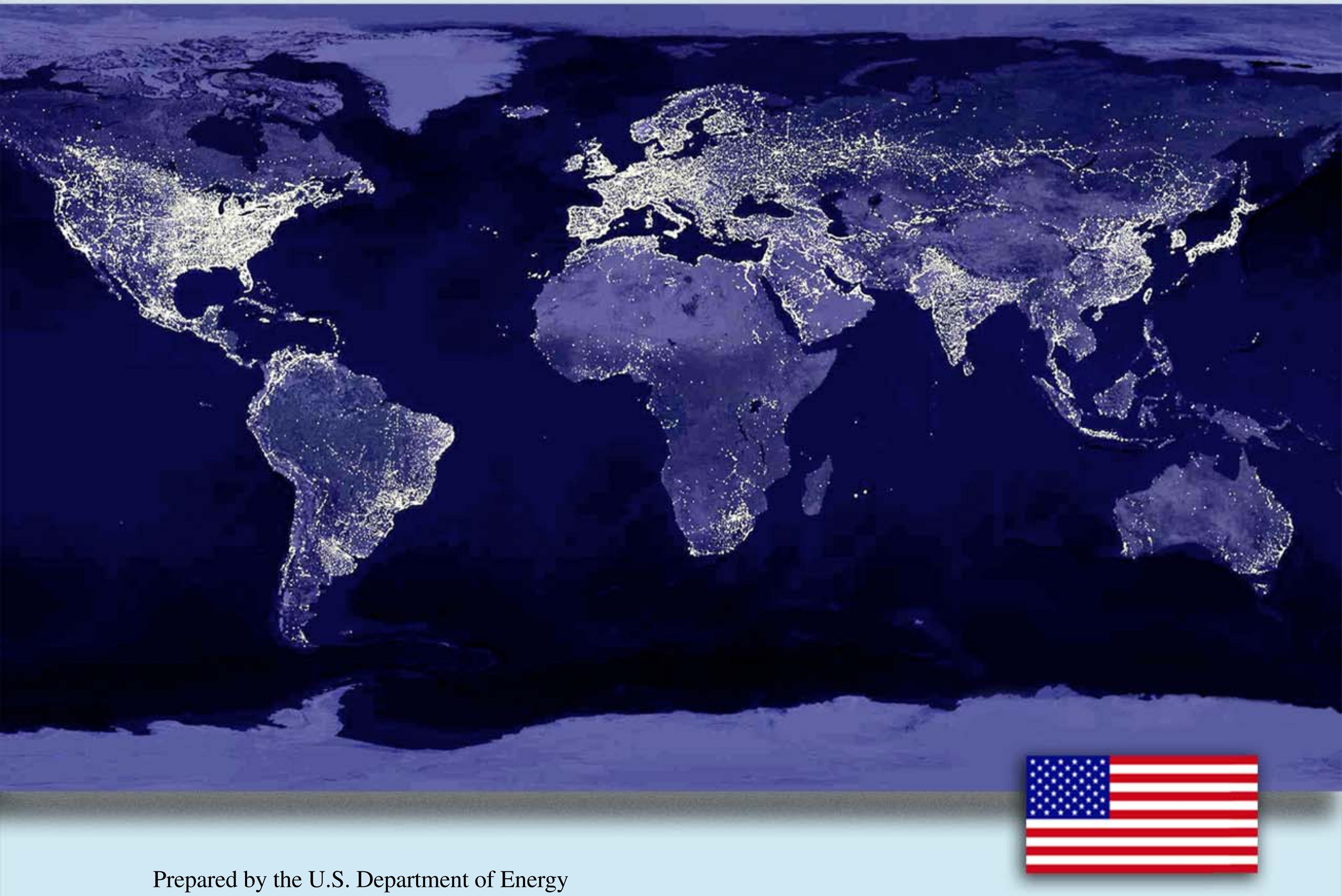
The U.S. Generation IV Implementation Strategy

September 2003

Preparing Today for Tomorrow's Energy Needs



Prepared by the U.S. Department of Energy
Office of Nuclear Energy, Science and Technology

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PREFACE

This report has been prepared by the U.S. Department of Energy (DOE) to respond to Congressional direction contained in Senate Report 107-220 from the Senate Committee on Appropriations regarding the Energy and Water Development Appropriations for 2003. In that report, the Committee instructed the Department to prepare a report regarding how it intends to carry out the results of the Generation IV Roadmap.

