Energy-Efficient Technologies

2. Industry

2.1 Energy Conversion and Utilization

2.2 Resource Recovery and Utilization

2.3 Industrial Process Efficiency

2.4 Enabling Technologies

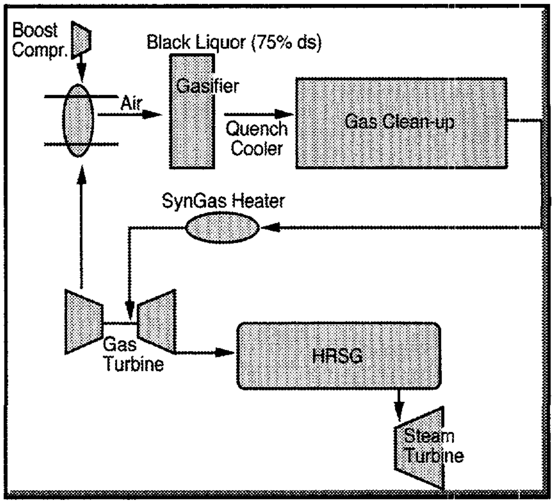
2.1 ENERGY CONVERSION AND UTILIZATION

Technology Description

A significant portion of the carbon emissions from the industrial sector are associated with the conversion and utilization of energy. A systems approach to energy conversion and utilization incorporating the best technologies could have a significant impact on GHG emissions and improve the competitive posture of the industrial sector. Many opportunities exist for improving the efficiency of energy generation, including ATS, fuel cells, gasification technologies, and advanced combustion technologies. As many opportunities exist in energy utilization, including economical use of waste heat and thermal cascading by using a systems approach to mill/plant design to minimize generation of low level heat.

System Concepts

- The industrial sector could significantly reduce GHG emissions by a combination of improvements in energy utilization efficiency, switching to low-GHG fuels, gasification of waste materials into useful fuels, advanced on-site high-efficiency, and low-GHG-emissions generation technologies such as advanced combustion turbines and fuel cells.
- Modern design techniques and a whole systems approach to mill/plant design could minimize the generation of excessive low-level heat that cannot be removed easily and economically.



Representative Technologies

A range of technologies and process improvements under development are promising:

- ATS
- Fuel cells
- Gasification of biomass and in-plant process streams (i.e., black liquor in the pulp and paper industry)
- Waste heat utilization
- Systems approach to mill/plant design
- Co-firing of biomass
- Advanced combustion technologies

Technology Status/Applications

- Energy generation technologies currently used by industry typically have thermal efficiencies ranging from 25 to 55%; the next generation of energy generation technologies promises thermal efficiencies ranging from 45 to 80%. This average 20% improvement would significantly reduce the amount of fuel required, and hence GHG emissions, to generate the energy required. Additionally, aggressive development and deployment of distributed on-site generation technologies could avoid transmission and distribution losses, which average approximately 7%.
- Energy utilization gains of as high as 30% could result from advanced energy utilization technologies and more integrated mill/plant designs.
- 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 of this technology and make it more cost-effective.

Current Research, Development, and Demonstration

RD&D Goals

- Significant gains in energy generation efficiency and GHG reductions could result from aggressively switching to highly efficient on-site generation technologies, such as advanced combustion turbines in combined cycle and fuel cells. Switching to low-carbon fuels such as natural gas or zero-carbon fuels such as biomass could bring additional GHG reductions.
- The chemical, petroleum refining, forest products, and steel industries account for over 2/3 of the energy use of the industrial sector. Therefore, efforts will continue to focus on these four industries.

RD&D Challenges

- Basic and applied research into advanced, low- or zero-GHG-emission generation technologies.
- In the near term, advanced industrial turbines with combined cycle generation, higher combustion efficiencies, waste heat utilization, a systems approach to mill/plant design, and biomass and black liquor gasification.
- Also in the near term, improvements in manufacturing such as advanced drying, more efficient lighting, and high-efficiency motor systems and drives for higher energy utilization efficiency.
- In the long term, continued work on advanced industrial turbines and noncombustion techniques such as fuel cells for high-efficiency energy generation.

RD&D Activities

- RD&D activities related to this pathway are sponsored by DOE, EPA, NIST-ATP, and other federal agencies. This pathway will work closely with and leverage past investments in these program areas.

