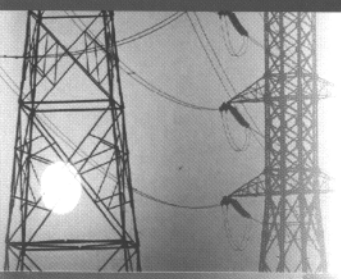
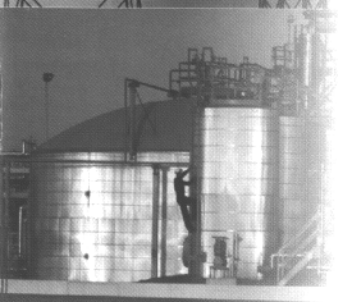
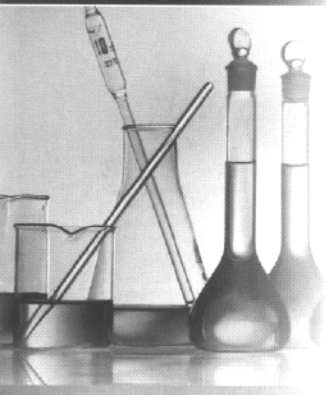
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

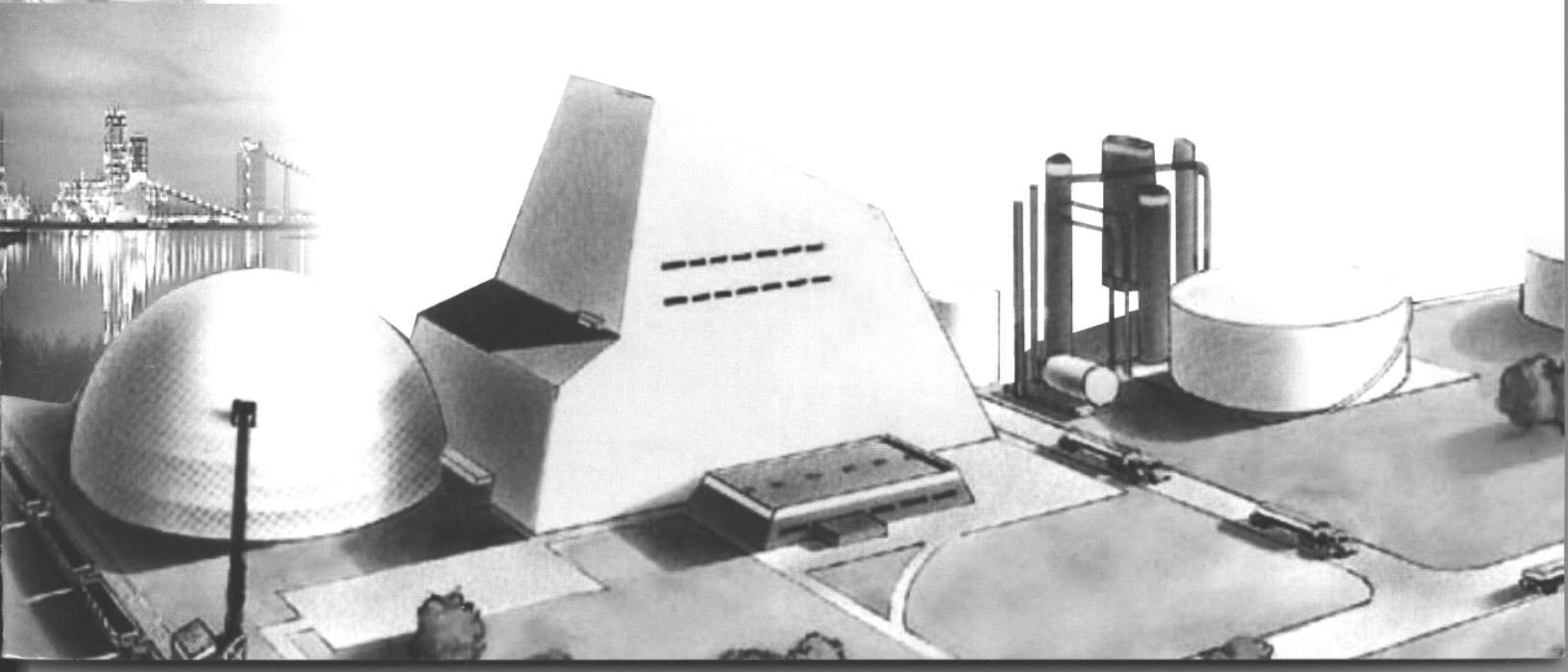






Gasification Technologies

A Program to Deliver Clean, Secure, and Affordable Energy



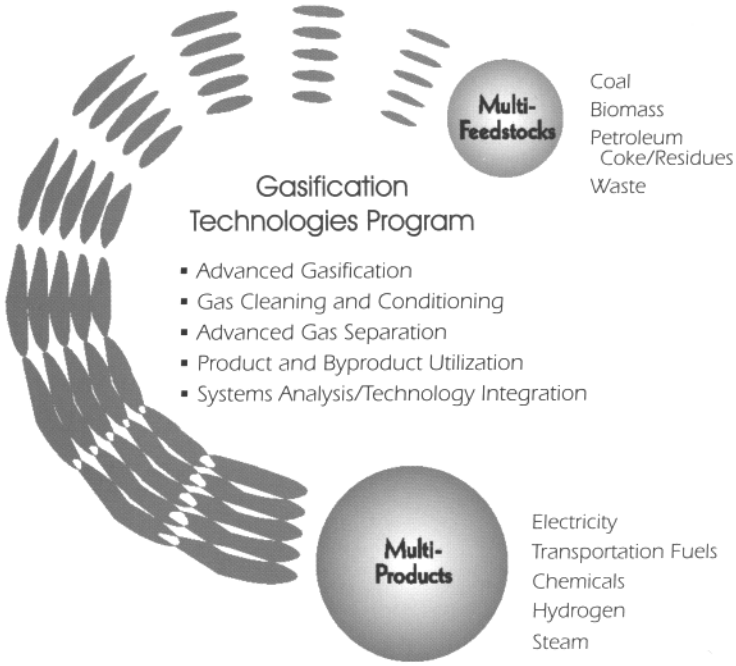
OVERVIEW

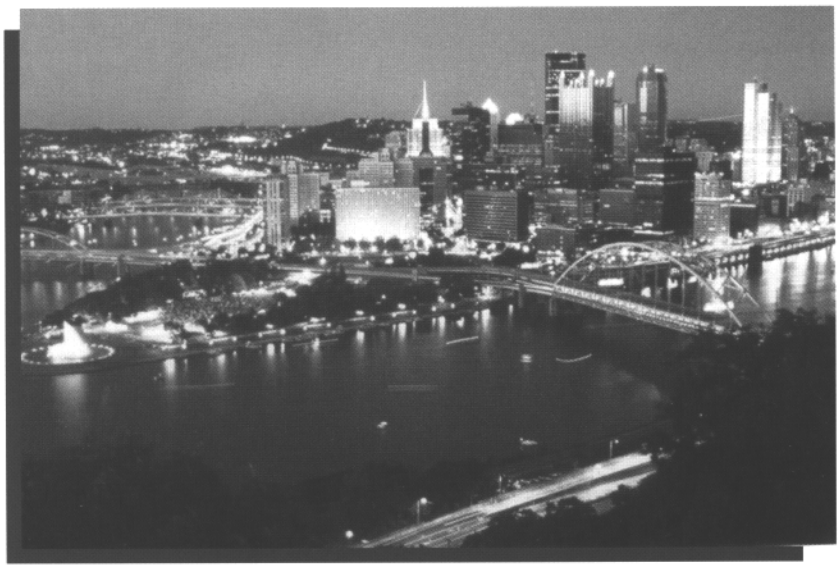
Gasification technologies represent the next generation of solid-feedstock-based energy production systems. Gasification breaks down virtually any carbon-based feedstock into its basic constituents. This enables the separation of pollutants and greenhouse gases to produce clean gas for efficient electricity generation and production of chemicals and clean liquid fuels.

In a time of electricity and fuel-price spikes, flexible gasification systems provide for operation on low-cost, widely available feedstocks. The recent National Research Council study, *Vision 21 – Fossil Fuel Options for the Future*, cites gasification as the focus of the Office of Fossil Energy's Vision 21 Program:

"The committee believes that the focus of the enabling technology programs (and of the Vision 21 Program) should be coal gasification . . ."

The DOE Gasification Technologies Program has a history of success in technology development and demonstration. The R&D portfolio of today's program will enable deployment of the clean and affordable energy systems required for growing energy markets.





BUILDING ON A HISTORY OF SUCCESS, THE GASIFICATION TECHNOLOGIES PROGRAM SUPPORTS A CLEAR PUBLIC INTEREST: A CLEAN, SECURE, AND AFFORDABLE ENERGY SUPPLY.

Public Benefits

The Gasification Technologies Program will yield a combination of superior technology characteristics — flexibility, efficiency, environmental performance, and economic attractiveness — to make gasification the technology of choice for a wide range of tomorrow's markets. Through stakeholder collaboration in technology and project planning, the program identifies and conducts work to support a clear public interest: providing a clean, secure, and affordable energy supply.

