ECONOMIC ASPECTS OF NUCLEAR FUEL REPROCESSING

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

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ECONOMIC ASPECTS OF NUCLEAR FUEL REPROCESSING

TUESDAY, JULY 12, 2005

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:00 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Judy Biggert [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Economic Aspects of Nuclear Fuel Reprocessing

Tuesday, July 12, 2005
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building (WEBCAST)

Witness List

Dr. Richard K. Lester
Director of the Industrial Performance Center, and Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology

Dr. Donald W. Jones
Vice President of Marketing and Senior Economist at RCF Economic and Financial Consulting, Inc.

Dr. Steve Fetter
Dean of the School of Public Policy at the University of Maryland

Mr. Marvin Fertel
Senior Vice President and Chief Nuclear Officer at the Nuclear Energy Institute

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HEARING CHARTER

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Economic Aspects of Nuclear Fuel Reprocessing

TUESDAY, JULY 12, 2005
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Tuesday, July 12, the Energy Subcommittee of the House Committee on Science will hold a hearing to examine whether it would be economical for the U.S. to reprocess spent nuclear fuel and what the potential cost implications are for the nuclear power industry and for the Federal Government. This hearing is a follow-up to the June 16 Energy Subcommittee hearing that examined the status of reprocessing technologies and the impact reprocessing would have on energy efficiency, nuclear waste management, and the potential for proliferation of weapons-grade nuclear materials.

2. Witnesses

Dr. Richard K. Lester is the Director of the Industrial Performance Center and a Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology. He co-authored a 2003 study entitled *The Future of Nuclear Power.*

Dr. Donald W. Jones is Vice President of Marketing and Senior Economist at RCF Economic and Financial Consulting, Inc. in Chicago, Illinois. He co-directed a 2004 study entitled *The Economic Future of Nuclear Power.*

Dr. Steve Fetter is the Dean of the School of Public Policy at the University of Maryland. He co-authored a 2005 paper entitled *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel.*

Mr. Marvin Fertel is the Senior Vice President and Chief Nuclear Officer at the Nuclear Energy Institute.

3. Overarching Questions

- Under what conditions would reprocessing be economically competitive, compared to both nuclear power that does not include fuel reprocessing, and other sources of electric power? What major assumptions underlie these analyses?
- What government subsidies might be necessary to introduce a more advanced nuclear fuel cycle (that includes reprocessing, recycling, and transmutation—"burning" the most radioactive waste products in an advanced reactor) in the U.S.?

4. Brief Overview of Nuclear Fuel Reprocessing (from June 16 hearing charter)

- Nuclear reactors generate about 20 percent of the electricity used in the U.S. No new nuclear plants have been ordered in the U.S. since 1973, but there is renewed interest in nuclear energy both because it could reduce U.S. dependence on foreign oil and because it produces no greenhouse gas emissions.
- One of the barriers to increased use of nuclear energy is concern about nuclear waste. Every nuclear power reactor produces approximately 20 tons of highly radioactive nuclear waste every year. Today, that waste is stored onsite at the nuclear reactors in water-filled cooling pools or, at some sites, after sufficient cooling, in dry casks above ground. About 50,000 metric tons of commercial spent fuel is being stored at 73 sites in 33 states. A recent report issued by the National Academy of Sciences concluded that this stored waste could be vulnerable to terrorist attacks.

- Under the current plan for long-term disposal of nuclear waste, the waste from around the country would be moved to a permanent repository at Yucca Mountain in Nevada, which is now scheduled to open around 2012. The Yucca Mountain facility continues to be a subject of controversy. But even if it opened and functioned as planned, it would have only enough space to store the nuclear waste the U.S. is expected to generate by about 2010.
- Consequently, there is growing interest in finding ways to reduce the quantity of nuclear waste. A number of other nations, most notably France and Japan, "reprocess" their nuclear waste. Reprocessing involves separating out the various components of nuclear waste so that a portion of the waste can be recycled and used again as nuclear fuel (instead of disposing of all of it). In addition to reducing the quantity of high-level nuclear waste, reprocessing makes it possible to use nuclear fuel more efficiently. With reprocessing, the same amount of nuclear fuel can generate more electricity because some components of it can be used as fuel more than once.
- The greatest drawback of reprocessing is that current reprocessing technologies produce weapons-grade plutonium (which is one of the components of the spent fuel). Any activity that increases the availability of plutonium increases the risk of nuclear weapons proliferation.
- Because of proliferation concerns, the U.S. decided in the 1970s not to engage in reprocessing. (The policy decision was reversed the following decade, but the U.S. still did not move toward reprocessing.) But the Department of Energy (DOE) has continued to fund research and development (R&D) on nuclear reprocessing technologies, including new technologies that their proponents claim would reduce the risk of proliferation from reprocessing.
- The report accompanying H.R. 2419, the *Energy and Water Development Appropriations Act for Fiscal Year 2006,* which the House passed in May, directed DOE to focus research in its Advanced Fuel Cycle Initiative program on improving nuclear reprocessing technologies. The report went on to state, "The Department shall accelerate this research in order to make a specific technology recommendation, not later than the end of fiscal year 2007, to the President and Congress on a particular reprocessing technology that should be implemented in the United States. In addition, the Department shall prepare an integrated spent fuel recycling plan for implementation beginning in fiscal year 2007, including recommendation of an advanced reprocessing technology and a competitive process to select one or more sites to develop integrated spent fuel recycling facilities."
- During floor debate on H.R. 2419, the House defeated an amendment that would have cut funding for research on reprocessing. In arguing for the amendment, its sponsor, Mr. Markey, explicitly raised the risks of weapons proliferation. Specifically, the amendment would have cut funding for reprocessing activities and interim storage programs by $15.5 million and shifted the funds to energy efficiency activities, effectively repudiating the report language. The amendment was defeated by a vote of 110–312.
- But nuclear reprocessing remains controversial, even within the scientific community. In May 2005, the American Physical Society (APS) Panel on Public Affairs, issued a report, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk.* APS, which is the leading organization of the Nation's physicists, is on record as strongly supporting nuclear power. But the APS report takes the opposite tack of the Appropriations report, stating, "There is no urgent need for the U.S. to initiate reprocessing or to develop additional national repositories. DOE programs should be aligned accordingly: shift the Advanced Fuel Cycle Initiative R&D away from an objective of laying the basis for a near-term reprocessing decision; increase support for proliferation-resistance R&D and technical support for institutional measures for the entire fuel cycle."
- Technological as well as policy questions remain regarding reprocessing. It is not clear whether the new reprocessing technologies that DOE is funding will be developed sufficiently by 2007 to allow the U.S. to select a technology to pursue. There is also debate about the extent to which new technologies can truly reduce the risks of proliferation.
- It is also unclear how selecting a reprocessing technology might relate to other pending technology decisions regarding nuclear energy. For example, the U.S. is in the midst of developing new designs for nuclear reactors under DOE's Generation IV program. Some of the potential new reactors would

produce types of nuclear waste that could not be reprocessed using some of the technologies now being developed with DOE funding.

5. Brief Overview of Economics of Reprocessing

- The economics of reprocessing are hard to predict with any certainty because there are few examples around the world on which economists might base a generalized model.
- Some of the major factors influencing the economic competitiveness of reprocessing are: the availability and cost of uranium, costs associated with interim storage and long-term disposal in a geologic repository, reprocessing plant construction and operating costs, and costs associated with transmutation, the process by which certain parts of the spent fuel are actively reduced in toxicity to address long-term waste management.
- Costs associated with reducing greenhouse gas emissions from fossil fuel-powered plants could help make nuclear power, including reprocessing, economically competitive with other sources of electricity in a free market.
- It is not clear who would pay for reprocessing in the U.S. The options are: the government paying, the utilities themselves paying (not likely) or consumers paying in the form of higher electric rates. Passing the cost increases on to the consumer may not be as simple as it seems in the context of the current regulatory environment. In States with regulated utilities, regulators generally insist on using the lowest-cost source of electricity available and in States with competing electricity providers, the utilities themselves favor the lowest-cost solutions for the power they provide. To the extent that reprocessing raises the cost of nuclear power relative to other sources, reprocessing would be less attractive in both of these situations. As a result, utilities have shown little interest in reprocessing.
- Three recent studies have examined the economics of nuclear power. In a study completed at the Massachusetts Institute of Technology in 2003, *The Future of Nuclear Power,* an interdisciplinary panel, including Professor Richard Lester, looked at all aspects of nuclear power from waste management to economics to public perception. In a study requested by the Department of Energy and conducted at the University of Chicago in 2004, *The Economic Future of Nuclear Power,* economist Dr. Donald Jones and his colleague compared costs of future nuclear power to other sources, and briefly looked at the incremental costs of an advanced fuel cycle. In a 2003 study conducted by a panel including Matthew Bunn (a witness at the June 16 hearing) and Professor Steve Fetter, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel,* the authors took a detailed look at the costs associated with an advanced fuel cycle. All three studies seem more or less to agree on cost estimates: the incremental cost of nuclear electricity to the consumer, with reprocessing, could be modest—on the order of 1–2 mills/kWh (0.1–0.2 cents per kilowatt-hour); on the other hand, this increase represents an approximate doubling (at least) of the costs attributable to spent fuel management, compared to the current fuel cycle (no reprocessing). Where they strongly disagree is on how large an impact this incremental cost will have on the competitiveness of nuclear power. The University of Chicago authors conclude that the cost of reprocessing is negligible in the big picture, where capital costs of new plants dominate all economic analyses. The other two studies take a more skeptical view—because new nuclear power would already be facing tough competition in the current market, any additional cost would further hinder the nuclear power industry, or become an unacceptable and unnecessary financial burden on the government.

6. Background

For a detailed background on the advanced fuel cycle (sometimes referred to as the closed fuel cycle), including reprocessing technologies, waste management and non-proliferation concerns, please refer to the charter from our June 16 hearing on *Nuclear Fuel Reprocessing* (attached).

Economic Future of Nuclear Power

The single biggest cost associated with nuclear power is the capital cost, i.e., the upfront money required to build a new plant. The 100+ nuclear plants now operating in the U.S. were built in a highly regulated electricity market in which it was a given that the costs would be passed on to the consumers. As a result, most of the utilities that own these plants today have long since paid off the capital costs.

With low operations and maintenance costs, existing plants are competitive with other sources of electric power. Nuclear power currently supplies 20 percent of U.S. electricity and, for some States, nuclear power represents more than 50 percent of their electricity supply. Demand for electricity in the U.S. is growing rapidly. In order for nuclear power to continue to supply at least 20 percent of U.S. electricity, several new plants will need to be built in next 5–10 years. The economic future of nuclear power, however, could depend on the costs of building new plants in either a deregulated, competitive environment, or a regulated environment that favors the lowest-cost option. In both of these cases, the capital costs for new plants are not so easily passed on to the consumers.

In a larger context, concerns about global warming have led to a different view of the economic competitiveness of new nuclear generating capacity. Right now, coal is the cheapest source of electricity, and coal resources are abundant in the U.S. If the government were to enforce a carbon cap or tax on the utilities, the price of coal-fired power would go up. Some utilities and DOE are already investing in technologies to reduce emissions in anticipation of such a cap. DOE's R&D plan for coal calls for greenhouse gas capture and disposal to add no more than 10 percent to the cost of coal-fired power, but it remains unclear to what extent that goal is achievable. In general, any significant changes in energy demand patterns will influence the economic attractiveness of nuclear, a source of power that does not emit greenhouse gases.

Economics of Reprocessing versus Direct Disposal

Spent fuel management is only a small part of the total cost of nuclear power, but it is the part at issue in the reprocessing debate. There is general agreement between economic analyses[1,2,3] that, given the market price of uranium (approximately $60/kg), and international experience with reprocessing, it remains cheaper to mine and enrich uranium ore than to reprocess and recycle spent fuel. Other major factors that will influence the economic balance between reprocessing and direct disposal include the costs of uranium enrichment, interim storage, long-term disposal in a geologic repository (including construction costs for the repository), mixed oxide (MOX) fuel fabrication, construction and operation of the reprocessing plant itself, construction and operation of facilities to "burn" or transmute the unusable parts of the waste, and various transportation and security requirements. Good data are available for the costs of enrichment, interim storage, transportation and security. All of the other costs have to be estimated, and estimates vary widely in some cases. There are also (or will also be) differences, for some steps in the fuel cycle, between the underlying costs and the market price. Uranium supply and enrichment, for example, operate in a competitive market environment, keeping the profit margin fairly predictable. On the other hand, a lack of competition in reprocessing and MOX fuel fabrication, at least internationally, results in a more ambiguous relationship between cost and price.

Nuclear power in the U.S. has long been subsidized by the Federal Government. The commercial nuclear industry grew out of multi-billion dollar government-funded research and development programs on nuclear weapons. The DOE has ongoing programs of research, development and demonstration of advanced nuclear technologies in addition to the Nuclear Power 2010 Program (funded at nearly $50 million in fiscal year 2005) to subsidize the costs of siting and licensing new commercial reactors this decade. Pending energy legislation in the 109th Congress authorizes continued tax credits and other incentives for future nuclear energy. If the market price of reprocessing is higher than electricity producers are willing or able to bear, and the government decides that the public benefits exceed the costs, some form of government funding will be necessary to bring reprocessing into the nuclear fuel cycle in the U.S.

7. Witness Questions

Dr. Lester:

- Under what conditions would nuclear fuel reprocessing be economically competitive with the open fuel cycle and with other sources of electric power? What major assumptions underlie your analysis? What steps might be available to reduce the costs of reprocessing?

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[1] Harvard University study, Project on Managing the Atom, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel,* December 2003.
[2] MIT Nuclear Energy Study, *The Future of Nuclear Power,* 2003.
[3] University of Chicago Study, *The Economic Future of Nuclear Power,* August 2004.

- What would it cost to efficiently manage nuclear waste by further integrating the fuel cycle through development of a system that includes reprocessing, recycling, and transmutation ("burning" the most radioactive waste products in an advanced reactor)?
- What government subsidies might be necessary to introduce a more advanced nuclear fuel cycle in the U.S.? What assumptions underlie those estimates?
- How would a decision to reprocess affect the economic future of nuclear power in the U.S.?

Dr. Jones:

- Under what conditions would nuclear fuel reprocessing be economically competitive with the open fuel cycle and with other sources of electric power? What major assumptions underlie your analysis?
- How will a decision to reprocess affect the economic future of nuclear power in the U.S.?

Dr. Fetter:

- Under what conditions would nuclear fuel reprocessing be economically competitive with the open fuel cycle and with other sources of electric power? What major assumptions underlie your analysis? What steps might be available to reduce the costs of reprocessing?
- What would it cost to efficiently manage nuclear waste by further integrating the fuel cycle through development of a system that includes reprocessing, recycling, and transmutation ("burning" the most radioactive waste products in an advanced reactor)?
- What government subsidies might be necessary to introduce a more advanced nuclear fuel cycle in the U.S.? What assumptions underlie those estimates?
- How would a decision to reprocess affect the economic future of nuclear power in the U.S.?

Mr. Fertel:

- Is there a consensus position among the nuclear plant-owning utilities regarding whether the U.S. should introduce reprocessing into the nuclear fuel cycle within the next five or ten years?
- What government subsidies might be necessary to introduce a more advanced nuclear fuel cycle (that includes reprocessing, recycling, and transmutation—"burning" the most radioactive waste products in an advanced reactor) in the U.S.? What assumptions underlie those estimates?
- How would a U.S. move to reprocessing affect utilities' long-term business planning?

Chairwoman BIGGERT. The hearing of the Subcommittee on Energy of the Science Committee will come to order.

Good afternoon to all of you, and I apologize that we had votes, but I am glad you stayed around.

Welcome to today's hearing on the *Economic Aspects of Nuclear Fuel Reprocessing*. As promised, this hearing is a follow-up to our June 16 Energy Subcommittee hearing that examined the status of reprocessing technologies and the impact reprocessing would have on energy efficiency, nuclear waste management, and the potential for proliferation of weapons-grade nuclear materials.

Today, we are going to hear from a representative of the nuclear utility industry and from a number of renowned economists and scientists on the economics of the nuclear fuel recycle. In particular, we are going to discuss what additional costs or savings might result if we switched from an open fuel cycle to an advanced fuel cycle and how those costs and savings compare with other sources of energy, especially fossil fuels.

There are many reasons why the United States should embrace an advanced fuel cycle that uses reprocessing, recycling, and transmutation, or the burning of the most radioactive parts of spent fuel, as a way to deal with our nuclear waste problem.

First, if we were to recycle what we call "nuclear waste," which is actually nuclear fuel, we will increase the amount of energy obtained from uranium resources by a factor of 10. Second, by the time Yucca Mountain opens, it technically will be filled to capacity with all of the waste generated up to 2010, requiring the second repository, or an expanded Yucca Mountain, for future waste. Third, the advanced fuel cycle promises to reduce the volume of our high-level nuclear waste, potentially by a factor of 60. Fourth, it also could reduce the toxicity the heat and radioactivity of the waste so that it would only have to be stored for 300 years rather than 10,000. And last, the advanced fuel cycle could render another Yucca Mountain unnecessary even if the nuclear power industry grows.

Why didn't I include economics as one of the reasons the United States should embrace the advanced fuel cycle? Because as long as uranium is cheap and abundant, mining and enriching it will continue to cost less than reprocessing and recycling spent fuel. But let us face it, the Federal Government does a lot that isn't economical often because doing so is in the best interest of the Nation for other reasons.

For instance, federal tax credits make renewable energy economical. As a result of our growing use of wind and solar power, our energy supplies are more diverse, and our nation is more energy independent and secure. And the economics could change. Concerns about global climate change and clean air may, in the future, make it more expensive to produce electricity using fossil fuels. If, or when this happens, nuclear energy becomes much more economical. Current analysis of the competitiveness of nuclear power doesn't account for the billions we will have to spend to address greenhouse gas emissions from fossil fuels and global climate change.

While economies alone should not dictate a decision to close a fuel cycle, it is still extremely important that we, as lawmakers, understand the relationship between costs and benefits in order to

make informed decisions about managing the growing stockpile of spent nuclear fuel. Understanding the economics of the advanced fuel cycle will allow us to prioritize research and development to greatly reduce costs and significantly improve the economic feasibility of closing the fuel cycle.

Besides, continued R&D costs can be reduced based on lessons learned from international programs and a well reasoned integrated plan. In this way, we can help the Department of Energy, energy producers, and other interested parties develop the best policies and plans possible to deal with growing quantities of spent nuclear fuel. Once we understand what the costs are, a decision will have to be made about who most appropriately should assume those costs. Under the *Nuclear Waste Policy Act,* consumers already pay 1/10 of one cent per kilowatt-hour for the Federal Government to take possession and dispose of the Nation's spent nuclear fuel.

Until, or unless, the law changes, the responsibility falls to us to use this money wisely and to explore ways to reduce the volume and toxicity of spent nuclear fuel and maximize the capability of Yucca Mountain. As someone who supports nuclear power and whose home state derives 50 percent of its electricity from emissions-free nuclear power, I would hate to see the industry's future growth constrained when Yucca Mountain is full and no plan has been developed to manage the waste from new nuclear power plants.

That is why we are here today to make sure we have the right plan for managing our growing inventory of spent nuclear fuel in the most efficient, economical, and environmentally-sensitive way possible.

I want to thank the witnesses for being here to enlighten us today, and I look forward to their testimony.

But before we get to that, I will yield to the Ranking Member, Mr. Honda, for his opening statement.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

I want to welcome everyone to this hearing on what impact reprocessing and recycling might have on the economics of the nuclear fuel cycle should we, as a nation, choose to use these technologies to better manage our growing inventory of spent nuclear fuel.

This is the Energy Subcommittee's second hearing on the topic of reprocessing and recycling of nuclear waste. Our first hearing, which occurred less than a month ago, focused on technology decisions and proliferation issues. At that hearing, we heard about reprocessing technologies in various stages of development, and how these advanced technologies are more proliferation-resistant than the 30-year-old technologies currently used throughout the world.

Today we are going to hear from a representative of the nuclear utility industry and from a number of renowned economists and scientists on the economics of the nuclear fuel cycle. In particular, we are going to discuss what additional costs or savings might result if we switch from an open fuel cycle to an advanced fuel cycle, and how those costs and savings compare with other sources of energy, especially fossil fuels.

There are many reasons why the United States should embrace an advanced fuel cycle that uses reprocessing, recycling, and transmutation—or the burning of the most radioactive parts of spent fuel—as a way to deal with our nuclear waste problem.

First, if we were to recycle what we call nuclear "waste," which is actually nuclear "fuel," we could increase the amount of energy obtained from uranium resources by a factor of 10.

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But let's face it, the Federal Government does a lot that isn't economical—often because doing so is in the best interest of the Nation for other reasons. For instance, federal tax credits make renewable energy economical. As a result of our growing use of wind and solar power, our energy supplies are more diverse and our nation is more energy independent and secure.

And the economics could change. Concerns about global climate change and clean air may in the future make it more expensive to produce electricity using fossil fuels. If or when this happens, nuclear energy becomes much more economical. Current analyses of the competitiveness of nuclear power don't account for the billions we will have to spend to address greenhouse gas emissions from fossil fuels and global climate change.

While economics alone should not dictate a decision to close the fuel cycle, it is still extremely important that we, as lawmakers, understand the relationship between costs and benefits in order to make informed decisions about managing the growing stockpile of spent nuclear fuel. Understanding the economics of the advanced fuel cycle will allow us to prioritize research and development to greatly reduce costs and significantly improve the economic feasibility of closing the fuel cycle. Besides continued R&D, costs can be reduced based on lessons learned from international programs and a well-reasoned, integrated plan. In this way, we can help the Department of Energy, energy producers, and other interested parties develop the best policies and plans possible to deal with growing quantities of spent nuclear fuel.

Once we understand what the costs are, a decision will have to be made about who most appropriately should assume those costs. Under the Nuclear Waste Policy Act, consumers already pay one-tenth of one cent per kilowatt-hour for the Federal Government to take possession and dispose of the Nation's spent nuclear fuel. Until or unless the law changes, the responsibility falls to us to use this money wisely, and to explore ways to reduce the volume and toxicity of spent nuclear fuel and maximize the capacity of Yucca Mountain.

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That's why we are here today—to make sure we have the right plan for managing our growing inventory of spent nuclear fuel in the most efficient, economical, and environmentally-sensitive way possible. I want to thank the witnesses for being here to enlighten us today. I look forward to their testimony. But before we get to that, I will yield to the Ranking Member, Mr. Honda, for his opening statement.

Mr. HONDA. Thank you, Madame Chair. Thank you for holding this important hearing today.

The timing of this hearing is critical, because recently the President has been talking more and more about encouraging the development of nuclear power for electricity generation.

As I noted at our previous meeting on nuclear fuel reprocessing, the original "plan" for our nation's nuclear energy program was to recycle the fuel used in the reactors to reduce the amount of material defined as waste and stretch the supply of available material needed for fuel.

The plan never took hold due to two principle factors: concerns about nuclear weapons proliferation and economics.

At our last hearing, we heard about some of the technical issues surrounding reprocessing and the nonproliferation implications of

reprocessing. Today, I am hoping the witnesses can help us get a handle on the economic viability of nuclear waste reprocessing, because if we are going to use the power, we must deal with the waste.

Up until now, it has not made economic sense to develop a domestic recycling capacity, partly because of the stagnation that developed in the U.S. nuclear energy construction program.

Also, the so-called "megatons to megawatts" program that takes Russian weapons-grade uranium and down-blends it to lower concentrations needed for nuclear power reactors has helped to keep down the cost of reactor fuel, making reprocessing uneconomical.

And if the Administration succeeds in increasing the use of nuclear energy for the production of electricity over the next several decades, there will be significant consequences in terms of nuclear fuel demand and nuclear waste disposal.

On the one hand, the new demand for fuel may drive up the cost of fuel and make the economics of reprocessing as a means of supplying material for fuel more favorable.

On the other hand, extended operations of existing reactors and any new reactors that are built will exceed Yucca Mountain's capacity, leaving limited options for what to do with the waste.

Building a new repository would face significant siting and licensing challenges and is unlikely. Absent a new repository, our options are limited. On-site storage via dry casks is an option, but one which is inconsistent with the Federal Government's commitment to take control of the waste.

Reprocessing is another answer, but it may well drive the cost of nuclear power above that of other fuel sources, making it economically non-competitive without government subsidies.

It is critical that we determine what the true cost of dealing with the waste material from nuclear power plants is going to be before we follow the Administration's plan to rely more heavily on nuclear power for electricity generation.

And to do that, it is critical that we know how much reprocessing may cost. We need to understand the cost if we use today's techniques, as well as how much we will need to spend on research to develop new techniques, and how much those techniques will cost.

To pursue the President's desire to expand the use of nuclear power without having a good idea of how we are going to deal with the waste and how much dealing with it will cost is unwise.

I look forward to hearing from the witnesses on what they believe the true costs of spent nuclear fuel reprocessing are and whether it will ever be a viable, economical alternative.

Again, thank you, Madame Chairwoman, and I yield back the balance of my time.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

Madam Chairwoman, thank you for holding this important hearing today.

The timing of this hearing is critical, because recently the President has been talking more and more about encouraging the development of nuclear power for electricity generation.

As I noted at our previous hearing on nuclear fuel reprocessing, the original "plan" for our nation's nuclear energy program was to recycle the fuel used in the reactors, to reduce the amount of material defined as waste and stretch the supply of available material needed for fuel.

The plan never took hold due to two principal factors: concerns about nuclear weapons proliferation and economics.

At our last hearing, we heard about some of the technical issues surrounding reprocessing and the nonproliferation implications of reprocessing. Today, I am hoping that the witnesses can help us get a handle on the economic viability of nuclear waste reprocessing, because if we are going to use the power, we must deal with the waste.

Up until now, it has not made economic sense to develop a domestic recycling capacity, partly because of the stagnation that developed in the U.S. nuclear energy construction program.

Also, the so-called "megatons to megawatts" program that takes Russian weapons-grade uranium and down-blends it to the lower concentrations needed for nuclear power reactors has helped to keep down the cost of reactor fuel, making reprocessing uneconomical.

If the Administration succeeds in increasing the use of nuclear energy for the production of electricity over the next several decades, there will be significant consequences in terms of nuclear fuel demand and nuclear waste disposal.