Recent Success

- A major carbon-reducing technology for industry between now and 2010 is a high-efficiency, environmentally superior, natural gas–fired turbine that cogenerates electricity and steam. The ATS program is developing these turbines for industry and electrical generation. When introduced in 2001, they will have CO_2 emissions 21 to 61% lower and thermal efficiencies 15% higher than conventional turbines and will reduce electrical generation costs by 10%.

Recent Success (continued)

- Integrated gasification of biomass and black liquor combined cycle technologies will impact the pulp and paper industry in two ways: by improving energy self-generation and use of waste biomass produced at mill sites and by improving forest management practices. The waste biomass and the black liquor are gasified and fired in an advanced gas turbine for high-efficiency electrical and steam generation. Black liquor gasification was demonstrated at the pilot scale in a pulp mill in 1995, and a near-commercial-scale biomass gasifier is under construction and expected to be operational in 1997.

Commercialization and Deployment

- Industry is already making substantial investments in commercializing and deploying economical technologies: combusting wastes and residues, fuel switching in combustion systems, better understanding of large energy consuming processes, and energy cascading from high temperature to lower temperature uses within plants. Availability of capital and the competition for R&D 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.

Potential Benefits and Costs

Carbon Reductions

Industrial sector

	1997 (base)	2010	2020	2030
BAU case quads	34.4	39.7	43.8	48.5
Eff. case(mod) quads		36.6	38.3	40.5
MtC reductions	0	25–50	65–95	100–140
(35% allocation to this pathway)				
MtC reductions		9–18	23–33	35–50

The estimated MtC reductions for the sector have wide ranges to account for uncertainties in market adoption and economics.

Assumptions (for all industrial sector):

- Growth rate in manufacturing output of 2.1%/year.
- For BAU case, energy intensity decreases by 1.1%/year (0.5%/year increases in efficiency and .6% composition).
- For the efficiency case, there is an additional 0.35%/year increase in energy intensity.
- Additional 10–12, 22–25, and 30–40 MtCe/year in 2010, 2020, and 2030, respectively, attributable to accelerated use of new technologies: ATS, biomass, and black liquor gasification.
- 35% of energy savings and carbon reductions in industrial sector attributable to the energy conversion and utilization pathway. This pathway has the potential for the largest impact in the industrial sector because of the use of new, more efficient energy technologies.

RD&D Expenditures

- Total federal expenditures in FY 1997 are estimated to be approximately $50M.
- Substantial R&D resources are required to accomplish the objectives of this technology pathway. A number of promising technologies will need cost sharing from the federal program for industry to obtain the needed information from the R&D process and then commercialize the technologies.
- Annual federal RD&D budget required for this pathway: 2000–2010, $140M/year; 2010–2020, $210M/year; 2020–2030, $140M/year.

Market

- The markets for the technologies developed in this pathway will be industry in general; however, the primary focus will be on the largest energy users: chemicals, steel, petroleum refining, and forest products.

Nonenergy Benefits and Costs

- More competitive industrial sector; export potential for advanced turbines, industrial fuel cells, and black liquor and biomass gasifiers; lower energy costs

Risk Factors

Technical Risk: 1 2 ③ 4 5 6 7 8 9 10 (Low – High)

Commercial Risk: 1 ② 3 4 5 6 7 8 9 10 (Low – High)

Ecological Risk: 1 2 ③ 4 5 6 7 8 9 10 (Low – High)

Human Health Risk: 1 ② 3 4 5 6 7 8 9 10 (Low – High)

Economic Risk: 1 2 3 ④ 5 6 7 8 9 10 (Low – High)

Regulatory Risk: 1 2 3 ④ 5 6 7 8 9 10 (Low – High)

- Uncertainties regarding the speed and nature of utility deregulation could hinder penetration of ATS.

Key Federal Actions

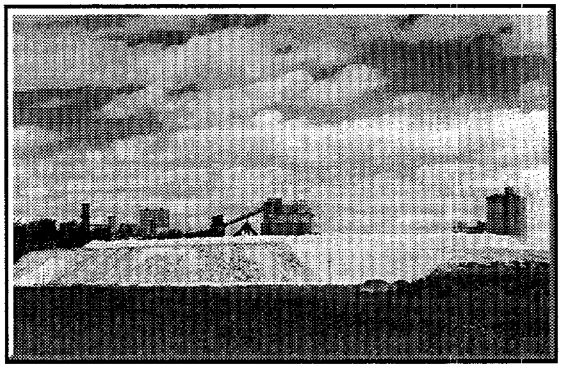
- Government/industry cost sharing partnerships are essential to the success of this pathway.
- Federal investment needs to be sustained.
- Utility restructuring to favor industrial self-generation and power sales could accelerate these technologies.

