Federal agencies. This pathway will work closely with these programs and also leverage past investments.

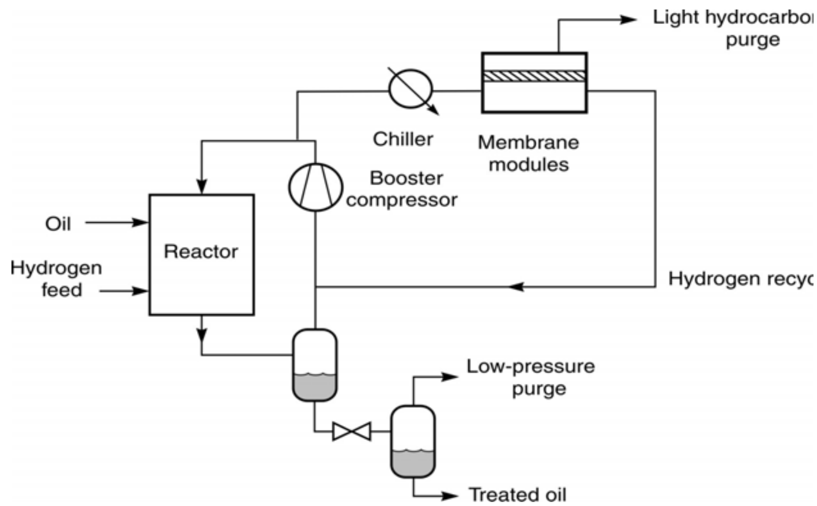
Recent Progress
• The UltraBlue burner was developed to maximize fired-heater efficiency and help the petroleum and chemical industries meet stringent environmental regulations. By 2020, advanced heaters incorporating ultra-high efficiency and ultra-clean combustion burners have the potential to save more than 84 trillion Btu/year and reduce NOx emissions by 150,000 tons annually. By late 2003, more than 1,300 UltraBlue burners had already been sold to the petroleum industry alone. • Waste heat was tapped at two refineries to power absorption refrigeration units. The power generated was used to chill waste fuel streams that contained substantial amounts of propane or heavier hydrocarbons. With chilling, the refineries were able to condense and recover about half of the valuable hydrocarbons in the waste streams for increased profits; and, at the same time, reduce the amount of gas flared off as waste, reducing carbon dioxide emissions to the atmosphere. • A dilute oxygen combustion system was developed and is now operating in two steel mills. The system increases the maximum production rate without additional capital investment, and significantly reduces fuel use. • A high-efficiency, high-capacity, low-NOx combustion system integrated with an innovative, low-cost, vacuum-swing-adsorption oxygen system has been developed and demonstrated. This system uses a novel air-oxygen-natural gas burner that provides 30% higher furnace productivity and 40% energy efficiency improvements with low NOx emissions relative to air-fuel burners.

Commercialization and Deployment Activities
• Industry is already making substantial investments in commercializing and deploying economical technologies: combusting wastes and residues, employing oxy-fuel combustion, efficiently generating electricity and heat on-site, and energy cascading from high temperature to lower temperature uses within plants. Availability of capital and competition for R&D and demonstration funds will impact deployment of new technology. Cost competitiveness with existing technologies will be achieved when the newer technologies have completed their R&D cycles.
Market Context
• Markets include all manufacturing industries that use boilers or process heating. In 1998, process heating and boiler fuel accounted for about 10 quads of fossil energy consumption in the manufacturing sector alone. Significant potential also exists for additional or more efficient on-site generation of electricity in a number of industry sectors, including chemicals, petroleum refining, food processing, pulp and paper, cement, and equipment manufacture (transport, heavy machinery).

1.4.2 RESOURCE RECOVERY AND UTILIZATION

Technology Description

Resource recovery and utilization technologies help minimize waste from industrial processes, reducing energy and material requirements. Wastes include materials, process byproducts, chemical reactants, gases, solvents, diluents, wastepaper, plastics, cooling water, and more. These materials can be reprocessed for use as feedstocks, used to make different products, burned as fuels, or recycled. These practices mitigate greenhouse gas (GHG) emissions by improving plant efficiency and eliminating the energy required to treat wastes and to produce the displaced feedstocks. One example of recovery and reuse is a membrane separation process being developed to recover valuable chemicals from gas streams that are currently burned as low-value fuel. The process will efficiently and economically separate light hydrocarbons (ethane, methane, ethylene, propylene) and hydrogen for use as chemical feedstocks, which are two to three times more valuable than the fuel.



Recovery of olefins such as ethylene and propylene reduces the use of fuel and feedstocks.