On the one hand, the new demand for fuel may drive up the cost of fuel and make the economics of reprocessing as a means of supplying material for fuel more favorable.

On the other hand, extended operations of existing reactors and any new reactors that are built will exceed Yucca Mountain's capacity, leaving limited options for what to do with the waste.

Building a new repository would face significant citing and licensing challenges and is unlikely. Absent a new repository, our options are limited—on-site storage via dry casks is an option, but one which is inconsistent with the Federal Government's commitment to take control of the waste.

Reprocessing is another answer, but it may well drive the cost of nuclear power above that of other fuel sources, making it economically noncompetitive without government subsidies.

It is critical that we determine what the true cost of dealing with the waste material from nuclear power plants is going to be before we follow the Administration's plan to rely more heavily on nuclear power for electricity generation.

And to do that, it is critical that we know how much reprocessing may cost. We need to understand the cost if we use today's techniques, as well as how much we will need to spend on research to develop new techniques and how much those techniques will cost.

To pursue the President's desire to expand the use of nuclear power without having a good idea of how we are going to deal with the waste and how much dealing with it will cost is unwise.

I look forward to hearing from the witnesses what they believe the true costs of spent nuclear fuel reprocessing are and whether it will ever be a viable, economical alternative.

Thank you again Madam Chairwoman and I yield back the balance of my time.

Chairwoman BIGGERT. Thank you very much.

Any additional opening statements submitted by the Members may be added into the record.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to examine the economic aspects of nuclear fuel reprocessing technologies in the United States. Currently the U.S. does not reprocess spent fuel from nuclear power reactors and defense facilities. However, other countries, notably France and Japan, do reprocess their spent fuel. Generally, reprocessing has been prohibited because of concerns that the process preferred by the U.S. called PUREX, would make plutonium available in a form suitable for the fabrication of weapons by terrorists or countries seeking to become nuclear powers. Today's oversight hearing will explore the costs of locating, permitting and building an additional repository site. It will also discuss the risks and difficulties of pursuing the reprocessing options.

Within my home State of Illinois, the only nuclear engineering department is at the University of Illinois. This is particularly alarming because our state has 11 operating nuclear power reactors, Argonne National Laboratory, where Dr. Phillip Finck is from, and other nuclear facilities. Illinois residents have paid more than $2.4 billion on the federal Nuclear Waste Fund. My state has a large stake in nu-

clear power and technology and under-supported programs and initiatives that could improve upon our nuclear capabilities are quite troubling.

I am aware that Congress may be called on to consider policy options on waste reprocessing in the next few years as the Administration moves to change nuclear waste policies that essentially have been in place since the Carter Administration. Therefore, I am pleased we are holding this hearing today to gather information on the economics of nuclear waste processing.

I welcome our witnesses and look forward to their testimony.

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Chairwoman Biggert, Ranking Member Honda,

I want to thank you for organizing this very important Energy Subcommittee hearing on the economic aspects of nuclear fuel reprocessing. This is not an issue that is embedded in the public consciousness, but it should be. The issue of nuclear waste and what to do with it is one that we have grappled with for decades and is a question that will only gain in importance as time goes on. I welcome the witnesses to this subcommittee and hope that through their testimony we get closer to understanding all the complexities of this issue.

Nuclear energy is very much apart of our national energy policy and in fact reactors generate about 20 percent of the electricity used in the U.S. However, with nuclear energy comes the concern about nuclear waste. The fact is that every nuclear power reactor produces approximately 20 tons of highly radioactive nuclear waste every year. Currently there are a few different methods to deal with this waste, some of it is stored on-site at the nuclear reactors in water-filled cooling pools, or at some other sites, waste is stored in dry casks above ground after sufficient cooling. About 50,000 metric tons of commercial spent fuel is being stored at 73 sites in 33 states.

Unfortunately the issue of nuclear waste is not only a scientific one, but also a security issue. As a member of the Homeland Security Committee I know that nuclear materials of any kind represent a threat to our safety if targeted by terrorists. In addition, the reprocessing of waste is also a homeland security threat because current reprocessing technologies produce weapons-grade plutonium. Clearly, increasing the availability of such dangerous materials only heightens the risk to our nation.

I hope that through the course of this hearing that we will be able to move closer to finding a method for nuclear reprocessing that will not result in weapons-grade plutonium. I applaud the report accompanying H.R. 2419, the *Energy and Water Development Appropriations Act for Fiscal Year 2006,* which the House passed in May, which directed the DOE to focus research in its Advanced Fuel Cycle Initiative program on improving nuclear reprocessing technologies. The report stated, "The Department shall accelerate this research in order to make a specific technology recommendation, not later than the end of fiscal year 2007, to the President and Congress on a particular reprocessing technology that should be implemented in the United States. In addition, the Department shall prepare an integrated spent fuel recycling plan for implementation beginning in fiscal year 2007, including recommendation of an advanced reprocessing technology and a competitive process to select one or more sites to develop integrated spent fuel recycling facilities." Currently, the situation as it stands with nuclear waste is much akin to being stuck between a rock and a hard place. I have full faith in our scientific community to devise a solution to this vital issue.

Chairwoman BIGGERT. And at this time, I would like to introduce all of our witnesses, and thank you for coming before us this afternoon.

First, we have Dr. Richard K. Lester, who is the Director of the Industrial Performance Center, and a Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology. He co-authored a 2003 study entitled "The Future of Nuclear Power." Thank you. Dr. Donald W. Jones is Vice President of Marketing and Senior Economist at RCF Economic and Financial Consulting in Chicago, Illinois. He co-directed a 2004 study entitled "The Economic Future of Nuclear Power." Welcome to you. And then Dr.

Steven Fetter is the Dean of the School of Public Policy at the University of Maryland. He co-authored a 2005 paper entitled "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel." And last, but not least, is Mr. Marvin Fertel, who is the Senior Vice President and Chief Nuclear Officer at the Nuclear Energy Institute.

As the witnesses know, spoken testimony will be limited to five minutes each, after which Members will have five minutes each to ask questions.

So we will begin with Dr. Lester.

STATEMENT OF DR. RICHARD K. LESTER, DIRECTOR, THE INDUSTRIAL PERFORMANCE CENTER; PROFESSOR OF NUCLEAR SCIENCE AND ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. LESTER. Thank you, Madame Chairman and Members of the Committee. It is a great honor to be called before you to discuss the subject of nuclear fuel reprocessing. I would like to ask your indulgence and request a short delay in submitting my written testimony. The theft of my computer in the United Kingdom two days ago, unfortunately, makes this necessary.

Chairwoman BIGGERT. Yes, we understand that you had a robbery.

Dr. LESTER. Thank you.

Closing the nuclear fuel cycle, that is reprocessing spent fuel and recycling the recovered plutonium, has long been a dream of many in the nuclear power industry. Here in the United States, that dream has been elusive, but lately it has been rekindled as attention focuses once again on the future role of nuclear in meeting our nation's energy needs.

I firmly believe that a major expansion of nuclear power will almost certainly be necessary if our offices, industries, and homes are to be assured of access to adequate supplies of energy at reasonable costs and with proper regard for the environment. However, in my judgment, an attempt to introduce spent fuel reprocessing here in the United States in the near-term would not only not help to ensure a greater role for nuclear power, but would actually make this outcome less likely.

There is no disagreement that the operations needed to close the fuel cycle, reprocessing and the fabrication of mixed oxide fuel, are costly and that their introduction would cause an increase in the overall cost of nuclear electricity relative to the once-through cycle with direct disposal of spent fuel.

Opinions differ as to how large the cost penalty would be. But given that unfavorable economics is one of the main barriers to new nuclear energy investment, any course of action that would result in an increase in nuclear-generating costs should be viewed with caution.

Those advocating near-term reprocessing make three arguments in response to these concerns.

First, that the closed nuclear fuel cycle is indeed more costly, but the cost penalty isn't large, and so we shouldn't worry too much about it.

Second, that although the closed fuel cycle is more expensive than the open cycle under current economic conditions, in the future this comparison is likely to be reversed.

And third, that the economic penalty associated with reprocessing and recycle is outweighed by the non-economic benefits that would accrue. In the past, advocates of reprocessing have emphasized its contributions to extending fuel supplies and to energy supply security. Today the principal claim is that reprocessing will facilitate and simplify the management and disposal of nuclear waste.

These arguments are, on the surface, attractive, but on closer analysis, none of them is persuasive. I would like briefly to comment on each point in turn.

First, how large is the cost penalty associated with reprocessing and recycle likely to be? An exact answer is not possible, because some of the most important contributing factors are uncertain.

However, under current economic conditions, and making generally optimistic assumptions about how much reprocessing and mixed oxide fabrication services would cost were they to be available in the United States, I estimate that a U.S. nuclear power plant opting to use these services would incur a total nuclear fuel cycle cost of about 1.8 cents per kilowatt hour of electricity, which is just over three times the total cost of the once-through fuel cycle used by nuclear plants today. Since fuel cycle expenses account for about 10 percent of the total cost of nuclear electricity from unamortized nuclear power plants, with capital-related costs accounting for most of the remainder, this would be equivalent to adding about 20 percent to the total nuclear generation cost.

The impact of reprocessing is often expressed in terms of the average cost for the entire fleet of nuclear power plants, with just enough plants using mixed oxide fuel to consume all of the plutonium recovered by reprocessing the spent fuel from the rest of the plant population. In that case, and using the same economic assumptions, the effect of reprocessing and plutonium recycle would be to increase the fleet average fuel cycle cost by a little over 0.2 cents per kilowatt hour, or about 40 percent. The total nuclear electricity cost in that case would increase by about four percent. However, while fleet averaging may be appropriate for a centrally-planned nuclear power industry like that of, say, France, where the enforcement of cross-subsidy arrangements ensuring uniformity of cost impacts across the entire industry is perhaps plausible, this would not be the case in the United States. Here, in the absence of a federal subsidy, nuclear plant owners opting for the closed fuel cycle would either have to absorb the entire cost increase themselves or pass part or all of it on to their customers. In the competitive wholesale regional power markets in which many U.S. nuclear power plants today are operating, it is unlikely that either option would be attractive to plant owners.

Could today's negative economic prognosis for reprocessing be reversed in the future? For at least the next few decades, this seems extremely unlikely. For example, the purchase price of natural uranium would have to increase to almost $400 per kilogram for reprocessing to be economic. By comparison, the average price of uranium delivered to U.S. nuclear power reactors under long-term con-

tract last year was about $32 per kilogram. Alternatively, the cost of reprocessing would have to fall to less than 25 percent of the already optimistic referenced reprocessing cost I have assumed. In neither of these scenarios do the necessary price movements fall within the bounds of the credible.

Indeed, the needed reduction in reprocessing costs would be particularly implausible given the requirement to select a specific reprocessing technology for large-scale implementation as early as 2007, as is called for in recent legislation. This requirement would effectively force the adoption of the PUREX technology currently in use in France, the United Kingdom, and Japan, since no alternative would be available in that time scale. And there is simply no possibility of achieving a cost reduction of 75 percent, or anything close to it, for this relative mature technology. Nor would the adoption of PUREX technology fundamentally change either the impending problem of inadequate interim spent fuel storage capacity or the problem of finding a suitable site for final waste disposal.

Advanced reprocessing technologies, if coupled with transmutation schemes, could, in principle, improve the prospects for successful disposal. The goals would be to reduce the thermal load on the repository, thereby increasing its storage capacity, and to shorten the time for which the waste must be isolated from the biosphere. But even in the best case, these technologies will not be available for large-scale deployment for at least two or three decades, and perhaps not on any time scale. Furthermore, they would very likely be more costly than conventional PUREX reprocessing and MOX recycle technologies since they would entail more complex separations processes, more complete recovery of radionuclides, a more complex fuel fabrication process, and the need to transmute a broader array of radionuclides than just plutonium.

The MIT Study on the Future of Nuclear Power considered a range of advanced fuel cycle options from a waste management perspective and reached the following conclusion: "We do not believe that a convincing case can be made on the basis of waste management considerations alone that the benefits of advanced, closed fuel cycle schemes would outweigh the attendant safety, environmental, and security risks and economic costs."

The MIT report further concluded that waste management strategies in the open fuel cycle are available that could yield long-term risk reduction benefits at least as great as those claimed for advanced reprocessing and transmutation schemes and with fewer short-term risks and lower development and deployment costs.

For all of these—I am sorry.

Chairwoman BIGGERT. If you could just sum up and we will get to the rest of it with questions, I am sure.

Dr. LESTER. For all of these reasons, as well as others I have not discussed here, the MIT study concluded that reprocessing and MOX recycle is not an attractive option for nuclear energy for at least the next 50 years, even assuming a major expansion of the nuclear industry, both in the United States and overseas.

Thank you, Madame Chairman.

[The prepared statement of Dr. Lester follows:]

PREPARED STATEMENT OF RICHARD K. LESTER

Madam Chairwoman and Members of the Committee:

It is an honor to be called before you to discuss the subject of nuclear fuel reprocessing—a matter of considerable importance to the future of nuclear energy, as well as to the effort to prevent the further spread of nuclear weapons.[1]

Closing the nuclear fuel cycle—that is, reprocessing spent nuclear fuel and recycling the recovered plutonium—has been a dream of many in the nuclear industry from its earliest days. Here in the U.S. that dream has long been elusive, but lately it has been rekindled as attention focuses once more on the future role of the nuclear industry in meeting our nation's energy needs. I believe that a major expansion of nuclear power will almost certainly be necessary if our industries, offices, and homes are to be assured of access to adequate supplies of energy at reasonable cost and with proper regard for the environment, especially given the crucial need to curtail carbon dioxide emissions. However, in my judgment an attempt to introduce spent fuel reprocessing here in the U.S. in the near-term would not only not help to ensure a greater role for nuclear power but would actually make this outcome less likely.

Spent nuclear fuel from commercial light water reactors typically contains about one percent of plutonium. Recovering this plutonium and recycling it in so-called MOX or mixed uranium-plutonium oxide fuel would reduce the requirement for natural uranium ore by about 17 percent and the requirement for uranium enrichment services by a similar amount. But the operations needed to accomplish this—reprocessing and the fabrication of mixed-oxide fuel—are costly, and adopting them would cause an increase in the overall cost of nuclear electricity relative to the open or once-through fuel cycle with direct disposal of spent fuel. There is no disagreement about this, although opinions differ as to how large the cost penalty would be. But given that unfavorable economics has been one of the main barriers to nuclear energy investment for decades, and that it remains a major issue today, any proposed course of action that would result in an increase in nuclear generating costs should be viewed with caution.

Those who advocate near-term reprocessing make three arguments in response to these concerns:

> *First,* that the closed fuel cycle is indeed more costly, but that the cost penalty is not large, and so we should not worry too much about it.
>
> *Second,* that although the closed fuel cycle is more expensive than the open cycle under current economic conditions, in the future this comparison is likely to be reversed.
>
> *Third,* that the economic penalty associated with reprocessing and recycle is outweighed by the non-economic benefits that would accrue. In the past, advocates of reprocessing have emphasized its contributions to extending fuel supplies and to energy supply security. Today the principal claim is that reprocessing will facilitate and simplify the management and disposal of nuclear waste.

These arguments are superficially attractive, but on closer analysis none of them carries real weight. Indeed, the preponderance of evidence in each case points in the opposite direction, to the need to avoid the implementation of reprocessing in the near-term. I will briefly comment on each point in turn.

First, how large is the cost penalty associated with reprocessing and recycle likely to be? An exact answer is not possible, because some of the most important contributing factors are uncertain or otherwise difficult to estimate. The biggest source of uncertainty, with the largest impact on overall cost, is associated with reprocessing itself. Other important uncertainties center on the cost of MOX fuel fabrication, and the cost of disposing of reprocessed high-level waste relative to the direct disposal of spent fuel.

Under current economic conditions, and making generally optimistic assumptions about how much reprocessing and MOX fabrication services would cost were they to be available in the U.S., I estimate that a U.S. nuclear power plant opting to use these services would incur a total nuclear fuel cycle cost of about 1.8 cents per kilowatt hour of electricity. By comparison, the total cost of the once through fuel cycle is a little under 0.6 cents per kilowatt hour. In other words, nuclear power plants operating on the closed fuel cycle would experience a nuclear fuel cycle cost increase of about 300 percent. Since fuel cycle expenses account for about 10 percent of the

[1] A previous hearing of this subcommittee reviewed the security aspects of reprocessing. In this testimony I focus on the economic dimension.

total cost of nuclear electricity from unamortized nuclear power plants (capital-related costs account for most of the remainder), this would be equivalent to an increase of about 20 percent in the total nuclear generation cost.[2]

In this analysis, disposing of reprocessed high-level waste was assumed to be 25 percent less expensive than disposing of spent fuel directly. In fact, there can be little confidence today in any estimate of such cost savings, especially if the need to dispose of non-high-level waste contaminated with significant quantities of long-lived transuranic radionuclides generated in reprocessing and MOX fabrication is also taken into account. But even if the cost of disposing of reprocessed high-level waste were zero, the basic conclusion that reprocessing is uneconomic would not change.

The impact of reprocessing is often expressed in terms of the *average* cost for the entire fleet of nuclear power plants. The usual assumption is that the fleet would be configured so as to be in balance with respect to plutonium flows, with just enough power plants using MOX fuel to consume all the plutonium recovered by reprocessing the spent fuel from the rest of the plant population. In that case, and using the same economic assumptions as before, the effect of reprocessing and plutonium recycle would be to increase the fleet-average fuel cycle cost by about 0.23 cents/kilowatt hour, or about 40 percent. The total nuclear electricity cost would increase by about four percent. However, while fleet-averaging may be appropriate for a centrally-planned nuclear power industry like that of, say, France, where the enforcement of cross-subsidy arrangements ensuring uniformity of cost impacts across the entire industry is perhaps plausible, this would not be the case in the U.S. Here, in the absence of a direct federal subsidy, nuclear plant owners opting for the closed fuel cycle would either have to absorb the entire cost increase themselves or pass part or all of it on to their customers. In the competitive wholesale regional power markets in which many U.S. nuclear power plants operate, it is unlikely that either option would be attractive to plant owners.

Could today's negative economic prognosis for reprocessing be reversed in the future? For at least the next few decades this seems extremely unlikely. For example, even with the same optimistic assumptions for reprocessing and MOX fabrication costs as before, the purchase price of natural uranium would have to increase to almost $400/kg for reprocessing to be economic. By comparison, the average price of uranium delivered to U.S. nuclear power reactors under long-term contract during 2004 was about $32/kg.[3] In recent months uranium prices have moved sharply higher, with long-term contract prices as of mid-May reportedly exceeding $70/kg. But this is still far below the break-even price of $400/kg. Alternatively, could reprocessing costs decline to the point at which MOX fuel would be competitive with low-enriched uranium fuel? At current uranium prices the cost of reprocessing would have to fall below about $260/kgHM, a reduction of about 75 percent relative to the (already optimistic) reference reprocessing cost assumed here. In neither of these scenarios do the necessary price movements fall within the bounds of the credible.

Indeed, the needed reduction in reprocessing costs would be particularly implausible given a requirement to select a specific reprocessing technology for large-scale implementation as early as 2007, as is called for in recent House legislation. This

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[2] In this analysis, the cost of reprocessing is assumed to be $1,000 per kilogram of heavy metal in spent fuel. This is an optimistic assumption, and is considerably lower than the estimate made by Matthew Bunn and his colleagues for a new reprocessing plant with the same technical and cost characteristics as BNFL's Thermal Oxide Reprocessing Plant (THORP) at Sellafield in the UK. (See Matthew Bunn, Steve Fetter, John Holdren, and Bob van der Zwaan, "The Economics of Reprocessing versus Direct Disposal of Spent Fuel," Project on Managing the Atom, Kennedy School of Government, Harvard University, December 2003.) Any new reprocessing plant committed for construction for at least the next decade would necessarily be modeled closely on the PUREX technology employed at THORP and at the French fuel cycle firm Areva's reprocessing complex at La Hague. According to the Harvard study, the cost at such a plant would range from $1,350 to $3,100 per kilogram, depending on the financing arrangements used. The low end of the range assumes a government-owned plant, with access to capital at risk-free interest rates; the upper end would apply to a privately-owned plant with no guaranteed rate of return on investment. Reports over the last few years indicate that reprocessing contracts offered by THORP and by Areva's UP–3 reprocessing plant at La Hague have recently been in the $600–$900 per kilogram range. But both of these plants have now been fully amortized, and the offered prices are believed only to cover operating costs. Earlier contracts at these plants, for which the price included a capital cost recovery component, were reportedly in the $1,700–$2,300/kg range (see Bunn et al., op.cit.) Thus the $1,000/kg cost assumed here is conservative even with respect to past experience. Moreover, future reprocessing plants would almost certainly be required to meet more stringent and hence more costly safety and environmental specifications than the plants at Sellafield and La Hague, including a zero-emission requirement for gaseous fission products and the need to harden facilities against the risk of terrorist attack.

[3] Energy Information Administration, "Uranium Marketing Annual Report—2004 Edition," release date: 29 April 29 2005, at *http://www.eia.doe.gov/cneaf/nuclear/umar/umar.html.*

requirement would effectively force the adoption of the PUREX technology that is currently in use in France, the United Kingdom, and Japan, since no alternative would be available on that time scale. And there is simply no possibility of achieving a cost reduction of 75 percent—or anything close to it—for this relatively mature technology.

A similar point can be made about the waste management implications of reprocessing. The selection of PUREX reprocessing technology would not fundamentally change either the impending problem of inadequate interim spent fuel storage capacity or the problem of finding a suitable site for final waste disposal. The need for additional storage capacity and for a final repository, whether at Yucca Mountain or elsewhere, would still remain.

Advanced reprocessing technologies, if coupled with transmutation schemes, could in principle improve the prospects for successful disposal. Such schemes would partition plutonium and other long-lived actinides from the spent fuel—and possibly also certain long-lived fission products—and transmute them into shorter-lived and more benign species. The goals would be to reduce the thermal load on the repository, thereby increasing its storage capacity, and to shorten the time for which the waste must be isolated from the biosphere. It is important for research to continue on advanced fuel cycle technologies potentially capable of achieving these goals. But even in the best case these technologies are not likely to be available for large-scale deployment for at least two or three decades. Indeed, there is no guarantee that the desired performance objectives could be achieved on any time scale. The eventual economic impact of such schemes cannot now be predicted with confidence. But the strong likelihood is that they would be more costly than conventional PUREX reprocessing and MOX recycle, since they would entail more complex separations processes, more complete recovery of radionuclides, a more complex fuel fabrication process, and the need to transmute a broader array of radionuclides than just the plutonium isotopes.

The MIT Study on the Future of Nuclear Power considered a range of advanced fuel cycle options from a waste management perspective, and reached the following conclusion:[4]

> "We do not believe that a convincing case can be made on the basis of waste management considerations alone that the benefits of advanced, closed fuel cycle schemes would outweigh the attendant safety, environmental, and security risks and economic costs."

The MIT report further concluded that waste management strategies in the open fuel cycle are available that could yield long-term risk reduction benefits at least as great as those claimed for advanced reprocessing and transmutation schemes, and with fewer short-term risks and lower development and deployment costs. These strategies include both relatively incremental improvements to the currently preferred approach of building mined geologic repositories as well as more far-reaching innovations such as deep borehole disposal.

For all these reasons, as well as others I have not discussed here, including the adequacy of natural uranium resources and the risks of nuclear weapons proliferation, the MIT Study concluded that reprocessing and MOX recycle is not an attractive option for nuclear energy for at least the next fifty years, even assuming substantial expansion of the nuclear industry both here in the U.S. and overseas, and that the open, once-through fuel cycle is the best choice for the nuclear power sector over that period. The report recommends that:

> "For the next decades, government and industry in the U.S. and elsewhere should give priority to the deployment of the once-through fuel cycle, rather than the development of more expensive closed fuel cycle technology involving reprocessing and new advanced thermal or fast reactor technologies."

Research on advanced reprocessing, recycling, and transmutation technologies should certainly continue. A closed fuel cycle will be necessary if fast-neutron breeder reactors ever become competitive. But that does not seem likely for the foreseeable future, and for now the primary goal of fuel cycle research should be to maximize the economic competitiveness, the proliferation resistance, and the safety both short- and long-term of the once-through fuel cycle.

What if, in spite of these arguments, Congress still seeks to intervene to stimulate large scale reprocessing in the near-term? Because a purely private initiative would be economically unviable, such an intervention, to be effective, would inevitably re-

[4] MIT Study Group, *The Future of Nuclear Power,* Massachusetts Institute of Technology, 2003.

quire a major commitment of federal funds.[5] The need for direct government involvement would also place heavy demands on the government's nuclear-skilled human resources, who would necessarily be involved in the selection of a site, the development of a licensing framework, the management of contractors, and so on. The resources—both human and financial—that are potentially available to the government to support the development of nuclear power are not unlimited. A new federal reprocessing initiative would therefore risk diverting resources from other policy initiatives that are likely to make a greater positive contribution to the future of nuclear power over the next few decades.

BIOGRAPHY FOR RICHARD K. LESTER

Richard Lester is the founding Director of the MIT Industrial Performance Center and a Professor of Nuclear Science and Engineering at MIT. His research and teaching focus on industrial innovation and technology management, with an emphasis on the energy and environmental industries. He has led several major studies of national and regional competitiveness and innovation performance commissioned by governments and industrial groups around the world.

Professor Lester is also internationally known for his research on the management and control of nuclear technology, and at MIT he continues to teach and supervise students in the fields of nuclear waste management and nuclear energy economics and policy.

Professor Lester is a widely published author. His recent books include *Innovation—The Missing Dimension* (Harvard University Press, 2004), jointly authored with Michael J. Piore; *Making Technology Work: Applications in Energy and the Environment* (Cambridge University Press, 2003), with John M. Deutch; and *Global Taiwan* (M.E. Sharpe, 2005), co-edited with Suzanne Berger. Other books include *The Productive Edge: How American Industries Are Pointing the Way to a New Era of Economic Growth* (W.W. Norton, 1998), *Made By Hong Kong* (Oxford University Press, 1997) with Suzanne Berger, and *Made in America* (MIT Press, 1989) with Michael Dertouzos and Robert Solow. (With over 300,000 copies in print in eight languages, *Made in America* is the best-selling title in the history of MIT Press.)