2.2 RESOURCE RECOVERY AND UTILIZATION

Technology Description

Resource recovery and utilization is waste minimization through recovery within the industrial process (treated largely under process efficiency) and/or end-of-pipe and post-consumer recovery and use of materials, process byproducts, chemical reactants, gases, solvents, diluents, steam, cooling water, and other waste. These materials can be reprocessed to reduce the burden on feedstocks, to make different products, to be used as fuels, or to be recycled. The practice mitigates CO_2 by eliminating the energy costs for replaced feedstocks and waste treatment and by improving plant efficiency. An example of recovery, recycle, and reuse is a process used at a cement kiln owned and operated by the Pasamaquoddy Tribe (see photo) wherein a waste (K_2O) is used in a scrubber and converted to K_2SO_4, which is sold as fertilizer. Distilled water is recovered from the crystallizer, and waste heat from the kiln is used to operate the crystallizer.

System Concepts



- Resource recovery and utilization involves cradle-to-grave stewardship over industrial products. In the example cited, the reuse of K_2O mitigates CO_2 emissions because it displaces fertilizer production elsewhere and avoids the cost of disposing of the waste.
- Components of the technology are advanced separations, improved chemistry, improved catalysts, advanced materials, optimal process and engineering design, sensors and controls, biotechnology, post-consumer processing, market sensitivity, and close integration between 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—filters, advanced separations, improved chemistry, sensors and controls.
- Reuse—recycling, improved chemistry, new markets, industrial ecology.
- Improved understanding of fundamental chemistry and biotechnology advances allow use of CO_2 and other recovered byproducts as feedstocks: algae to form carbonates, bioenzymes for biodegradable polymers, biomanufacturing, biomembranes for selective separations, bioremediation of wastes, biomass and agricultural waste for use as chemicals and as fuels when co-fired with fossil fuels, chemicals from CO_2, and fuels from plastics and rubber. Capture of methane (coal beds, landfills, agricultural), capture of CO and $N0_x$.
- Industrial ecology integrates producers and consumers closely to minimize waste; one plant's waste is another's feedstock. Transportation costs are avoided by siting plants in close proximity. Synergetic cost-effective relationships can result in energyplexes or ecoplexes where utilities, producers, and consumers are part of an integrated community.

Technology Status/Applications

- Major industry groups avoid 39.9 MtC/year (potential is 140.5 MtC/year).
- Industry recovers about 28% of potentially recoverable waste; thus 28% recovery must be viewed as cost-effective.

Current Research, Development, and Demonstration

RD&D Goals

- Identifying nontoxic alternative reagents through improved chemistry; improving separations to capture and recycle materials, byproducts, solvents, and process water; identifying new uses and markets for recovered materials, including ash and other residuals such as scrubber sludges.
- Industries of the future, agriculture, textiles manufacturers, utilities, and municipal waste facilities.

RD&D Challenges

- Better understanding of fundamental chemistry, advances in biotechnology, advanced computing and modeling capabilities for improved process and engineering design, and technology transfer.
- Improved chemistry, improved separations, new markets, improved sensors and controls, improved process and engineering design, and durable advanced materials.

RD&D Activities

- Industries of the Future solicitations have funded projects to improve energy efficiency and reduce waste; participants include industry, DOE laboratories, and academia. DOE has cooperative agreements with the Energy and Environmental Research Center and the Western Research Institute that require 50% cost sharing by industry; many of these projects focus on waste reduction.
- Ongoing activities include use of biomass feedstocks as an alternative to use of oil for deriving industrial chemicals, feedstock preparation so industry can confidently use recovered along with virgin materials in the production processes, and techniques for effective separation of materials in plant and post-consumer streams for recovery and reuse. Recovery of plastics and conversion to chemicals used in the manufacture of new polymers is another area of ongoing R&D.

Recent Success

- Recovery of methanol from industrial process, eliminating disposal of spent methanol via combustion.
- On-site recycling of chips resulting from machining of aluminum.
- Continuous preheating of steel scrap using furnace heat during steel production.
- An electrochemical de-zincing process that removes zinc from galvanized steel and recovers it for reuse.
- Recovery of salt from process brines to enable cost-effective saltcake recycling.

