Vision 21 - A Program for Clean Energy in the New Millennium

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Abstract

As the new millennium approaches, the United States and the world will continue to rely on fossil resources to meet the growing energy demand well into the 21st century. This demand is driven by the global desire for enhanced economic prosperity. The growing world population and the transition of developing countries towards industrialization creates the dual challenge of meeting this increasing energy demand affordably while addressing the environmental concerns. We now have an opportunity to meet this challenge by developing viably clean, affordable and efficient technology options that allow for the wise use of the global fossil resources. All the while, the energy landscape is evolving as the energy industry undergoes restructuring and privatization around the world. The development of these technology options to meet the future energy and environmental needs is the focus of the U.S. Department of Energy's Vision 21 program.

Vision 21 is a new approach to producing energy efficiently while removing environmental concerns related to the use of fossil resources, particularly coal. Vision 21 focuses on developing advanced technology modules that can be configured into a new class of energy plants (or powerplexes). These plants will have the flexibility of using a wide range of fossil fuels in combination with other feedstocks (such as biomass and wastes) to produce an economically competitive slate of energy products including any combination of electricity, clean fuels, chemicals, hydrogen, or high value heat. At the same time, Vision 21 energy plants will emit virtually zero pollutants such as sulfur dioxide, nitrogen oxides, particulates and other air toxics. It will also dramatically reduce carbon emissions through high conversion efficiencies and have the option of integrating with carbon dioxide sequestration systems, thus removing any concerns as a source of global climate change or greenhouse gas. Vision 21 will integrate the principles of industrial ecology by making use of any solid or liquid effluents. Lastly, and equally important is that these plants will be able to generate electricity and other energy products at competitively lower cost.

Realizing the achievement of Vision 21 requires the development of several key enabling technologies necessary for creating the building blocks or technology modules for Vision 21. In addition, supporting research, advanced modeling and simulations, advanced manufacturing

technology and system integration and analyses will be needed. A strategy of building on our technological successes will be pursued to provide a solid program foundation upon which to develop the necessary Vision 21 technology within a target time frame of 2015. This technological foundation includes the Clean Coal Technology research, development and demonstration programs as well as our ongoing research and technology development in areas such as gasification, advanced combustion, fuel cells, advanced turbines and engines.

With respect to program implementation, achieving the benefits of the Vision 21 technology requires effective government-stakeholder partnerships involving industry, academia, research laboratories, and other federal and state agencies, all of which will share in the costs and risk as well as the spin-off benefits along the way. The program rationale is to achieve overall public good and benefits through the use of market forces and competition. Therefore, the program will be industry driven. The market will ultimately determine the types of Vision 21 energy plants, size, and configuration that will be built and deployed by industry.

Vision 21 is an exciting new technological journey that will lead to viable options for fossil based energy in the 21st century. Its success will undoubtedly shape the future energy landscape and provide an avenue for sustaining our economic and environmental future with the clean, wise use of the earth's natural fossil energy resource.

Introduction

As we stand on the threshold of a new millennium, our countries face both tremendous opportunity for continued economic growth and the challenge of providing the energy necessary to sustain that growth. More specifically, the energy needed must come largely from fossil fuels, address growing global and regional environmental concerns, and remain low in cost to maintain competitiveness in the world market. To respond to these needs, the U.S. Department of Energy has recently embarked upon a new program, Vision 21, designed to produce energy efficiently and economically, while removing all environmental concerns associated with fossil fuel use.

The factors impacting on our country's energy sectors are markedly similar. We are both about to undergo restructuring of our utility sectors, which will place added pressure on new systems to be economically competitive. Deregulation in the U.S. is changing the way industry operates and invests in new facilities and technology. In this market-driven environment, power plant owners are concerned about profitability and ability to finance new investments. This causes owners to avoid technical risk and favor low capital cost alternatives.

Pressure to reduce pollutant emissions continues to increase. In the U.S., both source emission standards and ambient air standards are becoming increasingly stringent for particulate matter, sulfur dioxide, and nitrogen oxides. The result is that new plants coming into areas marginally within compliance must have near zero emissions. Recent actions taken in Korea to lower pollutant emission limits indicate a similar eventual outcome for Korean power plants.