Dr. Lester recently served as a member of the MIT study team that produced the 2003 report, *The Future of Nuclear Power,* and is currently participating in a follow-up MIT study on the global future of coal. Early in his career, Dr. Lester developed the Nation's first graduate-level course on nuclear waste management, and he is co-author, with Mason Willrich, of *Radioactive Waste: Management and Regulation* (Free Press, 1978).

Professor Lester obtained his undergraduate degree in chemical engineering from Imperial College and a doctorate in nuclear engineering from MIT. He has been a member of the MIT faculty since 1979. He serves as an advisor or consultant to numerous corporations, governments, foundations and non-profit groups, and lectures frequently to academic, business and general audiences throughout the world.

Chairwoman BIGGERT. Thank you very much.

Dr. Jones, you are recognized.

STATEMENT OF DR. DONALD W. JONES, VICE PRESIDENT OF MARKETING AND SENIOR ECONOMIST AT RCF ECONOMIC AND FINANCIAL CONSULTING, INC.

Dr. JONES. Good afternoon, Madame Chairman, Ranking Member Honda, and Members of the Energy Subcommittee of the House Committee on Science.

I am Dr. Donald W. Jones, Vice President of RCF Economic and Financial Consulting. Our firm, headquartered in Chicago, conducts analysis of energy and environmental issues, as well as other economic topics. Together with Dr. George S. Tolley, Professor Emeritus of Economics at the University of Chicago, I co-directed a study conducted at the University of Chicago entitled "The Economic Future of Nuclear Power." Our study was published in Au-

[5] A large new reprocessing facility using the same PUREX technology now in use in France and the UK would cost several billion dollars to build. The capital cost of the new Japanese PUREX reprocessing plant at Rokkasho-Mura reportedly exceeds $20 billion.

gust 2004 and was funded by the U.S. Department of Energy. My prepared statement today is based on the findings of our study. I ask that our study be submitted for the record.

Chairwoman BIGGERT. Without objection.

(The information appears in Appendix 2: Additional Material for the Record, p. 66.)

Dr. JONES. I have been asked by the Subcommittee to focus on the economics aspects of nuclear fuel reprocessing. In addition, the Subcommittee identified the following questions that should be specifically addressed. One, under what conditions would nuclear fuel reprocessing be economically competitive with the open fuel cycle and with other sources of electric power? What major assumptions underlie your analysis? And two, how would a decision to reprocess affect the economic future of nuclear power in the United States?

The financial model developed in our study projects that, in the absence of federal financial policies aimed at the nuclear industry, for example loan guarantees, accelerated depreciation, and investment or production tax credits, the first new nuclear plants coming on line will have a levelized cost of electricity, or LCOE, which is the price required to cover operating and capital costs, that ranges from $47 to $71 per megawatt hour. This price range exceeds projections of $33 to $41 for coal-fired plants and $35 to $45 for gas-fired plants. Our assumptions for new nuclear plants included accepted ranges of capital costs, $1,200 to $1,800 per kilowatt overnight costs, with a three percent risk premium on loans and equity, and seven-year estimated construction time. We found that capital cost is the single most important factor determining the economic competitiveness of nuclear power. After first-of-a-kind engineering costs are paid and the construction of the first few nuclear plants has been completed, there is a good prospect that lower LCOEs can be achieved that would allow nuclear to be directly competitive in the marketplace, without subsidies. For fossil generation, the assumptions included conservative, or low, ranges of capital and fuel costs. Recent increases in coal and gas prices will raise LCOEs for coal-fired and gas-fired plants. In the long-term, the competitiveness of new nuclear plants will be markedly enhanced by policies that required fossil-fired plants to control greenhouse gas emissions.

Our projected costs for new nuclear plants included nuclear fuel costs estimated at $4.35 per megawatt hour. This estimate included the cost of raw uranium ore, its conversion, its enrichment, and the cost to fabricate the nuclear fuel. An additional $1 per megawatt hour was included for the nuclear waste fee. The on-site storage cost was estimated to be about 10 cents per megawatt hour. Thus, the total nuclear fuel cycle cost, assuming direct disposal, is less than 10 percent of overall LCOE for the first few nuclear plants. The back-end costs are estimated to even a smaller percentage, about two percent of the cost of electricity.

Our study also examined the costs of reprocessing spent nuclear fuel. We used publicly available estimates: estimates reported by the Nuclear Energy Agency; work done at Harvard University, under the auspices of Matthew Bunn et al., "Project on Managing the Atom;" and work done by Simon Lobdell, "The Yucca Mountain Repository and the Future of Reprocessing." NEA estimated that

reprocessing costs were about $2.40 per megawatt hour, Bunn et al.'s estimate is about $1,000 per kilogram of heavy metal, or about $2.65 per megawatt hour, and Lobdell's estimate is about $2.80 per megawatt hour. Thus, the average of these estimates is about $2.65 per megawatt hour, which still represents a small percentage of the LCOE, a little less than five percent for the first new nuclear plants. The study did not include the added fabrication costs with recycling plutonium and uranium, or any net costs beyond the levelized cost estimates for an advanced reactor to consume the remaining actinides.

While the first new nuclear plants would not be competitive with fossil generation without some form of temporary assistance, reprocessing would have little influence on the assistance required to make it competitive. If carbon sequestration were to be required for fossil-fired generation, even the first new nuclear plants, with reprocessing, would be competitive.

To summarize, reprocessing would not be an important economic influence on the competitiveness of new nuclear plants under current regulatory and fuel-price circumstances. In addition, as pointed out in our study, there are broad policy issues that will more likely influence the choice to pursue reprocessing and more advanced fuel cycles than the economic factors.

Thank you very much, Madame Chairman and Subcommittee Members. This concludes my statement, and I would be pleased to answer any questions you might have.

[The prepared statement of Dr. Jones follows:]

PREPARED STATEMENT OF DONALD W. JONES

Good morning, Madame Chairwoman, Ranking Member Honda, and Members of the Energy Subcommittee of the House Committee on Science. I am Dr. Donald W. Jones, Vice President of RCF Economic and Financial Consulting. Our firm, headquartered in Chicago, conducts analysis of energy and environmental issues, as well as other economic topics. Together with Dr. George S. Tolley, Professor Emeritus of Economics at The University of Chicago, I co-directed a study conducted at The University of Chicago, entitled "The Economic Future of Nuclear Power." Our study was published in August 2004, and was funded by the U.S. Department of Energy. My prepared statement today is based on the findings of our study. I ask that our study be submitted for the record.

I have been asked by the Subcommittee to focus on the economic aspects of nuclear fuel reprocessing. In addition, the Subcommittee identified the following questions that should be specifically addressed:

1. Under what conditions would nuclear fuel reprocessing be economically competitive with the open fuel cycle and with other sources of electric power? What major assumptions underlie your analysis?
2. How would a decision to reprocess affect the economic future of nuclear power in the U.S.?

The financial model developed in our study projects that, in the absence of federal financial policies aimed at the nuclear industry (e.g., loan guarantees, accelerated depreciation, and investment or production tax credits), the first new nuclear plants coming on line will have a levelized cost of electricity (LCOE, i.e., the price required to cover operating and capital costs) that ranges from $47 to $71 per megawatt-hour (MWh). This price range exceeds projections of $33 to $41 for coal-fired plants and $35 to $45 for gas-fired plants. Our assumptions for new nuclear plants included accepted ranges of capital costs ($1,200 to $1,800 per kW overnight costs), with a three percent risk premium on loans and equity, and seven-year estimated construction time. We found that capital cost is the single most important factor determining the economic competitiveness of nuclear power. After first-of-a-kind engineering costs are paid and construction of the first few nuclear plants has been completed, there is a good prospect that lower LCOEs can be achieved that would allow nuclear

to be directly competitive in the marketplace (without subsidies). For fossil generation, the assumptions included conservative (low) ranges of capital and fuel costs. Recent increases in coal and gas prices will raise LCOEs for coal-fired and gas-fired plants. In the long-term, the competitiveness of new nuclear plants would be markedly enhanced by policies that required fossil-fired plants to control greenhouse gas emissions.

Our projected costs for new nuclear plants included nuclear fuel costs estimated at $4.35 per MWh. This estimate included the cost of raw uranium ore, its conversion, its enrichment, and the cost to fabricate the nuclear fuel. An additional $1 per MWh was included for the nuclear waste fee. The on-site storage cost was estimated to be about $0.10 per MWh. Thus, the total nuclear fuel cycle cost, assuming direct disposal, is less than ten percent of overall LCOE for the first few nuclear plants. The back-end costs are estimated to be even a smaller percentage, about two percent of the cost of electricity.

Our study also examined the costs of reprocessing spent nuclear fuel. We used publicly available estimates: estimates reported by Nuclear Energy Agency; work done at Harvard University, under the auspices of Mathew Bunn et al., "Project on Managing the Atom;" and work done by Simon Lobdell, "The Yucca Mountain Repository and the Future of Reprocessing." NEA estimated that reprocessing costs were about $2.40 per MWh, Bunn et al.'s estimate is about $1,000 per kilogram of heavy metal or about $2.65 per MWh, and Lobdell's estimate is about $2.80 per MWh. Thus, the average of these estimates is about $2.65 per MWh, which still represents a small percentage of the LCOE, about five percent, for the first new nuclear plants. The study did not include the added fabrication costs with recycling plutonium and uranium, or any net costs beyond the levelized cost estimates for an advanced reactor to consume the remaining actinides.

While the first new nuclear plants would not be competitive with fossil generation without some form of temporary assistance, reprocessing would have little influence on the assistance required to make it competitive. If carbon sequestration were to be required for fossil-fired generation, even the first new nuclear plants, with reprocessing, would be competitive.

To summarize, reprocessing would not be an important economic influence on the competitiveness of new nuclear plants under current regulatory and fuel-price circumstances. In addition, as pointed out in our study, there are broad policy issues that will more likely influence the choice to pursue reprocessing and more advanced fuel cycles than the economic factors.

Thank you very much Madame Chairwoman and Subcommittee Members. This concludes my statement, and I would be pleased to answer any questions you might have.

BIOGRAPHY FOR DONALD W. JONES

Donald Jones is Vice President and Senior Economist at RCF Economic and Financial Consulting in Chicago. In 2003 and 2004, he co-directed, with George Tolley of the University of Chicago's Economics Department, the Chicago study of the future of nuclear power in the United States. Prior to joining RCF, he has been a research staff member at Oak Ridge National Laboratory and has served on the faculties of the University of Chicago, the University of Colorado-Boulder, and the University of Tennessee. His background in energy includes price impacts of electricity deregulation, electricity reliability, energy conservation, renewable energy, environmental aspects of energy supply, strategic petroleum reserves, the macroeconomic impacts of oil supply disruptions, international trade in energy technologies, and various aspects of energy in economic development. He received his Ph.D. from the University of Chicago in 1974.

Chairwoman BIGGERT. Thank you very much.

Dr. Fetter, you are recognized.

STATEMENT OF DR. STEVE FETTER, DEAN, SCHOOL OF PUBLIC POLICY, UNIVERSITY OF MARYLAND

Dr. FETTER. Madame Chairman and Members of the Subcommittee, it is an honor to be invited here today to discuss the economics of reprocessing.

In a recent study of this issue with colleagues at Harvard University, we searched for information on the costs of reprocessing

and other fuel cycle services and examined studies by the OECD, the governments of France and Japan, the National Academy of Sciences, MIT Chicago, and others. I draw on these studies to address the specific questions raised in your letter to me.

First, under what conditions would reprocessing be economically competitive? There is widespread agreement that reprocessing is significantly more expensive than direct disposal. Official studies in France and Japan agree with this conclusion. At last year's average uranium prices, reprocessing would have to cost less than $400 per kilogram of spent fuel to be competitive with the once-through fuel cycle. For comparison, we estimate that reprocessing in a new U.S. facility built and operated by a private entity, similar to those in the United Kingdom and France, would cost over $2,000 per kilogram, five times more. But even if it only costs $1,000 per kilogram, which might be possible with government subsidies, the price of uranium would have to rise eight fold, to about $400 per kilogram, to break even with the once-through fuel cycle. We believe it is extremely unlikely that uranium prices will rise to this level in the next 50 years, even if nuclear power expands dramatically.

The PUREX process that has been in use—the PUREX process has been in use for more than five decades, and it is unlikely that dramatic cost reductions could be achieved with this or similar processes, such as UREX+. In fact, increasingly stringent environmental and safety regulations will put countervailing pressures on costs. The experience at the facility in Japan, which has seen capital cost estimates triple to $18 billion, should serve as a cautionary tale to any country contemplating reprocessing.

Pyroprocessing has also received attention, but a 1996 review by the National Academy concluded that it is by no means certain that pyroprocessing will be more economical than PUREX. And more recent reviews concluded that it would be substantially more expensive.

Second, what would it cost to manage nuclear waste through a system of reprocessing and transmutation? It is important to note that traditional approaches to reprocessing and recycle, as practiced in France and planned in Japan, do not have waste disposal advantages. That is because the required repository space is determined by the heat output of the wastes, not by their mass or volume. If just the plutonium recovered during reprocessing is recycled in existing reactors, the build up of heat-generating isotopes results in greater overall waste heat output.

Substantial reductions in repository requirements can be achieved only if all of the major, long-lived heat generating radionuclides are separated and transmuted. But a separation and transmutation system would be far more expensive than direct disposal.

How much more expensive? The 1996 National Academy report concluded that the excess cost would be "no less than $50 billion and easily could be over $100 billion for 62,000 tons of spent fuel." This is in addition to the cost of Yucca Mountain, which would still be needed for the disposal of high-level reprocessing waste.

Third, what government subsidies might be necessary? Because there is no commercial incentive to develop a system that is more

expensive for waste disposal, the U.S. Government would have to build and operate the required separations and transmutation facilities or create a legal framework that required reactor operators to reprocess their spent fuel. Based on the Academy estimate, which I think is conservative, the extra cost would be $100 to $200 billion to separate and transmute all of the spent fuel that has been or will be discharged by current reactors, assuming they all receive license extensions. These extra costs could be funded by tripling or quintupling the nuclear waste fund fee, thereby passing the extra costs, perhaps $2 to $3 billion per year at current levels of nuclear generation, along to the rate payer.

Fourth, how would reprocessing affect the economic future of nuclear power? I think nuclear power will become more attractive as natural gas prices rise and as we attempt to reduce carbon dioxide emissions. But nuclear will still have to compete with alternatives. Traditional reprocessing would add, perhaps, seven percent to the price of nuclear electricity. A separation and transmutation system would add still more. This can only hurt nuclear power in the economic competition with alternatives and could make the difference between a revitalized industry and continued stagnation.

Advocates of reprocessing point to the difficulty in opening Yucca Mountain as a barrier to the expansion of nuclear power. Reprocessing would not eliminate the need for Yucca Mountain, but a separation and transmutation system could delay, or perhaps even eliminate, the need to expand Yucca Mountain or build a second repository if nuclear expands. But I believe it would be far more difficult to gain public acceptance and licensing approval for the large number of separation and transmutation faculties that would be required as compared with an expansion of Yucca Mountain. Reprocessing has been fiercely opposed for decades, and there would be stiff opposition to having taxpayers, or ratepayers, subsidize this enterprise at the rate of several billion dollars per year.

Thank you, Madame Chairman.

[The prepared statement of Dr. Fetter follows:]

PREPARED STATEMENT OF STEVE FETTER

Madam Chairwoman and Members of the Committee:

It is an honor to be invited here today to discuss the economic aspects of nuclear fuel reprocessing. Together with colleagues at Harvard University, I recently completed an in-depth study of this issue,[1] the results of which were published recently in the journal *Nuclear Technology*.[2] In the course of this study we conducted an exhaustive search for information on historical and projected costs of reprocessing and other nuclear fuel-cycle services. We also examined previous studies of fuel-cycle economics by the Nuclear Energy Agency of the Organization of Economic Cooperation and Development (OECD), the governments of France and Japan, the U.S. National Academy of Sciences, the Massachusetts Institute of Technology, and others. Our conclusions are therefore well-grounded, and we have made our results transparent by documenting all of our assumptions and methods and by making spreadsheet versions of our economic models available on the web, so that anyone can reproduce

[1] Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003), available at *http://www.puaf.umd.edu/Fetter/2003-Bunn-repro.pdf*.

[2] Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, "The Economics of Reprocessing versus Direct Disposal of Spent Nuclear Fuel," Nuclear Technology, Vol. 150, pp. 209–230 (June 2005), available at *http://www.puaf.umd.edu/Fetter/2005-NT-repro.pdf*.

and check our results. With this background, let me turn to the specific questions raised in your letter to me.

Under what conditions would reprocessing be economically competitive with the once-through fuel cycle?

In the once-through fuel cycle, spent nuclear fuel discharged from light-water reactors is placed in a deep geological repository, such as the one being built at Yucca Mountain in Nevada. The main alternative, as practiced in France and planned in Japan, is to reprocesses spent fuel to separate the unburned plutonium and uranium from other radionuclides. The recovered plutonium is used to produce mixed-oxide (MOX) fuel for existing light-water reactors, and the high-level radioactive wastes are vitrified and stored pending disposal in a deep geologic repository. It is important to note that reprocessing does not eliminate high-level wastes or negate the need for a repository.

There is widespread agreement, in the United States and abroad, that reprocessing currently is significantly more expensive than direct disposal.[3] This is because reprocessing itself is an expensive process, and also because the MOX fuel produced using the recovered plutonium is more expensive, at current uranium prices, than the low-enriched uranium (LEU) that is normally used to fuel reactors. Last year, operators of U.S. nuclear reactors on average paid $33 per kilogram for uranium.[4] At this uranium price, reprocessing would have to cost less than $400 per kilogram of spent fuel in order to be competitive with direct disposal.[5] For comparison, we estimate that reprocessing in a new U.S. facility, similar to those in the United Kingdom and France, would cost over $2,000 per kilogram.[6] But even if reprocessing costs could be halved, to $1,000 per kilogram of spent fuel, the price of uranium would have to rise to nearly $400 per kilogram in order to break even with the once-through fuel cycle. It is extremely unlikely that uranium prices will rise to this level in the next 50 years, even if worldwide use of nuclear power expands dramatically.

Substantial reductions in the cost of reprocessing would be needed even to achieve the $1,000 per kilogram mentioned above. The Plutonium Redox Extraction (PUREX) process used in existing facilities has been perfected over more than five decades, and it seems unlikely that dramatic cost reductions could be achieved using this or similar aqueous technologies, such as UREX+. Moreover, increasingly stringent environmental and safety regulations will put countervailing pressures on costs. The experience at the Rokkasho-Mura reprocessing facility in Japan, which has seen initial capital cost estimates triple to $18 billion, should serve as a cautionary tale for any country contemplating going down this road.

A range of alternative chemical separations processes have been proposed over the years. Recently, attention has focused on electrometallurgical processing or "pyroprocessing." A 1996 review by the National Academy of Sciences concluded, however, that "it is by no means certain that pyroprocessing will prove more economical" than PUREX. Indeed, recent official reviews have concluded that such techniques are likely to be substantially more expensive than PUREX.[7]

It is conceivable, of course, that at some point in the long-term future research and development could lead to a fundamentally different approach that might have

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[3] See, for example, J-M. Charpin, B. Dessus, and R. Pellat, "Economic Forecast Study of the Nuclear Power Option," Office of the Prime Minister, Paris, France (July 2000); "Interim Report Concerning the Nuclear Fuel Cycle Policy," New Nuclear Policy-planning Council, Japan Atomic Energy Commission (November 2004), summary available at http://cnic.jp/english/topics/policy/chokei/longterminterim.html; *The Future of Nuclear Power* (MIT, 2003); available at http://web.mit.edu/nuclearpower.

[4] Energy Information Administration, Uranium Marketing Annual Report, 2004 Edition, 29 April 2005; available at *http://www.eia.doe.gov/cneaf/nuclear/umar/umar.html.*

[5] Computed with the spreadsheet available at http://www.puaf.umd.edu/Fetter/programs/COE-LWR.xls, using reference assumptions that are favorable to reprocessing, including a 50 percent reduction in waste-disposal costs.

[6] Assumes a plant throughput of 800 tons of spent fuel per year for 30 years; an overnight capital cost of $6 billion, repaid at interest rates appropriate for a regulated private entity with a guaranteed rate of return; annual operating costs of $560 million per year, and standard assumptions about construction time, taxes and insurance, and contingency, pre-operating, and decommissioning costs. For a government-financed facility with very low cost of money, the corresponding cost would be $1,350/kg; for an unregulated private venture, the cost would be $3,100/kg. See Bunn, et al., "The Economics of Reprocessing versus Direct Disposal of Spent Nuclear Fuel," p. 213.

[7] Generation IV Roadmap: Report of the Fuel Cycle Crosscut Group, U.S. Department of Energy, Office of Nuclear Energy, Washington, DC (March 2001); "Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study," OECD/NEA 03109, Organization for Economic Cooperation and Development, Nuclear Energy Agency (2002).

lower costs. But it does not appear likely that the cost of reprocessing will be reduced to levels that would be economically competitive with direct disposal in the foreseeable future.

What would it cost to manage nuclear waste through a system that includes reprocessing, recycling, and transmutation?

Traditional approaches to reprocessing and recycle, as practiced in France and planned in Japan, do not significantly reduce the amount of repository space required for the disposal of high-level radioactive wastes. The required repository area is determined by the heat output of the wastes, not by their mass or volume. If the plutonium recovered during reprocessing is recycled in existing light-water reactors, the build-up of heat-generating minor actinides would result in a greater total heat output from wastes than if the same amount of electricity was generated using the once-through fuel cycle.

Substantial reductions in repository requirements can be achieved only if all of the major long-lived heat-generating radionuclides are separated from the spent fuel and recycled as fuel for fast-neutron reactors, which can transmute these long-lived radionuclides. This separation-and-transmutation system would, however, almost certainly be far more expensive than the direct disposal of spent fuel, per unit of electricity generated. This is because reprocessing is expensive, because the costs of fabricating and using the highly radioactive fuel would be high, and because the fast-neutron reactors required to transmute the long-lived radionuclides will cost significantly more than light-water reactors.

How much more expensive? The National Academy of Sciences examined this question in a 1996 report and concluded that the excess cost for a separation-and-transmutation system over once-through disposal would be "no less than $50 billion and easily could be over $100 billion" for 62,000 tons of spent fuel (the current legislated limit on Yucca Mountain).[8] This conclusion remains valid today; there have no technical breakthroughs or dramatic cost reductions in either separation or transmutation technologies. Again, the separation-and-transmutation system would generate high-level wastes requiring geologic disposal and therefore would not eliminate the need for the Yucca Mountain repository.

What government subsidies might be necessary to introduce a separation-and-transmutation fuel cycle in the United States?

Today, nuclear reactor operators pay a small fee—$1 per megawatt-hour of electricity produced (about two percent of the wholesale price of nuclear-generated electricity)—for the geologic disposal of spent fuel. This fee, which is deposited into the Nuclear Waste Trust Fund, is considered adequate to pay for the full costs of geologic disposal.

As noted above, a separation-and-transmutation system would be considerably more expensive than direct disposal. Because there is no commercial incentive to develop a more expensive system for the disposal of disposal of wastes, the U.S. Government would, at a minimum, have to assume the entire costs of research and development, which would likely total several billion dollars. Given the lack of market incentives, the U.S. Government might also have to build and operate the required separations and transmutation facilities. If the National Academy's estimate is correct, the total extra cost would be $50 to $100 billion to process the 62,000 tons of fuel planned for Yucca Mountain. If the licenses of all currently operating reactors are extended, the amount of spent fuel and the total extra cost would be about twice as large—$100 to $200 billion—and would be still larger if new reactors are built. These extra costs could be funded by tripling or quintupling the nuclear waste fund fee, thereby passing the extra costs—$1.5 to $3 billion per year at current levels of nuclear generation—along to the rate payer. Alternatively, Congress could create a legal framework that would require reactor operators to reprocess their spent fuel, thereby artificially stimulating a market for private reprocessing and transmutation facilities. The final result would be the same, however: nuclear-generated electricity would become more expensive.

How would a decision to reprocess affect the economic future of nuclear power?

No nuclear reactors have been ordered in the United States since 1978, and no reactor ordered after 1974 was completed. Although public concern about reactor ac-

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[8] U.S. National Research Council, Committee on Separations Technology and Transmutation Systems, *Nuclear Wastes: Technologies for Separations and Transmutation,* National Academy Press, Washington DC (1996); executive summary available at *http://books.nap.edu/html/nuclear/summary.html.*

cidents had a role in the stagnation of nuclear power, it was driven primarily by economic considerations: in particular, the high capital costs and high financial risk of nuclear power compared to alternative methods of generating electricity or managing demand for electricity.

Increasing natural gas prices, and especially efforts to mitigate climate change by reducing emissions of carbon dioxide from the burning of fossil fuels, will increase the attractiveness of nuclear power. But nuclear power will still have to compete with other alternatives, including wind power, biomass, and coal-fired power plants with carbon sequestration. Traditional reprocessing would likely add three to seven percent to the wholesale price of nuclear-generated electricity, depending primarily on the cost of reprocessing;[9] a full separation-and-transmutation system would add still more. This can only hurt nuclear power in the economic competition with alternative methods of generating electricity, and could make the difference between a revitalized industry and continued stagnation and decline.

Advocates of reprocessing often point to the difficulty in licensing Yucca Mountain as a barrier to the expansion of nuclear power. As noted above, reprocessing would not eliminate the need for Yucca Mountain. A separation-and-transmutation system could, however, greatly delay—and might even eliminate—the need to expand the capacity of Yucca Mountain or to build a second repository. (As a purely technical matter, it is likely that the Yucca Mountain repository could be expanded to hold all of the waste that will be discharged by current reactors, even with license extensions.) Advocates of a separation-and-transmutation system implicitly assume that it would be easier to gain public acceptance and licensing approval for a large number of complex and expensive separation and transmutation facilities than for an expansion of Yucca Mountain or a second repository. This assumption is likely wrong. Reprocessing of spent fuel has been fiercely opposed by a substantial section of the interested public in the United States for decades, and there would stiff opposition to having taxpayers or ratepayers subsidize this enterprise at the rate of several billion dollars per year.

BIOGRAPHY FOR STEVE FETTER

Steve Fetter is Dean of the School of Public Policy at the University of Maryland, College Park, where he has been a Professor since 1988. His research interests include nuclear arms control and nonproliferation, nuclear energy and health effects of radiation, and climate change and carbon-free energy supply.

