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NEW ENERGY TECHNOLOGIES: A POLICY FRAMEWORK FOR MICRONUCLEAR TECHNOLOGY

Energy supply and environmental challenges facing the industrialized world in recent years have rekindled interest in the expansion of electricity generation from nuclear power, but the continued development of traditional large-scale nuclear reactors for power generation has faced obstacles. Nuclear power could be a significant contributor to the long-term global sustainable energy mix, but to play this role successfully, nuclear power will have to overcome economic and political barriers, including concerns over commercial competitiveness for new plants, nuclear waste disposal, safety, and proliferation resistance.

In many countries where nuclear power plays a major role, governments are reducing their presence in the electricity generation business. Increasingly, governments are permitting market-related pricing structures and ownership of generation facilities by private companies. As electricity markets become increasingly deregulated, nuclear facilities will have to compete on commercial grounds with generators using other, less problematic fuel sources. The international nuclear industry is expected to find this competition increasingly daunting given the long lead times generally required for site approval and construction of nuclear power plants.

In the 44 years since the first nuclear power facility was launched, the nuclear energy industry has gone through a number of transformations. Nuclear energy currently provides about 6 percent of primary energy worldwide and about one-sixth of global electricity. Its contribution to energy security in Japan has been particularly significant. Through increased use of nuclear energy, Japan has been able to reduce oil use from 77 percent of its total primary energy mix in the 1970s to less than 55 percent in 2000. In the U.S., nuclear power from 103 reactors supplies 20 percent of all electricity.

There are currently 447 nuclear reactors producing electricity in 31 countries across the globe. Total capacity is 348 gigawatts. Another 37 reactors are under construction in 12 countries, including South Korea, China, and India. Japan has plans to build 13 new nuclear reactors in the coming years, but nuclear accidents, such as the major incident in 1999 at Tokaimura, have undermined public confidence in atomic power. No new reactor has been ordered in the United States for over 20 years.

The debate over development of nuclear power came to greater prominence this year following the endorsement of nuclear energy as a clean source of power by Vice President Dick Cheney in his report on U.S. energy needs. The vice president endorsed the recertification of the current 103 nuclear energy facilities operating in the U.S. to allow 20-year extensions. The 40-year operating terms of the U.S. reactors will begin expiring in 2006 and all but two will do so by 2030. The U.S. Nuclear Regulatory Commission (NRC) has already granted 20-year extensions to at least seven nuclear reactors in the last year. Vice President Cheney asserted that the development of nuclear power deserves a fresh look as the U.S. strives to reduce its dependence on foreign oil imports by increasing domestic energy supplies.

But even with the support of the Bush administration, the question remains whether the nuclear industry can overcome the economic, social, and political barriers to the continued growth of nuclear power.

All U.S. nuclear reactors currently in operation are large-scale plants using tested technologies such as boiling water reactors (BWRs) or pressurized water reactors (PWRs). These facilities use low-enriched uranium fuel rods in a reactor core to create a controlled nuclear chain reaction.

In response to the changing market and social requirements, nuclear power companies have instituted design changes that are intended to enhance safety. Already, three companies—General Electric (GE), Westinghouse Electric, and ABB Combustion Engineering—have won approval from the U.S.'s Nuclear Regulatory Commission (NRC) for a new generation of reactor designs. The commission's preapproval of these designs means that if a plant is ordered, opponents will not be able to challenge their construction on safety grounds. Instead of using mechanical pumps to deliver cooling water to the hot reactor core, the Westinghouse AP-600 uses a passive design, with cooling water stored in tanks right above the reactor. In case of an accident, gravity would activate the release of thousands of gallons of specially treated water into the reactor container. Westinghouse claims that its AP-600 requires 35 percent fewer pumps and 50 percent fewer valves than conventional reactors, thereby reducing the chance for equipment failure.

Innovative Designs for 2020 and Beyond

The pace of expansion of traditional large-scale plants appears to be slowing internationally. Several countries, including Japan, have recently announced reductions in the number of planned nuclear plants. Germany has announced plans to phase out its program by 2025.