This report is the U.S. Department of Energy's response to the Congressional directive. It summarizes results from the Generation IV Technology Roadmap and the strategy for implementing of the Generation IV program in the United States.

Planning for the implementation of the Generation IV program is based on (1) the long-term outlook for nuclear energy in the United States, (2) the advice of the Nuclear Energy Research Advisory Committee during the two-year development of the Generation IV Technology Roadmap, and (3) the need for the Generation IV program to be integrated with other nuclear energy research programs of the Department. Considerable emphasis is given to developing the priorities and necessary timelines for the U.S. Generation IV Program, as well as developing international R&D cooperation that will benefit the program and strengthen U.S. leadership in nuclear technology R&D.

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I. THE NEED FOR GENERATION IV IN THE UNITED STATES

Introduction: Nuclear Energy's Successes and Barriers

From the early beginnings of nuclear energy in the 1940s to the present, the United States has led the development of three generations of nuclear energy. This leadership included the demonstration of early prototype reactors in the 1950s and 60s, construction of commercial power reactors in the 1970s and 80s, and development and certification of advanced light water reactors in the 1990s.

The first three generations of nuclear energy have been successful in the following ways:

- Nuclear energy supplies a significant share of electricity for today's needs—over 20% of U.S. and 16% of world demand. U.S. technology has formed the basis for most of the 438 nuclear plants deployed throughout the world.
- Nuclear energy plays a large role in the U.S. economy. In 2002, the 103 operating U.S. nuclear power plants generated 790 billion kilowatt-hours of electricity, valued at $50 billion.
- Through the use of nuclear energy, the United States has avoided over three billion tons of air emissions since 1970.
- U.S. nuclear plants are highly reliable and in 2001 produced electricity for 1.68 cents per kilowatt-hour on average. This low cost is second only to hydroelectric power among baseload generation options.
- In return for access to peaceful nuclear technology, over 180 countries have signed the Non-Proliferation Treaty to help ensure that peaceful nuclear activities will not be diverted to making nuclear weapons.

During these developments, however, barriers to the long-term expansion of nuclear energy in the United States have been encountered that have not been fully resolved:

- Public confidence in the safety of nuclear energy was challenged by the Three Mile Island accident in 1979 and Chernobyl in 1986. The nuclear industry has responded to achieve exceptionally high levels of safety and reliability in the current fleet of over 100 reactors in the United States. Research and development into new nuclear systems should strive to increase public confidence with clear and transparent safety approaches.
- High capital costs, and costs associated with construction delays and regulatory uncertainty, have discouraged commercial construction of nuclear plants. However, regulatory reforms and economic advances projected for advanced light water reactors have begun to stimulate industry interest in new plant orders. For the long term, significant R&D is needed on new systems that will have significantly reduced capital costs and construction times.
- Congress has approved the decision to proceed with a geological repository at Yucca Mountain, which provides a future path for the current fleet. Future long-term expansion of nuclear energy needs to make optimal use of the limited space in a geological repository and achieve the benefits of a closed fuel cycle. This will require significant R&D on fuel cycle technology and on new nuclear energy systems that are more sustainable.[1]
- Worldwide deployment of nuclear energy has led to concerns over the vulnerability of nuclear plants to terrorist attack and accumulating plutonium inventories that hold the potential for proliferation of nuclear weapons. R&D into new nuclear systems should provide increased physical protection against acts of terrorism and increase the assurance that these systems are a very unattractive route for nuclear proliferation.

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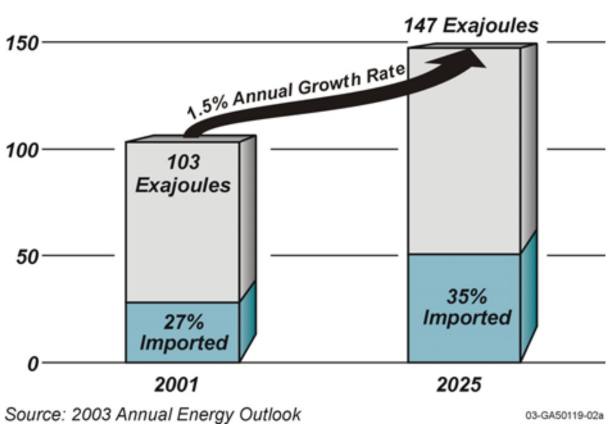
1. The term *sustainability* denotes the ability of systems, such as nuclear energy systems, to provide their benefits indefinitely into the future without placing undue burdens on society. These burdens could arise from the generation of large quantities of nuclear waste for ultimate disposal in geological repositories, or from the depletion of indigenous uranium ore resources. Advanced systems that generate much less nuclear waste and better utilize the energy content of the uranium are more sustainable than today's generation of reactors.