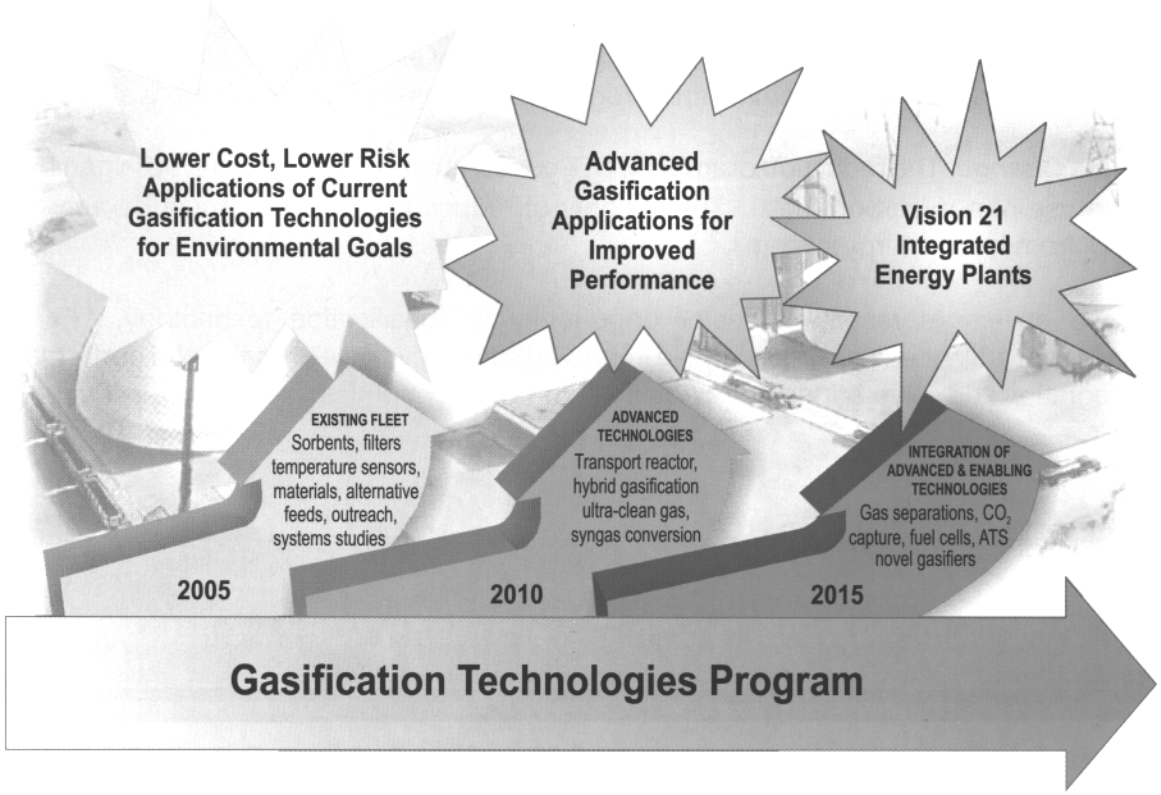
The Program's Vision for the Future

By targeting five key areas for technology development — advanced gasification, gas cleaning and conditioning, advanced gas separation, product and byproduct utilization, and systems analysis/technology integration — the program can achieve its mission and vision:

Foster the commercialization of gasification-based processes for the conversion of carbon-based feedstocks to a flexible combination of electricity, steam, fuels, chemicals, and hydrogen. It is envisioned that the program will lead to gasification-based processes that will be more economically attractive, have higher thermal efficiencies, and demonstrate superior environmental performance compared to competing technologies.

To achieve this vision, the program focuses on a series of technology developments that will enable the necessary improvements in current systems, in a new generation of gasification systems, and in high-efficiency, near-zero emissions (Vision 21) integrated energy plants.

Achieving the Vision Through Time-Phased R&D



PROGRAM DRIVERS AND GOALS

The nation's energy mix is dependent primarily on fossil energy. In Energy Information Administration forecasts, as well as in other public-sector and private-sector forecasts, the nation's electricity and transportation fuels will continue to be fossil-fuel based for the next 20 years — and likely well beyond.

This continued use, however, must be matched by combining energy availability at reasonable prices with increasingly clean environmental performance throughout the energy life cycle of production, conversion, and end-use. In the new millennium, the cornerstone of our energy will remain fossil-fuel based, but it will be cleaner and sustainable.

Markets, Energy Supply, and the Environment

The drivers that are promoting industry and market interest in gasification systems reflect changing environmental and market conditions.

Environmental Performance Several factors are driving the need for improved environmental performance. In general, emission standards are tightening. Moreover, large portions of market growth are occurring in areas where total allowable emissions are "capped," requiring near-zero-emission plants.

Improved Waste Management Gasification systems can process a wide range of materials, including hazardous wastes. Materials that would otherwise require waste treatment can be turned into benign or value-added byproducts.

Energy Supply and Price Stability Electricity supply shortages, and sharp natural gas price fluctuations nationwide, highlight the need for a secure energy supply at stable prices.

Market Flexibility As more industries become self-generators of electricity, systems that enable electricity production with coproducts (fuels, chemicals, hydrogen, and steam) are becoming more attractive.

Global Climate Change The reduction of ambient CO_2 concentrations can be achieved in part by efficiency gains and the use of non-carbon fuels. The majority of reductions, however, must be achieved by the removal of CO_2 from fossil-energy systems.

Each of these drivers represents a major opportunity for gasification technology. For example, improvements from advanced gasifiers will yield improved efficiency and environmental performance, while improved integration and value-added byproducts will improve economics.

ENERGY SUPPLY AT AFFORDABLE PRICES MUST BE COMBINED WITH IMPROVED ENVIRONMENTAL PERFORMANCE

Goals for Growing Markets

To capture the opportunity for broad public benefits — and to enable market development for gasification technologies — the program focuses on process efficiency, environmental performance, and plant economics. The program goals are:

- Near-zero emissions,
- Feedstock flexibility,
- Multiple, high-value products,
- Efficiency greater than 60% by 2015, and
- Cost competitiveness.

Related technical objectives such as modularity and standardization of plant design, improved plant availability, and the capability for CO_2 capture will help make gasification the choice for a range of markets. Achieving these goals can provide the clean, secure, and affordable energy the nation requires.

THE PROGRAM GOALS EMPHASIZE PROCESS EFFICIENCY, ENVIRONMENTAL PERFORMANCE, AND AFFORDABLE ECONOMICS FOR GROWING MARKETS

CONCEPTUAL DESIGN OF GASIFICATION-BASED VISION 21 PLANT

PROGRAM TECHNOLOGIES

The Gasification Process

Gasification utilizes virtually any carbon-containing material to produce a gaseous product "syngas." This syngas (made up primarily of H_2 and CO) can be used in many ways, including the production of electricity, chemicals, fuels, hydrogen, and as a source of substitute natural gas. Possible feedstocks include petroleum coke and other residue from petroleum processes, biomass, municipal and industrial waste, and coal.

The feedstock enters the gasifier, where it encounters steam and oxygen or air in an atmosphere of high temperature and high pressure. These conditions cause the feedstock to be broken down into syngas and a solid ash waste product. The ash is removed from the bottom of the gasifier while the syngas enters a purification system. Gas cleaning removes impurities including sulfur, particulates, and related products, the majority of which are saleable byproducts. Additional separation units can recover H_2 and remove CO_2.