Power grids in many countries that could consider utilization of nuclear power are not large enough to support deployment of very large units. Indeed, a key characteristic of electricity markets in the 21st century will likely be a move to smaller units. Industry, government, scientists, and engineers have begun to move away from the paradigm of large traditional centralized power stations and massive power grid models. Already, information technology firms are investing in colocated small or micropower sources to meet their energy needs more reliably. Microturbines, fuel cells, solar panels, and the like are examples of a new breed of flexibly distributed and utilized energy sources.

In response, new innovative designs for nuclear power deployment and utilization are under development. These designs, expected to come into play after 2020, aim to address the shortcomings of the traditional and newer larger-scale unit designs. Research and development have focused on making the reactors smaller with a reduced number of components and a simpler design that would produce a more simplified operation and maintenance. The designs conceptualize smaller plants that rely on passive safety systems and are more proliferation resistant. They promise that reactors could be constructed more rapidly and track actual capacity needs more closely, especially in the developing world. These new innovative reactors, it is hoped, can help nuclear power remain commercial in an increasingly competitive power generation market environment.

Among the most advanced new innovative designs under investigation are the International Reactor and Secure Nuclear Power System (IRIS) , a unique pressurized water reactor (PWR) concept with steam generators integrated within the reactor pressure vessel; the Pebble Bed Modular Reactor (PBMR), a modular graphite-moderated helium (He)-cooled reactor that employs fuel contained in small graphite-covered “balls” and a direct-cycle gas turbine (GT); the 4S, a sodium-cooled modular fast-reactor that is designed to operate for up to 30 years without refueling; and the Encapsulated Nuclear Heat Source Reactor (ENHS), a modular Pb-Bi (lead-bismuth) or lead-cooled reactor designed to function as a “nuclear battery,” as it is shipped to the site fueled and then replaced by a new module after 20 years of full-power operation.

In order to find a market, emerging nuclear technologies will have to offer significant advantages in five critical areas: commercial competitiveness, safety, waste disposal, proliferation resistance, and social acceptance. Several micronuclear concepts make clear gains in several of these five critical areas, but those gains are uneven and may not yet be sufficient to reverse the social and economic trends that are currently blocking the widespread growth of nuclear power.

In the area of safety, new innovative reactors eliminate the possibility of severe accidents with designs that rely on natural physical phenomena rather than on proper function of mechanical and electrical components such as pumps, valves, motors, and generators. Some of these new plant designs, by not relying on mechanical or other types of pumps that force coolant to circulate, have virtually eliminated the possibility of large loss-of-coolant-accidents (LOCA) or loss of all pumps (LOFA) (see working paper, Greenspan and Brown).

But the new SIR designs, which involve small, highly pressurized containments, do not eliminate the possibility of failure in the containment structure or problems that may arise from a degradation of materials, leaking pins, or other kinds of leaks. Moreover, autonomous systems can also fail or problems can arise with the fuel, says Ellis Merschoff, Administrator for Region 4 of the U.S. Nuclear Regulatory Commission (NRC).

It would also not be possible to fully test the fuel by heating it to extreme levels, creating a heavy reliance on testing at the theoretical modeling level. Given these and other factors, social acceptance might be low for new designs that do not allow for on-site inspections of the core while the plant is in operation, notes Ed Lyman, scientific director of the Nuclear Control Institute in Washington, D.C.

In the area of proliferation resistance, new designs offer several improvements: low frequency of refueling, restricted access to fuel, restricted access to neutrons, and elimination of the need by the host country to construct facilities that could be used for clandestine production of strategic nuclear materials. In several designs, the high burn-ups employed also lead to the generation of plutonium with an isotopic mix that significantly complicates its use in weapons production (see working paper, Greenspan and Brown).

However, no new reactor designs can be said to be proliferation proof. Advantages gained by very high burn-up rates can easily be obviated by operation at lower burn levels. Additionally, over time, the decay of the fission products will lower the radiation barrier of spent fuel, while the decay of PU-238 will make it easier to use the extracted plutonium for weapons.