In spite of these barriers, nuclear energy in the United States experienced an economic and regulatory recovery in the 1990s, with nearly all U.S. light water reactors expected to file for 20-year license extensions. It is clear, however, that new nuclear energy systems need to address issues of safety, economics, waste, and proliferation resistance and physical protection with a robust research and development program. Advances in all of these areas can contribute to increasing the sustainability of nuclear energy.

Expanding Nuclear Energy Generation to Meet Future U.S. Energy Demand

The outlook for energy demand in the United States underscores the need to increase the share of nuclear energy production. The *2003 Annual Energy Outlook* projects an annual growth rate of 1.5% in total energy consumption to the year 2025 (see figure below). At the same time, domestic energy production will grow only 0.9% per year, creating a widening gap to be filled by energy imports. Further, most of the domestic energy production increase is projected to be provided by coal and natural gas. Thus, the outlook implies an increasing burden from carbon emissions with the potential for long-term consequences from global climate change, as well as an increasing dependence on foreign energy sources. These create a strong motivation for seeking to increase the share of nuclear-generated electricity above its current 20% level. While third-generation advanced light water systems show promise for stimulating new plant orders, Generation IV systems have a clear advantage in overall sustainability.

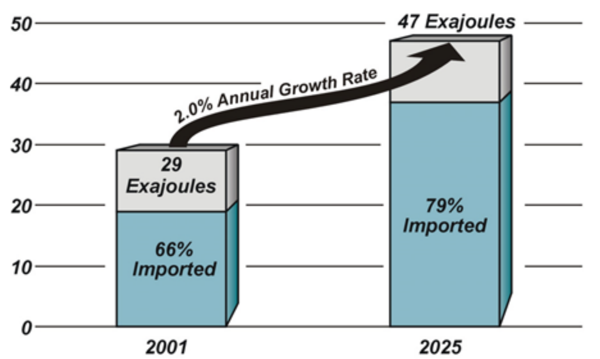
Growing U.S. Energy Demand and Imports
U. S. Total Energy Consumption (Exajoules)



Source: 2003 Annual Energy Outlook

The outlook for energy demand within the major sectors of energy use other than electricity also points out an emerging role for nuclear energy in the production of alternate energy products.[2,3] The *Annual Energy Outlook* projects an annual growth of 2.0% per year for the transportation sector (see figure below), while the electricity and heating sectors will grow at 1.4% and 1.2%, respectively. Transportation is almost exclusively dependent upon petroleum. This dependence has caused fluctuations in fuel prices of up to 30% and several 'energy shocks' since the 1970s. This volatility creates a significant need for seeking to diversify with new fuels, such as hydrogen for use in emissions-free fuel cells that power electric vehicles.

Growing U.S. Transportation Sector Energy Demand and Imports
U. S. Transportation Sector Energy Consumption (Exajoules)



Source: 2003 Annual Energy Outlook

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2. The *National Energy Policy* points out that, "alternative energy sources such as hydrogen show great promise" and that, "the energy for extracting hydrogen…could be derived from renewable energy sources such as solar, nuclear, and fossil, to achieve the cleanest possible energy cycle." "National Energy Policy: Report of the National Energy Policy Development Group," page 6-10, May, 2001, available at the Web site: http://energy.gov/HQPress/releases01/maypr/national_energy_policy.pdf.

3. The *National Hydrogen Energy Roadmap* recommends R&D on, "processes such as nuclear thermo-chemical water-splitting" that "require long-term, focused efforts to move toward commercial readiness." "National Hydrogen Energy Roadmap," page 9, November 2002, available at the Web site: http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/national

The Generation IV Technology Roadmap

Through an effort that began in January 2000, ten countries have joined together to form the Generation IV International Forum (GIF)[4] to develop future-generation nuclear energy systems. The GIF is interested in systems that can be licensed, constructed, and operated to provide competitively priced and reliable energy products while satisfactorily addressing nuclear safety, waste, proliferation, and public perception concerns. The overarching objective for these new nuclear energy systems—known as Generation IV Systems—is to have them available for international deployment before the year 2030.

