VISION 21

MEETING ENERGY NEEDS OF THE NEXT CENTURY

ENERGY FOR THE 21ST CENTURY WILL BE SUPPLIED BY HIGHLY EFFICIENT MODULAR FACILITIES THAT COULD BE CONFIGURED TO COPRODUCE ELECTRICITY, HEAT, TRANSPORTATION FUELS, AND CHEMICALS, WITH ALMOST NO AIR POLLUTANTS, SOLID WASTE, OR CO_2 EMISSIONS.

PROGRAM AREAS

* Enabling Technologies
* Supporting Technologies
* Systems/Market Analyses
* Vision 21 Plant Design

INTRODUCTION

WHY VISION 21 IS A NECESSITY

Vision 21 is a new approach to 21st-century energy production from fossil fuels. It will integrate advanced concepts for high-efficiency power generation and pollution control into a new class of fuel-flexible facilities capable of producing electric power, process heat, and high-value fuels and chemicals with virtually no emissions of air pollutants. These plants will be designed using a variety of configurations to meet differing market needs.

This concept is a vision of the way electricity needs to be generated in the 21st century in order to meet environmental requirements and keep energy costs affordable and consistent with robust economic growth. An aggressive industry cost-shared Vision 21 Program would:

- ***Remove environmental barriers to fossil fuel use.*** The technological innovations produced by the Vision 21 Program would allow use of a balanced mix of fossil fuels for our electricity and transportation fuels needs. Environmental barriers, including smog- and acid-rain-forming pollutants, would be effectively removed. Concerns over global climate change would be mitigated by carbon dioxide emission reductions as great as 50% resulting from thermal efficiency improvements. Net CO_2 emissions could be reduced to zero, if needed, through sequestration.
- ***Assure the availability of affordable transportation fuels.*** Vision 21 assures the U.S. of the availability of liquid transportation fuels that are cost-competitive with equivalent petroleum products. Our national security is increased because reliance on imported oil is reduced. Our international balance of trade is improved because oil imports can be reduced and also because the availability of alternative sources of transportation fuels tends to stabilize oil prices.
- ***Continue U.S. leadership role in clean energy technology***. By a recently published account, world trade in environmental controls has surpassed trade in armaments. Vision 21 would create the U.S. technology and know-how to promote the export of fossil energy technology, equipment, and services. U.S. fossil energy/environmental industries would expand and new industries would be created, providing local, regional, and national benefits.

BENEFITS TO THE NATION

High standard of living. Clean production of low-cost electricity and transportation fuels from coal will maintain or raise living standards for future generations.

Energy security. The availability of a clean, efficient fleet of powerplants for the 21st century will offer the U.S. the security of knowing that it can use its largest domestic resource to produce most of its energy needs. Fuel flexibility increases security by allowing the use of biomass and opportunity fuels.

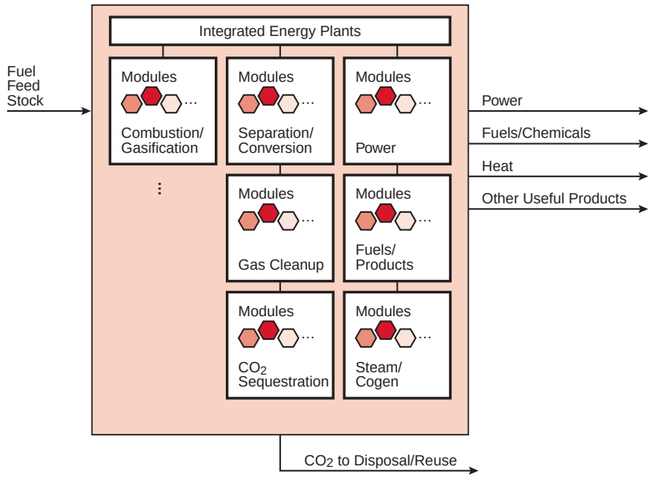
Economic security. The ultra-efficient use of resources in Vision 21 plants will support the continued strength of the U.S. economy, which is dependent on the availability of low-cost energy. Coproduction of high-value commodities will boost the economy further.