Program Strategy

While gasification systems are not new, most applications have focused on single products, generally electric power or chemicals. For a new generation of gasification systems, the program strategy is to enhance the flexibility of gasification in meeting new and growing markets. Achieving a combination of improvements in process efficiency, economics, and environmental performance will enable gasification to be the preferred technology in a wide range of markets.

The program implements strategic, time-phased R&D:

- Lower-cost, lower-risk technology to improve the environmental performance of existing systems by 2005,
- Advanced technologies for a new generation of gasification systems by 2010, and
- Advanced systems for Vision 21 integrated energy plants by 2015.

The program encompasses a diversified portfolio of technologies. It includes a mix of near-term, mid-term, and long-term R&D projects as well as laboratory, proof-of-concept, and demonstration projects to foster the commercial deployment of the technologies.

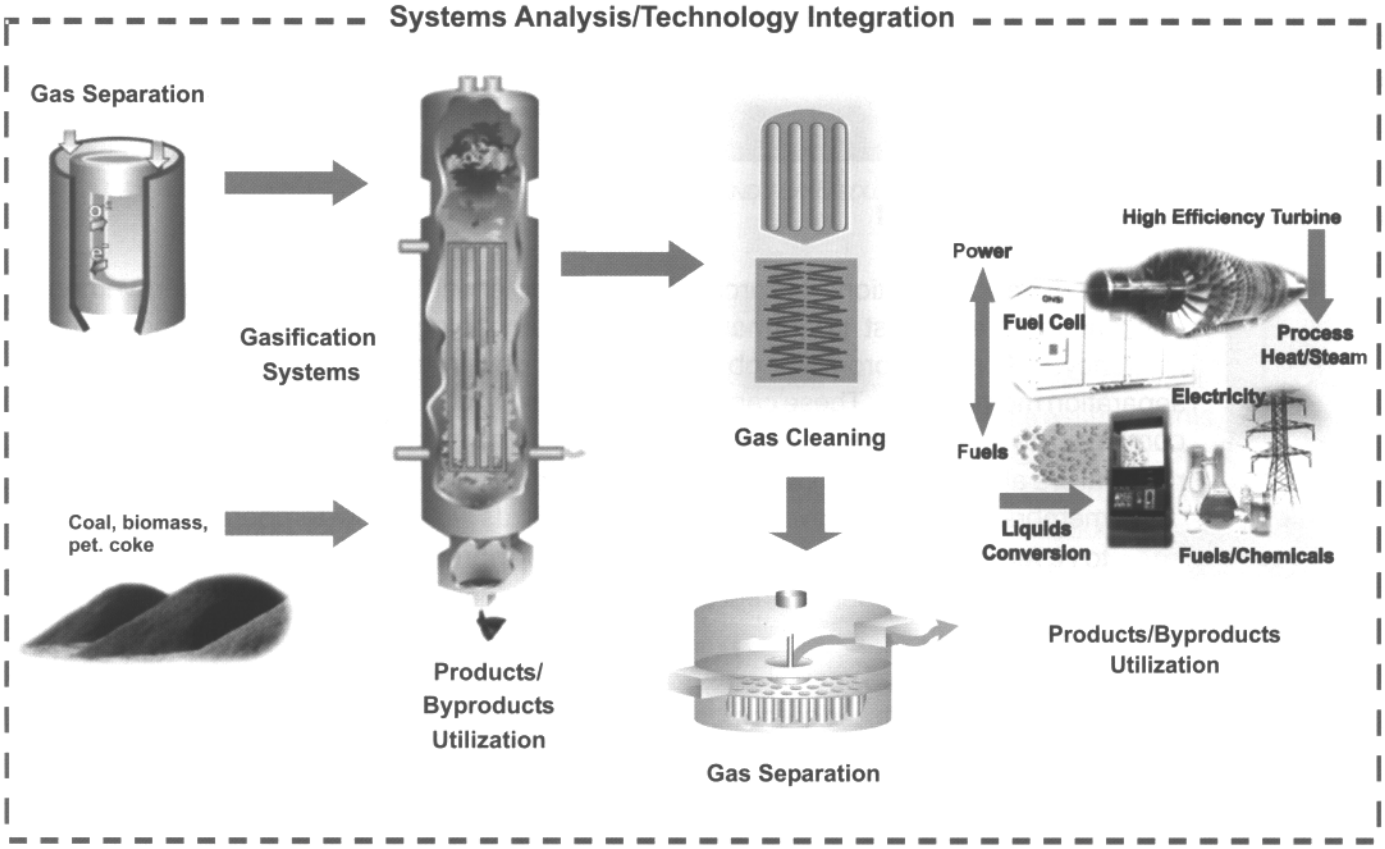
THE PROGRAM WILL YIELD IMPROVEMENTS IN EFFICIENCY, ECONOMICS, AND ENVIRONMENTAL PERFORMANCE TO MAKE GASIFICATION THE PREFERRED TECHNOLOGY IN A WIDE RANGE OF MARKETS

Program Technology Areas

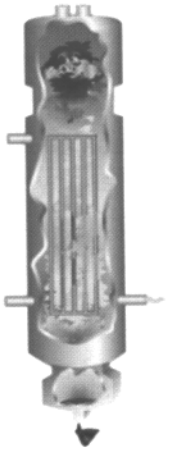
The program is currently structured in five technology areas:

- Developing **advanced gasification** to further fuel flexibility, efficiency, reliability, and economic and environmental performance;
- Evaluating novel **gas cleaning and conditioning** concepts to meet rigid syngas quality specifications for fuel cells and catalytic conversion processes;
- Investigating **advanced gas separation** alternatives to energy-intensive methods, such as cryogenic separation;
- Improving **product and byproduct utilization** to enhance project revenues and eliminate waste streams; and
- **Systems analysis and technology integration** to achieve improvements in plant economics.