From its beginning, the GIF discussed the R&D necessary to support next-generation nuclear energy systems. From those discussions a technology roadmap to guide the Generation IV effort began and was completed in two years with the participation of over 100 experts from the GIF countries. The effort ended in December 2002 with issue of the Generation IV Technology Roadmap.[5] In leading the formation of the GIF and the development of the technology roadmap, U.S. leadership in the peaceful uses of nuclear energy has been strengthened. Moreover, the effort has underscored the importance of collaborative R&D on future nuclear energy systems.

The roadmap evaluated over 100 future systems proposed by researchers around the world. The scope of the R&D described in the roadmap covers the six most promising Generation IV concepts. It is important to note that each GIF country will focus on those systems and the subset of R&D activities that are of greatest interest to them. Thus, the roadmap provides a foundation for formulating national and international program plans on which the GIF countries will collaborate to advance Generation IV systems. To carry out the results of the roadmap, this report to Congress describes the objectives and priorities for the U.S. Generation IV Program and the strategies and approaches to achieve them.

Results from the Generation IV Technology Roadmap

The roadmap identified the six most promising concepts and the recommended R&D needed to achieve them. Two employ a thermal neutron spectrum with coolants and temperatures that enable electricity or hydrogen production with high efficiency. Three employ a fast neutron spectrum to enable more effective management of actinides[6] through recycling of most components in the discharged fuel. One system employs a circulating liquid fuel mixture that offers considerable flexibility for recycling actinides, and may provide an alternative to accelerator-driven systems. The systems and areas of R&D are described in turn.

Thermal-Spectrum Systems

Very-High-Temperature Reactor System

The Very-High-Temperature Reactor (VHTR) system uses a thermal neutron spectrum and a once-through uranium cycle. The VHTR system is primarily aimed at nearer-term deployment of a system for both high-efficiency electricity production and high-temperature thermochemical hydrogen production. The VHTR system has coolant outlet temperatures above 1000°C that enable high-efficiency electricity production and/or thermochemical water splitting without carbon emissions. It could produce hydrogen through high-temperature steam electrolysis if that process is found to have better performance. The reference reactor concept has a 600-MWth helium-cooled core based on either the prismatic block or

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4. Argentina, Brazil, Canada, Euratom, France, Japan, the Republic of Korea, the Republic of South Africa, Switzerland, the United Kingdom, and the United States currently constitute the GIF. New members can be added by a process outlined in the GIF charter.

5. "A Technology Roadmap for Generation IV Nuclear Energy Systems," Generation IV International Forum, GIF-002-00, December 2002, available at the Web site: http://www.inel.gov/initiatives/generation.shtml, accessed February 2003.

6. The term *actinides* denotes both major actinides (the uranium and plutonium present in relatively large percentages in spent nuclear fuel) as well as minor actinides (the neptunium, americium, curium, and other heavier elements present in relatively small percentages). A number of the long-lived actinides place challenging requirements on the long-term performance of geological repositories. Recycling the actinides into new nuclear fuel for fast-spectrum reactors can be an effective strategy for managing actinides.

pebble bed fuel. Operating at an efficiency of over 50%, such a plant would produce over 200 metric tonnes of hydrogen per day. This is the equivalent of about 200,000 gallons of gasoline per day, or 3 million barrels of crude oil imports avoided each year.

The VHTR requires significant advances in fuel performance and high-temperature materials, as well as high-temperature alloys, fiber-reinforced ceramics or composite materials. Very importantly, processes for thermochemical water splitting and high temperature steam electrolysis need to be developed and integrated with the system.

Supercritical-Water-Cooled Reactor System

The Supercritical-Water-Cooled Reactor (SCWR) system features a once-through uranium fuel cycle with a thermal neutron spectrum reactor as the primary option. The system uses a high-temperature, high-pressure water-cooled reactor that operates above the thermodynamic critical point of water to achieve a thermal efficiency approaching 44%. The reference plant has a 1700°MWe power level and a reactor outlet temperature of 550°C. The SCWR system is highly ranked in economics because of the high thermal efficiency and plant simplification. The SCWR is primarily aimed at electricity production, where its high thermal efficiency and plant simplification may provide a breakthrough in system economics. The SCWR requires significant advances in materials and structures to serve in the corrosive high-temperature supercritical water environment, as well as a plant design that addresses several important safety and operational issues.