Competitive market position. Technologies developed under the Vision 21 Program will ensure that the U.S. will continue to lead the field in ultra-high-efficiency energy technologies with near-zero emissions.

Lower-cost electricity. Vision 21 plants will produce 10% to 20% cheaper electricity due to increased efficiency, the use of a variety of low-cost feedstocks, and the coproduction of high-value fuels and chemicals.

Consumer choices. Vision 21 technology will offer people in the U.S. the opportunity to choose the energy products best suited to their regional markets, economies, and geographies.

VISION 21 CONCEPT TECHNOLOGY MODULES



Discrete technology modules offer Vision 21 plant designers maximum flexibility in their choice of products, feedstocks, and environmental controls. Planners can select modules according to the feedstock supply and product demands of an individual region.

The rapidly changing domestic and international situation (i.e., climate change, oil security, environmental regulation, electric utility restructuring, aging U.S. energy infrastructure, global trade competition and privatization, and declining R&D budgets) requires that more be done. Vision 21 combines electricity- and fuel-producing subsystems in a way that seeks to maximize thermal efficiency, minimize emissions of traditional pollutants, and minimize cost, and yet is readily compatible with carbon dioxide sequestration.

LINKAGE TO OTHER STRATEGIC PROGRAMS

Vision 21 is seen as a long-range, cost-shared, industry-driven R&D program designed to produce public benefits from the present to 2030 and beyond. Partnerships and linkages are being created with industry, universities, private and public R&D laboratories, and Federal and State agencies. The Vision 21 Program includes enabling technologies, supporting technologies, systems integration and market analyses, and Vision 21 plant design. The product of a Vision 21 Program would be the design basis for commercial-scale Vision 21 plants.

Significant near-term benefits may be realized by the Nation as Vision 21 follows its technology roadmap toward its ultimate goal. For example, high-efficiency fuel cell/turbine cycles using natural gas would be developed for the distributed-power-generation market. Technology improvements that produce fuels or chemicals from coal and other solid hydrocarbon feedstock would be available for other applications besides Vision 21. The Vision 21 Program is also related to the Carbon Sequestration Research Program, focusing on cost-effective, high-efficiency technologies in configurations well-suited to CO_2 sequestration; and the Office of Fossil Energy (FE) Materials R&D Program is an essential partner in the development of the new materials required to pursue these new technologies.

ENABLING TECHNOLOGIES

Enabling technologies allow the Vision 21 modules to meet efficiency, environmental-performance, and cost targets. Some needed enabling technologies are described below.

OXYGEN-SEPARATION TECHNOLOGIES

Oxygen is a key ingredient in many Vision 21 modules. It is required for combustion, gasification, and effective concepts for limiting CO_2 production. Using pure oxygen rather than air allows CO_2 to be more easily concentrated for sequestration because the large quantities of nitrogen found in air are no longer present. Successful technology options need low-cost air-separation technologies capable of making high-purity oxygen.

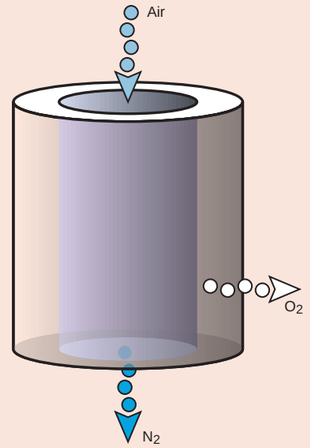
A novel class of dense ceramic materials called ion transport membranes (ITMs) have the potential to meet this need.

A recent study quantified the impact of advanced membrane technology on integrated gasification combined-cycle (IGCC) technology. The initial results showed a 31% decrease in the cost of oxygen, a decrease in total capital investment of $114 per kilowatt, a 2.9% increase in thermal efficiency, a 6.5% decrease in the cost of electricity, and a 500-fold decrease in SO_2 emissions.

Although these benefits are substantial, formidable obstacles must be overcome to develop this technology. These challenges are being addressed in a three-phase program spanning about seven years. The first phase addresses high-risk materials development, membrane fabrication, membrane performance, and engineering issues related to process integration. Subsequent phases will focus on scale-up of the membranes and fabrication techniques, evaluation of full-scale modules, process integration, and validation of process engineering and economic models.