Fetter serves on the National Academy of Sciences' Committee on International Security and Arms Control, the Department of Energy's Nuclear Energy Research Advisory Committee, the Department of Homeland Security's WMD Infrastructure Experts Team, the Board of Directors of the Sustainable Energy Institute and the Arms Control Association, the Board of Governors of the RAND Graduate School, the Advisory Board of Human Rights Watch's Arms Division, the University of Chicago's Advisory Committee on Nuclear Non-Proliferation, and the Board of Editors of Science and Global Security. He is a fellow of the American Physical Society, a recipient of its Joseph A. Burton Forum Award, and a member of its Panel on Public Affairs.

Fetter served as special assistant to the Assistant Secretary of Defense for International Security Policy (1993–94), and as an American Institute of Physics fellow (2004) and a Council on Foreign Relations international affairs fellow (1992) at the State Department. He has been a visiting fellow at Stanford's Center for International Security and Cooperation, Harvard's Center for Science and International Affairs, MIT's Plasma Fusion Center, and Lawrence Livermore National Laboratory. He has served as Vice Chairman of the Federation of American Scientists, and as Associate Director of the Joint Global Change Research Institute.

Fetter received a Ph.D. in energy and resources from the University of California, Berkeley, in 1985 and a S.B. in physics from MIT in 1981.

His articles have appeared in *Science, Nature, Scientific American, International Security, Science and Global Security, Nuclear Technology, Bulletin of the Atomic Scientists,* and *Arms Control Today.* He has contributed chapters to nearly two dozen edited volumes, is author or co-author of several books and monographs, including *Toward a Comprehensive Test Ban, The Future of U.S. Nuclear Weapons Policy, The Nuclear Turning Point, Monitoring Nuclear Weapons and Nuclear Explo-*

[9] Assuming reprocessing costs of $1,000 to $2,000 per kilogram of spent fuel, uranium at $50 per kilogram, and other costs that are generally favorable to reprocessing, the additional cost of reprocessing and recycle is $1.3 to $3.5 per megawatt-hour; the assumed wholesale electricity price is $50/MWh for direct disposal.

sive Materials, Effects of Nuclear Earth-Penetrator and Other Weapons, and *Climate Change and the Transformation of World Energy Supply.*

School of Public Policy
University of Maryland
College Park, MD 20783

11 June 2005

The Honorable Judy Biggert
Chairman, Subcommittee on Energy
Committee on Science
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

Dear Ms. Biggert,

With regard to my testimony on "Economic Aspects of Nuclear Fuel Reprocessing" before your subcommittee on 12 June 2005:

I do not currently receive any federal funding, nor have I ever directly received federal funding to support research on the economic aspects of nuclear fuel reprocessing. I, did, however, collaborate in research on this topic which was supported in part by the U.S. Department of Energy under award DE-FG26-99FT40281 to Harvard University.

Sincerely,

Steve Fetter
Dean and Professor

Chairwoman BIGGERT. Thank you very much.

And now, Mr. Fertel, you are recognized for five minutes.

STATEMENT OF MR. MARVIN S. FERTEL, SENIOR VICE PRESIDENT AND CHIEF NUCLEAR OFFICER, THE NUCLEAR ENERGY INSTITUTE

Mr. FERTEL. Thank you. Madame Chairman, Ranking Member Honda, Members of the Subcommittee, on behalf of the Nuclear Energy Institute, more than 250 members, I thank you for the opportunity to testify today on the economic aspects of nuclear fuel reprocessing. I would also like to thank this subcommittee for its leadership in addressing other issues important to the nuclear industry, like support for university programs and workforce activities. Thank you very much.

With specific regard to reprocessing, I would like to emphasize the following key points to start.

First, reprocessing could play an important role in the future of nuclear energy by providing needed nuclear fuel supplies, but it must be integrated into the overall nuclear fuel cycle.

Second, current reprocessing technology offers limited short-term benefits to use nuclear fuel disposal but has the future potential to provide benefits that will make disposal more efficient and cost effective. Under all circumstances, however, we will still need a deep geologic repository to dispose of the residual waste and Yucca Mountain will still be necessary.

Third, potentially, reprocessing in the United States and other reliable nations could further non-proliferation goals, but the additional costs associated with Federal Government reprocessing to achieve those goals should not be borne by the electricity customers.

And fourth, and important to this subcommittee, I think, the Federal Government should put in place firm, long-range policies that support reprocessing and pursue the research, development, and demonstration of new improved proliferation-resistant reprocessing technologies.

In preparing for this hearing, the Committee asked me to address three questions. First, is there a consensus position among the nuclear plant owning utilities regarding whether the United States should introduce reprocessing into the nuclear fuel cycle within the next five to 10 years?

Within the U.S. nuclear industry, a dialogue on the benefits of reprocessing is really just beginning. However, what seems clear at this time is that the long-term benefits to fuel supply and waste management of improved recycling technologies warrants a systematic research and development program. And that R&D program should certainly be well-developed and producing results within the next five to 10 years. The actual deployment of new reprocessing facilities in this country would take more than a decade to license, construct, and commission after the R&D was completed and then appropriate technologies were selected.

The decision of when to actually deploy recycling technology should be based upon a combination of considerations, including the growth of nuclear energy in this country, the market economics of the fuel supply system, government decisions regarding the management and ultimate disposal of used nuclear fuel, and non-proliferation strategies, which could involve the taking of used fuel from outside the United States and/or the provision of mixed oxide fuel to users outside the United States.

The second question asked by the Committee related to what government investment might be necessary to introduce a more advanced nuclear fuel cycle in the United States.

As I mentioned earlier, from a commercial industry perspective, the dialogue and assessments of reprocessing, transmutation, and the use of fast reactors is at an early stage, and we have not performed any economic evaluations of the alternatives and have just begun to study the experience of other countries, like, France, England, and Japan.

However, in the countries that have reprocessing, the decision was based on government policy. And the resources committed to develop, deploy, and operate the technology were all government funded. Assuming similar policy decisions in the United States and the actual deployment of new recycling technology, the need for federal investment, if any, would be determined by the difference

between the cost of producing reactor fuel versus the market price for fuel at that time. While no others are willing to provide the Committee with such estimates, the industry has not performed the evaluations necessary to provide such estimates with any degree of confidence.

The last question asked was how would the United States move to reprocessing impact utilities' long-term business planning.

First, it is important to recognize that decision on reprocessing impact more than the long-term business planning for utilities. Such decisions would have direct and potentially profound, though not necessarily negative, impacts on the fuel supply sector, including uranium producers, converters, enrichers, and fabricators. For both utilities and fuel suppliers, certainty in government policy, certainty in performance of the technology and in its deployment and economics will be the factors that would impact long-term business planning the most.

As currently demonstrated by Duke Power, the use of mixed oxide fuel is clearly an acceptable fuel supply option, therefore, accommodating fuel produced after reprocessing is neither a major technical nor regulatory issue that couldn't be accommodated into long-term planning. The greater planning challenges relate to consistent, long-term, stable government policy, high reliability of performance of stability—of facilities and stability in the price of that fuel produced.

In closing, President Bush's energy plan in 2001 called for development of, and I will quote, "reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste intensive, and more proliferation-resistant." The nuclear energy industry supports that goal. Now 40 years later and with the growing recognition of the need for more nuclear plants in this country and worldwide, it is even more imperative that our nation move forward to complete the research on reprocessing technology and to define the government policies affecting the use of that technology.

We look forward to working with the Committee, others in Congress, and the Administration towards achieving those goals.

Thank you for the opportunity to appear here today, and I would be pleased to answer any questions you may have.

[The prepared statement of Mr. Fertel follows:]

PREPARED STATEMENT OF MARVIN S. FERTEL

The Nuclear Energy Institute (NEI) appreciates the opportunity to provide this testimony for the record on reprocessing used fuel from commercial nuclear power plants. The nuclear energy industry recognizes that safe, secure and efficient management of the Nation's used nuclear fuel is critical to ensuring nuclear energy's future contribution to our nation's energy supply.

NEI is responsible for developing policy for the U.S. nuclear energy industry. Our organization's 250 member companies represent a broad spectrum of interests, including every U.S. energy company that operates a nuclear power plant. NEI's membership also includes nuclear fuel cycle companies, suppliers, engineering and consulting firms, national research laboratories, manufacturers of radiopharmaceuticals, universities, labor unions and law firms.

America's nuclear power plants are the most efficient and reliable in the world. Nuclear energy is the largest source of emission-free electricity in the United States and our nation's second largest source of electricity after coal. Nuclear power plants in 31 states provide electricity for one of every five U.S. homes and businesses. More

than eight out of 10 Americans believe nuclear energy should play an important role in the country's energy future.[1]

Given these facts and the strategic importance of nuclear energy to our nation's energy security and economic growth, NEI encourages Congress to maintain policies that ensure continued operation of our nation's nuclear plants, and to provide the impetus required to expand emission-free nuclear energy as a vital part of our nation's diverse energy mix.

This testimony makes four important points:

- Reprocessing could play an important role in the future of nuclear energy by providing needed nuclear fuel supplies, but it must be part of an economic nuclear fuel cycle;
- Current reprocessing technology offers limited assistance to used nuclear fuel disposal, but has the future potential to provide benefits that will make disposal more efficient and cost effective;
- Potentially, reprocessing in the United States and other reliable nations could further non-proliferation goals, but the additional costs associated with reprocessing to achieve these goals should not be borne by the electricity consumer; and
- The Federal Government should put in place firm, long-range policies that support reprocessing and pursue the research, development and demonstration of new, improved, proliferation-resistant reprocessing technologies.

INDUSTRY CONSENSUS

The fuel used by nuclear power plants in the United States comes from newly mined uranium or uranium that has been derived from nuclear weapons from the former Soviet Union and blended down to a much lower enrichment level that is appropriate for commercial reactors. The cost of nuclear fuel is an important component and it accounts for 25 percent of the production cost of electricity from nuclear plants. Uranium must be processed through milling, conversion, enrichment, and fabrication to be made into nuclear fuel usable in power reactors.

The safe and efficient management of used nuclear fuel rods is a critical component of the nuclear energy industry's exemplary record of safety and environmental stewardship. The Federal Government is developing a specially designed, underground repository at Yucca Mountain, Nev., to manage used fuel from our nation's commercial reactors and defense sites. The Yucca Mountain program has made significant progress over the past few years and is expected to move into the licensing phase in the near future.

The consensus in the nuclear energy industry is that nuclear fuel costs should be kept as low as possible, consistent with the need for a competitive long-term fuel supply. Doing so may require reprocessing nuclear fuel to provide fuel supplies well into the future, but that period is difficult to predict. There are numerous unknown factors, such as future demand and cost of uranium, the cost of reprocessing and the reprocessing technology to be used.

The re-emergence of nuclear energy in the United States, together with rapidly expanding nuclear energy sectors in nations such as China and India, will place additional pressure on uranium supplies and increase uranium prices still further. This could increase the attractiveness of reprocessing, but would do so only at prices that are well above today's market. Reprocessing also would increase access to fuel supplies by making recycled fuel available and thereby reduce the volume of uranium imported by the United States.

In a "closed" fuel cycle, fuel from reprocessing would be another avenue of supply for the nuclear fuel market. Utilities would evaluate supplies from reprocessed fuel and the use of mixed-oxide fuel in the same way they consider the variety of suppliers of new fuel today. These factors include cost, reliability and diversity of supply; quality of fuel; and the effect of the fuel on reactor core design. Long-term business planning would be affected in terms of supplier and fuel design, but only if the overall costs are equal to or lower than fuel from current suppliers.

Developing new reprocessing technologies for used nuclear fuel in the United States also offers the long-term potential for aiding used nuclear fuel disposal and furthering global non-proliferation goals. At the moment, the United States does not

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[1] Bisconti Research Inc./NOP World, May 2005, Survey of 1,000 U.S. adults with a margin of errors at +/- three percentage points. Question: "How important do you think nuclear energy will be in meeting this nation's electricity in the years ahead? Do you think nuclear energy will be very important, somewhat important, not too important, or not important at all?" Responses: 83 percent important, 13 percent not important, four percent don't know.

have the policies, the technologies nor the infrastructure in place to support reprocessing.

In 2001, President Bush's energy plan called for development of ". . .reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste intensive and more proliferation resistant."[2] The nuclear energy industry supports this goal. U.S. leadership in nuclear energy research and development is vital to our national interests and will result in a safer world by safeguarding nuclear weapons material and technologies.

REPROCESSING IS A WORTHY FUTURE GOAL, BUT HAS CHALLENGES TO OVERCOME

Of the 33 nations that use nuclear power, 12 reprocess used nuclear fuel for a variety of reasons. France, Japan and the United Kingdom use Purex technology for their reprocessing programs, which recycle used reactor fuel safely and securely. Japan will continue to use reprocessing facilities in France and Britain until its Rokkasho Reprocessing Plant opens in the near future at a reported cost of $18 billion. It is worth noting that all these facilities were paid for through some form of government funding.

Future reprocessing of used nuclear fuel is a worthy goal, but it must overcome several challenges before it can be used in the United States. Currently, the cost of nuclear fuel from reprocessing is more expensive than new production of fuel. Any reprocessing also requires massive and expensive facilities, similar to large chemical plants, that the public or private sector must develop and license with the U.S. Nuclear Regulatory Commission. In the end, the use of reprocessing would not lessen the need for a national repository, but it would reduce the volume of material to be managed at the facility. Other byproducts, radioactive and non-radioactive, from the reprocessing plant also must be managed. In addition, reprocessing poses security considerations that governments worldwide must address.

Current reprocessing technology makes it possible to recycle and reuse uranium and plutonium from commercial nuclear fuel. This is done by separating radioactive waste from uranium and plutonium that still contain energy. The reusable fuel can be returned to reactors, but only after significant additional processing and fuel fabrication in specially designed and licensed facilities. In addition, the same long-lived radioactive waste products remain and ultimately require disposal. With current technology, the recycled material has a limited life time and will eventually require disposal. Countries that currently reprocess nuclear fuel also are working to develop geologic repositories.

Until the mid-1970s, the U.S. Government encouraged reprocessing using the Purex process, which chemically separates plutonium from uranium in the fuel rods. This process was first used to produce plutonium for the nuclear weapons program. Later, commercial reprocessing facilities were established in Barnwell, S.C.; Morris, Ill.; and West Valley, N.Y. President Gerald Ford suggested suspending the use of reprocessing in 1976 in view of nonproliferation concerns relating to plutonium. President Jimmy Carter acted on the ban the following year. President Ronald Reagan lifted the ban on reprocessing in the 1980s, but economic factors prevented any new investment in the technology. The ban was reinstated under President Bill Clinton and remains in effect today.

Early commercial reprocessing ventures in the United States were not successful. The West Valley facility operated for a short period of time in the late 1960s and early 1970s, then was shut down because of rising costs and regulatory uncertainties. It took a federal program and funding to clean up the facility. The Morris facility never operated because of technical difficulties and serves today as a used nuclear fuel storage facility. The Barnwell facility was not completed because of rising costs, falling uranium demand in that era and regulatory uncertainty.

The difficulties encountered by these early efforts need to be addressed in any reprocessing program going forward. Foremost among these is the need for a firm, unchanging national policy that supports development of reprocessing and a set of regulatory standards and implementing guidelines tailored to reprocessing plants.

REPROCESSING CAN REDUCE WASTE VOLUME, BUT YUCCA MOUNTAIN IS STILL NEEDED

No technology can destroy radioactivity from used nuclear fuel and other high-level radioactive wastes, nor is there a proven means to shorten the time that the material is radioactive. Reprocessing can only separate the various radionuclides and change their chemical and physical form. Scientists are studying technologies,

[2] "National Energy Policy—Report of the National Energy Policy Development Group," May 2001.

such as accelerator- and reactor-based transmutation, that may eventually reduce the radioactivity in used nuclear fuel. However, none of these could eliminate radioactivity altogether. Any program involving reprocessing, transmutation or related technologies must be undertaken in conjunction with a federal repository.

Disposal capacity for used nuclear fuel should not be a deterrent to future expansion of nuclear energy. Depending on future industry expansion, additional used nuclear fuel disposal capacity will be needed, but it is impossible at this time to know when and how much capacity will be needed. Federal policies must consider all contingencies and remain flexible.

The Nuclear Waste Policy Act limits Yucca Mountain's capacity to 70,000 metric tons (MT) of used nuclear fuel or the high-level radioactive waste derived from 70,000 MT of used nuclear fuel. Current plans call for 63,000 MT of commercial used fuel and 7,000 MT of defense used nuclear fuel or the high-level waste derived from used fuel. The Department of Energy estimates that there will be at least 70,000 MT at various sites throughout the United States when the Yucca Mountain repository opens.

Congress established the capacity limitation on Yucca Mountain artificially, not by technical analysis. If the capacity of Yucca Mountain were to be increased to its technical limit, it still might not be enough to preclude the need for a second repository given the expected expansion of nuclear energy. However, reprocessing could reduce the volume of waste and possibly make additional repositories unnecessary.

In addition, current reprocessing of used fuel from commercial nuclear power plants could reduce the number of used fuel containers needed to store, transport and dispose used nuclear fuel, which would lower the cost of DOE's waste management program. This needs to be explored further as a possible benefit from reprocessing.

REPROCESSING MUST OVERCOME COST, BUT NOT AT THE EXPENSE OF NUCLEAR ENERGY

The debate over reprocessing of used nuclear fuel in the United States is longstanding. Reprocessed fuel is more expensive than new uranium oxide fuel. In addition, reprocessing requires new capital-intensive facilities and other infrastructure that must be licensed by the Nuclear Regulatory Commission.

The use of reprocessing would require significant investment. New fuel fabrication and enrichment facilities also will be needed. Federal agencies, such as the Nuclear Regulatory Commission, must license and provide independent government oversight of these new facilities. All of this will take many years to accomplish.

If the Federal Government determines that used nuclear fuel should be reprocessed, nuclear energy consumers should not bear the additional costs of reprocessing. Unlike other energy sources, the nuclear power sector covers the costs of its "externalities," including nuclear power plant decommissioning and used nuclear fuel disposal. Under the Nuclear Waste Policy Act, the Federal Government collects fees (one-tenth of a cent per kilowatt-hour from consumers of electricity generated at nuclear power plants) that are intended to pay for Yucca Mountain and associated programs. No other energy source covers its waste management costs in this manner. Assessing an additional fee for reprocessing would unnecessarily raise the cost of nuclear-generated electricity and create an inequitable situation that would harm the competitiveness of the U.S. energy sector.

NON-PROLIFERATION GOALS CAN BE ADVANCED BY REPROCESSING DEVELOPMENT IN THE UNITED STATES

Non-proliferation is the other principle challenge facing reprocessing, because current reprocessing technology yields separated plutonium. In sophisticated hands and with the right expertise and facilities, plutonium recovered from commercial reactor fuel can be made into a crude nuclear weapon. Opposition to the reprocessing initiatives in North Korea is based on concerns over the production of plutonium for nuclear weapons. However, after being used in mixed oxide reactor fuel (MOX), plutonium is less suitable for weapons applications. The United States recently began testing weapons-grade plutonium fabricated into MOX fuel as a means of eliminating plutonium.

The United States should pursue proliferation-resistant reprocessing technologies. By developing reprocessing in the United States and other reliable nations, we can better assure a fuel supply for the global nuclear energy sector and limit the risks associated with reprocessing.

DOE is investigating several new technologies as part of its Advanced Fuel Cycle Initiative. These include the Urex process, which recovers the uranium for disposal as low-level radioactive waste. Another technology now undergoing research is pyroprocessing, which retains the uranium and plutonium for use in a fast reactor.

The industry fully supports the development of advanced fuel cycles to improve the efficiency of nuclear power facilities. Further research in reprocessing and other technologies could yield important benefits. It is important that the government begin laying the foundation now for future nuclear fuel supply and waste treatment processes, as these take many years to develop and implement. However, DOE and other federal agencies should carry out this research in addition to existing waste management programs.

CONCLUSIONS AND RECOMMENDATIONS

Reprocessing used nuclear fuel has the potential to provide numerous benefits, but also poses multiple challenges. The implications of resuming reprocessing the United States must be fully understood before embarking on any large-scale initiative. The industry fully supports the Administration's goal of developing nuclear fuel that is yet safer, more efficient and more proliferation-resistant. The Federal Government is well-served by the development of fuel technologies that support these objectives, including technologies pursued as part of the Advanced Fuel Cycle Initiative. However, the government must develop these technologies parallel with the development of Yucca Mountain and in a manner that will make the Yucca Mountain repository more efficient. Reprocessing could help avoid or delay the need for a second repository.

Development of these technologies in the United States and other reliable nations will make the world safer. However, despite its advantages, reprocessing has several key challenges that must be overcome, including cost and non-proliferation issues. Even with significant increases in uranium prices and the rising costs of on-site fuel storage, reprocessed fuel is still more expensive than nuclear fuel from current sources. Reprocessing will require investment in new infrastructure, but this investment should not be borne by a tax on consumers of nuclear energy. Consideration of reprocessing technologies also must take into account the proliferation risks of separated plutonium.

Congress must ensure that federal agencies are conducting research and development programs in areas such as reprocessing that help prepare for our nation's energy future. The government must do all it can to ensure that Americans continue to have access to affordable and environmentally friendly sources of electricity. Nuclear energy plays an important role in providing this power reliably, efficiently and without producing greenhouse gases.

BIOGRAPHY FOR MARVIN S. FERTEL

Marvin S. Fertel is Senior Vice President and Chief Nuclear Officer at the Nuclear Energy Institute (NEI), the industry organization responsible for establishing unified nuclear industry policy on matters affecting the nuclear energy industry.

He has 35 years of experience consulting to electric utilities on issues related to designing, siting, licensing and management of both fossil and nuclear plants.

He has worked in executive positions with organizations such as Ebasco, Management Analysis Company, and Tenera. In November 1990 he joined the U.S. Council for Energy Awareness as Vice President, Technical Programs. With the formation of NEI in 1994, he became NEI's Vice President of Nuclear Economics and Fuel Supply. He assumed his current position as head of the Nuclear Generation Division at NEI in March 2003.

Currently, Mr. Fertel is responsible for leading NEI's programs related to ensuring an effective and safety-focused regulatory process. He is responsible for directing industry-wide efforts to ensure adequate security is provided at nuclear power plants and for addressing generic technical issues related to commercial nuclear facilities. The Nuclear Generation Division is responsible for NEI's activities related to improving the economic performance at existing facilities through industry-wide benchmarking activities; the promotion of policies to achieve a long-term reliable and economic supply of nuclear fuel; and for policy initiative and industry programmatic activities that support the development of new commercial nuclear projects. Mr. Fertel is also responsible for overseeing NEI's activities related to the management of used nuclear fuel and other waste products, including achieving success in the U.S. Government's program for the storage and ultimate disposal of used nuclear fuel.

Mr. Fertel holds a Bachelor of Science degree in civil engineering from Northeastern University, Boston; a Master of Science in Civil Engineering from the Polytechnic Institute of Technology, New York; and has participated in the doctorate of public administration program at New York University.

DISCUSSION

Chairwoman BIGGERT. Thank you very much, Mr. Fertel.

We will now start our questioning, and I will yield myself five minutes.

Dr. Lester, 50 years is a long time. If I had to be able to know whether you were correct in saying we should postpone any reprocessing for 50 years, I won't be around to know if you were correct or not, which would be very disappointing. Fifty years ago, a gallon of gasoline cost less than a dime, and so I wonder, does your analysis assume that there are no changes in the market for electricity in the next 50 years, like the impact of global warming and the effect on the price of electricity produced from fossil fuels?

Dr. LESTER. Madame Chairman, our analysis did try to address a series of changes that may take place over that time frame that you mentioned. One of the big questions, obviously, over that time frame, is what is likely to happen to the demand for uranium, and how is that affected by the future expansion of nuclear power. On that issue, we assumed a three-fold increase, approximately, in the installed capacity of nuclear power plants, both in the United States and globally. And even on that basis, and of course what we are talking about is something like a 300 gigawatt, or 300 large nuclear power plants, operating by mid-century. Even on that basis, our conclusion was that the demand for uranium would not drive the price of uranium to the level at which the introduction of reprocessing and mixed oxides recycle could be or would be economically warranted.

Chairwoman BIGGERT. But—and this would be for Dr. Jones, too. Is the potential cost of carbon capture and disposal for fossil-generated electricity comparable on a per-kilowatt-hour basis with the waste disposal costs of nuclear energy?

Dr. LESTER. Well, we certainly—we did make, or have tried to make, a consistent comparison of fossil and nuclear costs, in particular coal-fired generation with nuclear costs. And we estimated that with plausible, although optimistic, reductions in nuclear power plant capital costs, combined with the introduction of some form of penalty or tax on carbon emissions——

Chairwoman BIGGERT. But was that taken into account? And what we are hearing now is, you know, the impact of the climate change and how we are going to have to deal a lot more with those fossil fuels and the increase in the pollution in our air quality. And that takes into account that we will probably be doing more in that area?

Dr. LESTER. Yes.

Chairwoman BIGGERT. Do more regulation or restrictions on——

Dr. LESTER. I think we would anticipate that, yes.

Dr. JONES. Madame Chairman?

Chairwoman BIGGERT. Yes, Dr. Jones?

Dr. JONES. We estimated the cost of coal-fired generation with carbon sequestration would rise to the range of $83 to $91 per megawatt hour from the level of $33 to $41, and gas-fired generation costs to rise to $58 to $68 range from current $35 to $45.

Chairwoman BIGGERT. Okay. Is—what about the market price for electricity? Would that include climate change and carbon taxes?

Dr. JONES. Only if those things are priced, and the government is in a position to price that.

Chairwoman BIGGERT. Okay. Then, Dr. Fetter, what would the economic cost of delaying a decision on selection of a reprocessing technology—what would be the economic cost of delaying that decision?

Dr. FETTER. I don't think there would be any economic cost at all of a delay to reprocess—a delay in the decision to reprocess.

Chairwoman BIGGERT. Is there a particular threshold, for example, at the point where a second disposal site would be necessary? Would that change the cost?