TO DEVELOP A NEW GENERATION OF TECHNOLOGIES, THE PROGRAM FOCUSES ON FIVE KEY TECHNOLOGY AREAS

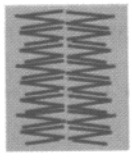


Advanced Gasification



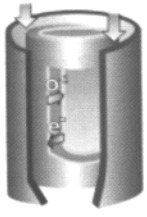
Advances in the gasifier itself to enhance efficiency, reliability, and feedstock flexibility and economics are crucial for gasification system improvements. Research is being conducted on advanced gasifiers, such as the transport gasifier, so higher performance goals can be reached and the variety of possible feedstocks can be further expanded. Advanced refractory materials and new process instrumentation are being developed to improve system reliability and availability, operational control, and overall system performance. Studies of alternative feedstocks (biomass and waste from refineries, industries, and municipalities) will improve gasifier flexibility and utility. Data from fluid dynamic models are being used to develop and improve advanced gasification. Promising developments will be tested and evaluated in large demonstration and/or commercial-scale gasifiers.

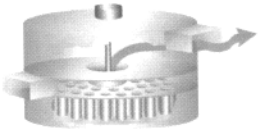
Gas Cleaning and Conditioning



In the Gas Cleaning and Conditioning area, the goal is to achieve near-zero emissions while simultaneously reducing capital and operating costs. Novel gas cleaning and conditioning technologies are undergoing development to reach this goal. Processes that operate at mild to high temperatures and incorporate multi-contaminant control to parts-per-billion levels are being explored. These include a two-stage process for H_2S, trace metals, HCl, and particulates removal; membrane processes for control of H_2S, Hg, and CO_2; and sorbents for NH_3 control. Both ceramic and metallic filters are being assessed. Furthermore, investigation of technologies for mercury removal is currently underway. Promising technologies will be scaled-up and integrated into existing demonstration facilities.

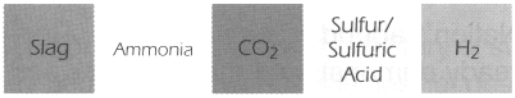
Advanced Gas Separation





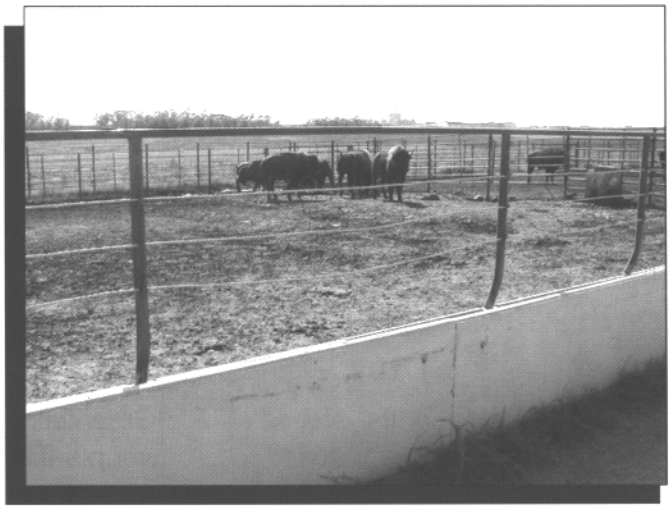
Advanced gas separation research offers the potential for substantial improvement in environmental and cost performance. These technologies will also enhance process efficiency. A major program objective is the development of cost-effective oxygen-separation membranes. These can provide substantial cost reduction for oxygen separation compared to conventional cryogenic methods. Improved hydrogen recovery and CO_2 removal are also important. Currently, the program is developing high-temperature ceramic membranes for H_2 recovery from gas streams, as well as low-temperature approaches to H_2 recovery and CO_2 removal. Other novel approaches for O_2 and H_2 separation will be investigated under different operating conditions.

Product and Byproduct Utilization



The economics of gasification can be improved by fully utilizing all outlet streams of the process. Sale of value-added byproducts from waste streams and minimization of waste disposal can substantially improve the economics of gasification processes. Byproducts include pressurized CO_2, ash/slag, sulfur and/or sulfuric acid, hydrogen, and ammonia. Program activity seeks to expand market options, such as improving the quality of slags and improving the use of sulfur. The program is developing a bench-scale demonstration of a direct sulfur-reduction process. The development of advanced concepts for hot-gas desulfurization technology are targeted as well as a one-step process for production of elemental sulfur. Methodology is also being developed to produce a lightweight aggregate from gasification ash.

BYPRODUCT UTILIZATION FOR CONSTRUCTION



AND FOR FEEDLOT STABILIZATION

Systems Analysis/Technology Integration

The Systems Analysis/Technology Integration area targets integration of all relevant gasification technologies, regardless of the end-products. Economic analyses, performance assessments, and market studies provide guidance for future R&D and deployment opportunities. Barriers to deployment are identified and system performance targets are developed. Studies are conducted on topics such as novel hot/warm gas cleaning, CO_2 concentration, membrane-based separation, and co-feeding applications.

Also, product outreach activity focuses on the public benefits of gasification today and in the future. Stakeholders include the public, industry officials, environmental groups, and local, state, and Federal legislators and regulators. Efforts are underway through discussions with industry stakeholders to identify technology and environmental issues, and to facilitate commercialization.