ION TRANSPORT MEMBRANE

New low-cost air-separation technologies are an essential factor in realizing Vision 21. Producing high-purity streams of oxygen will reduce capital costs and increase efficiency, and separating hydrogen for sale will increase profitability significantly. Pure oxygen is also required by technologies that concentrate CO_2 for sequestration. DOE-sponsored R&D has identified a novel class of dense ceramic materials called ion transport membranes, which use mixed-conducting ionic ceramics to conduct both oxygen ions and electrons through the membrane wall. No external electric circuit is required to move electrons through the membrane, so the process produces virtually pure oxygen at far less cost than alternatives.



HYDROGEN-SEPARATION TECHNOLOGIES

One solution to global climate change is to develop a hydrogen economy based on renewable energy resources such as biomass or the photovoltaic splitting of water. In such an economy, the transportation sector would use hydrogen as a fuel, and electricity would be produced using hydrogen in high-efficiency fuel cells. In this scenario, there would be no net CO_2 emissions, a result that would stabilize or decrease the concentration of CO_2 in the atmosphere.

An alternative path to a hydrogen economy could use carbonaceous fuels as a source of hydrogen, with the sequestration of CO_2. However, no commercial technologies exist today that can accomplish the separation of hydrogen from other gases (for example, N_2, CO_2, CO) at high temperatures and pressures. Ceramic membranes could accomplish the desired separation economically. The first approach being pursued is to concentrate on fabricating membranes (molecular sieves) that have sufficiently small pores to permit only the passage of hydrogen molecules through the membrane wall at high temperatures and pressures.

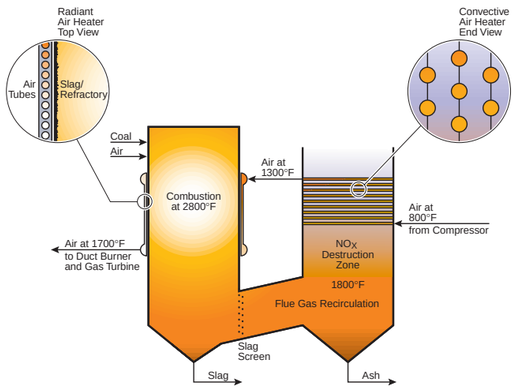
A second approach centers on the development of dense ceramic membranes that conduct hydrogen as protons (proton transfer membranes) through the membrane wall in much the same way as an ion transfer membrane (ITM). Both approaches focus R&D efforts on the water-gas shift reaction to produce hydrogen.

HIGH-TEMPERATURE HEAT EXCHANGERS

One way to increase efficiency in a powerplant is to operate at higher temperatures. The efficiency of a steam turbine (Rankine cycle) increases with the temperature of the steam entering the turbine, and the efficiency of a gas turbine (Brayton cycle) increases with the temperature of gases at the turbine inlet. High-temperature heat exchangers are key to achieving these higher temperatures.