System Concepts

- Resource recovery and utilization involves cradle-to-grave stewardship over industrial products. In the example cited, the recovery of feedstock chemicals mitigates CO_2 emissions because it increases product yield and displaces some of the fuel energy initially required to produce the feedstock, which is a petroleum fraction.
- The approximate 30 million tons of iron-making and steelmaking byproducts generated each year – oxide dusts, sludges, scale, and slags – contain nearly 7 million tons of valuable iron units. Currently, about 50% of this volume is recovered and recycled. Research leading to increased internal recycling of these residues can increase the steel industry's primary yield while reducing disposal costs and saving energy.
- Resource recovery and utilization can involve advanced separations, new chemistries, improved catalysts, advanced materials, optimal process and engineering design, sensors and controls, post-consumer processing, market sensitivity, and close coordination among producers, users, and post-consumer processors.
- This pathway includes technologies that impact the other three industry technology pathways, particularly energy conversion and utilization and industrial process efficiency.

Representative Technologies

- Recovery technologies include advanced separations, new and improved chemistries, sensors and controls, and the capture of carbon monoxide and NO_x.
- Reuse technologies include recycling; design-for-recycle or reuse; new and improved chemistries; and closed-loop, sustainable plant design.
- Improved understanding of fundamental chemistry allows use of carbon dioxide and other recovered byproducts as feedstocks. Technologies include C1 chemistry (single carbon) to produce chemicals from carbon dioxide, and chemistries to create fuels from plastics and rubber.
- Component technologies include advanced separations, improved chemistry and catalysts, advanced materials, optimal process and engineering design, sensors and controls, and post-consumer processing.

Technology Status/Applications

- Many industries make a concerted effort to reuse wastes to minimize the high cost of handling and disposal. Others, like the refining and pulp-making industries, rely heavily on byproduct fuels produced on site. However, there are still many opportunities to reuse wastes and byproducts that are not captured because technology does not exist, is currently not economical, or is not practical for other reasons.

Current Research, Development, and Demonstration

RD&D Goals

- Research program goals in this area target a range of improved recycling/recovery efficiencies. For example, in the chemicals industry, the goal is to improve recyclability of materials by as much as 30%.
- Additional goals target new and improved processes to use wastes or byproducts; improve separations to capture and recycle materials, byproducts, solvents, and process water; identify new markets for recovered materials, including ash and other residuals such as scrubber sludges.

RD&D Challenges

- Specifically target the energy-intensive U.S. industries and contribute to their goals of reducing energy, water use, and toxic and pollutant dispersion per unit of output.
- Gaining a better understanding of the fundamentals behind separations and new chemical pathways; modeling capabilities for improved process and engineering design; and technology transfer.
- Efficient and economical separation processes; demonstrating the viability of new markets; improving sensing and control capabilities; analyzing process and engineering design for optimized materials use and durable advanced materials.

RD&D Activities

- Solicitations issued by the Industrial Technologies Program have funded projects to improve energy efficiency and reduce waste; participants include industry, DOE laboratories, small businesses, and academia.
- Ongoing activities include novel techniques for effective separation of materials in industrial streams for recovery and reuse, recycling of water and other liquid and solid-waste streams, recycling of wood byproducts and pulping waste into high-value products, and recycling of problematic wastes such as sludges, refractories, slag, and mill scale.
- DOE is working with CQ Inc. and other partners to improve energy recovery and reduce waste in coal processing. By adding a binding agent into the process, mills can improve the physical characteristics of the coal to create a more acceptable fuel, improve processing efficiency, and reduce environmental impact.

Recent Progress

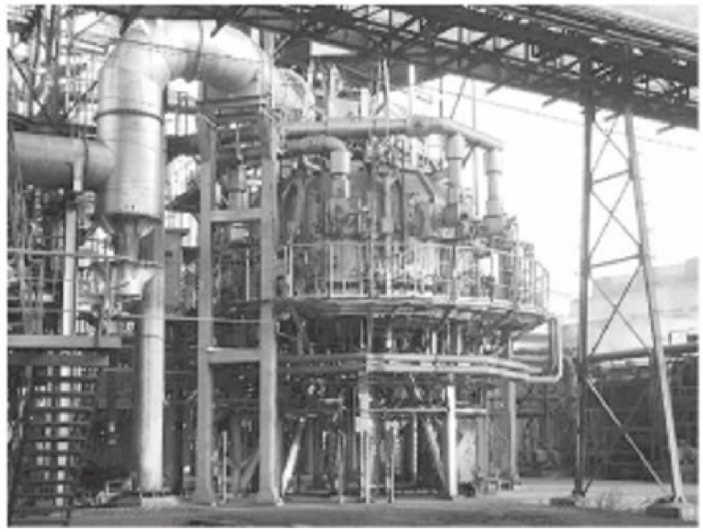
- DOE supported Air Products in the development of an energy-efficient process employing pressure swing adsorption refrigeration (PSA) for the recovery of olefins from polyolefin plant vent gases. There already are two commercial applications of the PSA technology. Widespread commercialization could yield a recovery rate of more than 17 million pounds of olefins per year, as well as energy and emission reductions.
- Development is underway of advanced membrane technology that enables separation of hydrocarbons from various gaseous streams. The technology could enhance recovery and use of volatile compounds, carbon dioxide, and other chemicals in waste streams.