ACCOMPLISHMENTS

Gasification represents clean, efficient, and flexible ways to use the Nation's abundant coal reserves. First-generation Integrated Gasification Combined Cycle plants have already demonstrated the efficiency and environmental performance benefits. Working with a broad range of industrial, university, and national laboratory stakeholders, the program will establish the technology capability to expand the success to a new generation of technology that will serve broader markets — for electricity, fuels, chemicals, hydrogen, and steam — with improved economics.

A Demonstrated Success - The Clean Coal Projects

The Wabash River Coal Gasification Repowering Project was the first full-size commercial gasification combined-cycle plant built in the United States that repowered an existing pulverized coal plant. Located outside West Terre Haute, Indiana, the plant is one of the world's largest single-train gasification combined-cycle plants operating commercially. The project received the 1996 Powerplant Award from *Power* magazine.

WABASH REPOWERING PROJECT

The Tampa Electric Polk Station Project near Mulberry, Florida, is the Nation's first "Greenfield" (built as a brand new plant) commercial gasification combined cycle power station. The power plant is one of the world's cleanest. The plant's gas cleaning technology removes more than 98% of the sulfur in coal, converting it to a commercial product. Nitrogen oxide emissions are reduced by more than 90%. The project received the 1997 Powerplant Award from *Power* magazine.

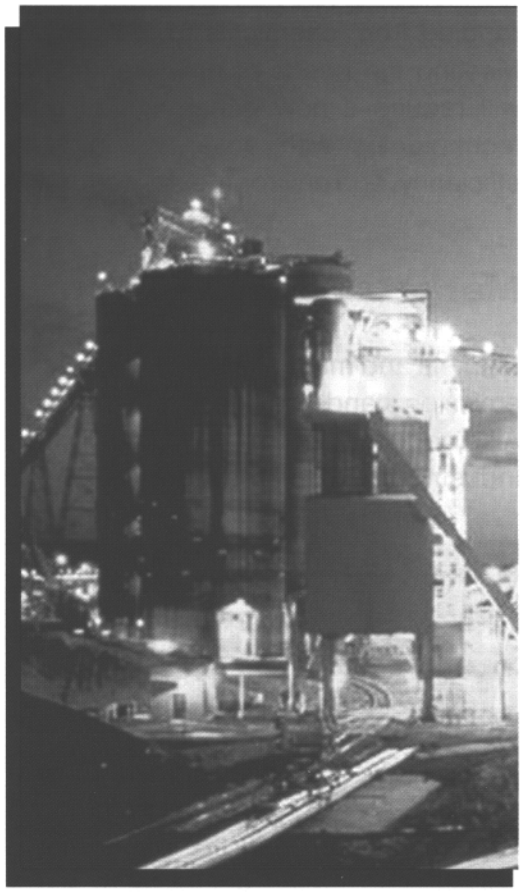
TAMPA ELECTRIC PROJECT

The Air Products Liquid Phase Methanol™ Project in Kingsport, Tennessee has successfully demonstrated the production of methanol from coal gas at commercial scale. The methanol can be used directly as a fuel product or as an intermediary for a wide range of petrochemical products. This technology could be the forerunner of stand-alone facilities to produce liquids from coal. In emerging market areas, it could be the liquids-producing module of a multi-product energy plant such as DOE's Vision 21 plant.

Today's Technical Successes — Leading the Way To Tomorrow's Markets

The program builds on this history of success by producing results that will enable clean, affordable energy systems. Improvements in gasifier design and efficiency, in gas-stream cleanup and byproduct quality, and in systems integration will provide both enhanced environmental performance and process economics. Recent successes in the R&D program point to the future deployment of new technologies for both current and new markets.

- ***Gasification Design Optimization:*** The application of value engineering to the design of gasification-based processes resulted in the identification of over 300 ideas that had potential for significant capital and O&M cost savings. Preliminary results from incorporation of the most promising ideas into the design indicate at least a 20% reduction in capital cost and about an 11-month reduction in the engineering, procurement, and construction schedule.



LIQUID PHASE METHANOL PROJECT

- ***Air Separation Membranes:*** Recent process analyses on a variety of gasification-based processes continue to show significant cost and efficiency advantages with the application of high-temperature membranes for oxygen production compared to conventional cryogenic technology. Membranes were fabricated that meet or exceed commercial flux targets. Full-scale membranes were fabricated and modules are being developed for scale-up to 1-5 tons/day oxygen production. The first commercial offering of the technology is expected in 2006-2007.

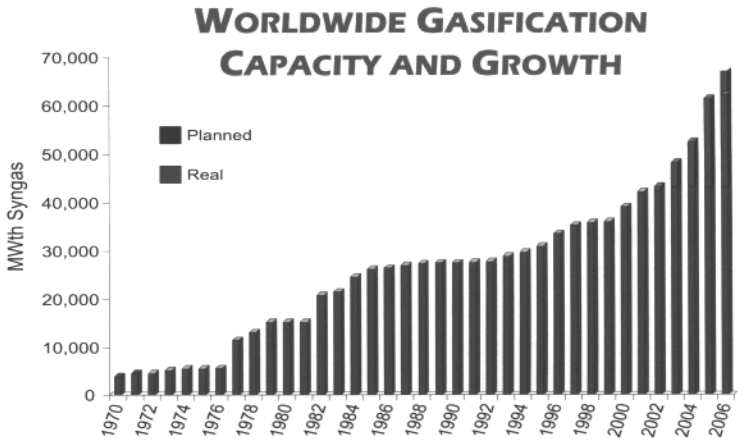
- ***Hydrogen-Recovery Membranes:*** Ceramic membranes were synthesized that have fluxes approaching that of commercial interest while simultaneously operating at lower temperatures than previously available materials. Two industrial teams have received cooperative agreements to pursue development of these materials, focusing on gasification-based processes, chemicals production, and small-scale refueling applications for fuel cell vehicles.