Finally, the new reactor designs would use uranium that is more highly enriched than in current reactors, though still far from weapon-grade. This means that a potential proliferant, if successful in obtaining the uranium, would require less separation work for production of weapons-grade uranium than for ordinary light water uranium fuel (see working paper, Feiveson).

Some designs, such as SIR hub-spoke concepts, propose to cluster all sensitive nuclear facilities in centralized, heavily guarded nuclear parks, perhaps under international control. Long-life reactor cores would be assembled at the central facility, imagined either as an international center or a center located in a “safe” and stable country with established nuclear power programs. The reactors would be sealed and then exported to users in other countries where it could be “plugged in” to the remainder of the electric generation system for 15 years or so with no refueling. After some years, the core / spent fuel would be returned to the central facility or to some international spent fuel repository. Such international energy parks would clearly offer advantages over existing operating systems from the point of view of proliferation resistance. Practically speaking, however, the hub-spoke concept may be politically difficult to implement.

A key advantage to SIR designs is that their modularity may reduce the cost of building nuclear energy systems by shortening the extensive time now required for on-site construction, assembly, and equipment installation at traditional plants and by allowing plant size to be increased gradually to meet customized needs of clients. While construction times on conventional large-scale nuclear plants usually run four to five years in the best of circumstances, it is projected that the smaller units as reflected in the SIR designs could be built within roughly the same on-site construction time as gas turbine power systems which can be built in less than one year.

But such economy of scale advantages can only be replicated by producing many plants. Pilot projects will be needed to reduce the economic penalty of creating a factory just to make one plant. The chicken/egg problem of the manufacturing facilities for each module will, nonetheless, stand as a barrier to entry. In addition, cost estimates for the new designs, while on paper competitive, have yet to be verified by demonstration and operating experience. Experience in the development of the nuclear industry has shown that unexpected additions to operating costs cannot be ruled out.

Virtually whatever the reactor technology, waste disposal challenges will be daunting. If nuclear power were to become the electricity fuel of choice in line with the high-demand scenario of the Intergovernmental Panel on Climate Change (IPCC), worldwide capacity would rise to 6500 Gwe. If this total capacity were based on a once-through fuel cycle using light water reactors, it would generate roughly 1200 tons of plutonium annually (see working paper, Feiveson). If based on liquid-metal plutonium breeder reactors, it would involve the fabrication into fresh fuel annually of over ten thousand tons of plutonium. Given plausible burn-up rates, the spent fuel generated annually could hardly be less than about 50,000 tons—equivalent to one Yucca Mountain repository being constructed roughly every 18 months.

To gain social acceptance, a new technology must be beneficial and demonstrate enough trouble-free operation that people begin to see it as a “normal” phenomenon. Nuclear energy began to lose this status following a series of major accidents in its formative years. According to MIT professor Michael Golay, acceptance accorded to nuclear power may be trust based rather than technology based. In other words, acceptance might be related to public trust of the organizations and individuals utilizing the technology as opposed to understanding of the available evidence regarding the technology. Golay questions the entire concept that social acceptance of nuclear power can be gained through the creation of demonstrably safer technologies (see working paper, Golay).

While the U.S. nuclear industry has seen well over a decade or two of seemingly trouble-free operation that shows up in improved polling statistics for public acceptance, nuclear power’s global experience does not mirror this trend. Persistent problems in Japan and the former Soviet Union continue to fuel public safety concerns and in some cases, even a rise in antinuclear sentiment abroad, raising questions about whether nuclear energy can realistically register strong growth in the developing world.