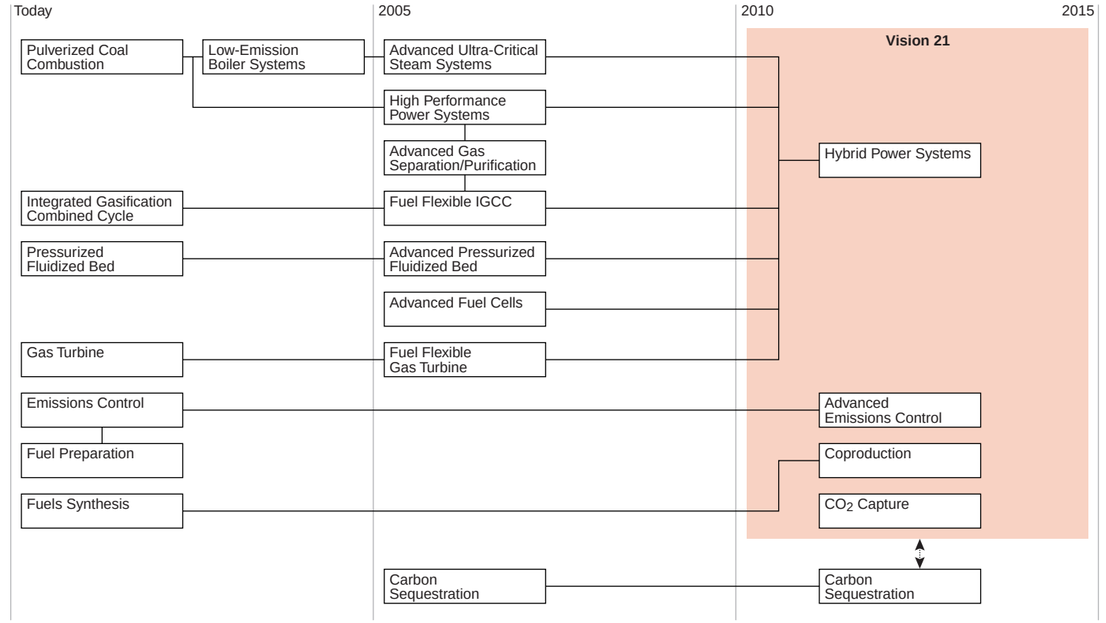
The materials available today limit the maximum temperatures in steam turbine plants to about 1,050°F to 1,100°F. For more efficient plants, high-efficiency heat exchangers are needed to superheat and reheat steam to temperatures of 1,300°F or higher. The Advanced Materials Program is meeting this need by developing advanced alloys that have both high-temperature strength and corrosion resistance for use in heat exchangers. When these improved alloys are available, conventional powerplants with efficiencies of 45% to 50% will become possible and Vision 21 plants with 60% efficiency will be achievable.

HIGH-TEMPERATURE AIR FURNACE



A team led by United Technologies Research Center is developing a high-temperature air furnace (HITAF) for heating turbine air in high-performance power systems, a type of indirectly fired cycle. The HITAF uses advanced materials and a highly innovative design that prevents hot heat exchanger tubes from contacting corrosive coal-combustion products. Such design concepts and approaches will be needed in Vision 21 plants.

ROADMAP FOR VISION 21 PROGRAM



FUEL-FLEXIBLE GASIFICATION

The Vision 21 concept depends on the ability to use the fuels, including waste materials, that are available at lowest cost in the area where the plant is located. This capability is being created by the development of advanced gasification technology to process a variety of feedstocks.

Investigations are focusing on:

- Defining the availability and cost of alternative feedstocks and identifying obstacles to achieving technical success.
- Evaluating alternative feedstocks in existing gasification facilities such as Clean Coal Technology projects and in developmental units.
- Developing novel gasification concepts that can lower costs and improve efficiency, feedstock flexibility, and modularity. Such technologies may include catalytic gasification, the use of novel ceramic membrane approaches, and the use of CO_2 instead of steam as the diluent for oxygen feed to the gasifier in systems that capture CO_2 for sequestration.

ADVANCED HOT-GAS CLEANUP

Key to achieving Vision 21 goals of high efficiencies, near-zero emissions, and low cost, is the cleaning and conditioning of gasification and combustion-product gases. Product gases must be cleaned of all particulate matter, all sulfur- and nitrogen-containing compounds, and all traces of other hazardous compounds that may affect downstream operations or be emitted into the atmosphere.

A ROADMAP OF VISION 21 TECHNOLOGY

Vision 21 provides a technology roadmap for progressively cleaner and more efficient energy production. The roadmap brings together enabling technologies, such as advanced, low-cost hydrogen and oxygen separation and advanced gas cleaning, that are needed to realize performance targets of efficiency and cost. It integrates and builds on advanced technologies now in the R&D and demonstration phase, such as those in the Clean Coal Technology Program.

Additional process improvements will be achieved through such supporting technologies as advanced materials and components, improved catalysts, environmental-control technologies, sensors and controls, and virtual demonstrations. Careful cost and market analyses will be pursued concurrently with technology development to ensure that resultant technologies achieve market acceptance.

Gases must be cleaned at temperatures and pressures close to gasifier/combustor operating conditions and those of downstream operations. Research activities are focusing on:

- Developing high-efficiency, high-temperature particulate filters that operate in either an oxidizing or a reducing environment.
- Investigating new classes of catalysts or sorbents capable of decomposing and/or removing chemical contaminants at high temperatures.