Exacerbating environmental pressures is the magnitude of energy growth projected to sustain the economies of both our countries. In the U.S. alone, demand for electricity will require an estimated 363 gigawatts of new capacity by 2020.

There is increasing pressure in the world community to reduce greenhouse gas emissions. This comes as world energy consumption is projected to escalate 65 percent by 2020. In response to global climate change concerns, the U.S. is striving to enhance power generation efficiency. While Korea is not under the same pressures, generation efficiency is probably of equal importance because resources are largely imported.

Increased dependence on oil imports is a concern as well. In a world experiencing rapid economic growth, the demand on petroleum resources for transportation fuels will grow exponentially. This strongly suggests that alternative means for producing transportation fuels be pursued.

There is a threat to maintaining the fuel diversity, which is essential to ensuring reliable and affordable energy. Fuel diversity affords the flexibility to adjust to changing circumstances. In the U.S., public environmental policy is placing pressure on continued use of coal, our most abundant resource, and on maintaining our nuclear capacity. Similar actions around the world, plus advances in natural-gas-based technology are making natural gas the fuel of choice, which could soon strain gas resources.

Lastly, both the U.S. and Korea have become dependent upon electricity to fuel our economies and provide for our people's needs. Low-cost, reliable, and high quality electricity is crucial to our populace and industries that have become dependent upon electronics.

Vision 21–The Evolution

Vision 21 evolved out of the recognition that fossil fuels must be relied upon well into the next millennium to meet energy needs here and abroad. World energy consumption will place tremendous pressure on resources and the environment. The public will not tolerate the environmental consequences envisioned for this magnitude of fossil energy use, which assumes application of today's technologies. Renewables simply cannot meet the energy needs. Emerging technologies such as integrated gasification combined-cycle (IGCC) and pressurized fluidized-bed combustion (PFBC) along with continued evolutionary improvements in gas turbines will mitigate the problem. But individually, these technologies cannot achieve the required environmental, economic, and operational performance. Only integration of multiple technologies and development of key component hardware will achieve the necessary "leapfrog" cost and performance improvements.

Vision 21–Defined

Vision 21 is a government-industry-academia collaboration to develop technology that will effectively remove all environmental concerns associated with the use of fossil fuels for producing electricity and transportation fuels. The approach is to develop a suite of technology modules that can be interconnected in different configurations to produce selected products. These modular facilities will be capable of using a multiplicity of fuels (such as coal, natural gas, petroleum coke, and municipal waste) to competitively produce a number of commodities (such as electricity, steam, fuels, and chemicals) at efficiencies greater than 60 percent and with near zero emissions. Vision 21 builds on a portfolio of technologies already being developed, including IGCC and PFBC, advanced gas turbines, fuel cells, and fuels synthesis, and adds other critical technologies and system integration techniques. When coupled with CO_2 capture and recycling or sequestration, Vision 21 systems would achieve no net CO_2 emissions and no environmental impact outside of their physical footprint. The concept of Vision 21 has been endorsed by the President's Committee of Advisors on Science and Technology and is supported by various industry stakeholder groups.

Vision 21–Objectives

The specific performance targets, costs, and timing for Vision 21 systems are:

Efficiency–Electricity Generation	Coal-based systems 60% (HHV); Natural gas-based systems 75% (LHV) with no credit for cogenerated steam*
Efficiency–Combined Heat & Power	Overall thermal efficiency above 85% (HHV); also meets efficiency goals for electricity*
Efficiency–Fuels Plant Only	Fuel utilization efficiency of 75% (LHV)* when producing coal-derived fuels;
Environmental	Near zero emissions of sulfur, nitrogen oxides, particulate matter, trace elements, and organic compounds; 40–50% reduction in CO_2 emissions by efficiency improvement; 100% reduction with sequestration
Costs	Cost of electricity 10% lower than conventional systems; products of Vision 21 plants must be cost competitive with market clearing prices;
Timing	Major spinoffs such as improved gasifiers, advanced combustors, high temperature filters and heat exchangers, and gas separation membranes begin by 2004; designs for most Vision 21 subsystems and modules available by 2012; Vision 21 commercial plant designs available by 2015

* The efficiency goal for a plant co-feeding coal and natural gas will be calculated on a pro-rata basis. Likewise, the efficiency goal for a plant producing both electricity and fuels will be calculated on a pro-rata basis.