Commercialization and Deployment Activities
• Technologies that compete with resource recovery and utilization include waste disposal in landfills, incinerators, and approved hazardous waste-disposal sites. • The economics of resource recovery and utilization technologies are an important factor in deployment. Markets and applications for recovered materials must be well-defined if commercialization is to be successful. **Market Context** • Markets for recovered materials are as diverse as the manufacturing industry and the products it creates. Significant commercial success already has been achieved in various markets, such as the use of recovered post-use steel, aluminum, paper, glass, and plastic. Several new market opportunities are available in these – as well as other – areas and are just now being explored.

1.4.3 INDUSTRIAL PROCESS EFFICIENCY

Technology Description

Industrial process efficiency is affected by a number of factors: technology design, age and sophistication of equipment, materials of construction, mechanical and chemical constraints, inadequate or overly complex designs, and external factors such as operating environment and maintenance and repair practices. Processes typically use a lot more energy than the practical minimum energy that is required. In the chemical industry, for example, distillation columns operate at efficiencies as low as 20%-30%. In this case, thermodynamic and equipment limitations (e.g., height of the column) directly impact efficiency and increase energy use.



A new one-step furnace operation could revolutionize iron making and substantially reduce energy use and associated emissions.

Technologies under development focus on removing or reducing process inefficiencies, lowering energy consumption for heat and power, and reducing the associated greenhouse gas emissions. One example is a revolutionary cokeless iron-making process that redesigns the steel supply chain by relocating iron making to the iron-ore mine.

System Concepts

- Process efficiency is improved by optimizing individual processes, eliminating process steps, or substituting processes within the principal manufacturing steps for primary conversion of raw materials, secondary or value-added processing, and product separation. Optimizing the overall manufacturing chain also improves process efficiency, including the material and energy balance.

Representative Technologies

- Process redesign can eliminate energy-intensive process steps, as demonstrated by the cokeless iron-making process. Process intensification seeks to produce chemicals in one-two reaction steps rather than three-five, reducing feedstock and heat/power requirements. Technology options include developing a new route to the same product, or using innovative reactor designs and new process chemistry.
- Smaller changes to a process can also result in increased process efficiency. For example, DOE is supporting research to modify steel-casting methods that will reduce energy use and produce cleaner, lower-weight castings of improved quality.
- Advanced separation technologies include membrane separation and hybrid distillation systems, where novel separation technologies are combined to reduce energy demand. Advanced water removal technologies can also substantially reduce energy use in drying and concentration processes.
- Advanced separation technologies include membrane separation and pressure swing adsorption, where separation is facilitated by novel materials and is energy-efficient.

Technology Status/Applications

- Components of more efficient processing technologies under development (e.g., membranes) are in limited use today, but many need stronger economics or demonstrated technical reliability in service to increase their attractiveness to industry. The biggest opportunities to reduce GHG emissions in industrial processing will come from introducing revolutionary technologies as replacements for conventional operations. Examples include next-generation steelmaking and the use of membranes in conjunction with energy-intensive distillation. Other options include developing new processes that increase product yields, reduce byproducts and wastes, or use alternative manufacturing pathways.

Current Research, Development, and Demonstration

RD&D Goals

- The overall research program goal in this area is to contribute, before 2020, a 20% improvement in energy intensity by the energy-intensive industries through the development and implementation of new and improved processes, materials, and manufacturing practices.
- Specific goals for the pulp and paper industry include, by 2010, to assist efforts to implement advanced water-removal technologies in papermaking resulting in an energy efficiency improvement of 10% in paper production.
- For the iron and steel industry, by 2010, assist efforts to develop a commercially viable technology that will eliminate the use of blast furnaces and natural gas-driven, iron-making processes.
- More generally in the separations area, demonstrate advanced hybrid separations technology, by 2016, including separations combined with distillation (membranes, adsorption, and extraction), reactive separations, and separative reactors for use across various industries (chemicals, refining, pulp and paper).