Commercialization and Deployment

- Technologies that compete with resource recovery and utilization include waste disposal in landfills, incinerators, and approved hazardous waste disposal sites.
- Advantages—initially less expensive and more convenient. Disadvantages—industry and the public do not realize the benefits of recovery, recycle, and reuse. Eventually, environmental cleanup, remediation, and brownfields-type recovery projects may be required.
- Improved chemistry, sensors and controls, materials, process and engineering design, biotechnology, and technology transfer are needed to develop alternative recovery, recycle, and reuse options, including new markets.

Potential Benefits and Costs

Carbon Reductions:
(*All industrial sector*)

	1997 (base)	2010	2020	2030
BAU case quads	34.4	39.7	43.8	48.5
Eff. case(mod) quads		36.6	38.3	40.5
MtC reductions	0	25-50	65-95	100-140
(*15% allocation to this pathway*)				
MtC reductions		4–8	10–14	15–18

The estimated MtC reductions for the sector have wide ranges to account for uncertainties in market adoption and economics.

- Assumptions (for all industrial sectors):
- Growth rate in manufacturing output of 2.1%/year.
- For BAU case, energy intensity decreases by 1.1%/year (0.5%/year—increases in efficiency and 0.6%—composition).
- For efficiency case, energy intensity increases by an additional 0.35%/year.
- Additional 10–12, 22–25, and 30–40 MtC/year in 2010, 2020, and 2030, respectively, attributable to accelerated use of new technologies: ATS, biomass, and black liquor gasification.
- 15% of energy savings and carbon reductions in industrial sector are attributable to this resource recovery and utilization pathway.

RD&D Expenditures

- Total federal RD&D expenditures in FY 1997 are estimated to be approximately $23M.
- Substantial R&D resources are required to accomplish the objectives of this technology pathway. Several promising technologies will need cost sharing from the federal program for industry to obtain the needed information from the R&D process and then commercialize the technologies.
- Annual federal RD&D budget required for this pathway: 2000–2010, $60M/year; 2010–2020, $100M/year; 2020–2030, $60M/year.

Market

- Seven major industries—including rubber and oils, chemicals and plastics, wood and paper, textiles, food and agriculture, and construction—offer the potential to save 140 MtC/year; they mitigate 40 MtC/year using existing technologies.

Nonenergy Benefits and Costs

- Reductions of CH_4, CO, and $N0_x$ as surrogates for CO_2 as well as GHG results in equivalents of 8, 40, and 21 tons, respectively, per ton of CO_2, as well as benefits to the environment, particularly ground-level ozone reduction. Reduced impacts on remaining landfill capacity and reduced need for incinerators and approved hazardous waste sites.

Risk Factors

Technical Risk

1 2 ③ 4 5 6 7 8 9 10
Low — High

Commercial Risk

1 2 3 4 ⑤ 6 7 8 9 10
Low — High

Ecological Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

- Sustainable positive impact is expected as a result of more efficient use of materials and resources.

Human Health Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

- Positive impact because of more efficient use of resources.

Economic Risk

1 2 3 ④ 5 6 7 8 9 10
Low — High

Regulatory Risk

1 2 3 ④ 5 6 7 8 9 10
Low — High

Key Federal Actions

- Federal support for research in fundamental and applied chemistry, advanced separations, biotechnology.

2.3 INDUSTRIAL PROCESS EFFICIENCY

Technology Description

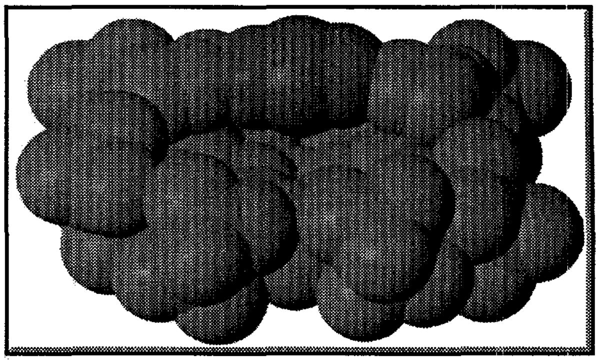
A significant source of carbon emissions from the industrial sector may be process material and energy inefficiencies in primary or secondary manufacturing. These contribute to GHG emissions through both excess energy expenditures (increasing fossil fuel consumption) and generation of waste byproducts. Waste generation represents inadequate use of carbon-containing feedstocks and requires energy expenditure for treatment/abatement. Increases in unit process efficiency through individual process optimization or new process introduction will reduce GHG emissions and offer the potential for increased growth at reduced environmental risk.