Vision 21–Plant Characteristics

- Must involve a conversion of fuels such as coal or natural gas to high-value products such as electricity or transportation fuels (steam or heat may be secondary products);
- Will be large stand-alone energy facilities, generally larger than 30 MWe or equivalent energy output for fuels or chemical production;
- May be either a central or distributed power facility, but distributed power systems would be for large industrial consumers only (although spinoff technologies may find small distributed power applications);
- Will use fossil fuel-based feedstocks, either alone or in combination with biomass and/or

opportunity feedstocks such as petroleum coke, refuse-derived fuel (RDF), municipal solid waste, and sewage sludge (biomass only plants are excluded);

- Will emphasize market flexibility through fuel and product flexibility;

- Will be composed of two or more modules with “smart” systems integration; and

- Will facilitate capture and concentration of CO_2 for sequestration.

Vision 21–Concept Plant Example

Figure 1 shows an artist’s rendition of a Vision 21 plant. The plant features modular design and uses multiple feedstocks to make a market driven product slate. Coal and opportunity feedstocks are gasified using oxygen produced with a low-cost air separation membrane. The fuel gas is cleaned and a second membrane is used to separate hydrogen. Carbon monoxide in the fuel gas may be shifted to CO_2 and the CO_2 sequestered if necessary. Electricity is generated with a fuel cell using the hydrogen and with a gas turbine using the energy in the fuel cell exhaust. Heat remaining in the turbine exhaust is used to generate steam for process heat. A portion of the fuel gas is diverted for the production of liquid fuels and high-value chemicals.

Vision 21–Technologies

Critical technologies have been identified for Vision 21 that fall into two groups, enabling technologies and supporting technologies. Enabling technologies provide the foundation for the subsystems, or modules, that form the building blocks of a Vision 21 plant. Some enabling technologies like IGCC and PFBC are being demonstrated in the Clean Coal Technology Demonstration Program. The enabling technologies include:

- **Oxygen Separation Membrane**. Advanced membrane technology shows promise for significantly reducing the cost of the existing energy intensive, cryogenic air separation process used to produce oxygen. Low-cost oxygen is key to both advanced gasification and combustion systems seeking to reduce cost, nitrogen oxide formation, and facilitate CO_2 capture by not diluting the process gases.

- **Hydrogen Separation Membrane**. High-temperature, ceramic membranes provide an energy efficient, cost effective means of separating hydrogen from syngas for powering fuel cells and producing fuels or chemicals.

- **High Temperature Heat Exchangers**. High-temperature heat exchangers enable efficient transfer of the heat of combustion to clean working fluids for advanced turbines operating around 2700 °F and to air and other gases used in advanced processes.

- **Fuel Flexible Gasification**. Fuel flexibility allows use of low-cost feedstocks and takes advantage of synergies with industries such as pulp and paper, oil refining, and sewage treatment.

- **Gas Stream Purification**. High-temperature particulate filtration and chemical contaminate removal systems: (1) realize the efficiency benefits of not having to cool process gases; (2) enable the use of high-temperature hydrogen separation membranes; and (3) meet stringent gas quality requirements for advanced combustion, synthesis gas conversion, and fuel cell systems.

- **Advanced Combustion Systems**. Advanced combustion systems provide benefits of low nitrogen oxide emissions and ease of CO_2 capture by using oxygen and CO_2 mixtures for combustion and recycling the CO_2 exhaust.

- **Fuel Flexible Turbines**. Fuel flexible turbines use advanced heat transfer, aerodynamics, and materials to enable turbine combustion systems to operate under extremely high temperatures (3000 °F) and corrosive environments. The high temperatures support efficiency goals and the corrosion resistance addresses fuel flexibility issues.