RD&D Challenges

- Specific R&D needs are unique to each individual industry. In general, R&D challenges include economic and innovative separation techniques, improved understanding and prediction of chemical and material behavior, materials fabrication methods, demonstration of performance and reliability, *in situ* and/or rapid analytical protocols and process screening procedures, advanced computational tools, and more efficient process design.

RD&D Activities

- RD&D activities relating to these technology areas are sponsored by DOE, the Department of Commerce, the Department of Defense, the National Science Foundation, and the Environmental Protection Agency. DOE has funded projects to improve process energy efficiency and promote clean manufacturing; participants include industry, DOE laboratories, small businesses, private research institutes, and academia.
- Ongoing activities include development of technology to enable more efficient processes in the following industries: aluminum, chemicals, forest products, glass, steel, metal casting, mining, and supporting industries such as forging, welding, and others. The primary focus of R&D is the development of economic, energy-efficient, commercially viable, and environmentally sound manufacturing technology. Industrial partners are involved with R&D early on to facilitate deployment and commercialization. Specific selected activities include cokeless iron making, next-generation steelmaking, advanced water removal, hybrid distillation, microchannel reactors for process intensification, improved chemical reactors and synthesis pathways, and a metal-casting future plant initiative.

Recent Progress
• A fiber-optic sensor for on-line measurement of paper basis weight has been developed and tested to improve wet-end control in papermaking and produce fine paper with more uniform basis weight. The sensor enables continuous measurements across the full paper sheet and will minimize raw material and energy requirements in the paper industry. • A revolutionary process was developed with DOE support that could completely revolutionize iron-making capabilities. The ITmk3 process uses low-grade ore to produce iron nuggets that are superior in quality to conventional nuggets, without the coke and agglomeration steps. The process achieves a 30% reduction in energy use over conventional integrated steel-making processes.
Commercialization and Deployment Activities
• Applications of many of the described technologies already have an impact in the marketplace. For example, catalytic processes are responsible for about 75% by value of all chemical and petroleum processing products. Catalytic processes generate about $900B in products annually. The ready acceptance of certain applications of these technologies reduces barriers to implementation of process improvements or their application in new processes. Powerful drivers still exist for implementing advancements in these technologies for GHG reduction. The estimated total annual consumption of energy (fuels and electricity) by the U.S. chemical process industries is 5.8 quads; nearly 43% of that (2.5 quads) is required for separation processes, including distillation, extraction, adsorption, crystallization, and membrane-based technologies. Any process facilitating such separations will result in enormous savings of both energy and waste. Given the scale of many relevant industrial processes, the chief barriers to technology deployment are likely to be the capital expenditures required for any substantial process modifications. **Market Context** • The markets for these technologies are industry-specific. Targets of opportunity are the basic industries, including aluminum, chemicals, forest products, glass, mining, steel, and crosscutting industries such as forging, metal-casting, and welding.

1.4.4 ENABLING TECHNOLOGIES FOR INDUSTRIAL PROCESSES

Technology Description

Improvements in the enabling technologies used broadly throughout industry can provide new operational capabilities, as well as significant energy and carbon savings. Greenhouse gases can be reduced by increasing the efficiency of industrial processes, reducing waste and rework of products, and achieving a longer and more controlled operating lifetime for industrial components. Enabling technologies will increase understanding of the processes and systems required to make products, facilitate improvements, and enable new manufacturing processes. The technologies range from advanced materials, sensors and controls systems, and chemical pathways, to systems and product-oriented design and processing that incorporate environmental and energy benefits in their initial and overall implementation. These types of activities will impact the reduction and more efficient use of energy in current and new industrial processes.

Advanced nickel aluminide materials used in transfer rolls of steel reheat furnaces reduce product defects and reprocessing requirements.

System Concepts

- Enabling technologies will complement and be developed cooperatively with other technology pathways, particularly the energy conversion and utilization – as well as the industrial process efficiency – pathways. Enabling technologies will have a positive impact in many industrial areas.
- Increased understanding of processes, development of new materials and control methods, and innovative techniques for fabricating products will impact the entire industrial sector.

Representative Technologies

- Advanced materials with attributes such as improved corrosion resistance and the ability to operate at higher temperatures and pressures enable more efficient industrial processes. New thermoelectric materials, for example, can enable recovery of high-temperature waste energy from industrial processes. Material categories under investigation include degradation-resistant materials, thin-film thermoelectric materials, materials for separations, metal alloys, ceramics, composites, polymers, and nano-materials.
- Sensors, controls, and automation enable more robust industrial process operations. Areas of emphasis include inferential controls; real-time, nondestructive sensing and monitoring; wireless technologies; and distributed intelligence to interpret and integrate data from various sensor types to aid in optimizing process control.
- Other enabling technologies with potentially large industrial impacts include combinatorial methods; and predictive modeling and simulations, which complement development of control technology, as well as new product and process design.