- ***Sorbent Development:*** A new sorbent has been developed that is capable of removing sulfur to 1 ppm or less at more moderate temperatures. The sorbent won an R&D 100 award in 2000 in new innovative products to be commercialized. Industry has expressed interest in possible applications, and the sorbent is currently being evaluated with feedstocks representative of commercial gasifiers.

- ***Co-Production of Electricity and Fuels:*** Three industrial teams are currently assessing the technical and economic feasibility of co-producing electricity and fuels from coal. Preliminary results from two projects indicate that the production of methanol and Fischer-Tropsch products are economically viable as coproducts of power generation, provided certain technical risks can be mitigated. The teams envision constructing a facility within the next few years to demonstrate their concepts.

MARKET OPPORTUNITIES

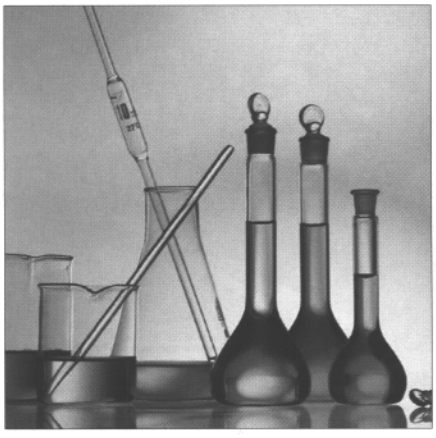
The success of gasification technologies has been proven in applications worldwide, with production of over 40,000 MWth of syngas in 2000. Successful commercial facilities have used "first generation" gasification technologies for over 20 years for products ranging from chemicals to fuels to electricity. Meeting the needs of new markets, however, will require a new generation of gasification technologies with advances in economics, efficiency, and environmental performance.

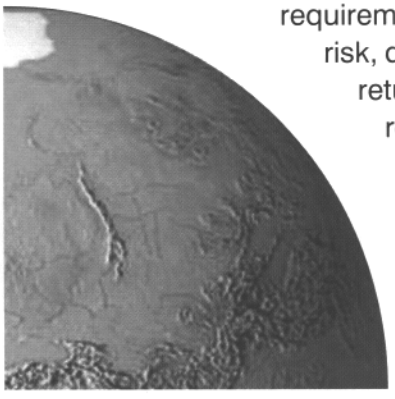


Source: SFA Pacific

Markets Today and Tomorrow

Markets and market drivers are changing at a rapid pace. Environmental performance is a greater factor as emission standards tighten and market growth occurs in areas where total allowable emissions are capped. Also, reduction of carbon dioxide emissions is one of the challenges in response to global climate change. Industries have expressed a need for more environmentally sound processes, more efficient and reliable systems, and an ever-present demand for higher profitability. They need a technology that can match these requirements — a means to remain flexible, reduce risk, decrease emissions, increase stockholder return on investment, and consume fewer resources. Gasification is the technology that can meet these requirements.





Today, the majority of existing applications have been geared toward the production of a single product or a constant ratio of two or more products per facility. Tomorrow, the potential of gasification in expanding markets is in its use of low-cost and blended feedstocks and its multiproduct flexibility. With deregulation, rapidly changing market demands, fluctuation in natural-gas prices, and increased environmental concerns, gasification will become the cornerstone technology for market flexibility.

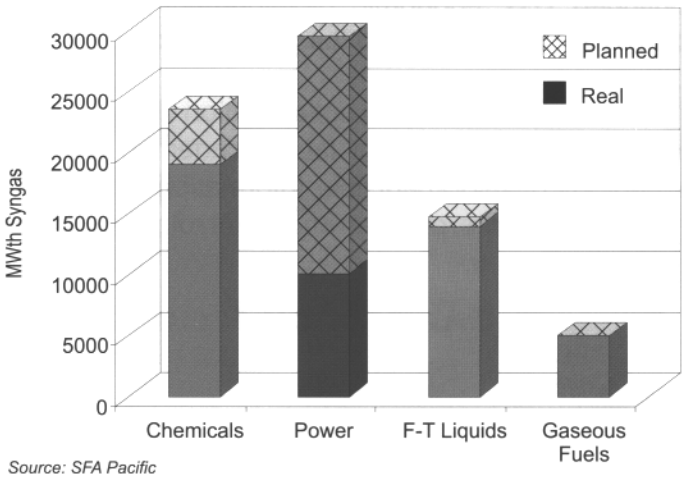
Clean, Affordable Energy Options for the Future

New markets are emerging that will benefit significantly from the flexibility, environmental improvements, economic successes, and efficiency of gasification. There is a growing potential for new applications in the refining and chemical industry, the pulp and paper industry, the power generation industry, and others.

Three examples of emerging markets are repowering, multi-production, and pulp and paper production.

- **Repowering of existing coal plants:** As demand for power production increases, the nation's coal plants — the heart of stable and affordable electric power in the United States — face the need for ever-cleaner power production. Repowering of these plants with gasification can offer major benefits: improved environmental performance, reduced capital investment, feedstock flexibility, and capacity increases due to improved process efficiency. Also, gasification can be used to repower existing gas-fired facilities. A gasifier placed upstream of existing natural-gas-fired turbines can provide an alternative to natural gas with long-term price stability.