- **Fuel Cells**. By integrating high-temperature fuel cells with gas turbines into hybrid systems, synergistic effects lead to electrical conversion efficiencies of more than 70 percent (LHV). The process uses rejected thermal energy from the high-temperature fuel cells to drive the gas turbine.

- **Advanced Fuels and Chemicals Development**. Advanced fuels and chemicals development provides co-production capability of Vision 21 systems. The high-value products include substitutes for petroleum-based transportation fuels and special fuels for fuel cell vehicles that facilitate reforming.

Supporting technologies are cross-cutting technologies that are common to many Vision 21 subsystems and modules and may be important in applications other than Vision 21. The supporting technologies are:

- **Materials**. New alloy and ceramic materials development and attendant development of fabrication technology address the increasingly high temperatures and corrosive environments associated with Vision 21 systems.

- **Advanced Computational Modeling, Virtual Demonstration**. The use of virtual demonstrations, already being applied in other industries, offers a cost-effective way to reduce the number of scale-up steps and cut development and design costs. The effort focuses on developing the computer simulations for the subsystems and the integration of the subsystems.

- **Advanced Controls and Sensors**. Advanced controls and sensors provide sensors robust enough to withstand the hostile environment of combustors and gasifiers, which enables direct (rather than the current indirect) process measurements critical to process efficiency, reliability, and availability. Moreover, sensor integration into intelligent control systems allows optimum control of a multitude of parameters.

- **Advanced Environmental Control Technology**. Advanced environmental control technology addresses the issue of controlling respirable particulate matter in the 2.5 micron or less range. Furthermore, it deals with the industrial ecology principles of minimizing wastes through recycling and other measures.

- **Advanced Manufacturing and Modularization**. Advanced manufacturing and modularization reduces design and production costs by developing modular design and construction methodologies.

Vision 21–Implementation

The Vision 21 program plan contains five program elements: systems analysis, enabling technologies, supporting technologies, systems integration, and plant designs. Planned activities include the development of subsystems, components, and design tools, and the concomitant modeling, analysis, and experimental work. The scale of the experimental activities will range from laboratory-, bench-, and pilot-scale, up to and including scales needed to obtain data for demonstrating the feasibility of prototype and commercial-scale plants. Demonstration activities, the exact timing of which will depend on prevailing economic conditions and market forces, will be left to private industry. DOE's role will be to facilitate the transfer of the Vision 21 knowledge base to industry.

To accelerate market entry of Vision 21 systems, the implementation strategy includes having early entry spinoff technologies, which become commercial products over the 15 year span of the program. The spinoffs will realize early commercialization because they represent significant breakthroughs in cost and performance, such as the air separation membrane for low-cost oxygen production. Oxygen represents the third most marketed commodity in the U.S. The first Vision 21 plants will integrate many of these advanced spinoff components, which will have already been demonstrated in different applications. This method reduces risk and is expected to take the place of government funded full scale Vision 21 plant demonstrations. Subscale integration tests, using both computational simulation and hardware, will be conducted to prove out the systems integration technology.

Actions are being taken to help ensure that the Vision 21 program meets the needs of our industry

stakeholders, the public, and our nation's long-term interests. For example, a workshop was held in Pittsburgh in December 1998 to introduce the Vision 21 program rationale to industry and to obtain feedback. Further industry workshops are planned. In a separate ongoing activity, the National Research Council has assembled a committee of industry and academic leaders to assess the Vision 21 program and will provide recommendations.

To implement Vision 21, partnerships will be created with industry, universities, private and public R&D laboratories, and federal and state agencies. DOE will issue a series of competitive solicitations, create consortia, and implement Cooperative Research and Development Agreements. The first of these solicitations has been drafted for public comment and is available on our web site www.fetc.doe.gov. DOE expects to issue the final solicitations, after considering the stakeholder feedback, by the end of the 1999 fiscal year.

Conclusion

Vision 21 is an exciting new technological journey that will lead to viable options for fossil based energy in the 21st century. Its success will undoubtedly shape the future energy landscape and provide an avenue for sustaining our economic and environmental future with the clean, wise use of the earth's natural fossil energy resource.