Dr. FETTER. It—based on the cost of Yucca Mountain, which is funded by a small fee added to the price of nuclear electricity, nuclear-generated electricity, I would think that one could easily expand the Yucca Mountain site, up to doubling its capacity, or open a new facility for about the same fee, for about the $1 per megawatt hour.

Chairwoman BIGGERT. Of course, we haven't even been able to get this one open yet, so that is a small problem.

But thank you. My time has expired.

Mr. Honda.

Mr. HONDA. The cost of reprocessing has been something that has been a reminder of whether it is going to be economical or not, and I have heard some comments about the economy—the economics of it would have to be plausible. I guess I have been hearing that the extent of two or three or four decades out. Was that correct information that I heard? Did I hear it correctly?

Dr. LESTER. I think my comment was that over the next two or three or four decades, it would be hard to imagine that it would be economic.

Mr. HONDA. And could you help me to understand why that would be? Is it a lack of our funding more research and development or what are the dynamics in that?

Dr. LESTER. The question of whether it is economical or not hinges on, obviously, the cost that one would have to pay to do it, on the one side——

Mr. HONDA. Yeah.

Dr. LESTER.—and on the other side, the amount of money that one would save by not having to buy as much uranium, not having to buy as much uranium-enrichment services, and potentially also having to pay less to dispose of the reprocessed high-level waste that one would be producing instead of disposing directly of the spent fuel. So the issue of whether it is economical or not depends on balancing those extra costs with the savings, and it is on that basis that I concluded that over the next three or four decades, even with real investment in reprocessing research and development, which I do certainly support, it would be very unlikely to see a situation in which the costs would be outweighed by those economic benefits.

Mr. HONDA. And that is taken in the context of the nuclear power arena. If you look at that in the context of other fuels, in-

creasing fuels in other areas, is there impact there? I mean, the reason why the Administration is looking at reprocessing and building more plants, I suspect, is because it is an opportune time to do that, given the picture of the cost of petroleum, the cost of crude oil and things like that. What are the dynamics there?

Dr. LESTER. Well, as you know, the electricity industry in this country is becoming more and more competitive, at least in some parts of the country. And therefore, the situation of nuclear power in those markets depends upon its ability to compete on a price basis with the alternatives. At present, its ability to compete with coal, which is the main alternative today to nuclear for baseload generation, its ability to compete is, at best, marginal. And therefore, any action that we take that would result in an increase in the generation cost of nuclear electricity would make it less able to compete. And so I think we need to be very careful before advocating a course of action that would result in a significant increase in the nuclear generation cost. Now it is likely, if we do introduce a cap-and-trade scheme for dealing with carbon emissions or a tax or whatever we may choose to do as a nation, it is likely that the cost of coal-fired generation will increase over time. But still, the ability of nuclear to compete and to penetrate these competitive markets will depend on our success in keeping the costs down. And so again, we need to be cautious about advocating a course of action that would result in an increase in those costs.

Mr. FERTEL. Mr. Honda, maybe I could add a slightly different perspective and then build upon what Dr. Lester has said.

Putting aside the economics for just a minute, though that is the purpose of this hearing, there is a practicality of implementing reprocessing effectively in our country within the next five or 10 years, and that is what we are looking at. The current reprocessing technology, as I think everybody else on the panel has eluded to, while it works, it doesn't do all of the things you would like. It doesn't dramatically help us on the waste side, because it doesn't take the fission products out. It doesn't do transmutation, which gets rid of the long-lived radioisotopes that cause you a problem in the repository. It does reduce the volume, but it doesn't necessarily change the size of my repository. And in fact, the repository right now, which has a 70,000 Congressionally-mandated limit, not physical limit, that is a Congressional limit that Congress can deal with, basically says it is limited by the spent fuel that we generate. Even if we changed the nature of that fuel to be reprocessing, we would still be limited unless you change the law.

So we need to go to the next evolution of technology, which I think you heard about at the previous meeting. That is going to take some time. And one thing this committee can do is hold our government, our Administration accountable to get something done. Madame Chairman spoke about Yucca Mountain not moving along. We don't move along in R&D all that fast either, let alone something like a big project. So getting the R&D done is one thing, and that is why we are thinking that is a five-year to 10-year project to get to technologies you want to deploy, putting aside economics.

At that point, and assuming the economics even make sense, and they may make sense for looking at it, it is at least a decade to

deploy facilities. These are very, very large complex chemical and laser facilities, if you go to transmutation. They will require significant licensing and construction and commissioning. And so you are into—I hate to say it this way. You are into, almost, a couple of decades to honestly deploy the facilities that you want, assuming they are economic, assuming they really are the things you want to do.

On the economics, the reason we haven't given you numbers is we are—we don't believe we are smart enough to tell you what the markets look like in 20 years. Madame Chairman asked a good question about sequestration. I just saw a study that said that that could be about exactly what Dr. Lester said, it was about 1.7 cents per kilowatt-hour. What is probably not in the best interest of our consumers, whether they are a residence or they are commercial or they are industrial customers, is to just raise the price of electricity everywhere. Okay. Electricity is the lifeblood of our economy and our quality of life. And what you would like to do is not raise it, if you don't have to, or temper it somehow. Conservation can do that. Efficiency can do that. But you have to generate electricity. One of the attributes of nuclear energy that the financial community and big customers like is we have very good price stability, and we have very low marginal costs. Our capital costs are our big thing. Our marginal costs are low. So we would look to try and keep marginal costs lower to keep the average electricity prices down. That doesn't mean you shouldn't be reprocessing. It just means you have got to go about it smarter. And I think we are not at a point of knowing how to do that quite yet, even though everybody may have numbers and thoughts. And you shouldn't wait 50 years. You should begin to develop the technology and make decisions over the next 10 to 20 years on its use.

Mr. HONDA. Thank you.

And thank you, Madame Chair. And my time is up, but I appreciated your comment, Mr. Fertel, and I was trying to also get out of the discussion not only the economics, because it doesn't seem smart just to be talking about that if we have a larger picture that we have to deal with in the future, too. And what is the cost? What—you know, what other costs do we pay if we don't pay attention to the other kinds of things?

So thank you very much.

Chairwoman BIGGERT. And the gentleman yields back.

The gentleman from Michigan, Dr. Ehlers.

Mr. EHLERS. Thank you, Madame Chair.

Before I ask a question, I would just comment.

Mr. Fertel, you asked for some less uncertainty in the behavior of the Congress, if I understood you correctly. That is a lot to ask for.

Mr. FERTEL. Well, the Administration, too.

Mr. EHLERS. You would include that, too. The Congress and the Administration are certainly less predictable than nuclear reactors. The reason is simple. I can write the equations covered in the nuclear reactor. I can't write any equations predicting what Congress will do. If I did, I could certainly make more money than I am now.

The question I have for all of you is what do you believe are the biggest unknowns? I am surprised at the disagreement here about

the cost. What do you think are the biggest unknowns and any cost predictions for the advanced fuel cycle or for reprocessing in general? What—why is it so uncertain that you can't agree? What is going on here?

We will start with Dr. Lester.

Dr. LESTER. Actually, I am not sure that the level of disagreement between us is that great. I think there are some disagreements about how to interpret those numbers, but the actual numbers, if I understood what my colleagues said, are not that far apart.

If we take reprocessing, which is the—probably the biggest area of cost uncertainty of all of the elements that go into figuring out the overall economics of the fuel cycle or closed fuel cycle, I think what we have heard this afternoon is that optimistically—a relatively optimistic estimate of reprocessing costs is about $1,000 a kilogram.

The consequence of that cost for the consumer, in terms of the amount that would be paid by the consumer of electricity, depends on whether you do the calculation in terms of the average over all of the nuclear power plants in the country or whether you assign the cost of reprocessing and also the fabrication of the mixed oxide fuel only to the power plants that are actually availing themselves of those services. And depending on how that calculation is done, if you take the averaging approach, the calculation would lead you to conclude that the impact on the consumer would be about an extra 2/10 of one cent per kilowatt-hour. If, on the other hand, you ascribe all of these costs only to the reactors that are availing themselves of these services, the impact on the consumer would probably be a little over one cent, perhaps 1.2 cents per kilowatt hour.

So I think, perhaps, the difference that you—we have been hearing has to do with how to apply these basic cost numbers for reprocessing.

Mr. EHLERS. Thank you.

Dr. Jones, it seemed to me you were a little more optimistic about the costs, or did I misunderstand you?

Dr. JONES. No, you didn't misunderstand me.

We are all using the same cost numbers. And when we examine the generating cost of a single plant, using those same numbers, reprocessing that adds $2.65 per megawatt hour, it is going to add about 4.3 percent to the generation cost of that plant that uses that fuel. That was our conclusion.

Mr. EHLERS. Okay. Dr. Fetter, you seemed to have assigned fairly high costs to this. What is your comment?

Dr. FETTER. Well, I think the reason there is so much uncertainty is, at least partly, for traditional reprocessing, there has been no open market either for the reprocessing services or for the MOX fuel fabrication. The contracts—the prices paid have been confidential and proprietary information. So mostly one has to work backwards to figure out how much it costs.

But for separation and transmutation, the uncertainties are even greater, because those separation processes have not even been done yet and would almost certainly be more complicated and more expensive. The fuel fabrication would almost certainly be more ex-

pensive than MOX. And finally, the transmutation facilities, if they are fast reactors or accelerators, would almost certainly be more expensive, but exactly how much more expensive than light water reactors is hard to say. But the experience around the world with fast reactors has not been encouraging.

So I think one can say fairly confidently that it would be more expensive than the once-through fuel cycle, but it is hard to say just how much more expensive.

Mr. EHLERS. And Mr. Fertel, you were smart enough not to give any numbers.

Mr. FERTEL. Well, actually, I would agree. Your question was what are the biggest unknowns, and I think Steve hit on, in my mind, what the biggest unknowns are. It is the performance of the facilities. We have not operated accelerators for transmutation on any large scale. We haven't done the separation. We do know how to do PUREX, but we don't know how to do a lot of the advanced reprocessing technologies yet. And to be honest, that is why our position is: what we need to do is go with a meaningful R&D program and figure out what makes sense. And then it does take government policy decision. And my illusion to certainty is if you look at our nation and the whole concept of reprocessing, it was the way we started. It was stopped during the Ford-Carter Administration. It was restarted during the Reagan Administration. It was stopped during the Clinton Administration. The Bush Administration would restart it. It is very hard on the business side for people to make decisions. And it is not just decisions of the reactor owners on where they buy their fuel or what they do, it is decisions on the fuel suppliers to invest in properties and their facilities. So there has to be some stability. And it is government policy in those areas, sir, that plays a key role.

But I would agree with where Steve was. It is operation of facilities that cause us the most concern right now to make sure they are going to work. Then you can do the numbers. Then you can get better numbers.

Mr. EHLERS. Okay. For—just to—it sounds to me like the only way to resolve this is to—that the government has to make a policy decision as to whether or not reprocessing is or is not a good thing to do, as compared to trying to deal with the carbon problem in some other way. And once you—once that decision is made, we have to stick by it, and we have to—our citizens have to pay the costs or—in order to receive the benefits.

I would like to have your reaction to that, but my time is expired, so I won't.

Chairwoman BIGGERT. Thank you.

Well, perhaps we will have time for that later.

The gentlelady from Texas, Ms. Johnson, is recognized for five minutes.

Ms. JOHNSON. Thank you very much.

Let me thank the panel. It has been informative to listen to you.

I live in two places. I am more here than I am some other place. And one place that I live does have nuclear—have a nuclear plant. It costs me five times more for the electricity where I spend less time, than what it costs up here. How long does it take to pay for

those? Any estimate? It has been over 20 years that we have been paying. Anybody willing to comment?

Mr. FERTEL. Well, the only comment—I am not sure where in Texas you live.

Ms. JOHNSON. Dallas.

Mr. FERTEL. Dallas? Okay. So you get your power from Comanche Peak.

Ms. JOHNSON. Yes.

Mr. FERTEL. Comanche Peak was an extremely expensive plant due to delays and other things that it ran into. And as I am sure you know, the way the market works in Texas, or worked in Texas, the rates were set by the Public Utility Commission, not by the market itself. So basically, they have set rates and they work it off. Other parts of the country it is much better. I hate to say that, but——

Ms. JOHNSON. I think you are right.

Mr. FERTEL. And clearly, the intent for anybody looking to build plants going forward is to make sure the plants not only come in at a competitive capital price, but they get built on schedule and on time, because the markets won't take them otherwise. So I hate to say it this way, but I think that, in the future, this won't be a problem, but I am not sure how to solve your problem right now.

Ms. JOHNSON. Well, I know how to solve it, I just don't know whether I have the wherewithal to get enough people to go down to the Public Utility Commission and complain.

I am concerned about the reprocessing. I think I heard two different versions. Some said—I think one said they didn't think it was safe or practical, and someone else said they thought it was okay. Now what—am I hearing wrong?

Dr. LESTER. I think that there were different—I think you heard different things about the economic consequences of reprocessing. I am not sure that—certainly I didn't address the issue of the safety of reprocessing. I think that is an important consideration and an important issue, but it was not the subject of my testimony.

Ms. JOHNSON. Okay. Did anyone mention safety?

Mr. FERTEL. In my comment, I quoted the President's statement that he was looking to get new, safer technology—new, safer, and more proliferation-resistant, but there is no reason reprocessing can't be done safely, the same way you can operate reactors safely. You need to pay attention and do it right.

Ms. JOHNSON. What would be the effect on the environment to reprocess? Would it be any different?

Dr. LESTER. Well, I think that there are two parts to the answer to that question. One has to do with the operational safety of the plant itself. The other has to do with the relative ease or relative difficulty of handling the wastes that are produced by the plant relative to what you would have to deal with if you didn't do reprocessing at all, which is spent fuel. When it comes to the operational safety issues, the fact of the matter is that if we have reprocessing plants, they will present safety challenges, just like any large industrial facility would present, in this case, of course, greatly complicated by the fact that one would have very large inventories of radionuclides in the plant, and one would have to be concerned about occupational safety, environmental health, and so on. The

record that we have to look at on the basis of reprocessing plants that have operated in France and in the United Kingdom, Japan also, is it has to be said somewhat mixed. The performance of the French reprocessing plants has been, from a safety point of view, environmental point of view, very strong. The performance of the plant in the United Kingdom and the performance of a smaller plant in Japan has been, over the years, somewhat mixed. I think the lesson there is that we have to work very hard to ensure that these big reprocessing plants perform safely, and from an environmental point of view, benignly.

The other part of the question has to do with the waste management implications of reprocessing. And there, I think what we have heard is that for advanced reprocessing schemes, there is at least the potential to reduce the long-term risk from the high-level waste that we produce relative to the disposal of spent fuel, which is what we would have to deal with if we didn't reprocess.

Ms. JOHNSON. Thank you very much. My time is up. Thank you.

Chairwoman BIGGERT. The gentlelady's time has expired.

Dr. Bartlett, you are recognized for five minutes.

Mr. BARTLETT. Thank you very much.

With some obvious limitations, energy is fungible. It is unlikely, then, that one source of energy can be enormously increased in costs while other sources of energy remain at a low cost. Looking ahead two, three, or four decades, what kind of assumptions are you—were you making about what oil would cost?

Dr. JONES. Oil, in fact, doesn't have that much to do with electricity generation. We looked more at the future of gas prices and coal prices, and of course, uranium prices. With the—when we were doing our study, it was the summer of the big gas price spike. We did not assume that that price would stay up at that level for the next 40 years. We assumed it would come back down, according to the EIA forecasts.

Mr. BARTLETT. Yeah. I would caution that I would not be overly optimistic about judging what is going to happen in the future by the Energy Information Agency prognostications.

There is a big article in the New York Times today on oil and several statements in there of some significance to the problem that you all are addressing. They said that the oil production has probably plateaued, that there are an increasing number of authorities who believe that the world's demand for oil is going to exceed the world's ability to produce oil. Oil today is over $60 a barrel. The Chairman of our Transportation Committee says it will be $80 a barrel by the end of the year. Goldman Sachs says it will go to $105 a barrel. I don't remember, they had a time period on that. I would suggest, gentlemen, that in four decades from now the availability of oil will be markedly less than it is now and the price through the ceiling.

Do you know the name M. King Hubbard? His prediction that the United States would peak in oil production in 1970 was correct. We did. It has been downhill ever since. He predicted the world would peak in oil production about now. Considering he was exactly right about the United States, is there any reason to believe that we shouldn't have had some concern that he might be right about the world?

Dr. LESTER. I certainly would agree with the general gist of your comments that we are facing a long-term imbalance between supply and demand of oil. I think, to some degree, that imbalance, which with all of its profound consequences for our society, can be separated from the question of nuclear technology, because, at least to a first order, nuclear technology competes in the electricity market, oil is largely absent from the electricity market. Now at some level, in some parts of the economy, of course, these two things coincide.

Mr. BARTLETT. But if oil sort of got very expensive and gasoline was $8 or $10 a gallon, don't you think there would be some incentive to maybe go to some electric use in transportation? And don't you think that these uses of energy will change so that the costs will not be all that much different for any one source of energy? Isn't energy reasonably fungible? We are now running cars on gasoline. Couldn't we run them on electricity?

Dr. LESTER. I think we certainly could. Indeed, as you know, some vehicles already are using electricity. So yes, it is certainly correct to say that the influence of very high oil prices may be to increase the demand for electricity in parts of the economy.

Dr. FETTER. Could I just also comment that there is an interesting connection between M. King Hubbard and the economics of reprocessing? One of the disciples of Hubbard is Kenneth Deffeyes at Princeton University who wrote a book called "Hubbard's Peak" and a recent book, "Beyond Oil." It was actually the work of Deffeyes on the availability of uranium resources at various prices that we used in our study to determine what the likely uranium price would be as nuclear power grew over the next 50 to 100 years. And based on that work, which is based on data collected by the Department of Energy, it appears that there is plenty of inexpensive—relatively inexpensive uranium available at a price less than $130 per kilogram to fuel a greatly expanded nuclear power industry through at least the next 50 years.

Mr. BARTLETT. Thank you, Madame Chairman.

Chairwoman BIGGERT. Thank you.

The gentleman from Texas, Mr. Green.

Mr. GREEN. Thank you, Madame Chair, and thank you, Mr. Ranking Member.

And thank you, friends, for visiting with us today.

This is not the best picture that we are having painted for us, and it does cause a great amount of consternation. So I would ask each of you, how do you recommend we proceed? Let me just start with Mr. Lester. How do you recommend that we proceed? Should we proceed with the building and storage, assuming that certain things will happen with storage or that we will find a—some new technology for reprocessing? Or should we stagnate and wait? How do you recommend we proceed?

Dr. LESTER. I think that we—it is of great importance to our country that we prepare the ground, so to speak, for a major expansion in nuclear power generation, because I don't see any way that we can address the problem of carbon emissions without doing that. And so the question really is what is the best thing that we could do or what are the best things that we could do to prepare the ground for a major expansion of nuclear power.

Our assessment of the technological choices leads us to the conclusion, when I say "our," I am referring to the MIT study that I was a participant in, leads us to the conclusion that our government and our industry should give priority to the deployment of the once-through nuclear fuel cycle involving direct disposal of spent fuel rather than the development of more expensive, closed-fuel cycle technology involving reprocessing and new advanced thermal or fast reactor technologies for at least the next few decades. We are not able to see beyond that. I think there is some skepticism that we can even see that far ahead, but to our—to the best of our ability, we do believe that the best way to ensure a major—not ensure, but make at least possible a major expansion of the nuclear power industry in this country would be for government and industry to focus on making the open, once-through fuel cycle as competitive as possible.

Mr. GREEN. Let me hear, if I may, from Dr. Jones.

Dr. JONES. Our study's conclusion was very limited on reprocessing. It was simply that it didn't seem to be an important economic consideration in the generation cost of electricity. That frees up other motivations for considering reprocessing.

Mr. GREEN. So your recommendation is that we do what?

Dr. JONES. I would be going outside what we actually studied to make any specific recommendations on reprocessing or not, what type of reprocessing to pursue, but if there are other motivations for considering reprocessing, you should not stumble over the extra cost of it on generation cost of electricity.

Mr. GREEN. All right. Let us move to our next panelist, Mr. Fetter.

Dr. FETTER. Yes, I would recommend that there be no near-term decision to reprocess spent fuel and that for the near-term we proceed with the once-through fuel cycle. I do support research, just research, not research and development, on advanced fuel cycle technologies with a view to making them cheaper, but more particularly with a view to making advanced fuel cycles more proliferation-resistant, not more resistant to proliferation than PUREX, but more proliferation-resistant than the once-through fuel cycle, because I think if any expansion—well, I think any expansion of nuclear power in the United States, or in the world, should not increase the potential for the spread of nuclear weapons. I think that is the overriding consideration beyond waste or economics.

Mr. GREEN. The final panelist, please, Mr. Fertel, is it?

Mr. FERTEL. Yes, thank you.

Congressman Green, I think that it—my suggestion would be, first of all, move forward on implementing the current obligation the government has with Yucca Mountain. Okay. You need to take the used fuel from the sites and move it to Nevada and move forward on doing what we need to there.

Second, I think that I would go further than Steve. I think that we should go forward and develop a road map or a project plan for both the research and development for reprocessing, and I am thinking beyond just reprocessing. I think you need to look at separation and transmutation so you can make conscious decisions. I think, Congressman, you don't have to make the commitment yet,

but I think you do need to think about the policies the government should have as part of the road map so that somewhere by the end of this decade our government is in a position of knowing what technologies they think they would like to pursue and whether they end up being commercialized or not is still an open question, and also what policies you need to put in place. And I think that doing that, you are still accepting—you are not going to be deployed and implementing them before 2025. I mean, you are not—you know, you could start today, and you will not get facilities of the magnitude we are talking about in commercial commissioned operation for 20 years.

Mr. GREEN. Thank you, Madame Chair. I yield back the balance of my time.

Chairwoman BIGGERT. Thank you.

I think that there is a clause in the appropriation bill, which—in the energy and water, which requests that they make—a decision be made by 2007 and what process to pursue, so I think that this is something that is upon us.

Mr. Reichert from Washington, you are recognized for five minutes.

Mr. REICHERT. Thank you, Madame Chair.

I just want to make sure I understand. I come from a law enforcement background, so this is all new and exciting stuff.

Nuclear fuel reprocessing, so we have stopped and started the process several times. We must complete, at least research, maybe development, according to some on the panel, and that is a five- to 10-year process. So far, am I on track? And then if we deploy, it is at least another decade after that? The people that I talk to—and I know you have probably had similar conversations, and I know Members of the Committee have—we just want cheap power, efficient power, environmentally-friendly, and safe. So that is your assignment. No heavy burden there at all.

Just a real simple question. What is the biggest reservation that each of you have about the possible U.S. transition to nuclear spent fuel reprocessing? The biggest reservation? The single most—the biggest reservation that you have.

Dr. FETTER. Could I jump in?

Mr. REICHERT. Sure.

Dr. FETTER. It is the example that it would send to other countries. As you know, it has been the policy of the United States to oppose the spread of reprocessing technologies, because of concerns about the use or misuse of that technology to separate plutonium for nuclear weapons. And it is also the—has been the position of this Administration to oppose the spread of reprocessing technologies. And I think it would be difficult if the United States decided to reprocess for its own waste disposal management concerns to maintain what would essentially be a double standard: to say, "Well, we can do it and certain other responsible countries, like Japan and France, can do it, but no other country, or no countries of concern can do it." So that would be my primary concern with the decision to move to reprocessing.

Dr. LESTER. May I comment?

Mr. REICHERT. Yes.

Dr. LESTER. My major concerns are that it is going to be costly, that it may not lead to the benefits on the waste management and disposal from—that are claimed for it, and as Steve has indicated, that it will complicate our efforts to prevent other countries from exploiting plutonium for malign uses.

Mr. REICHERT. Others on the panel?

Mr. FERTEL. Yes. Let me take a slightly different view. My major concern is we will debate it for decades and never do it while everybody else does their thing. This is what we did in the '70s. Steve is expressing the belief that we had in the '70s, and I am as committed as he is to making sure other people don't get nuclear weapons and bad people don't get nuclear material. But there is a leadership role the United States needs to play. I think we made a strategic mistake when we stopped research in the '70s. We didn't have to deploy, but we could have done research to have better, safer, more proliferation-resistant technology, and what we did was we said, "If we don't do it, no one else will," and everybody else that wanted to went and did it. And I think the President has said what Steve said, that he doesn't want other countries doing it, but he has also said that the way he will get them not to do things, like build enrichment facilities, is by providing them fuel. Well, if they want to use MOX fuel and we have no capability of providing MOX fuel, we can't provide MOX fuel. So I think that you can look at this as either you are setting an example that is bad or you can look at it that you are setting an example that is good. And I think that what we will do is we will debate this for years and go nowhere with it if we are not careful, and that would be my biggest concern.

Mr. REICHERT. Thank you. And you have said that the French, British, and Japanese, if I understood correctly again, pay for their systems—the government pays for their systems. Do you think the costs are comparable, as we look at those systems here in the United States? Could we learn something from those three countries as far as cost goes?

Dr. LESTER. We—I am sorry. We do learn a number of things. One of the striking things about that experience is that the Japanese, who are the most recent—which is the most recent country to move towards reprocessing, using more or less the same technology that the French and the British have used, have completed a reprocessing plant that is—estimates vary, but almost certainly at least three times more expensive than the plants that were built some years earlier in France and the United Kingdom. So that enormous cost range is one of the things that makes this discussion so complicated or so difficult, because we have this vast range of costs, with the Japanese plant approaching $20 billion, or perhaps even more, in capital costs for a plant that, you know, from a distance, looks rather like the French plant and the British plant.

Mr. REICHERT. Thank you, Madame Chair.

Chairwoman BIGGERT. Thank you.

The gentleman from Utah, Mr. Matheson.

Mr. MATHESON. Thank you, Madame Chairwoman.

I have got four points to do in five minutes, so I will try to move quickly.

Just one quick comment. Mr. Fertel, I think you are right on in talking about we need to emphasize moving ahead with R&D. And for this subcommittee, that is the relevant role we can play, and so I appreciate those comments.

Secondly, Dr. Jones, did you say your levelized costs were over a 40-year period?

Dr. JONES. Yes.