WORLDWIDE GASIFICATION CAPACITY BY APPLICATION



Source: SFA Pacific

- **Multi-production facilities for industry:** Feedstock and product options will become increasingly important as the nation continues to make the difficult transition from a regulated environment to one having market-based energy options. Gasification offers the most flexible route to using variable feedstocks and producing electric power, fuels, hydrogen, chemicals, or steam. Feedstock flexibility, with feedstocks that include coal, biomass, petroleum "bottoms" (coke and residuum), and waste materials, will ensure that stable, low-cost fuel sources are available. The ability to vary the product slate will both improve plant economics *and* support market stability. For example, refineries can employ gasification to produce hydrogen for heavy crude hydrocracking, heat for steam production, and electricity for the facility and sale to the grid.

- **Pulp and paper industry:** The gasification of biomass and the "black-liquor" from pulping processes can dramatically improve plant performance in the pulp and paper industry. Advantages include improved waste management, reduced chemical consumption, and improved power production. The favorable heat-to-power ratio of gasification will meet the needs for both power and heat without the purchase of electricity. Gasification systems can improve energy efficiency, environmental performance, and waste management.

FLEXIBILITY OF GASIFICATION SYSTEMS — IN FEEDSTOCKS AND PRODUCTS — WILL BE KEY TO EMERGING CLEAN-ENERGY MARKETS, AND A STABLE, AFFORDABLE ENERGY SUPPLY

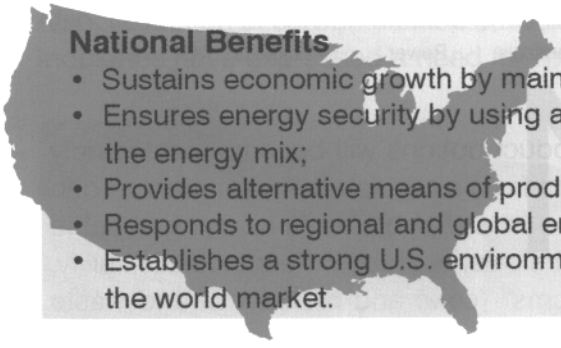
PARTNERSHIPS TO ACHIEVE PUBLIC BENEFITS

First-generation gasification facilities are being constructed and demonstrated today. The products of today's research and development will build on this foundation to generate the improvements — in efficiency, environmental performance, and economics — that will enable widespread use of gasification technologies to meet growing market opportunities.

Achieving this will provide significant public benefits. Chief among them are improved environmental quality and an affordable, stable energy supply through use of domestic resources. The program supports continued U.S. economic development achieved through stable prices for energy products and a competitive U.S. industry in the global energy technology marketplace.

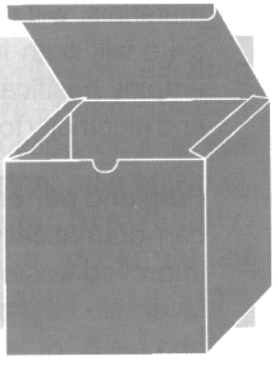
These benefits are built on collaboration with program partners and performers. The program collaborates with industry, government labs, academia, and public stakeholders to leverage resources and lower technology-development risk. Information outreach to stakeholders, including decision makers in the public and private sectors, plays an important role in technology planning and implementation.

GASIFICATION TECHNOLOGIES PROGRAM: PUBLIC BENEFITS



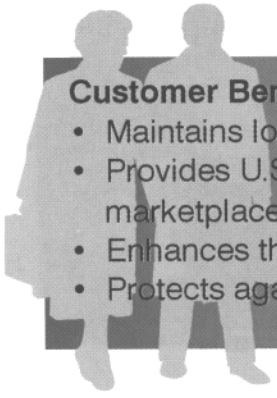
National Benefits

- Sustains economic growth by maintaining low-cost electricity vital to the U.S. economy;
- Ensures energy security by using abundant indigenous resources for a significant component of the energy mix;
- Provides alternative means of producing critical chemicals and fuels;
- Responds to regional and global environmental concerns; and
- Establishes a strong U.S. environmental and power-generation technology position for export to the world market.



Supplier Benefits

- Enables electricity suppliers to cost-effectively adjust to regional energy and environmental demands and
- Broadens the market beyond simply supplying electricity.



Customer Benefits

- Maintains low-cost electricity rates, which are already among the lowest in the world;
- Provides U.S. industrial users a competitive edge for their products in the world marketplace;
- Enhances the local, regional, and global environment; and
- Protects against price shocks in industrial chemicals and transportation fuels.

Program Partners and Performers — A Collaborative Program for a Clean, Secure, And Affordable Energy Supply

Academic

Carnegie Mellon
North Carolina State
Pennsylvania State
University of Pennsylvania
Univ. of North Dakota EERC
Virginia Tech

Industrial

Air Products
Bechtel
Ceramatec
Chevron
Consol Energy
Dow Chemical
Dow Corning
Eltron Research
EnerTech Environmental
Fluent
FluoreScience
Foster Wheeler
General Electric
Global Energy
GRS Associates
Integrated Environmental Technologies
IPSI
ITN Energy Systems
Kellogg Brown & Root
McDermott
MEDAL
Methanex
Nexant
Praxair
Protech
SASOL Technology
SFA Pacific
Siemens Westinghouse
Simtechе
Southern Company
Texaco
UCI
Waste Management & Processors

Federal/National Labs

Albany Research Center
ANL
LANL
ORNL
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Not for Profit

Gas Technology Institute
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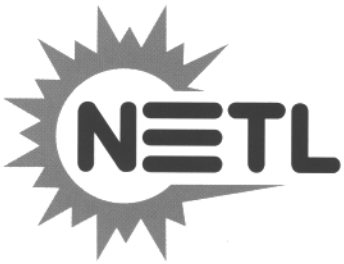

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