It has been speculated that nuclear power’s contribution to limiting greenhouse gases will foster greater public acceptance for the fuel source. At present, nuclear energy worldwide generates approximately 2200 billion kWh per year. Were this amount of electricity generated instead by coal plants, an additional quantity of carbon dioxide containing 550 million metric tons of carbon would be emitted to the atmosphere each year. This is about 8.5 percent of total carbon emissions from fossil fuel combustion (6500 million tons per year). But if this electricity were generated by natural gas, the extra carbon emitted by the gas plants would be about two-fifths of the 550 metric tons noted above, or 220 million tons per year, a contribution of only about 1.5 percent to total extra carbon emitted over the coming thirty years. In the long run of 50 to 100 years, nuclear power could play a bigger role in reducing greenhouse gases but not decisively so.

Policy Implications and Conclusions

For nuclear power to gain a broader constituency over the long term, it will have to overcome stiff commercial competition from other fuel sources and technologies. For nuclear energy to face a viable future, technological innovation is needed that will address the serious challenges of waste management and proliferation risk.

A great number of the benefits that can be offered by new energy technologies, especially in environmental protection and providing diversity of supply and supply security, are public, rather than private, benefits. As the economics literature demonstrates, private firms are unlikely to provide such innovation at socially optimal prices. Thus, there is a strong argument for public sector investment in the development of improved energy technologies with significant environmental claims, such as small innovative reactors. The trick will be, however, how to implement such programs in a manner that doesn’t encourage the government to pick winners without considerable study and testing.

The first step to healthy and viable innovation is to ensure government support for training in energy technologies including nuclear science and technology. In the U.S., for example, there has been a precipitous drop in the number of American students studying nuclear engineering, and some leading universities are on the threshold of irrevocably cutting out relevant educational programs and infrastructures. The U.S. administration and relevant departments of government need to work with the university community to sustain nuclear science and technology education during the next decade in order to help preserve the nuclear power option. Similarly, Japan and other nations with a stake in nuclear energy must maintain R & D capabilities, and governments should promote support of long-term research, development, demonstration; innovation in waste management and disposal; preparation of human and technical infrastructure; and development of effective nuclear power regulations and restrictions that allow for a predictable and stable investment climate.

While national initiatives still hold promise, strategies must also reflect the growing trend toward internationalization of technological research. Linear and rigid development of nuclear power by single countries is becoming outdated, and the U.S., Japan, and other nations should work together to shape a future nuclear fuel cycle that can garner shared support. All nations have an interest in shaping future technologies that satisfy nonproliferation concerns and energy security needs while minimizing waste and enhancing safety.

To avoid the wasteful allocation of public funds on technologies that might not be able to attain public acceptance, stronger links are needed between the process of scientific design, evaluation, deployment, and public policy. It is important that scientific and technical innovation not be developed in isolation but that ideas eventually be vetted in forums designed to promote dialogue on the goals and benefits of emerging technologies as well as on their costs and drawbacks. In this fashion, it will be more difficult for design R & D to become entrenched. Deployment can be improved as a broader range of stakeholders, including public advocacy groups, industry representatives, public policy officials, academic public policy specialists, and diplomats, can influence the particulars of the development of new technologies, thereby improving the chances for social acceptance.

In order to achieve this purpose, the U.S. and other allied governments should support universities and think tanks to convene workshops on emerging nuclear and other energy technologies, opening to public debate various aspects of emerging designs and future deployment planning. Competing designs should be compared in relation to their technical merits, potential economic competitiveness, safety, environmental impact, proliferation resistance, and potential social acceptance. By bringing public action groups and other specialized commentators in at the conceptual ground floor, scientists and public policy decision-makers can receive public feedback and promote education about new designs before expensive demonstration manufacturing begins, creating more transparency of information for nonscientist policy-makers who participate in discussions of government budget R & D allocations on an annualized basis.

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Resolution of disposition of current nuclear power plant spent fuel and high-level defense waste will be critical to preserving viable nuclear options for the U.S. This will require high-level administration attention. The administration should work with states, nuclear utilities, and other stakeholders to develop a path forward to resolve current disputes and develop a viable strategy for the federal government to meet its responsibilities for accepting spent fuel and disposing of high-level waste fuel. Without a solution to this issue, nuclear power will have difficulty attaining the social acceptance needed to site new facilities and to remain a commercially viable option for electricity generation.

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