System Concepts

- Process efficiency is enhanced through single-process optimization or process substitution in the principal manufacturing steps of raw material primary conversion, secondary or value-added processing, and product separation. It also results from overall optimization of a manufacturing chain with resulting improvements in material and energy balance.

Representative Technologies

- Many opportunities exist for improving process energy and materials efficiency in unit operations via new or more selective catalysts, advanced separations, new material- and energy-efficient reactor concepts, and the further development and introduction of biotechnology/bio-derived materials.



CO_2 conversion catalysts.

Technology Status/Applications

- Technologies such as catalysts, membranes for separations, and bio-derived materials are already in the marketplace in the production of both commodity and specialty products, particularly in the materials and chemical processing industries. Such technologies already allow the manufacture of many common products today (see Commercialization section). The biggest gains to be made in GHG reduction in industrial process energy or carbon-feedstock efficiency, however, will still come from introducing these technologies into new processes (e.g., membranes as substitutes for energy-intensive distillation separations or new process introduction using bio-based feedstocks) or enhancements in current practices (e.g., enhancing selectivity in partial catalytic hydrocarbon oxidation or developing more energy-efficient process reactors). These technologies will benefit both commodity production (in the form of incremental process improvement yielding gains in energy efficiency) and the generation of specialty products (where more significant savings in waste generation are likely to result).

Current Research, Development, and Demonstration

RD&D Goals

- Catalysis—target processes for improvement are selective oxidation, hydrocarbon activation, byproduct and waste minimization, stereoselective synthesis, functional olefin polymerization, alkylation, living polymerization, and alternative renewable feedstocks.
- Advanced separations—membrane separations (advanced inorganic membranes, ruggedized membranes, selective membranes, antifouling), reactive separations, separative reactors.
- Development of biotechnology/bio-derived materials—biofeedstocks that directly displace fossil-derived products (modified or alternative processes), improving the performance of biocatalysts.
- Advanced chemical reactors—short contact-time reactors, reactors for nonthermal processes (plasma, microwave, photochemical), reactors for alternative media or dry processing, flexible processing units.

RD&D Challenges

- Specific R&D needs that impact these technology areas include improved understanding and prediction of chemical and material behavior, materials fabrication methods, in situ and/or rapid analytical protocols and process screening procedures, and computational tools.

RD&D Activities

- RD&D activities relating to these technology areas are sponsored by DOE, DOC, DOD, NSF, and EPA. Comparable investments in these technology areas are made abroad.

Recent Success

- Many recent examples of industrial successes and implementation of new technology exist. For example, in the membrane area, Pittsburgh Plate Glass has successfully installed an ultrafiltration and reverse osmosis system to remove paints and reuse the water in the process. Caterpillar has developed and installed, in a cost-shared project with DOE, a system for recovery and reuse of paints in its production process. Improvement in catalysts and their uses is another area where industry has implemented improved processes and is working on other processes involving converting polymers and deriving chemicals from biomass feedstocks.

Commercialization and Deployment

- Applications of many of the described technologies already have an impact in the marketplace. For example, catalytic processes are responsible for about 75% of chemical and petroleum processing products by value. 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. The chief barriers to deploying of technologies are likely to be capital expenditures required for any substantial process modification, given the scale of many relevant industrial processes.

Potential Benefits and Costs

Carbon Reductions
(All industrial sector)

	1997 (base)	2010	2020	2030
BAU case quads	34.4	39.7	43.8	48.5
Eff. case(mod) quads		36.6	38.3	40.5
MtC reductions	0	25–50	65–95	100–140
(30% allocation to this pathway)				
MtC reductions		8–15	20–29	30–42

The estimated MtC reductions for the sector have wide ranges to account for uncertainties in market adoption and economics.

Assumptions (for all industrial sectors):
- Growth rate in manufacturing output of 2.1%/year.
- For BAU case energy intensity decreases by 1.1%/year (0.5%/year–increases in efficiency and 0.6%–composition).
- For the efficiency case, there is an additional 0.35%/year increase in energy intensity.
- Additional 10 to12, 22 to 25, and 30 to 40 MtC/year in 2010, 2020, and 2030, respectively, attributable to accelerated use of new technologies: ATS, biomass, and black liquor gasification.
- 30% of energy savings and carbon reductions in industrial sector are attributable to this industrial process efficiency pathway.