Fast-Spectrum Systems

Gas-Cooled Fast Reactor System

The Gas-Cooled Fast Reactor (GFR) system features a fast neutron spectrum and closed fuel cycle for efficient management of actinides and conversion of fertile uranium. Core configurations are based on pin- or plate-based fuel assemblies or prismatic blocks, with a total core power of 288 MWe. The GFR system is strong in sustainability because of its closed fuel cycle and excellent performance in actinide management. It is primarily envisioned for missions in electricity production and actinide management, although it may be able to support hydrogen production economically. The GFR requires significant advances in fuels and materials for high temperature service in a fast reactor spectrum, as well as a design that can address safety issues during off-normal conditions, and fuel recycle technology.

Lead-Cooled Fast Reactor System

The Lead-Cooled Fast Reactor (LFR) system features a fast neutron spectrum and a closed fuel cycle for efficient management of actinides and conversion of fertile uranium. The system uses a lead or lead/bismuth eutectic liquid-metal-cooled reactor. The reactor is cooled by natural convection and sized between 50–1200 MWe, with a reactor outlet coolant temperature of 550°C, possibly ranging up to 800°C, depending upon the success of the materials R&D. The LFR system is strong in sustainability because a closed fuel cycle is used, and in proliferation resistance and physical protection because it employs a long-life core (i.e., up to 30 years in some concepts). The safety is enhanced by the choice of a relatively inert coolant. It is primarily envisioned for missions in electricity and hydrogen production and actinide management with good proliferation resistance. The LFR requires significant advances in materials to serve in a corrosive, high-temperature environment, as well as a plant design to address several operational issues and fuel recycle technology.

Sodium-Cooled Fast Reactor System

The Sodium-Cooled Fast Reactor (SFR) system features a fast neutron spectrum and a closed fuel cycle for efficient management of actinides and conversion of fertile uranium. A full actinide recycle fuel cycle is envisioned with two major options: One is an intermediate size (150 to 500 MWe) sodium-cooled reactor with a uranium-plutonium-minor-actinide-zirconium metal alloy fuel, supported by a fuel cycle based on pyrometallurgical processing in co-located facilities. The second is a medium to large (500 to 1500 MWe) sodium-cooled fast reactor with mixed uranium- plutonium oxide fuel, supported by a fuel cycle based upon advanced aqueous processing at a central location serving a number of reactors. The outlet temperature is approximately 550°C for both. The SFR system is strong in sustainability because of its closed fuel cycle and excellent potential for actinide management. It is primarily envisioned for missions in electricity production and actinide management. The SFR requires significant advances in plant simplification and the demonstration of its fuel recycling technology.

Liquid-Fuel System

Molten Salt Reactor System

The Molten Salt Reactor (MSR) system features an epithermal to thermal neutron spectrum and a closed fuel cycle tailored to the efficient utilization of plutonium and minor actinides. In the MSR system, the fuel is a circulating liquid mixture of fluorides of sodium, zirconium, and uranium. The reference plant has a power level of 1000 MWe. The system operates at low pressure (about 5 atmospheres) and has a coolant outlet temperature above 700°C, affording improved thermal efficiency. The MSR system is strong in sustainability because of its closed fuel cycle and excellent flexibility in actinide destruction. The economics are not as favorable for this system because of its large number of subsystems for maintenance of the fuel and coolant. The MSR system is primarily envisioned for missions in electricity production and the destruction of plutonium and minor actinides. The MSR requires significant advances in its process chemistry and plant design.

Crosscutting R&D

The Generation IV Technology Roadmap defined a number of common, or crosscutting, R&D areas for the six selected reactor concepts. These areas included fuel cycle, fuels and materials, energy conversion, risk and safety, economics, and proliferation resistance and physical protection. Many of the Generation IV reactor concepts share similar development needs and, in total, the R&D recommended for crosscutting R&D is about equal to that for any particular concept.

II. OBJECTIVES AND PRIORITIES FOR DEVELOPMENT OF GENERATION IV IN THE UNITED STATES

In the United States, the Generation IV Technology Roadmap is complemented by an earlier Near-Term Deployment Roadmap,[7] a report on the Business Case for New Nuclear Power Plants,[8] and a Report to Congress on the Advanced Fuel Cycle Initiative.[9] These documents are the foundations for the research, development, and demonstration programs within the DOE Office of Nuclear Energy, Science and Technology that encompass the following three major objectives:

- *Deploy third generation nuclear energy systems in the United States.* This is undertaken in the Nuclear Power 2010 program announced by Secretary Abraham in February 2002. This program seeks to reduce the regulatory, economic and technical uncertainties associated with the licensing and construction of new nuclear power plants. Nuclear Power 2010 is an industry cost shared effort to identify sites for new nuclear plants, develop advanced nuclear plant technologies, evaluate the nuclear business case, and demonstrate untested regulatory processes leading to an industry decision by 2005 to order a new nuclear plant for deployment in the 2010 timeframe.
- *Develop separations and transmutation technology for reducing the volume and radiotoxicity of accumulated spent nuclear fuel*. This is undertaken in the Advanced Fuel Cycle Initiative (AFCI). This initiative addresses the intermediate-term issues associated with spent nuclear fuel, specifically reducing the volume of material requiring geologic disposition by extracting the uranium (which represents 96% of the constituents of spent nuclear fuel), and reducing the proliferation risk through the destruction of significant quantities of plutonium contained in spent nuclear fuel. The AFCI also addresses long-term issues associated with spent nuclear fuel, specifically the development of fuel cycle technologies that could sharply reduce the long-term radiotoxicity and long-term heat load of high-level waste sent to a geologic repository.
- *Develop fourth-generation nuclear energy systems for the long term that employ AFCI fuel cycle technologies.* This is undertaken in the Generation IV Program. Successful development and deployment of Generation IV systems would provide a very long-term, sustainable fuel supply for the expanded use of nuclear energy. Systems developed under Generation IV and deployed in the United States would complement the existing fleet of reactors, and all would use fuel cycle technologies developed under AFCI.

Priorities for the U.S. Generation IV Program

The three major objectives for the development of Generation IV in the United States are supported by two priorities for R&D, one for the mid-term and one for the long-term:

Priority 1: Develop a Next Generation Nuclear Plant to achieve economically competitive energy products, including electricity and hydrogen in the mid-term

The highest priority is on the development of a more economically competitive system to meet growing energy demand and maintain the share of

7. "A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010, Volume I, Summary Report," U.S. Department of Energy Nuclear Energy Research Advisory Committee Subcommittee on Generation IV Technology Planning, available at the Web site: http://nuclear.gov/nerac/ntdroadmapvolume1.pdf.

8. "Business Case for New Nuclear Power Plants, Bringing Public and Private Resources Together for Nuclear Energy," Final Draft report prepared for the U.S Department of Energy by Scully Capital in July 2002, available at Web site: http://www.nuclear.gov/home/bc/businesscase.html.

9. "Report to Congress on Advanced Fuel Cycle Initiative: The Future Path Forward for Advanced Spent Fuel Treatment and Transmutation Research," U.S. Department of Energy Office of Nuclear Energy, Science and Technology, available at the Web site: http://nuclear.gov/reports/AFCI_CongRpt2003.pdf.

nuclear energy in the United States. Successful development of an economically competitive nuclear energy system will be a major focus of the Office of Nuclear Energy, Science and Technology through the development of a VHTR-based system that is designed to produce cost-effective electricity, and which offers the potential to produce commercial quantities of hydrogen in the future. This technology is known as the Next Generation Nuclear Plant (NGNP). The Department expects to complete key R&D for the NGNP by about 2010. This technology is partially enabled by many prior developments in high-temperature gas-cooled reactors internationally. The development of an NGNP would have a number of associated benefits such as spinoff technology in fuel, materials, safety design, and energy conversion. Further, the development of gas reactor technology will help to establish a basis for development of a fast spectrum gas reactor discussed in the next priority.

A second thermal-spectrum system also holds very good potential: The SCWR offers potentially significant advances in economics through plant simplification and increased thermal efficiency. The Department anticipates an international effort to resolve the most pressing materials and system design uncertainties needed to demonstrate technical viability of the SCWR. If justified by future research results, the SCWR should be afforded additional resources to develop it more quickly.

Priority 2: Develop a fast reactor to achieve significant advances in proliferation resistance and sustainability for the long term

Fast reactors have very good potential to make significant gains in reducing the volume and radiotoxicity and increasing the manageability of spent nuclear fuel wastes. Fast reactors also hold the potential for extending the useful energy yield of the world's finite uranium supply many fold in the very long term. The chief issue in the development of a next-generation fast-spectrum reactor for use in the United States is its economic competitiveness.

Three of the most promising Generation IV concepts are fast-spectrum (the GFR, LFR, SFR) for enhanced sustainability, and one (the MSR) employs a reactor specialized for actinide destruction. Among these four, DOE expects that the GFR will be given the most emphasis in order to resolve its issues and uncertainties, since fast gas reactors have not been fully demonstrated. The SFR is already at a fairly advanced state of development, and some technologies for the LFR have been demonstrated internationally. All of these systems should be brought to a state where the best system can be chosen based on economics, safety, reliability, sustainability, proliferation resistance, and physical protection. Finally, the MSR should be studied with a lower priority, given the system's uncertainties and development needs.