Mr. MATHESON. I just—I would agree with Dr. Bartlett in saying that the Energy Information Administration data is probably not reliable, and while if the most relevant cost comparison is going to be reprocessing through—compared to the once-through fuel cycle, if we have a levelized cost of natural gas plants for capital and operating costs that you got over 40 years, I sure hope you are right, but I would bet you are not. I bet it is going to be more expensive, and I just—look, we all have trouble—I mean, it is a—when you are projecting the future, nobody knows what is going to happen, but I think gas prices are going to jump up a lot more than this reflection of this levelized cost.

Two quick questions, though, I want to ask.

Dr. Fetter, in your testimony, you talked about the concern of if we do a separation and transmutation system that there is going to be a real problem in terms of public acceptance about locating these facilities compared to a repository. And I just was curious if you are aware that the Federal Government right now is moving ahead with not just looking at Yucca Mountain. In fact, the Federal Government is looking at licensing privately-owned, above-ground facilities to store high-level nuclear waste. And as—coming from a state where they are doing that, I can tell you public acceptance isn't very big on this idea. So I know this was a discussion of economics and—but since you raised this issue in your testimony, I guess, did you consider the notion of comparing separation and transmutation system locations compared to doing various locations of above-ground, high-level nuclear waste?

Dr. FETTER. Well, in fact, I do think that the above-ground storage of high-level waste—of spent fuel is an excellent option for the next 50 to 100 years. In fact, I think the Nuclear Regulatory Commission recently said this was a safe and effective—and it is also a relatively inexpensive option that would last up to 100 years. And it is done at several locations already——

Mr. MATHESON. Sure.

Dr. FETTER.—around the United States with dry cask storage.

Mr. MATHESON. I guess this is not the forum to do it, but the fact that they didn't consider a terrorist risk and it is in the flight plan to a test and training range where F–16s crash, I am not so sure that putting it into Tooele County, Utah is the right place to be doing an above-ground storage facility.

Let me move on now to Dr. Lester. You cite, in your testimony, MIT's Future of Nuclear Power report, and it mentions some alternatives to a mined geologic repository. You mentioned the term "nuclear boreholes." Could you explain to us what they are and what the pros and cons might be of disposing of nuclear waste in this manner?

Dr. LESTER. Yes. The proposal here is instead of constructing mined structures a few hundred meters below the Earth's surface,

we would, instead, drill several kilometers below the surface and essentially stack canisters of waste, one on top of the other, for, perhaps, one or two kilometers of the hole depth and then backfill the upper two to three kilometers, whatever it is, with sealing material. The advantage of going to that depth is that at that depth, you—it is not—the kind of near-surface processes that we have to worry about when we build repositories, in particular the movement of ground water, is simply not a factor. So one avoids the—at least some of the complexities, by no means all, but some of the complexities that are associated with the attempt, for example, to license the Yucca Mountain facility. And after looking at this option, we do believe that the deep borehole strategy does have some attractive features that would warrant a serious research effort to try to answer some of the key questions about it.

Mr. MATHESON. I guess you were anticipating my next question, which is what are the next steps. How much is known about this now or what—if we were doing—if we were to pursue this alternative in whatever form, what would—what are the next steps we need to be taking?

Dr. LESTER. Well, clearly, the deeper you go into the Earth's crust, the less you know. And so there are important research issues that have to be dealt with about the characteristics of the crust at that depth as well as engineering issues that involve, you know, what would be involved in then placing a canister at a depth of three or four kilometers. What would happen if it hung up in the hole, and would it be possible to retrieve it? There are a series of questions. Our estimate is that a five- to 10-year research program would be effective at relatively modest cost, I should say, in answering at least a number of those questions.

Mr. MATHESON. And is any of that research going on now, to your knowledge?

Dr. LESTER. No, essentially not. Nothing of that kind is going on at the moment.

Mr. MATHESON. Okay. Thank you.

Dr. LESTER. At least in the United States.

Mr. MATHESON. Thank you, Madame Chairwoman.

Chairwoman BIGGERT. Thank you.

Dr. Schwarz from Michigan is recognized for five minutes.

Mr. SCHWARZ. Just to kind of—to clear that up a little bit, this is the second hearing that we have had on what to do with spent nuclear fuel and nuclear reprocessing, which I am sure someone has mentioned today. A friend of mine said it took 30 million years to get all of that carbon into the ground and it has only taken 300 years to get it out, so we, indeed, have a problem as to what we are going to use for fuel to, probably more than anything else, produce electricity. Is the changeover in the next 50 to 75 years to nuclear power inevitable, question number one? Question number two, and then just put on your Buck Rogers hats for a minute, as we move away from carbon-based fuels, is there any other fuel out there that can be harvested or produced in adequate volume to be an alternative to nuclear fuel? And my third question is, if, in fact, there is a mass transition to nuclear fuel, which I believe, in fact, there will be and to nuclear-produced electricity, is there an adequate uranium supply worldwide, as far as we know, to do pre-

cisely that and to keep producing electricity from nuclear processes over the next century or two? Anybody that wants to pick that up and run with it, go ahead.

Dr. FETTER. Well, I don't think that a transition to nuclear is necessary an inevitable. Nuclear is certainly one of, I count, five main carbon-free energy sources.

Mr. SCHWARZ. Please elucidate on the other four.

Dr. FETTER. Well, there are enormous resources of fossil fuels, unconventional fossil fuels and coal, which could be used in an environmentally-responsible manner with carbon sequestration. There is also solar, which is quite expensive now. Photovoltaics are very expensive, but could become much cheaper in the future. Biomass fuels could be used on a large scale. And then finally wind power, which is already economically competitive in some areas of the country.

Mr. SCHWARZ. Well, let me interrupt you for just a second. We are told by people who profess to be experts that neither solar power nor wind power could, in any way, produce enough energy to really be effective in our world.

Dr. FETTER. Well, certainly solar power could produce far more than enough energy to supply the world economy. The main question is the cost, right now, the cost, in particular, of photovoltaics. And there is also the issue of the cost of energy storage in the case of solar, because the sun only shines during the daytime, so one would have to find a way to——

Mr. SCHWARZ. In Michigan, sometimes not even in the daytime.

Dr. FETTER. Now with regard to uranium supply, this is something that I and my colleagues have looked fairly closely at, and we are convinced that there is plenty of relatively inexpensive uranium to fuel a major expansion of the nuclear industry worldwide for at least the next 50 years based on a once-through fuel cycle. So there is no need, on this time scale, I think, to go to a reprocessing and recycle option.

Mr. SCHWARZ. Anyone else who wants to pick that one up, please go ahead.

Dr. LESTER. Very briefly, I think we are going to need all of these things, and I see no possibility that we will be able to achieve our goals for restricting carbon emissions globally without a major expansion of nuclear power. We will need solar. We will need wind. We will need more efficient energy use. We will need carbon sequestration with coal. We will need all of those things, but I see no possibility, based on my assessment of supply and demand and global climate change issues, I see no possibility that we will be able to get by without a major expansion of nuclear power over the next 50 to 75 years. Beyond that time, I don't know. But over that kind of period, that is to say between now and the end of this century, I see no possibility of managing this problem of climate change without a major expansion of nuclear power.

Mr. FERTEL. Congressman Schwarz, I would agree with what my two colleagues said, and the only thing I would add is that we see hydrogen as becoming a player, and we actually see nuclear as a player in producing hydrogen, not necessarily through electrolysis, but through chemical processes at high temperatures.

The other thing, on the adequacy of uranium supply, there are a lot of projections on the adequacy of the uranium supply. Uranium prices are up 150 percent in the last year because of questions about uranium availability, and that is today. So there is uranium out there, but that doesn't mean you shouldn't be looking at smarter recycling techniques. And I think that that is important to do, not just from fuel supply, but from the way that the gentleman started, which is fundamentally from a waste management perspective. You can't keep building large repositories worldwide. And yes, you can store it above ground, but ultimately our responsibility to the people living today, our children, and our grandchildren is to dispose of it. And we ought to deal with it. Okay. We are smart enough to deal with it. We ought to get on with it and deal with it. And that would seem to be the thing that responsibly this country, again, could provide leadership on.

Congresswoman Biggert, you mentioned what Chairman Hobson put in the energy and water appropriations bill, and we certainly respect Chairman Hobson's desire to get it done by 2007. We only wish we could. What we would like to do is take his leadership and leverage off of that and say that if we can move forward with the government, the DOE looking at a road map or whatever that can move the R&D down the road quicker, that would be very good. I still think deployment is a long way off, just practically.

Mr. SCHWARZ. Thank you, gentlemen.

Thank you, Madame Chair.

Chairwoman BIGGERT. Thank you.

And certainly, Chairman Hobson is the appropriator, but we are the authorizing committee, and so this is something that we need to address and I, for one, you know, would want to push that.

The gentlelady from Texas, Ms. Jackson Lee, for five minutes.

Ms. JACKSON LEE. I thank the Chairwoman very much and the Ranking Member for the opportunity for such an important hearing.

And I would ask unanimous consent that my opening statement be allowed to be submitted into the record in its entirety.

Chairwoman BIGGERT. Without objection.

Ms. JACKSON LEE. I think that there is a large question on the idea of nuclear energy and nuclear waste. I have, for a long period of time, challenged Yucca Mountain as to whether or not that is the best approach. My concern, of course, is that anything that is geographically or population-wise geographically bare, meaning that it is an open, unused area, with the growing population that we have in the United States, one can never tell, as populations grow and expand, what may be an unpopulated area today may be a populated area tomorrow.

With that in mind, this whole question of reprocessing poses a great deal of interest, particularly if it has some economic benefit to it and as much if it has some ability to be secure, because one of the concerns those of us who serve on the Homeland Security Committee, and we have a Subcommittee dealing with the issue of nuclear materials, is the question of security, certainly in the backdrop of the recent tragic incident in London, England.

Dr. Fetter, I would like to query you on if you would point to the viability of reprocessing from the points that I have just made.

One, we can never guarantee areas that may remain unpopulated. I am sure that the fans of the Yucca Mountain process, of course, will argue of its deep embeddedness and that it does not pose a threat, but you might want to comment on that, not on the Yucca Mountain per se, but the fact is that wherever you put nuclear waste, there may be the possibility of it being near population sites. But I think I am interested in this whole question of the processing being secure, the processing being a ready technology that is comparable and ready to move on now, and the kind of expertise that would be needed to engage in reprocessing in a massive scale. And I thank the witnesses for their testimony.

Dr. FETTER. Well, I think it is important to note that reprocessing does not eliminate the waste, and it doesn't remove the need for a deep geologic repository. Even with a complete separations and transmutation system, there would still be the need for a deep geologic repository, like the one at Yucca Mountain. And while I am not an expert on geologic disposal, I know there have been many studies by the National Academy of Sciences on the safety of Yucca Mountain, which have concluded that one can adequately protect public health and safety through the geologic disposal of waste at Yucca Mountain.

The issue of security is one that I do worry about. Even in the United States, I worry about the security of—the security implications of reprocessing and, in particular, the transport and use of mixed oxide fuel around the United States, because that material, if it were stolen and diverted, could be used to build nuclear weapons. And as I have also said, I worry particularly about the security implications of a move by the United States toward reprocessing and the example that it would set for other countries.

Ms. JACKSON LEE. Did you answer the question about expertise in the reprocessing area, the amount of trained personnel that you need to train more personnel, the process that would be needed?

Dr. FETTER. Well, one would need a fairly extensive research program to develop the—these technologies more fully, and in the process of conducting that research and development, one would naturally, I think, develop the necessary expertise that would be needed to do this well. I think that can be done with the existing university infrastructure that we have in the United States.

Ms. JACKSON LEE. Anyone else want to comment quickly on the training aspect over the expertise needed in the reprocessing?

Dr. LESTER. Well, if I may just add a word about that. I—because a purely private initiative in reprocessing would be unviable economically, it would necessitate a federal intervention, which would involve a commitment of funds, obviously, but perhaps equally importantly would place heavy demands on the government's own nuclear-trained human resources, who would necessarily have to be involved in the selection of sites and the development of a licensing framework and the management of contractors and so on. And the resources, both human and financial, that are potentially available to the Federal Government to support the development of nuclear power, are not unlimited, and therefore, a new initiative in reprocessing could risk diverting resources from other policy initiatives that might make a greater positive contribution to the future of nuclear power over the next few decades.

Mr. FERTEL. Again, a slightly—twist on what Dr. Fetter just said.

The government is spending resources right now looking at advanced fuel cycle initiatives, which include looking at transmutation and reprocessing. What, again, this committee can do is help make sure that they are using their resources most effectively in doing that as opposed to piece meal in different laboratories and different parts of the bureaucracy. So there are resources currently being committed. Your question is a very good one, and I think Richard's answer is a good one, but there are bodies and minds working this right now. And what could be looked at is: are they working it as smart and as efficiently as they can be and in as an integrative way as possible?

Ms. JACKSON LEE. I appreciate that answer.

Madame Chairperson, I thank you. I think the two prior speakers gave me the gist, which is if we take a lot of dollars and take away from another effort, we have a problem, but we already have dollars, and if we organize them better, we might be able to move forward on what may be important research.

I thank the Chairwoman, and I yield back my time.

Chairwoman BIGGERT. Thank you very much.

I think if we can—briefly, if there are other people that have what—further questions, and I do, or maybe it is going to turn out to be more of a statement, but I recognize myself for five minutes.

And I would agree with Mr. Fertel when he talked about how we tried to set an example 30 years ago that really nobody paid attention to it and the nuclear non-proliferation, and we, obviously, thought we were being the leaders and shut down everything, and everybody else went ahead. And what has—but the research has not died on this, and it never did. I was over in France to look at the research over there, and all they did is talk about how they had gotten their research from Argonne in Illinois, and that is—they were using that process that was developed 20 to 30 years ago. And they are still using an old process. But since I have been in Congress and I have worked on this committee, Argonne has been working on the reprocessing starting with the electrometallurgical process and then into the pyroprocessing, which was the—looking at the EBR to the breeder reactor and that—and then going further to the spent fuel pyroprocessing and transmutation. So it is not as if there has been a void here in looking at reprocessing at all, and I think that is very important, because this is—this committee looks at basic science, looks at the research, basic research and development, and this, I think, is another area that we cannot just look to industry and say, "Well, you go out and do it," because it is a very expensive process. But in the long run, to me, reprocessing goes along with the advanced fuel cycle and the closed—and we are—we haven't built a reactor in how many years, 30 years, and it is going to take a while to do that. So why can't we do the whole thing at once and have something that is going to last, that is going to cut out the fuel? And we heard in testimony the last time that if we had reprocessing—take all of the materials that we have now, that we would never have to build another Yucca Mountain. We would be able to use one that—for hopefully centuries, that

would be the place to put the spent fuel that would remain—it would not—and it would only last 300 years and et cetera.

So anyway, that is my soapbox. But do you think, and I will—and I come back to this again. I think it is the way that we started. Do you think with what we are developing and the time that it is going to take us to do the whole process, that we will be able to do that in less than 50 years and yet we will be able to do all of this?

So I am going to start with Mr. Fertel. Start the other way this time.

Mr. FERTEL. Yeah, I actually think that you could be deploying by 2025, if that is what the government decided was the right thing to do. I think that what you need to get there, but—is a conscious plan going forward, which is technology and policy, because if it doesn't include the policy decisions, you are going to have a problem on what happens on the buying side, on the implementation side. I don't think there is any question about the growth of nuclear energy in the world and in our country as an integral part of what is going to help satisfy both energy and environmental needs, and therefore, whether we have a uranium problem or not, we are going to have to do something smarter with the used nuclear fuel, and doing it smarter with—and I am totally cognizant of what Steve said about the examples we set and from a non-proliferation standpoint, making sure that we are not creating problems, particularly in the world we live in today.

Chairwoman BIGGERT. Well, I think we heard that at our last hearing that really the new process would really reduce, reduce, reduce the nuclear proliferation problem.

Mr. FERTEL. Done right and done with the right leadership.

Chairwoman BIGGERT. Dr. Fetter.

Dr. FETTER. Well, as I said, I do—even though I don't support any near-term reprocessing, I do support research on advanced reprocessing and recycle technologies, ones that would be, hopefully, cheaper, but most importantly, would be more proliferation-resistant. It is my understanding that the proposals that have been currently put forward, though, are not more proliferation resistant. For example, the UREX+ process, which was part of the program, I think, Bill Magwood would testify that that, in fact, was not more proliferation-resistant than the PUREX—or didn't—maybe he didn't testify. Perhaps he stated that this was not more proliferation-resistant. So I think that in future research, much attention and perhaps real team effort should be devoted to ensuring that any new process that is developed is more proliferation-resistant.

Chairwoman BIGGERT. I think what he said was that there is—that it hasn't been—any large reprocessing that has not been done yet, but it is—the research is there. Now it just needs the application.

Dr. Jones.

Dr. JONES. The reprocessing technology alternatives were really outside the scope of our study, so I didn't——

Chairwoman BIGGERT. Thank you.

Dr. Lester.

Dr. LESTER. Well, Madame Chair, your question is essentially, I think, how long will it take. And the answer is it depends on what

you want. If you want a PUREX-type of modest modification to a PUREX-type reprocessing——

Chairwoman BIGGERT. No, I think we are talking about the reprocessing that has transmutation that is not nuclear—or there will not be nuclear proliferation.

Dr. LESTER. If you want that, and if you want, moreover, a configuration, a scheme, that would remove all of the troublesome radionuclides from the waste, the long-lived ones, and moreover, figure out how to fabricate them into appropriate targets and then transmute them so that there is very little left, if you want to achieve all of that and have a proliferation-resistant scheme, I think this is not going to take one decade. I am not even sure it is going to take less than two decades. I think we are talking about a long-term program for which I certainly believe that we should be doing serious, careful, long-term research. But I don't think this is something that would be available to us by, for example, the year 2020.

Chairwoman BIGGERT. Thank you.

Thank you.

Mr. Honda, do you have any questions? Okay. Thank you.

Dr. Ehlers is recognized.

Mr. EHLERS. Just a few, Madame Chair.

First of all, one thing that we haven't mentioned at all, which I think is a very important part of the current energy needs, is to improve our efficiency of energy use. That is the single biggest, cheapest thing we can do immediately to solve our short-term energy problem. And I realize it is a one-term bump, but it is something that, once established, will pay off tremendously over many years.

Secondly, I wanted to support my colleague from Maryland, Dr. Bartlett's comments about fossil fuel, although there is—appears to be ample coal at the moment. Certainly, there are some environmental side effects, and we need a lot of work on trying to resolve that problem if we are going to use it. Oil is not a factor, as you said, simply because the costs are going to escalate. I think—and I believe the same thing is true of natural gas. I—we have—I firmly believe natural gas is too valuable to burn. It is an incredibly good feed stock for the petrochemical industry, and we are basically, because of its good environmental effects now, we are burning it to produce electrical energy when there are other alternatives available.

I would also disagree with the comments about photovoltaics, and I would refer you to an article in the APS, American Physical Society, newsletter not too long ago, a very good review of photovoltaic technology and much more optimistic than you testified about. It doesn't solve the storage problem, of course, but I have a friend who has built a house in northern Michigan, which is certainly not a warm and friendly climate, and he is five miles from the nearest power line, and it is totally solar-powered. They have never had a problem of any sort with it, in spite of our miserable weather, both cloudy and cold.

The proliferation issue I don't think is an issue anymore as it relates to the fuel cycle. I think the greatest risk right now is the plutonium floating around in the former Soviet Union and—which

is not being properly accounted for and cared for. We also have a number of other nations producing plutonium, and I think that genie is out of the bottle. There are a lot of good reasons not to create more. I understand that. But it is not a stopper, in my mind.

And finally, just a little pet peeve of mine, which I developed years ago as a county commissioner and Chairman of the Board of Public Works. I proposed we rename our county landfill, which was called the "Kent County Waste Disposal System," and rename it as the "Kent County Waste Storage System." Just because you put it in our ground doesn't mean it is gone. It is still there. You have not disposed of it. It is stored there, and as our county commission found out when it began leaking into rivers and ponds, and we had to spend millions of dollars in remediation. The same is true of nuclear waste. You are not disposing of it. The question is how can we most carefully and properly store it, and particularly, how can we most economically retrieve the materials and correct the problem when problems will occur, because they will occur. And I think the emphasis on disposal at Yucca Mountain is a major part of the problem. And recording a 10,000-year guarantee is a major part of the problem. Monitored retrievable storage, I believe, is safer and likely to be less expensive and certainly more acceptable politically. And I think if we had gone that route, I believe we would have Yucca Mountain operating at this point.

With that, I yield back.

Chairwoman BIGGERT. Thank you.

Dr. Bartlett, the gentleman from Maryland.

Mr. BARTLETT. Thank you very much.

Dr. Ehlers mentioned coal. We have about 250 years of coal reserves in our country at current use rates. But yet, to ramp up the use of coal, as we certainly will, as other energy sources become less available, if the—you increase only two percent exponentially, that now shrinks to about 85 years. And when you recognize that for many purposes, you are going to have to transform the coal into a gas or a liquid, now you have shrunk to about 50 years. So there is about 50 years of coal left with a two-percent growth, exponential growth, if you are transforming it to a form where you can put it in your car or do other things with it.

One of you mentioned that there were five sources, four in addition to nuclear energy. The other alternatives are going to require very large investments of time and energy, and we are running out of both of those.

I would just like to comment very briefly on two of them you mentioned.

One was unconventional fossil fuels. The Tar Sands of Canada, I am going up there this summer to look at those, I believe, they are now producing oil out of those at about $30 a barrel, and with oil today more than $60 a barrel, gee, that sounds good. And there is lots of oil there, and so we will just harvest that. But I am also told that there is a net energy deficit in doing that. They are getting the oil out of the ground by drilling two wells, ultimately—they are horizontally. In the upper well, they put a lot of steam, hot water, which they generate with gas, and that they, in fact—and then it softens the oil and it can flow down and be picked up by the second well, which is drilled under that, that they are, in

fact, using more energy from the gas that they are getting out of the oil. Now if that is true, this is not a solution to our energy problem. As long as gas is cheap and it is there and you can put oil in a pipeline and move it here, that may be justified, but I would really like to second what Dr. Ehlers said. Gas is, in fact, too good to burn. As a matter of fact, nearly half the energy in producing a bushel of corn is represented by the gas that is used to make nitrogen fertilizer. Very few people recognize that.

The other potential source is biomass. Until we learned how to do no-till farming, we were losing the battle with maintaining our topsoils. They are now all down in the Mississippi Delta from the central part of our country. Now we are barely able to maintain our topsoils, and that is permitting much of this, what you call biomass to go back to become humus. If you take that away, then the soils become, in effect, a soup when it is wet and a brick when it is dry, so you make brick. You take soil that has no humus in it, it is called clay, and you put it in an oven and bake it, and that is a brick.

So although we can certainly get some energy out of biomass, I would caution that our ability to do that is very limited compared to the amount of energy that we get from fossil fuels that we have got to replace.

Just one little illustration of the enormous energy density in fossil fuels. One barrel of oil, the refined product of which gasoline you can now buy at the pump, 42 gallons, roughly $100 will buy that for you at the pump, right. That will buy you the work output of 12 people working full-time for you one year.

To give you another perspective of the enormous energy density in fossil fuels, if you go out this weekend and work very hard in physical labor all day long, I will get more mechanical work out of an electric motor with less than 25 cents worth of electricity. Your worth for manual labor, less than 25 cents a day. And that is the challenge we have in transitioning from these fossil fuels to these alternatives. Enormous energy density.

We have 5,000 years of recorded history. We are not a bit over 100 years into the age of oil. In another 100 years, we will be out of the age of oil. If not massive nuclear, what then? I am glad that you were—you are a great audience. Most of the audiences, less than two percent of the people know anything about M. King Hubbard and "Hubbard's Peak," and all of you seem to know about that. Congratulations.

Madame Chairman, thank you very much for hosting this meeting, because it gives us an opportunity to look at the overall energy problem we face. And again, I would counsel that I wouldn't bet the ranch on the prognostications of the Energy Information Agency.

Chairwoman BIGGERT. Okay. Thank you. The gentleman yields back.

Before we close the hearing, I would like to recognize Bill Carney, a former Science Committee Member, is sitting in the back of the room. Do you want to raise your hand? Welcome. I am glad you came back to see how we are doing.

I want to thank our panelists for testifying before this subcommittee today. It has really been enlightening, and thank you for

spending the time with us and really helping us in our policy deliberations. We really appreciate all that you have had to say.

And if there is no objection, the record will remain open for additional statements from Members and for answers to any follow-up questions the Subcommittee may ask the panelists.

Without objection, so ordered.

This hearing is now adjourned.

[Whereupon, at 4:15 p.m., the Subcommittee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Richard K. Lester, Director, the Industrial Performance Center; Professor of Nuclear Science and Engineering, Massachusetts Institute of Technology

Questions submitted by Chairman Judy Biggert

Q1. What steps are available to reduce the costs associated with an advanced fuel cycle? Specifically, which steps or technologies have fixed costs that can't be reduced and which steps or technologies might see significant cost reductions with further research and development?

A1. Every stage in the nuclear fuel cycle has the potential for cost reduction through the implementation of new technologies as well as the exploitation of insights from accumulated operating experience. This is true of the front-end stages, including uranium resource exploration and production and uranium enrichment, as well as back-end stages such as interim spent fuel storage, reprocessing, and waste disposal. Uncertainties in cost are greatest at those stages of the fuel cycle where there is a lack of significant-scale practical operating experience, including actinide partitioning and transmutation schemes. Research and development can play an important role in reducing these uncertainties, as well as, potentially, reducing costs. Most current research, development, and analysis on back-end fuel cycle stages is focused on providing information about the operation of a single process, set up in one way. While these activities produce knowledge, they do not allow for transferring information to new, related situations and thus provide no foundation for the accumulation of information about how variations in the operation of plants and other parts of the fuel cycle affect costs, safety, waste and proliferation resistant characteristics. A modeling, analysis, and simulation program is needed that will permit evaluations of how changes in one feature of a design for the sake of, say, safety may affect other aspects of the design, the overall performance of the system, and the cost of operation. Laboratory-scale research on new separations methods with the goal of developing technologies that are less costly and more proliferation resistant is also important. However, expensive projects for development and demonstration of advanced back-end fuel cycle technologies carried out too far in advance of any credible deployment opportunity and without benefit of the technical basis provided by analysis and research can be counterproductive for cost reduction efforts.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Donald W. Jones, Vice President of Marketing and Senior Economist at RCF Economic and Financial Consulting, Inc.