RD&D Expenditures
- Total federal RD&D expenditures in FY 1997 are estimated to be approximately \$46M.
- Substantial R&D resources are required to accomplish the objectives of this technology pathway. Several promising technologies will need cost sharing from the federal program for industry to obtain the needed information from R&D process and then commercialize the technologies.
- Annual federal RD&D budget required for this pathway: 2000–2010, \$120M/year; 2010–2020, \$160M/year; 2020–2030, \$120M/year.

Market
- Application of the industrial processes described is central to the energy- and material-intensive industries with the largest energy consumption factors (chemicals, petroleum, forest products), shipping products valued at over \$700B.

Nonenergy Benefits and Costs
- Implementing these technologies will likely result in substantial economic benefits (reduced pollution abatement costs) and result in enhanced export potential (based on the global nature of the market).

Risk Factors

Technical Risk

1 2 3 4 ⑤ 6 7 8 9 10
Low — High

- Initial gains likely to be incremental.

Commercial Risk

1 2 3 4 ⑤ 6 7 8 9 10
Low — High

- May mandate capital investment.

Ecological Risk

1 2 3 ④ 5 6 7 8 9 10
Low — High

- Sustained positive impact due to efficient use of materials and resources.

Human Health Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

- Does not add substantially to current practices.

Economic Risk

1 2 ③ 4 5 6 7 8 9 10
Low — High

Regulatory Risk

1 2 3 ④ 5 6 7 8 9 10
Low — High

Key Federal Actions

- Government/industry partnerships are recommended to move precompetitive research forward.
- Incentives for capital investment would speed implementation.

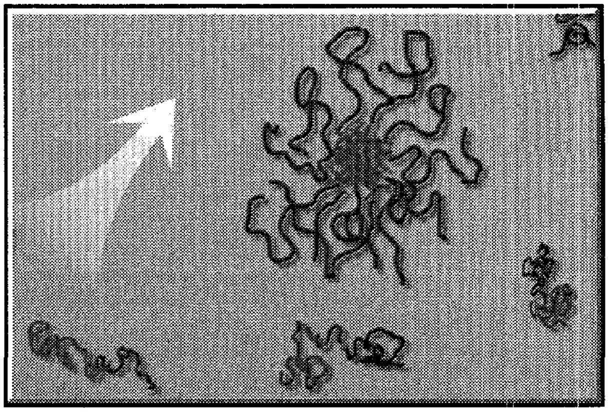
2.4 ENABLING TECHNOLOGIES

Technology Description

Enabling technologies are new systems requiring R&D that impact all other pathways and that can provide significant improvements and new operational capabilities in many types of industries. GHGs can be reduced by increasing the efficiency of industrial processes, reducing waste and rework of products, and achieving a longer and more controlled operating life time for industrial components. Increased understanding of processes and systems required to make products will permit improvements and new manufacturing processes. The technologies range from advanced chemical reactions, materials, and measurement and controls systems, 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 fossil and electrical energy in current and new industrial processes.

System Concepts

- Technologies developed through enabling technologies programs will complement and be developed cooperatively with those of other pathways, in particular energy conversion and utilization and the industrial process efficiency. Technologies included in this pathway will have positive impact in many industrial areas.
- Increased understanding of processes and application of new methods in fabricating products will impact the entire industrial sector.



Neutron scattering aids the design of environmentally friendly ways to make polymers.

Representative Technologies

- A number of enabling technologies can have positive impacts on GHG emissions, including
  - Advanced materials
  - Measurements and controls
  - New chemical reactions
  - Modeling and simulations
- Holistic product/process design (including environment and energy).
- Just-in-place processing.

Technology Status/Applications

- Increased understanding of processes and energy generation technologies can lead to both incremental and revolutionary improvements.
- Increased efficiencies and impact on reducing GHG emissions will be obtained by increasing the efficiency of processes:
  - Raising operational temperatures.
  - Developing higher temperature corrosion resistant advanced materials.
  - Finding new ways to determine and then monitor the most important process parameters affecting processes and the intelligent control of those processes.
  - Developing more efficient heat recovery and utilization.
  - Developing completely new processes.
  - Making products or energy where needed, including new and holistic design technologies incorporating environmental and energy needs from initial concepts.