ADVANCED COMBUSTION SYSTEMS

Highly efficient, clean advanced combustion systems are being developed for Vision 21. These systems focus on the indirectly fired cycle because this cycle is inherently fuel flexible and highly efficient. A key characteristic of the indirectly fired cycle is that combustion products do not contact the turbine, thereby avoiding potentially serious corrosion problems that may arise from the use of sulfur- and ash-containing fuels and expanding the types of fuel that can be used.

FUEL CELL HYBRIDS

The Vision 21 concept is expanding the possibilities for advanced power generation systems to work together to achieve efficiencies that could not be attained in a single system. When a fuel cell and advanced gas turbine are integrated in a Vision 21 concept, the efficiency of the system is expected to exceed 70%. Many types of fuel cell hybrids are being studied to understand their potential.

FUEL-FLEXIBLE TURBINES

By 2002, advanced materials, combustion systems, and cooling techniques developed under the Advanced Turbine Systems (ATS) Program will provide the cleanest, most efficient natural gas turbine combined-cycle powerplant on the commercial market.

Vision 21 demands that these achievements be extended to other fuels, including fuel gas produced from coal and hydrogen. This goal is being pursued through the development of advanced-cycle configurations with increased pressure ratios, advanced alloys and ceramic materials, and combustion technology that could advance gas turbines to higher levels of performance at reduced cost.

COPRODUCTION

Coproduction integrates IGCC power production and indirect liquefaction to produce both electricity and fuels or chemicals in a single plant. Both IGCC and indirect liquefaction are now practiced commercially, but not together. One driver that could make coproduction in a Vision 21 facility attractive is CO_2 management.

The basic IGCC process gasifies carbonaceous feed at high temperatures to produce synthesis gas—a mixture of carbon monoxide and hydrogen. The gas is then cleaned of contaminants and fed to a gas turbine/generator and steam-bottoming cycle. In the coproduction mode, a portion of the synthesis gas is directed to a reactor that catalytically converts the gas into premium diesel fuels, gasoline, or chemicals.

The novelty of coproduction in a Vision 21 facility is integration of a highly efficient power cycle with fuel production in a way that facilitates the capture and sequestration of substantially all CO_2 produced.

SUPPORTING TECHNOLOGIES

Integral to the Vision 21 concept of clean and cost-effective use of fossil fuels is directed research on materials, components, controls, sensors, computer modeling, and other supporting technologies that cut across existing product lines and provide support to achieve program goals. These technologies are also applicable to other FE and DOE research and technology development programs. Much of this work is jointly defined and co-sponsored by a diverse group of industrial partners.

MATERIALS AND COMPONENTS

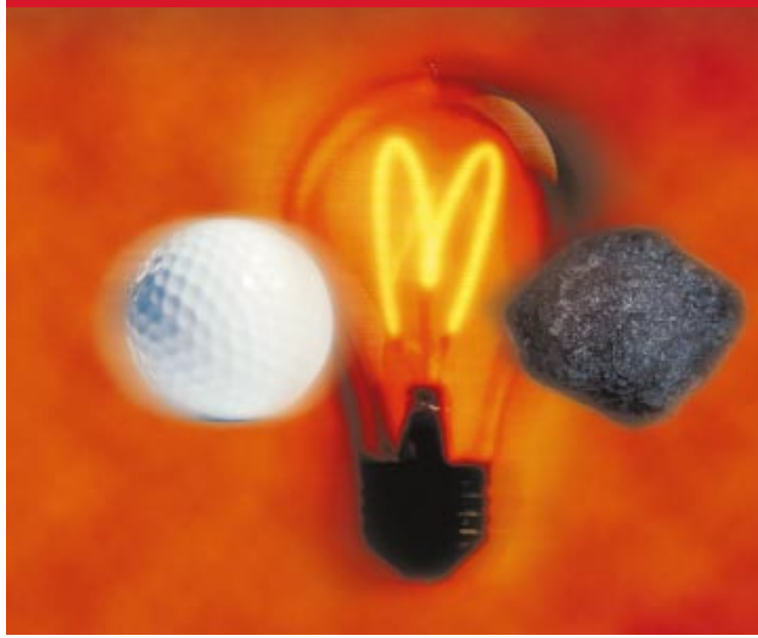
New materials and components are being developed to address the special needs of Vision 21. The ceramic materials required for novel membrane applications and special alloys for high-temperature heat exchangers are examples of products of this activity that are critical to the timely deployment of Vision 21 plants.