Q1. Dr. Lester, in his testimony, makes the point that fleet-wide averaging of costs isn't possible in the U.S. industry as it is in France, for example. Do you agree? In the complicated situation here in the U.S., with some States regulated, others deregulated, and all setting their own policies, how easy or difficult is it to pass the costs of reprocessing on to the consumer in the form of higher rates?

A1. Electricity pricing is much more complex in the United States than in France. Deregulation has separated generators from retail distribution, where consumer pricing occurs. Some generators may have customers in both regulated and deregulated markets, and the constraints on retail pricing in regulated markets may affect wholesale pricing to those markets in ways that are not applicable in sales to retailers in deregulated markets.

However, the estimates of the additional cost of reprocessing indicate that those costs are so small that consumers simply will not notice them. This result in no way depends on a utility being able to spread reprocessing costs across all of its generation facilities, conventional as well as nuclear. The full fuel cycle cost of new nuclear plants, without reprocessing, our study calculated to be about ½ cent per kilowatt hour. Publicly available estimates from the Harvard study, the Nuclear Energy Agency, and a report by Simon Lobdell suggest that reprocessing would increase the full fuel cycle cost to about six-tenths of a cent per kilowatt hour. Adding this cost to a generation cost of 6.2 cents per kilowatt hour, which is a wholesale price that excludes any transmission and distribution costs which final consumers face, I believe would not have an appreciable effect on consumers.

The United States currently does not have commercial reprocessing infrastructure, and the cost calculations presented above do not take into consideration any broader costs required to bring such an infrastructure into existence.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Steve Fetter, Dean, School of Public Policy, University of Maryland

Questions submitted by Chairman Judy Biggert

Q1. Why do you think the cost estimates for the Japanese Rokkasho plant tripled from the original estimates? What economic lessons can we learn from their experience?

A1. In the late 1980s, when the construction plan for the Rokkasho reprocessing plant was approved, the estimated construction cost was about $7 billion and estimated operating date was December 1997. Because the design was based on the French UP3 plant, which was built at a cost of about $5 billion, this initial estimate seemed reasonable. It now appears that the plant will not begin commercial operation before 2007, and that the total construction cost will be over $21 billion. A full explanation for the tripling in cost would require a detailed investigation. The plant operator, Japan Nuclear Fuels, Ltd. (JNFL), has cited construction delays resulting from a series of design changes to comply with increased seismic and other safety requirements. Others have suggested poor project management by JNFL and a lack of competition among plant contractors and vendors as major reasons for the dramatic cost escalation.

One lesson that could be learned from the Japanese experience is that a lack of domestic experience with the construction and operation of commercial reprocessing plants can lead to substantial cost overruns. The only commercial reprocessing facility to operate in the United States, at West Valley, New York, closed in 1972 after a few years of troubled operation. (The site is still the location of an ongoing, multi-billion dollar, government-funded radioactive waste cleanup project.) The lack of domestic experience, combined with a relative lack of competition among the few foreign firms with the necessary experience, are bound to drive up costs for a new U.S. reprocessing facility substantially above initial estimates.

Q2. You say that increasing natural gas prices and that costs of carbon dioxide emission reductions will make nuclear more competitive, but that it will still have to compete with wind, biomass and coal-fired plants with sequestration. Biomass and sequestration in particular are not mature technologies with known costs and will require government research subsidies to become so. In terms of incremental cost per kilowatt-hour, how might those subsidies compare to the subsidies we are talking about for reprocessing?

A2. Government funding for research and development for new technologies cannot be directly compared to subsidies for the operation of existing types of facilities. Government funding to develop new technologies is required when the financial risks are too great and the time scales too long to allow private firms to recover their investments in research and development in a timely manner. The development of light-water nuclear reactor technology is one example from the past; the development of advanced technologies for biomass, solar photovoltaics, and carbon sequestration are current examples. If basic research yields a new, economically competitive method of energy production, private firms can adopt and deploy the technology with no ongoing subsidy. If the technology is successful, the initial federal investment in research and development can be a very small compared to the ultimate benefits to the U.S. economy.

The management of spent nuclear fuel is fundamentally different. Utilities currently are expected to pay the full cost of the geological disposal of spent fuel in the Yucca Mountain repository. Reprocessing using current technologies will double or triple total spent-fuel management costs, while having no waste-disposal advantages and increasing risks of nuclear theft and proliferation. New approaches to reprocessing, which promise to decrease requirements for geological repository space, are certain to be even more expensive and to be less proliferation-resistant as direct geological disposal. Even if demand for nuclear power increases rapidly, reprocessing would require an ongoing subsidy for the next 50 to 100 years.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Marvin S. Fertel, Senior Vice President and Chief Nuclear Officer, The Nuclear Energy Institute

Question submitted by Chairman Judy Biggert

Q1. In your testimony, you state more than once that the consumers of nuclear energy should not bear the additional costs of reprocessing. If we make a transition to reprocessing, how should the costs be covered?

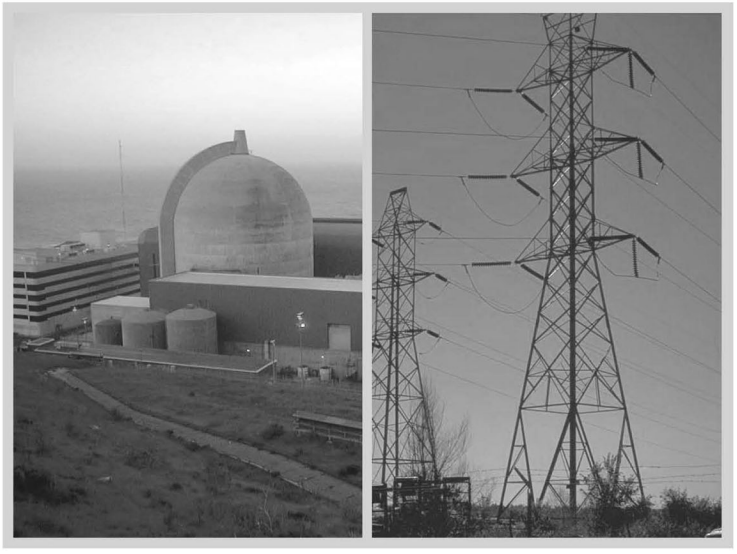
A1. Electricity consumers should only be charged for the reasonable costs of services that benefit them directly as part of the cost of electricity. The Nuclear Waste Fee ($0.001 per kWhr) is such a cost appropriately charged to electricity consumers. There is no evidence that the costs of used nuclear fuel disposal by the Federal Government under the *Nuclear Waste Policy Act* should lead to an increase in the Fee. If reprocessing is carried out to serve a national objective, but would raise the cost to electricity consumers beyond what consumers would pay without reprocessing, then the costs should fairly be borne by the Federal Government on behalf of the Nation.

There are three reasons that the Nation might re-engage in reprocessing: fuel supply, waste disposal, and non-proliferation. To the extent that the cost of reprocessing raises the cost of either nuclear fuel supply or used fuel disposal beyond the cost without reprocessing, the additional cost should rightfully be borne by the Federal Government, because the only reason to carry out reprocessing would be for some broader, national benefit. Non-proliferation is clearly a broader, national benefit and any costs of reprocessing associated with non-proliferation should rightfully be borne by the Federal Government.

Appendix 2:

Additional Material for the Record

THE ECONOMIC FUTURE OF NUCLEAR POWER



A Study Conducted at The University of Chicago

August 2004

THE ECONOMIC FUTURE OF NUCLEAR POWER

A Study Conducted at The University of Chicago

August 2004

STUDY PARTICIPANTS

George S. Tolley, Professor Emeritus at The University of Chicago, and Donald W. Jones, Vice President of RCF Economic and Financial Consulting, Inc., directed the study.

The study was carried out in cooperation with the Department of Economics, the Graduate School of Business, and the Harris School of Public Policy of The University of Chicago. Graduate students and advanced undergraduate students coauthored the study as follows:

Name	Topic	Affiliation
Martin Castellano	Nonproliferation	Harris School of Public Policy
William Clune	Nuclear Waste Disposal Nuclear Fuel Cycle Nuclear Regulation	Harris School of Public Policy
Philo Davidson	Future Electricity Capacity	Economics
Kant Desai	Nuclear Technologies Hydrogen, Gas, and Coal Technologies Environmental Policies	Harris School of Public Policy
Amelia Foo	Hydrogen	Economics
Adrian Kats	Energy Security	Economics
Minghao Liao	Levelized Costs of Electricity	Economics
Emil Iantchev	Energy Security	Economics
Nathan Ilten	International Comparisons	Economics
Wei Li	Financing Issues	Graduate School of Business
Mark Nielson	Financing Issues	Economics
Ashwin Rode	Fuel Prices	Economics
James Taylor	Nuclear Technologies Hydrogen	Harris School of Public Policy
Walter Theseira	Electricity Futures	Economics
Stephanie Waldhoff	Environmental Policies	Harris School of Public Policy
Daniel Weitzenfeld	Learning by Doing	Economics
Jie Zheng	Financing Issues Nuclear Scenarios: 2015	Graduate School of Business

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TABLES(contd.)

PREFACE

In 2003, the U.S. Department of Energy (DOE), acting through Argonne National Laboratory (ANL), requested a study of the economic factors affecting the future of nuclear power in the United States. The study was carried out at The University of Chicago.

The present report gives the results of the study. Intended to be a white paper, it is a systematic review of the economics of nuclear power that can serve as a reference for future studies. It does not take a position on policy subjects. Rather, it reviews and evaluates alternative sources of information bearing on the nuclear power industry, and presents scenarios encompassing a reasonable range of future possibilities.

Part I considers factors affecting the competitiveness of nuclear power. Topics include (1) levelized costs, (2) comparisons with international nuclear costs, (3) capital costs, (4) effects of learning by doing, and (5) financing issues.

Part II analyzes gas-fired and coal-fired technologies as the major baseload competitors to nuclear generation. Topics include technologies that could reduce the costs of gas- and coal-fired electricity, future fuel price changes, and the potential economic impact of greenhouse gas control policies and technology.

Part III analyzes several federal financial policy alternatives designed to make nuclear power competitive in the next decade and beyond.

The Appendix provides comprehensive background information underpinning the body of the study. Previous nuclear energy studies were less comprehensive. The demand for new electricity generating capacity in the United States is estimated. A major concern is the viability of new nuclear plants as a way to meet growing electrical demand during the next decade. The study focuses on baseload electrical capacity. Appendices A1 through A9 address the major factors that affect the desirability and the viability of nuclear power. Conclusions include the following:

- Waste disposal issues remain to be settled.
- U.S. policy regarding nonproliferation goals will affect future fuel cycle decisions.
- Regulatory simplification shows promise of reducing plant construction times.
- A transition from oil-based to hydrogen-based transportation could, in the longer run, increase the demand for nuclear power as a non-polluting way to produce hydrogen.
- If gas imports increase, nuclear power could substitute for gas and contribute to energy security.

DOE NUCLEAR POWER 2010 PROGRAM *

In FY 2003, the U.S. Department of Energy (DOE) initiated a University of Chicago study on the economic viability of new nuclear power plants in the United States. This report describes the results of that study. According to DOE's Fiscal Year 2005 Budget Report, "the information obtained from this study is used to focus the program's activities on issues of the greatest impact" (DOE 2004, p. 397).

The Nuclear Power 2010 program is a joint government-industry cost-shared effort involved with identifying sites for new nuclear power plants, developing advanced nuclear plant technologies, evaluating the business case for building new nuclear power plants, and demonstrating untested regulatory processes. These efforts are designed to pave the way for an industry decision by the end of 2005 to order a new nuclear power plant. The regulatory tasks include demonstration of the Early Site Permit (ESP) and combined Construction and Operating License (COL) processes to reduce licensing uncertainties and minimize attendant financial risks to the licensee.

The Nuclear Power 2010 program continues to evaluate the economic and business case for building new nuclear power plants. This evaluation includes identification of the economic conditions under which power generation companies would add new nuclear capacity. In July 2002, DOE published a draft report, "Business Case for New Nuclear Power Plants in the United States," which provided recommendations for federal government assistance. DOE continues to develop and evaluate strategies to mitigate specific financial risks associated with deployment of new nuclear power plants identified in that report.

Recently, DOE solicited proposals from teams led by power generation companies to initiate new nuclear plant licensing demonstration projects. Under a cost-sharing arrangement, power companies will conduct studies, analyses, and other activities necessary to select an advanced reactor technology and prepare a site-specific, technology-specific COL application. DOE has already received responses from several utility consortia.

DOE has also initiated a technology assessment of nuclear power plant construction, which is being conducted in cooperation with the power generation companies. That study has assessed schedules and construction methods for the nuclear power plant designs most likely to be built in the near term.

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*Source: U.S. Department of Energy (DOE). (2004). "FY 2005 DOE Budget Request, Energy and Water Development Appropriations," Vol. 3, Nuclear Energy, pp. 395-398. http://www.mbe.doe.gov/budget/05budget/content/es/nuclear.pdf.

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ABSTRACT

Developments in the U.S. economy that will affect the nuclear power industry in coming years include the emergence of new nuclear technologies, waste disposal issues, proliferation concerns, the streamlining of nuclear regulation, a possible transition to a hydrogen economy, policies toward national energy security, and environmental policy. These developments will affect both the competitiveness of nuclear power and appropriate nuclear energy policies. A financial model developed in this study projects that, in the absence of federal financial policies aimed at the nuclear industry, the first new nuclear plants coming on line will have a levelized cost of electricity (LCOE, i.e., the price required to cover operating and capital costs) that ranges from $47 to $71 per megawatt-hour (MWh). This price range exceeds projections of $33 to $41 for coal-fired plants and $35 to $45 for gas-fired plants. After engineering costs are paid and construction of the first few nuclear plants has been completed, there is a good prospect that lower nuclear LCOEs can be achieved and that these lower costs would allow nuclear energy to be competitive in the marketplace. Federal financial policies that could help make early nuclear plants more competitive include loan guarantees, accelerated depreciation, investment tax credits, and production tax credits. In the long term, the competitiveness of nuclear power could be further enhanced by rising concerns about greenhouse gas emissions from fossil-fuel power generation.

EXECUTIVE SUMMARY

Context

Developments in the U.S. economy that will affect the nuclear industry in the future include the emergence of new nuclear technologies, decisions about nuclear fuel disposition, proliferation concerns, regulatory reform, a potential transition to a hydrogen economy, national energy security policies, and environmental policies. A successful transition from oil-based to hydrogen-based transportation could, in the long run, increase the demand for nuclear energy as a nonpolluting way to produce hydrogen.

The U.S. Department of Energy (DOE) currently supports research on designs for advanced nuclear power plants that can produce hydrogen as well as increase the sustainability and proliferation-resistance of nuclear energy and help lower nuclear energy costs. DOE also supports the certification of new nuclear reactor designs and the early site permitting process that will help make the licensing of new nuclear plants more predictable. Such predictability promises to lower financial risk by reducing the time required to construct and license new plants.

This study analyzes the economic competitiveness of nuclear, gas-fired, and coal-fired electricity.

Summary of Economic Findings

Economics of Deploying Plants during the Next Decade

- Capital cost is the single most important factor determining the economic competitiveness of nuclear energy.
- First-of-a-kind engineering (FOAKE) costs for new nuclear designs could increase capital costs by 35 percent, adversely affecting nuclear energy's competitiveness.
- The risk premium paid to bond and equity holders for financing new nuclear plants is an influential factor in the economic competitiveness of nuclear energy. A 3 percent risk premium on bonds and equity is estimated to be appropriate for the first few new plants.
- Without federal financial policy assistance, new nuclear plants coming on line in the next decade are projected to have a levelized cost of electricity (LCOE) of $47 to $71 per megawatt-hour (MWh). This study provides a full range of LCOEs for first nuclear plants for alternative construction periods, plant lives, capacity factors, and overnight cost estimates. LCOEs for coal- and gas-fired electricity are estimated to be $33 to $41 per MWh and $35 to $45 per MWh, respectively.

- With assistance in the form of loan guarantees, accelerated depreciation, investment tax credits, and production tax credits, new nuclear plants could become more competitive, with LCOEs reaching $32 to $50 per MWh.

Economics of Deploying the Next Series of Nuclear Plants

- With the benefit of the experience from the first few plants, LCOEs are expected to fall to the range of $31 to $46 per MWh; no continued financial assistance is required at this level.

Future Greenhouse Gas Policies

- If stringent greenhouse policies are implemented and advances in carbon capture and sequestration prove less effective than hoped, coal-fired electricity's LCOE could rise as high as $91 per MWh and gas-fired electricity's LCOE could rise as high as $68 per MWh. These LCOEs would fully assure the competitiveness of nuclear energy.

SUMMARY

Background

The focus of this study is baseload electricity as supplied by nuclear, coal-fired, and gas-fired technologies. Baseload power is power that a utility generates continuously, year round, in anticipation of the minimum customer demand that will occur, regardless of daily and seasonal fluctuations. Nuclear energy, coal, and gas are the major baseload fuel alternatives. Renewables are not considered since they are used minimally to meet baseload demand. While hydroelectric facilities supply baseload generation in some parts of the United States, the major opportunities for hydroelectric projects have already been taken. Table 1 presents the shares of generation furnished by various technologies in the United States. This study synthesizes the current understanding of the factors affecting the economic viability of nuclear power and estimates its viability under a range of future scenarios.

Table 1: Shares of Total U.S. Electricity Generation, by Type of Generation, 2003[a]

Energy Source	Net Generation, Percent
Coal	50.1
Nuclear	20.2
Natural Gas	17.9
Hydroelectric	6.6
Petroleum	2.5
Non-hydro Renewables	2.3
Other Sources	0.4
Total	**100**

[a]Identical to Table A1-1.

Part One: Economic Competitiveness of Nuclear Energy

This study first develops a pre-tax levelized cost of electricity (LCOE) model and uses it to calculate LCOEs for nuclear, coal, and gas generation based on values from recent plant models and data developed for use in those models. The LCOE is the price at the busbar needed to cover operating costs plus annualized capital costs. Table 2 summarizes these results.

Table 2: Summary Worksheet for Busbar Cost Comparisons, $ per MWh, with Capital Costs in $ per kW, 2003 Prices[a]

Technology	Sandia Model GenSim		SAIC Model Power Choice			Scully Capital Report			EIA – AEO 2004	
	r=10%	r=15%	Debt r = 8%; Disc r = 8%	Debt r =10%; Disc r = 8%	Debt r =10%; Disc r = 10%	r = 8%	r = 10%	r = 10%	Debt r =10%; Eq = 15%; Disc r = 10%	Debt r =8%; Eq = 10%; Disc r = 10%
Nuclear (capital cost)	51 (1,853)	83 (1,853)								
Legacy Nuclear (capital cost)			65 (2,000)	70 (2,000)	77 (2,000)					
EIA Reference Case, New Nuclear (capital cost)									63 to 68 (1,752 to 1,928)	
EIA Advanced Technology Case, New Nuclear (capital cost)									43 to 53 (1,080 to 1,555)	
ABWR (capital cost)			53 (1,600)	50 (1,600)	55 (1,600)					
AP 1000 (capital cost)			49 (1,365)	46 (1,365)	51 (1,365)	36 (1,247)	40 (1,247)	44 (1,455)		
Pebble Bed Modular Reactor (PBMR) (capital cost)			40 (1,365)	41 (1,365)	45 (1,365)					
Gas Turbine Modular Helium Reactor (GT-MHR) (capital cost)			39 (1,126)	39 (1,126)	43 (1,126)					
Advanced Fast Reactor (AFR) (capital cost)			57 (1,126)	57 (1,126)	64 (1,126)					
Coal (capital cost)	37 (1,094)	48 (1,094)	43 (1,350)	44 (1,350)	49 (1,350)					38 (1,169)
Gas Turbine Combined Cycle (capital cost)	35 (472)	40 (472)	38 (590)	38 (590)	40 (590)					41 (466)
Gas Combustion Turbine (capital cost)	56 (571)	68 (571)								
Solar-Photovoltaic	202	308								
Solar-Thermal	158	235								
Wind	55	77								

[a]Identical to Table 1-1.

To illuminate the reasons for the ranges of LCOEs estimated in prior studies, this study calculates LCOEs using the cost and performance assumptions used in three plant models identified in Appendix A2 (Table A2-1) and in the National Energy Modeling System (NEMS), as reported in the Energy Information Administration's (EIA's) *Annual Energy Outlook*. The Sandia model, GenSim, does not specify a particular nuclear technology; rather, it adopts EIA's specifications from the 2003 *Annual Energy Outlook* (AEO 2003). At a base capital cost of $1,853 per kW, increasing the discount rate from 10 to 15 percent raises the GenSim busbar nuclear cost from $51 to $83 per megawatt-hour (MWh). GenSim's estimates for competitors to nuclear are: $37 to $48 per MWh for coal, $35 to $40 per MWh for gas turbine combined cycle, and $56 to $68 per MWh for gas combustion turbines. The SAIC model, Power Choice, considers several nuclear technologies; cost estimates range from $39 per MWh for the Gas Turbine Modular Helium Reactor (GT-MHR) to $77 per MWh for existing nuclear technology. Coal-fired costs are on a par with the Pebble Bed Modular Reactor (PBMR) costs, at $43 to $49 per MWh. Gas turbine combined cycle costs are in the range of $35 to $48 per MWh. The Scully model compares alternative financing plans for a technology that broadly corresponds to the AP1000. The busbar cost range is $36 to $44 per MWh. The reference case in EIA's recent *Annual Energy Outlook* (AEO 2004) considers future construction of historical designs. Its assumptions regarding capital costs and interest rates result in a nuclear busbar cost of $63 to $68 per MWh, which is higher than most other studies. However, its cost for coal generation is $38 per MWh. Its advanced technology case lowers capital costs, partly to reflect learning effects in construction, which produces LCOEs of $43 to $53 per MWh.

Worldwide Cost Estimates

This study compares U.S. nuclear busbar costs with those in other countries that use electricity generated from nuclear energy, coal, and gas. U.S. nuclear busbar costs are estimated to be somewhat below the middle of the worldwide range for countries not reprocessing spent fuel, i.e., $36 to $65 per MWh. LCOEs of new nuclear plants in the United States compare favorably to prospective costs for new nuclear plants in France. Table 3 reports the nuclear busbar costs for various countries; separate estimates are provided for fuel cycles that dispose of spent fuel directly and those that reprocess spent fuel.

Table 3: Organization for Economic Co-operation and Development (OECD) Busbar Costs, 75 Percent Capacity Factor, 40-Year Plant Life, $ per MWh, 2003 Prices[a]

Plant Type	Country	Discount Rate (To Derive Net Present Value)	
		8 Percent	10 Percent
		$ per MWh	
Nuclear, Spent Fuel Disposal	Finland, new SWR 1000	36	42
	Canada	39 to 45	48 to 53
	China	44	54
	United States	45	53
	Russia	45	55
	Romania	49	59
	Korea	49	59
	India	52	64
	Turkey	53	64
	Finland	58	68
	Spain	65	78
Nuclear with Reprocessing	China	39 to 50	47 to 61
	France	50	60
	Japan	83	97
Gas Turbine Combined Cycle	OECD average	30 to 66	38 to 65
Advanced Gas Turbine Combined Cycle	United States	26	27
Pulverized Coal Combustion	OECD average	36 to 74	43 to 84
Coal Circulating Fluidized Bed	Canada	56	63
Coal Integrated Gasification Combined Cycle (IGCC)	OECD average	36 to 66	42 to 74

[a] From Tables 2-5 and 2-6.

Overnight Capital Cost Estimates

Capital costs, the single most important cost component for nuclear power, are analyzed in detail. For the Advanced Boiling Water Reactor (ABWR), already built in Asia, and the AP1000, a smaller scale version of which has been certified by the U.S. Nuclear Regulatory Commission (NRC), overnight capital costs, or undiscounted capital outlays, account for over a third of LCOE; interest costs on the overnight costs account for another quarter of the LCOE. Overnight cost estimates from different sources have ranged from less than $1,000 per kilowatt (kW) to as much as $2,300 per kw. This study examines the reasons for the differences in these estimates, with the aim of estimating a narrower plausible range.

One reason that early plants are more expensive is the impact of first-of-a-kind engineering (FOAKE) costs. Several hundred million dollars may be expended to complete the engineering design specifications for Generation III or III+ reactors. Such costs are incurred for early nuclear plants built of any type. Although building a reactor of a particular design in one country may enable transfer of part of the engineering that will be used in another country, some partial FOAKE costs may still be incurred for the first construction in any given country.

FOAKE costs are a fixed cost of a particular reactor design. How a vendor allocates FOAKE costs across all the reactors it sells can affect the overnight cost of early reactors considerably. A vendor may be concerned about its ability to sell multiple reactors and therefore want to recover all FOAKE costs on its first plant. FOAKE costs could raise the overnight cost of the first plant by 35 percent.

This study uses the Advanced Boiling Water Reactor (ABWR), the CANDU ACR-700, the AP1000, and the Framatome SWR 1000 as reasonable candidates for deployment in the United States by 2015.

- An overnight cost of $1,200 per kW is assumed for a generic class of mature designs.
- An overnight cost of $1,500 per kW is assumed for a generic class of designs that require payment of FOAKE costs.
- An overnight cost of $1,800 per kW is assumed for a generic class of more advanced designs that also require FOAKE costs.

Consideration of the four reactor types contributes to the choice of $1,200, $1,500, and $1,800 per kW for overnight costs, a range consistent with estimates identified in EIA's 2004 advanced technology case. (See AEO 2004.)

Learning by Doing

The study finds that reductions in capital costs between a first new nuclear plant and some n^{th} plant of the same design can be critically important to eventual commercial viability. In building the early units of a new reactor design, engineers and construction workers learn how to build the plants more efficiently with each plant they build. A case can be made that the nuclear industry will start with very little learning from previous experience when the first new nuclear construction occurs in the United States. The paucity of new nuclear construction over the past twenty years in the United States, together with the entry of new technologies and a new regulatory system, has eliminated much of the applicable U.S. experience. On the other hand, participation in overseas construction may have given some U.S. engineers experience that is transferable to construction in the United States.

This study uses a range of 3 to 10 percent for future learning rates in the U.S. nuclear construction industry, where learning rate is the percent reduction in cost resulting from doubling the number of plants built. Table 4 summarizes the conditions associated with different learning rates.