The development of a Generation IV fast reactor should meet the need for an effective transmutation system in the Advanced Fuel Cycle Initiative (AFCI). However, it will be a number of years before decisions on advanced fuel cycles can be made. Therefore, in the near term, the Office of Nuclear Energy, Science and Technology will place a higher priority on fuel cycle development rather than on fast reactor technology development. The intent is for work under AFCI and Generation IV to recommend and develop a single system.

Timeframes for the Generation IV Systems

For Priority 1, a 15-year timeline is required for the development of the NGNP. This balances the benefit of demonstrating a large-scale economically competitive nuclear hydrogen system with the technical issues and risks establishing an aggressive schedule for its development. While this is an aggressive schedule given the technical issues and risks, it would demonstrate timely the feasibility of large-scale, economically competitive nuclear hydrogen production.

For Priority 2, a 20–25-year timeframe is required for the development of a fast reactor. This fits with the expected future need for radiotoxicity reduction and closure of the U.S. nuclear fuel cycle, and allows research and development of several most promising candidates for about a decade, followed by selection of one technology and a demonstration of all elements of a closed fuel cycle within about a decade thereafter.

III. GENERATION IV RESEARCH PROGRAM NEEDS

A key benefit of the Generation IV International Forum is the ability to conduct R&D on a cost-shared basis, greatly reducing the resources needed by any individual country. While the GIF is now working to develop the project teams and implementing arrangements that will undertake and govern the R&D collaborations, the details of their expected resource needs are not yet available.

During the roadmap development process, the working groups prepared draft conceptual estimates of total R&D resource needs. These were based on expert judgment, not detailed cost analysis. Assumptions were made about the systems having relatively successful advances without contingency for setbacks or changes in approach. The research programs were estimated to require 15–20-year timelines that included both viability phase and performance phase R&D. Following these two phases, given the successful resolution of all issues, a system could enter a demonstration phase. This was estimated to require six or more years with funding for licensing, construction, and startup of the demonstration system at a cost of several billion dollars. Commercialization would follow the successful demonstration.

The needed infrastructure for research, development, testing, and demonstration is also in an initial state of planning. Major categories of needed facilities are found in the following areas:

- Thermal-spectrum fuels testing for the NGNP and SCWR is needed to meet the objectives of these development efforts. Thermal irradiation testing of NGNP fuel is planned to begin in FY 2004 at the Department's Advanced Test Reactor (ATR) in Idaho. In-core loop facilities at the ATR need to be developed to create the unique high temperature environment needed for the tests.

- Hydrogen production technology demonstration for the NGNP is needed. It will also benefit the lower-temperature GFR and LFR systems. A number of candidate production technologies will need to be evaluated and a few demonstrated at engineering scale. A non-nuclear testbed is needed to ensure that the technologies are sufficiently developed for the successful demonstration of the NGNP.

- Fast-spectrum fuels testing for the GFR and LFR is needed. The longer-term development needs of sustainable systems require fast-spectrum irradiation testing. Such capability does not exist in the United States, and the limited capabilities in the world are in decline. Options for reestablishing this capability in the United States need to be developed and evaluated, including the possibility of a new fast neutron research facility.

- Materials testing is needed for in-core and structural systems, as well as for balance-of-plant, recycle and energy conversion equipment for all systems. This underscores the need to revitalize test capabilities for nuclear-rated materials.

IV. STRATEGIC PARTNERSHIPS

A key to the successful long-term implementation of research development, testing, and demonstration of next-generation nuclear energy systems will be strategic partnerships that can combine the needed talents, infrastructures, and resources. Of special importance are partnerships of the DOE with industry, researchers at universities and national laboratories, and other GIF countries. Discussions thus far with both the private sector and international partners indicate that DOE should be able to draw upon significant collaboration and cost sharing in carrying out its Generation IV Program.

Industry Partnerships

The nuclear industry is interested in Generation IV systems for two reasons. One is the potential commercialization of new Generation IV systems in the long term. The other is the significant potential for spinoff technology that can be applied to improve systems deployed in the nearer term. In both priority areas for implementation of Generation IV systems in the United States, advances in fuels, materials, systems design, and energy conversion will be readily applied to these nearer-term deployments. In the first steps of the U.S. Generation IV Program, partnerships with industry are expected to be cost-shared projects that explore the key viability issues and develop performance data. When ready, the partnerships are expected to broaden into full-fledged demonstration projects that address detailed design, construction, licensing, and operational aspects of the systems. In the case of the nuclear hydrogen initiative, a partnership for collaborative demonstration of the NGNP may be formed within a year or two.