VIRTUAL DEMONSTRATIONS

Virtual demonstrations—the use of computer models and simulations to develop, test, and evaluate the design of new concepts—are critical to speed progress and reduce the cost of making Vision 21 plants a reality. Virtual demonstrations are already being used in other industries, e.g., aircraft design and manufacturing, as a cost-effective tool to reduce scale-up, construction, and operational risks. The ability to visually "walk" through a three-dimensional rendition of a new design for a plant and simulate its operation in different situations would be invaluable for identifying opportunities, steering supporting research, and confirming the performance of the design.

The Vision 21 concept provides maximum flexibility with respect to products, feedstocks, and environmental controls. Individual modules could be linked together in many different combinations to create Vision 21 plants. The only way to demonstrate all of these combinations is by using virtual demonstrations. In addition, virtual demonstrations could be used in a predictive fashion to prioritize combinations of modules for a Vision 21 plant for a specific site, based on feedstock availability, population density, environmental goals, and markets for coproducts.

POWERPLANT EFFICIENCY MATTERS



One golf-ball-size lump of coal would produce enough electricity to light a 100-watt bulb for 75 minutes in a conventional powerplant, 90 minutes in plants in the CCT program, 100 minutes in "nth" of a kind CCT units, and 140 minutes in Vision 21 plants (which also produce steam, chemicals, heat, and other by-products).

ADVANCED CONTROLS AND SENSOR SYSTEMS

With the advent of advanced power-generation and fuel-conversion technologies such as those proposed for Vision 21, a new generation of advanced controls and sensors must be developed. The new controls and sensors will be compact, modular, inexpensive, and easy to maintain. They will maximize the operational efficiency of advanced fossil-fueled processes while reducing emissions.

MODULARIZATION

Most large industrial and utility fossil fuel plants are designed on a site-by-site basis. Vision 21 plants will be built from modules available in several fixed-size ranges.

Modular design and construction would maximize shop fabrication, minimize expensive field construction, and maintain flexibility in the design and deployment of Vision 21 plants.

SYSTEMS/MARKET ANALYSES

Systems analysis is a critical part of the Vision 21 Program and serves to guide all activities. The key role of systems analysis is to develop Vision 21 system configurations that meet program objectives, and to define performance targets for individual subsystems and supporting technology needs.

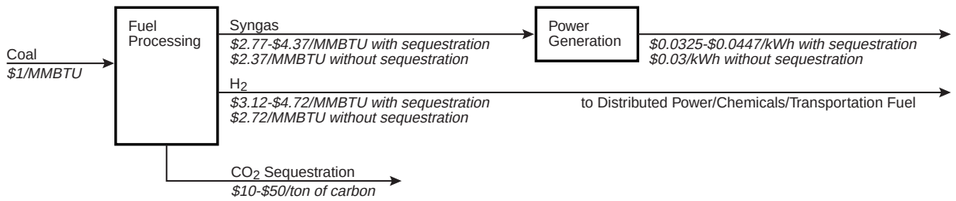
Market analyses will be concurrently performed to determine the acceptability of the most promising systems in both national and international markets. The results of market and system analyses will be used to ensure that Vision 21 closely meets market requirements.

VISION 21 PLANT DESIGN

The Vision 21 Program will produce engineering-level designs for prototype (small commercial) and large commercial plants. The major products of the program are:

- ***Component/subsystem designs.*** The development of enabling technologies provides the building blocks for integration into Vision 21 systems.
- ***Prototype plant designs.*** Designs of prototype plants of varying complexity will be produced. The plants will utilize a range of feedstocks and produce various products.
- ***Commercial plant designs.*** The best of the prototype plants will serve as the basis for designs of large, commercial plants of varying complexity and product slates.

A VISION 21 CONCEPT



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