Current Research, Development, and Demonstration

RD&D Goals

- New enabling technologies have 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 be between 0.5 to 2 times those of typical technologies.
- 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.

RD&D Challenges

Research areas include

- New materials compositions.
- Measurement technologies and intelligent control and predictive maintenance systems.
- Increased understanding of chemicals metallurgical and biotechnology processes.
- Validated mathematical models to enable improved and integrated design and operations.
- Methods and design concepts that will enable fabricating or producing energy where it is required.
- Industrial systems components including high-temperature and corrosion-resistant production systems used for melting, heat treating, or combustion systems; chemicals and pulp and paper processing systems; processing including boilers and gasifiers; and industrial cogeneration systems.

RD&D Activities

- Ongoing R&D activities on enabling technologies include the Advanced Industrial Materials, Continuous Fiber Ceramic Composite, and ATS programs in DOE. Additional activities are in the DOC ATP program and in EPA.

Recent Success

- A high-efficiency, recuperated industrial gas turbine for the generation of electricity recently was announced. The increased firing temperature was made possible through developments in the casting of advanced single crystal superalloy airfoils.
- Currently an advanced intermetallic alloy, Ni_3Al, is being used for rolls in the heat treating of steels and as metalforming dies.

Commercialization and Deployment

- 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; understanding of chemicals processes is leading to improved processes; and new capabilities in design and modeling methodologies are reducing the energy usage and GHG emissions of production plants.
- The introduction of new technologies is often sensitive to initial cost, and cost benefits must be made on life cycle benefits.
- Success rests on sustained development efforts coupled with implementation efforts. Thus partnering of government, industry, universities, and national laboratories is critical. Industry is eager to deploy cost-effective technologies and improved enabling technologies for process improvements to stay competitive in the world market.

Potential Benefits and Costs

Carbon Reductions
(All industrial sector)

	1997 (base)	2010	2020	2030
BAU case quads	34.4	39.7	43.8	48.5
Eff. case(mod) quads		36.6	38.3	40.5
MtC reductions	0	25–50	65–95	100–140
(20% *allocation to this pathway*)				
MtC reductions		5–10	13–19	20–28

The estimated MtC reductions for the sector have wide ranges to account for uncertainties in market adoption and economics.

Assumptions (for all industrial sectors):

- Growth rate in manufacturing output of 2.1%/year.
- For BAU case, energy intensity decreases by 1.1%/year (0.5%/year–increases in efficiency and .6%–composition).
- For efficiency case, there is an additional 0.35%/year increase in energy intensity.
- Additional 10–12, 22–25, and 30–40 MtC/year in 2010, 2020, and 2030, respectively, attributable to accelerated use of new technologies: advanced turbine systems, biomass and black liquor gasification.
- 20% of energy savings and carbon reductions in industrial sector attributable to this enabling technologies pathway.

RD&D Expenditures

- Total federal RD&D expenditures in FY 1997 are estimated to be approximately $31M.
- Substantial R&D resources are required to accomplish the objectives of this technology pathway. A number of promising technologies will need cost sharing from the federal program for industry to obtain the needed information from R&D process and then commercialize the technologies.
- Annual federal RD&D budget required for this pathway: 2000–2010, $80M/year; 2010–2020, $130M/year; 2020–2030, $80M/year.

Market

- The energy impacts will be across the various energy sectors. Reductions will occur related to natural gas, electric power, coal, and oil.

Nonenergy Benefits and Costs

- New technologies will be highly valued and also suitable for export. The industrial sector will remain strong due to the use of new and advanced systems and the creation of new intellectual property. The advances will strengthen current industries and generate new industries and areas of commerce.

Risk Factors

Technical Risk

1 2 3 4 ⑤ 6 7 8 9 10
Low — High

Commercial Risk

1 2 3 4 ⑤ 6 7 8 9 10
Low — High

- Requires successful developments and commercialization.

Ecological Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

- Technologies inherently ecological.

Human Health Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

- Technologies inherently ecological.

Economic Risk

1 ② 3 4 5 6 7 8 9 10
Low — High

Regulatory Risk

1 2 3 ④ 5 6 7 8 9 10
Low — High

Key Federal Actions

- Federal actions include facilitation and coordination; enhancement of partnerships between government, industry, universities, and national laboratories; and sustained investment in R&D.