Academic and University Partnerships

The U.S. Generation IV Program is focused on aggressive technology advances, which will require many innovations and explorations of alternatives for its success. The role of U.S. universities and national laboratories will be central to these advances. Throughout the first R&D phases of the U.S. Generation IV Program, the nature of these partnerships will focus on peer-reviewed, investigator-led projects in academia that are of high relevance to the program outcomes, as well as program R&D tasks jointly undertaken by the national laboratories and universities. The coordination of R&D solicitations and definition of tasks will be the responsibility of the Generation IV Program technical integration staff. Appropriate interfaces with related projects in near-term nuclear power development and fuel cycle development will be maintained to avoid overlap and utilize resources more effectively.

International Partnerships

The GIF is currently making plans for collaborative R&D projects. The DOE will give special emphasis to the projects that can best support its priorities and leverage its own efforts. At this point, the GIF is considering the necessary arrangements that will be the basis for multilateral R&D collaborations. Also, GIF member countries have been identified that will organize and lead the collaborative R&D projects for the most promising systems. While a few bilateral R&D collaborations are already underway, others are expected to follow within the next year under existing agreements.

V. GENERATION IV PROGRAM ORGANIZATION AND RELATION TO OTHER DOE PROGRAMS

Program Organization

The U.S. program is part of a larger international effort by the Generation IV International Forum. The U.S. Generation IV Program is being organized to provide leadership for both system-specific and crosscutting R&D. The responsibility for the progress of individual Generation IV systems in the United States is assigned to *product managers*, who serve as principal investigators for the overall R&D of each system. A product manager has been appointed for each of the six systems, and the level of R&D corresponds to the priorities discussed in this report. The responsibility for developing required technical solutions identified by product managers and the advancement of crosscutting R&D to support the systems is assigned to *national technical directors*, who serve as resource managers for the development and execution of projects within the program. National directors have been named in six functional areas needed by the program: systems analysis, fuels, materials, energy conversion, chemical separations, and system design and evaluation. The national director for systems analysis serves as the overall technical leader for the program. A five-year program plan has been drafted for the approval of the Department.

Important Linkages and Interfaces to Other DOE Programs

A very important link exists to the AFCI, owing to the strong common interest of the Generation IV Program and the AFCI in the development of advanced fuel cycle technology for the United States. In practice, the link is established by the sharing of several national technical directors with the AFCI whose functional disciplines are needed by Generation IV, and vice versa. Specifically, the areas of fuels, materials, chemical separations, and systems analysis are shared. While the projects of the two programs are separate, the overall managers of the resources maintain a view into the needs, activities, and accomplishments of both programs. In this way, the two programs share common technologies and avoid overlap and duplication of their efforts. The link to the Nuclear Power 2010 Program is also of considerable importance. The likelihood exists that technology developed for Generation IV systems—especially in the areas of fuel technology, system design, and, possibly, energy conversion technology—may be of near term benefit to the deployment of plants in the United States over the next few decades. The linkage is being made by the specific involvement of U.S. industry in the Generation IV Program as members of projects that are ongoing or planned, as well as being technical advisors in areas of key technology development for the program. This will allow U.S. industry to help define and develop technologies of interest to their near-term needs.

A key interface is with the Fusion Energy Program of the DOE Office of Fusion Energy Sciences. Fusion energy systems have a strong interest in the development of new materials for high-temperature, high-fluence conditions, and sharing of R&D with fission energy systems will afford many benefits for both. Other programs in defense and national security have similar interests in new materials. Interfaces will be created with the national technical director for materials in the Generation IV Program.

Another key interface is with the Yucca Mountain Project (YMP) of the DOE Office of Civilian Radioactive Waste Management. An interface already exists between the YMP and the AFCI for sharing repository requirements, operational parameters, and technology needs and developments. A similar interface with the national technical director for systems in the Generation IV Program will be created.

A third key interface is with the Hydrogen Fuel Initiative of the DOE Offices of Energy Efficiency and Renewable Energy and Fossil Energy. The sharing of requirements and technology needs and developments for future hydrogen production would benefit the Generation IV and hydrogen programs, and an interface for this purpose will be created with the national technical director for energy conversion in the Generation IV Program.