Technology Status/Applications

- Advances are being made continuously in the development of new materials, including high-temperature materials, new coatings, smart materials, nano-materials, films, and materials with reactive or self-assembly properties. Abundant opportunities remain for developing new materials that can make a significant impact on industrial energy use and emissions (e.g., catalysts, inorganic-organic hybrids, thin film composites, refractories, sensor materials).
- Intelligent controls have been implemented in industry, but are still technically inadequate in a number of areas. Further impacts can be made in global and remote sensing, inferential sensor and control technology; and nondestructive on-line evaluation of process parameters and equipment.
- New computational techniques are emerging every day, but have yet to keep pace with the phenomenal increase in computing power. Experimental methods based on combinatorial techniques – such as those used in drug discovery – could revolutionize the way new materials and products are developed, but are only slowly being adapted to industrial use.

- The use of model-based control systems and neural networks that can "learn" and improve process/energy efficiency will lower emissions of GHG from manufacturing processes.

Current Research, Development, and Demonstration

RD&D Goals

- Research program goals for this area target new enabling technologies that meet a range of cost goals depending on the technologies and on the applications where they are to be used. Cost targets when considered on a system basis are expected to range between 0.5 to 2 times those of typical technologies.
- By 2010, demonstrate production and application for nano-structured diamond coatings and composites and other ultra-hard materials for use in wear-intensive industrial applications; and develop materials for use in a wide array of severe industrial environments (corrosive, high temperature, and pressure).
- By 2012, demonstrate the generation of efficient power from high-temperature waste heat using systems with thermoelectric materials.
- By 2017, develop and demonstrate integration of sensing technologies with information processing to control plant production.

RD&D Challenges

- Develop new, economic material compositions, measurement technologies, and inferential control and predictive maintenance systems.
- Enable increased understanding of chemical, metallurgical, and related processes impacting efficiency process design and control.
- Develop functional and protective materials for sensors, actuators, and other devices deployed in industrial environments.
- Develop materials property/engineering databases for materials used in industrial applications.
- Validate mathematical models to enable improved and integrated process design and operations.
- Scaling up of technologies from the laboratory to commercial application while achieving anticipated economies of scale, maintaining performance goals, and ensuring component integrity.
- Assuring compatibility with real-world manufacturing environment to avoid degrading performance of existing processing and production systems.

RD&D Activities

- Development of industrial system components including high-temperature and corrosion-resistant materials used in melting, heat treating, or combustion systems; chemicals and pulp- and paper-processing systems; and boilers and gasifiers.
- Ongoing R&D activities on enabling technologies include the Advanced Industrial Materials and Sensors and Automation projects in DOE. Modeling and simulation activities are supported by DOE throughout all program areas as appropriate. Additional applied research activities are in the Department of Commerce Advanced Technology Program and in the Environmental Protection Agency. Basic research activities are in DOE's Office of Science and the National Science Foundation (NSF).

Recent Progress

- Laser Induced Breakdown Spectroscopy (LIBS) technology has been developed to effectively measure the composition of molten metal and glass in real time. The technology, which is now in commercial use, has the potential to reduce energy consumption by 5-10 trillion Btu annually.
- Nickel aluminides have been developed for heat-treating furnace fixtures that last three-five times longer than high-performance steels, and improve production and energy efficiency in carburizing furnaces by as much as 33%.
- Thin intermetallic alloys developed for coating the inside of reactor tubes used in production of ethylene will be used to reduce coke formation, increasing tube life and improving reaction conditions. Potential energy savings could be more than 400 trillion Btu per year.
- A new distillation column flooding predictor has been developed, which will enable petroleum refineries to increase column throughout by 2%-5%, improving safety margins and increasing efficiency and gasoline production for the same amount of energy.

Commercialization and Deployment Activities
• The industrial segment of the economy is substantial, and enabling technologies are impacting every industrial sector. New materials are being introduced in the manufacturing of steel; new measurement systems and *in situ* temperature measurements in harsh environments have been developed and are being used in industry; and new capabilities in design and modeling methodologies are reducing the energy use and greenhouse gas emissions of production plants. • The introduction of new technologies is often sensitive to initial cost, and cost benefits must be evaluated based on life-cycle benefits. **Market Context** • Applications for enabling technologies are many and encompass the various industrial segments of the economy. Every industry segment will benefit from the activities, and the efforts will be coordinated with other pathways.