Table 4: Conditions Associated with Alternative Learning Rates[a]

Learning Rate (Percent for Doubling Plants Built)	Pace of Reactor Orders	Number of Reactors Built at a Single Site	Construction Market	Reactor Design Standardization	Regulation Impacts
3	Spread apart 1 year or more	Capacity saturated; no multiple units	Not highly competitive; can retain savings from learning	Not highly standardized	Some construction delays
5	Somewhat more continuous construction	Somewhat greater demand for new capacity; multiple units still uncommon	More competitive; most cost reductions from learning passed on to buyers	Narrower array of designs	Delays uncommon
10	Continuous construction	High capacity demand growth; multiple units common	Highly competitive; all cost reductions passed on	Several designs; sufficient orders for each to achieve standardization learning effects	Construction time reduced and delays largely eliminated

[a]Identical to Table 4-6.

The Financial Model

This study employs a financial model for businesses that is based on the following equation:

PRESENT VALUE OF EQUITY INVESTMENT DURING THE CONSTRUCTION PERIOD = PRESENT VALUE OF NET REVENUE EARNED BY EQUITY OVER THE LIFE OF THE PLANT

where

NET REVENUE = EARNINGS FROM LCOE REVENUE BEFORE INTEREST AND TAXES (EBIT) – INTEREST EXPENSE – TAX EXPENSE + DEPRECIATION – REPAYMENT OF DEBT

Because risk is a major consideration for investors, its treatment in the financial model is an important factor in deriving the required net revenue. The perceived risk of investments in new nuclear facilities contributes to the risk premium on new nuclear construction. Principal

sources of risk are the possibilities that construction delays will escalate costs and that new plants will exceed original cost estimates for other reasons. This study uses guidelines from the corporate finance literature, previous nuclear studies, and opinions of investment analysts to specify likely relationships between project risk and risk premiums for corporate bonds and equity capital. Risks associated with building a new nuclear plant are estimated to raise the required rate of return on equity to 15 percent, compared to 12 percent for other types of facilities, and debt cost to rise to 10 percent from 7 percent.

Table 5 specifies the parameter values for LCOE calculations under the assumption that no financial policies benefiting nuclear power are in effect. In using the financial model to study sensitivities, overnight costs of $1,200, $1,500, and $1,800 per kW are used. Table 6 summarizes the "no-policy" LCOEs for the three nuclear capital costs, each under 5-year and 7-year anticipated construction times. These construction times are expected values perceived by investors, based on both previous nuclear construction experience and new information. This study assumes investors will conservatively expect a 7-year construction period for the first few new plants. If actual construction times prove to be 5 years, investors will revise their expectations downward accordingly for subsequent plants.

Table 5: Parameter Values for No-Policy Nuclear LCOE Calculations[a]

Item	Parameter Value
Overnight Capital Cost	$1,200 per kW $1,500 per kW $1,800 per kW
Plant Life	40 years
Construction Time	7 years
Plant Size	1,000 MW
Capacity Factor	85 percent
Hours per Year	8,760 hours
Cost of Debt	10 percent
Cost of Equity	15 percent
Debt Term	15 years
Depreciation Term	15 years
Depreciation Schedule	MACRS[b]
Debt Finance	50 percent
Equity Finance	50 percent
Tax Rate	38 percent
Nuclear Fuel Cost	$4.35 per MWh
Nuclear Fixed O&M Cost	$60 per kW
Nuclear Variable O&M Cost	$0.45 per MWh
Nuclear Incremental Capital Expense	$10.50 per kW per year
Nuclear Decommissioning Cost	$350 million
Nuclear Waste Fee	$1 per MWh

[a]Identical to Table 5-1.
[b]Modified Accelerated Cost Recovery System.

Table 6: First-Plant LCOEs for Three Reactor Costs, 5- and 7-Year Construction Periods, $ per MWh, 2003 Prices[a]

Construction Period	Mature Design FOAKE Costs Paid, $1,200 per kW Overnight Cost	New Design FOAKE Costs Not Yet Paid, $1,500 per kW Overnight Cost	Advanced New Design FOAKE Costs Not Yet Paid, $1,800 per kW Overnight Cost
5 years	47	54	62
7 years	53	62	71

[a]Identical to Table 5-3.

Table 7 presents a full range of LCOEs for first nuclear plants, for alternative construction periods, plant lives, and capacity factors and for each of the three overnight costs specified in Table 5. The table shows the relative importance of the various characteristics for generation cost. Overnight capital cost is clearly most important, but the two-year difference in construction period is nearly as important. If investors were convinced of the likelihood of a 5-year construction period, they would estimate the generation cost of the $1,800 per kW plant to equal that of the $1,500 per kW plant built in 7 years; similarly, the $1,500 per kW plant anticipated to be built in 5 years would have a generation cost nearly that of the $1,200 per kW plant anticipated to be built in 7 years. Capacity factor also exerts a significant influence on generation cost. However, the effect of longer plant life is relatively minor because these benefits occur in the distant future and are discounted.

Table 7: Effects of Capacity Factor, Construction Period, and Plant Life on First-Plant Nuclear LCOE for Three Reactor Costs, $ per MWh, 2003 Prices[a]

Capacity Factor, Percent	Overnight Cost					
	$1,200 per kW		$1,500 per kW		$1,800 per kW	
	5-year construction period					
	Plant Life		Plant Life		Plant Life	
	40 years	60 years	40 years	60 years	40 years	60 years
85	47	47	54	53	62	61
90	44	43	51	50	58	58
95	42	41	49	48	56	55
	7-year construction period					
	Plant Life		Plant Life		Plant Life	
	40 years	60 years	40 years	60 years	40 years	60 years
85	53	53	62	61	71	70
90	50	49	58	58	67	66
95	47	47	56	55	64	63

[a]Identical to Table 5-6.

Table 8 presents LCOEs for coal and gas alternatives. Given the capital cost range, the LCOE of new nuclear plants in the absence of federal financial policies is from $53 to $71 per MWh with a 7-year construction time. The range is from $47 to $62 per MWh with a 5-year construction time. Costs remain above the range of competitiveness with coal and gas generation, which have LCOEs ranging from $33 to $45 per MWh. For the $1,500 and $1,800 per kW plants, FOAKE costs of roughly $300 per kW are assumed to be paid off with the first plant, which lowers the LCOE for the second plants by 13 to 15 percent.

Table 8: LCOEs for Pulverized Coal and Gas Turbine Combined Cycle Plants, $ per MWh, 2003 Prices[a]

Coal	33 to 41
Gas	35 to 45

[a]From Tables 5-4 and 5-5.

Part Two: Outlook for Nuclear Energy's Competitors

Gas and Coal Technologies

This study examines the near-term prospects for improvements in gas- and coal-fired electricity generation that would affect their costs relative to nuclear power. Table 9 summarizes the cost estimates, construction times, and thermal efficiencies of fossil-fired electricity generation. Some modest thermal efficiency improvements are foreseen in the near term for gas technologies, but similar improvements for coal technologies appear to be farther in the future. The most common combustion technology used in coal plants recently built in the United States is pulverized coal combustion. Fluidized bed combustion is a cleaner alternative, and the thermal efficiency of most fluidized beds used for power generation is similar to that of pulverized coal. However, the cost competitiveness of fluidized bed combustion remains a question. Integrated coal gasification combined cycle, while attractive from the perspective of thermal efficiency and emissions, is likely to be too expensive to enter the U.S. market in the near term. More advanced coal-fired technologies are still in early R&D stages.

Since fuel costs are generally two-thirds of the levelized cost of gas-generated power, a 5 percentage point increase in efficiency in gas turbine combined cycle plants could decrease the cost of gas-generated electricity by approximately 8 percent.

Table 9: Cost Characteristics of Fossil-Fired Electricity Generation[a]

	Pulverized Coal Combustion	Coal, Circulating Fluidized Bed	Coal, Integrated Gasification Combined Cycle	Gas Turbine Combined Cycle
Capital Cost ($ per kW)	1,189	1,200	1,338	590
Fuel Cost ($ per MWh)	11.26	12.04	9.44	23.60
Total Operations and Maintenance Cost (O&M) ($ per MWh)	7.73	5.87	5.19	2.60
Construction time (years)	4	4	4	3
Current Thermal Efficiency (percent)	30 to 35	30 to 35	40 to 45	55 to 60
R&D Thermal Efficiency Targets (percent)	45	45	60	65

[a] Identical to Table 6-6.

Fuel Prices

This study examines forecasts for three fuels: coal, natural gas, and uranium.

Coal and Gas

Coal supplies worldwide are expected to be sufficiently price elastic that even a doubling of demand would not increase price appreciably. Previous forecasts generally agree that coal production will increase 35 to 50 percent over the next 25 years. Forecasts for the U.S. coal price to utilities uniformly predict a decline of about 10 percent.

Forecasts for natural gas prices are mixed (see Table 10). EIA's forecasts have changed sharply as prices experienced during the base years of 2000 to 2003 have fluctuated considerably. Expressed in 2003 prices, the Lower 48 wellhead price rose from $3.93 per 1000 cu. ft. in 2000 to $4.24 in 2001, then fell to $3.02 in 2002. The 2003 price of $5.01 was the highest in recent years. EIA's 2003 forecast for 2020, in 2003 prices, was $3.75, but its 2004 forecast for the same date is $4.34. The 2002 price of $3.02 was below both 2020 forecasts, but the 2003 price of $5.01 was well above both. As Table 10 shows, EIA's 2004 forecast for 2020 was for an 11 percent increase over 2000 prices, equivalent to a 40 percent increase over 2002 prices but a 13 percent decrease from 2003 prices.

Table 10: Natural Gas Price Projections[a]

Year	2000[b]	2005	2010	2015	2020
NEMS[c], Lower 48 U.S. Wellhead Price, AEO 2003	100[d]	75	86	93	96
NEMS[c], Lower 48 U.S. Wellhead Price, AEO 2004	100[d]	92	88	109	111

[a]Abridged version of Table 7-2, Year 2000=100.
[b]Year 2000=100.
[c]National Energy Modeling System (NEMS).
[d]$3.93 per 1,000 cu. ft.

Sensitivity analyses for gas-fired LCOEs use three alternative time paths for natural gas prices. One is an average of the 2001and 2002 gas price, which results in forecasts for 2010 to 2015 of $3.39 per MMBtu, assumed constant over the plant life. Another uses the 2003 gas price forecast for 2010 to 2015 of $4.30, also assumed constant over the plant life. The third uses EIA's 2004 forecast of gas prices from 2015 through the end of the plant life, which begins at $4.25 in 2015, peaks at $4.51 in 2021, falls to $4.48 by 2025, and remains at that level for the remainder of the plant life. All prices are in 2003 dollars.

Uranium

The supply elasticity of uranium is estimated by several sources to be between 2.3 and 3.3, which should be sufficiently large to keep uranium prices down in the range of $15 per pound over the next several years. Since fuel cost accounts for only about 10 percent of total nuclear generation cost, variation in uranium prices will have only a limited effect on the overall cost of nuclear generation of electricity.

Environmental Policies

As opposed to technology advances and possible fuel price decreases that could reduce coal- and gas-fired costs, environmental considerations could raise the cost of these sources because they emit air pollutants. This study assesses potential cost increases from more stringent environmental compliance for coal- and gas-generated electricity.

- Despite global climate concerns, carbon remains an important but largely uncontrolled emission that could be subject to future controls through carbon capture and sequestration.

- Although the technologies of carbon capture, transport, injection, and sequestration are not yet commercialized, estimates of current and future costs are available.

Assuming 100 km transportation by pipeline, this study reports the following costs per MWh generated:

- $36 to $65 per MWh for pulverized coal, including an energy penalty of 16 to 34 percent
- $17 to $29 per MWh for gas turbine combined cycle, including an energy penalty of 10 to 16 percent
- $20 to $44 per MWh for integrated gasification combined cycle, including an energy penalty of 6 to 21 percent

- An alternative measurement of the future costs of carbon control can be obtained by examining permit markets. In particular, prices generated through permit market trading can be interpreted as the approximate future cost of reducing present emissions. This study uses a carbon price range of $50 to $250 per ton to construct upper and lower bounds of the electricity cost impact. For coal-fired electricity, the cost impact is likely to be between $15 and $75 per MWh; for gas-fired electricity, the cost impact is likely to be between $10 and $50 per MWh. These estimates are subject to significant uncertainty, particularly because of uncertainty about the overall amount of carbon that will be controlled.

Part Three: Nuclear Energy in the Years Ahead

Nuclear Energy Scenarios: 2015

The year 2015 is chosen as a reasonable year for the first new nuclear plants to come on line, allowing for time lags required for design certification, site selection and planning, licensing, and construction. This study considers the effects of several possible federal policies targeting the first plants.

Individual Federal Financial Policies Considered for the First Plants

- According to this study's financial model, a loan guarantee of 50 percent of construction loan costs would reduce the nuclear LCOE for the lowest-cost reactor from $53 to $49 per MWh (see Table 11).
- Accelerated depreciation would reduce the LCOE for the lowest-cost reactor to $47 per MWh (see Table 12).
- An investment tax credit of 20 percent, refundable so as to be applicable as an offset to a utility's non-nuclear activities, would reduce the nuclear LCOE to $44 per MWh for the lowest-cost reactor (see Table 13).

- A production tax credit of $18 per MWh for the first 8 years (as proposed in 2004 legislation) would reduce the LCOE of the lowest-cost reactor to $38 per MWh, which is within the required competitive range (see Table 14).

This study uses a 7-year construction schedule because the financial community is likely to assume that duration for the first plants constructed, for financial planning purposes. If shorter construction times are proven with early experience, the construction period used for financial planning would be reduced accordingly for subsequent plants.

Table 11: Nuclear LCOEs with Loan Guarantees, $ per MWh, 2003 Prices[a]

Loan Guarantee Policy	Mature Design $1,200 per kW	New Design $1,500 per kW	Advanced New Design $1,800 per kW
0 (no policy)	53	62	71
25 percent of loan	50	58	67
50 percent of loan	49	57	65

[a]From Table 9-3.

Table 12: Nuclear LCOEs with Accelerated Depreciation Allowances, $ per MWh, 2003 Prices[a]

Depreciation Policy	Mature Design $1,200 per kW	New Design $1,500 per kW	Advanced New Design $1,800 per kW
15 years (no policy)	53	62	71
7 years	50	58	67
Expensing (1 year)	47	54	62

[a]From Table 9-4.

Table 13: Nuclear LCOEs with Investment Tax Credits, $ per MWh, 2003 Prices[a]

Tax Credit Policy	Mature Design $1,200 per kW	New Design $1,500 per kW	Advanced New Design $1,800 per kW
0 percent (no policy)	53	62	71
10 percent	47	55	63
20 percent	44	51	58

[a]From Table 9-5.

Table 14: Nuclear LCOEs with Production Tax Credits, $18 per MWh, 8-Year Duration, $ per MWh, 2003 Prices

Tax Credit Policy	Mature Design $1,200 per kW	New Design $1,500 per kW	Advanced New Design $1,800 per kW
0 (no policy)	53	62	71
$18 per MWh, 8-year duration	38	47	56

[a]From Table 9-6.

Combination of Federal Financial Policies and Streamlined Licensing

While the most of the individual financial policies considered in this study appear to be insufficient to enable nuclear power to enter the marketplace competitively, the financial model indicates that a combination of policies at reasonable levels could do so. As shown in Table 15, an $18 per MWh production tax credit for 8 years together with a 20 percent investment tax credit could bring the LCOE of the lower-cost reactors ($1,200 and $1,500 per kW) within the competitive range with a 7-year anticipated construction time. This policy package would bring the LCOE of the $1,800 per kW reactor close to the anticipated competitive range with the 7-year construction time and well within it with a 5-year construction period.

Table 15: Effects of Combined $18 per MWh 8-Year Production Tax Credits and 20 Percent Investment Tax Credits on Nuclear Plants' LCOEs, $ per MWh, 2003 Prices

Mature Design $1,200 per kW		New Design $1,500 per kW		Advanced New Design $1,800 per kW	
Construction Time		Construction Time		Construction Time	
5 years	7 years	5 years	7 years	5 years	7 years
No policies:					
47	53	54	62	62	71
With combination of policies:					
26	31	31	38	37	46

[a]Identical to Table 9-7.

N^{th} Plants and Nuclear Competitiveness

Under aggressive assumptions regarding learning by doing, the LCOE for the fifth plant, when most learning has been achieved, is $44 per MWh for the lowest-cost nuclear reactor, assuming that for the first plant the business community anticipates a construction period of 7 years and uses a 3 percent risk premium on debt and equity interest rates (see Table 16).

Table 16: LCOEs for the Fifth Nuclear Plant, with No Policy Assistance, 7-Year Construction Time, 10 Percent Interest Rate on Debt, and 15 Percent Rate on Equity $ per MWh, 2003 Prices[a]

Learning Rate (Percent for Doubling Plants Built)	Initial Overnight Cost, $ per kW	
	1,200 and 1,500	1,800
3	50	58
5	48	56
10	44	52

[a]From Table 9-8.

This study goes on to report LCOEs for the fifth plant assuming that, with favorable regulatory experience, the business community comes to expect a 5-year construction period and more favorable risks, comparable to gas and coal. Under these conditions, the fifth-plant LCOEs for nuclear reactors reach the required range of competitiveness. The two lower-cost nuclear reactors have LCOEs of about $35 per MWh even under the most pessimistic learning rate (see Table 17). If the reduced risk encourages a higher ratio of debt to equity in financing, LCOEs would be further reduced: by nearly 3 percent with 60 percent debt instead of 50 percent or by 8.5 percent with 70 percent debt instead of 50 percent.

This study found that, even under pessimistic learning assumptions, nuclear power could become self-sufficient in the market after cessation of initial policy assistance if overnight costs were $1,200 or $1,500 per kW and a 5-year construction schedule was maintained. Depending on where fossil LCOEs emerge within the ranges calculated here, the $1,800 per kW nuclear plant could become self-sufficient as well.

Table 17: LCOEs for the Fifth Nuclear Plant, with No Policy Assistance, 5-Year Construction Time, 7 Percent Interest Rate on Debt, and 12 Percent Rate on Equity $ per MWh, 2003 Prices[a]

Learning Rate (Percent for Doubling Plants Built)	Initial Overnight Cost, $ per kW	
	1,200 and 1,500	1,800
3	35	40
5	34	39
10	32	36

[a]From Table 9-11.

Robustness of Conclusions

The results of this study are sensitive to assumptions about overnight costs and plant construction times, but are not very sensitive to assumptions about plant life and capacity factors.

Environmental Policies for Fossil Generation

Stringent measures to control greenhouse gases would raise costs for both gas- and coal-fired plants, making nuclear energy easily competitive in the market place, as shown in Table 18.

Table 18: Fossil LCOEs with and without Greenhouse Policies, $ per MWh, 2003 Prices[a]

	Under Current Environmental Policies	Under Greenhouse Policy
Coal-Fired	33 to 41	83 to 91
Gas-Fired	35 to 45	58 to 68

[a]Identical to Table 9-12.

2025 and Beyond

The long gestation periods involved in nuclear energy research and the long lags entailed in gearing up the nuclear industry to construct new power plants make it prudent to look several decades ahead when making decisions about nuclear energy policy.

Nuclear Energy Technology. The importance of cost reductions from first-of-a-kind-engineering (FOAKE) costs and learning by doing beyond FOAKE has been documented in this study. If presently available Generation III technologies are deployed for several years beginning in 2015, as contemplated in this study, significant cost reductions from their replication could extend to 2025 and beyond. Research and development on Generation III and IV designs is expected to allow commercialization of lower-cost reactors in later years.

Global Warming. The longer the time horizon, the more likely the United States will place an increased priority on global warming, leading to an urgent need to replace coal- and gas-fired electricity generation. In view of the time it takes to gear up the nuclear industry, the prospect of this need is one of the reasons for national concern with maintaining a nuclear energy capability. If environmental policies greatly restrict carbon emissions in the period after 2025, fossil-fired LCOEs could increase by 50 to 100 percent over current levels. Nuclear power would then acquire an unquestioned cost advantage over its gas and coal competitors.

Hydrogen. The widespread introduction of hydrogen-powered vehicles to replace gasoline-powered vehicles would greatly increase the demand for energy to produce hydrogen. Some impacts could occur by 2015, but this study is conservative and does not consider those

impacts when projecting demand for nuclear energy in the 2015 timeframe. If the expressed national commitment to developing a commercially viable hydrogen vehicle proves successful, nuclear power could become a major producer of this transportation fuel. A full analysis of the implications of increased demand for hydrogen is beyond the scope of this study.

Despite the many uncertainties in the future beyond 2025, the findings in this study suggest the likelihood of an increased demand for nuclear energy beyond 2025.

APPENDIX

Background

Purpose and Organization of Study

This study aims to synthesize what is known about the factors affecting the economic viability of nuclear power and to estimate its viability under a range of future scenarios. The focus is on generating baseload electricity—nuclear, coal-fired, and gas-fired technologies. Renewables are not considered because they are rarely used to meet baseload demand. While hydroelectric facilities supply baseload generation to some parts of the United States, the major opportunities for hydroelectric projects have already been taken.

Electricity Futures

This study uses two principal types of models to investigate electricity futures:

- *Plant models* calculate the cost of electricity generation from a specific type of power plant. Costs are calculated on a levelized basis (LCOE), combining operating and capital costs to arrive at a cost per megawatt-hour (MWh), that must be recouped in the price of electricity. Costs are calculated at the busbar level in order to focus on electricity generation costs and abstract from locally varying distribution costs.

- *Market models* forecast the demand for electricity and the mix of electricity generating capacity that will come online to meet future levels of expected demand. Aggregate demand and supply functions are estimated and brought together to simulate market behavior, often at the regional level.

Table A-1 summarizes the characteristics of the various plant and market models that are reviewed in this study. The table distinguishes the plant types, forecast horizons, treatments of environmental costs, and nuclear power data sources that have been used.

Table A-1: Plant and Market Model Summary[a]

Model Identification	Plant Type	Forecast Horizon	Treatment of Environmental Costs	Source of Nuclear Power Data
Plant Models				
Scully Capital-DOE (Nuclear Energy)	Nuclear (AP1000)	Up to 2010	No	Vendor, 2002
Electricity Generation Cost Simulation Model (GenSim)/Sandia	Wide spectrum of energy sources	Current year	Has capability	Energy Information Administration (EIA) and Platt's (McGraw-Hill) Database, 2003
MIT Study	Nuclear, coal, gas	Up to 2050	Carbon tax	EIA, 2003
Market Models				
National Energy Modeling System (NEMS)-EIA	Wide spectrum of energy sources	20 years from present	No	EIA, 2003
NEMS-Electric Power Research Institute (EPRI)	Nuclear, coal, gas	Up to 2050	Carbon tax	Vendors, 2002
All Modular Industry Growth Assessment Modeling System (AMIGA)/ Pew Charitable Trust	Wide spectrum of energy sources	Up to 2035	Yes	Argonne National Laboratory, Vendors, 2001
Integrated Planning Model (IPM)/Environmental Protection Agency (EPA)	Nuclear, coal, gas	20 years from present	Yes	EIA
Hybrid Models				
Science Applications International Corporation (SAIC) Power Choice Model	Nuclear, coal, gas	80 years from present	Carbon tax	DOE and Vendors, 2001

[a]Identical to Table A2-1.

Within each model category, different underlying numerical assumptions cause the principal differences in electricity cost projections. The most significant of these are differences in capital costs and interest rates for nuclear capacity, capital costs for coal generation, and fuel costs for gas generation. The market models are sufficiently complex that reasons for differences in their projections frequently are difficult to pinpoint. Plant models are better suited for studying the economic viability of nuclear energy. However, while the plant model structures are straightforward, documentation of underlying data is not always sufficient to allow detailed economic analysis. Four of the plant models, identified in bold font in Table A-1, are used for comparison purposes later in this study: the Scully model, GenSim, NEMS, and SAIC's Power Choice model.

Need for New Generating Capacity in the United States

This study analyzes future electricity demand and compares it with existing capacity to estimate a future time range when construction of added capacity must start. Projections by EIA and the North American Electric Reliability Council (NERC) are compared with projections based on historical relationships between electricity demand growth and gross domestic product (GDP) growth. The historical relationships estimated for this study imply electricity demand growth rates that are roughly one percentage point higher than EIA's forecasts and a half percentage point above NERC's forecasts. From a national perspective, even with an annual growth rate in electricity demand of 2.7 percent, which is above the EIA and NERC forecasts, new capacity will not be needed before 2011. On a regional basis, new capacity may be required as early as 2006. (See Appendix A3, "Need for New Generating Capacity in the United States.")

Major Issues Affecting the Nuclear Power Industry in the U.S. Economy

Technologies for New Nuclear Facilities

The nuclear reactors currently in use in the United States, denoted as Generation II, were deployed in the 1970s and 1980s. They include boiling water reactors and pressurized water reactors. Advanced modular reactor designs are denoted as Generation III. Some have passive safety features, and all have been developed to be more cost competitive. Generation III designs include the ABWR design and the pressurized water reactor, both of which use passive safety systems; they also include the AP600/AP1000 and the light-water-cooled heavy-water-moderated CANDU ACR-700. The nuclear industry has continued to develop yet more innovative Generation III+ designs. Generation III+ designs may have lower generating costs than Generation III designs, but the U.S. Nuclear Regulatory Commission (NRC) has not yet certified them, and their cost estimates have greater uncertainty. DOE is developing Generation IV nuclear energy systems that use even more advanced designs intended to further reduce life cycle costs.

Table A-2 summarizes the characteristics and NRC certification status of the reactor designs reviewed in this study.

Table A-2: Summary of New Reactor Designs[a]

Design	Supplier	Size and Type	U.S. Deployment Prospects and Overseas Deployment	NRC Certification Status
ABWR	General Electric	1,350 MW BWR	Operating in Japan, under construction in Taiwan.	Certified in 1996.
AP1000	Westinghouse	1,090 MW PWR	Additional design work to be done before plant ready for construction.	Design certification expected September 2005.
SWR 1000	Framatome Advanced Nuclear Power (ANP)	1,013 MW BWR	Under consideration for construction in Finland, designed to meet European requirements.	Submission of materials for pre-application review to begin in mid-2004. Pre-application review completion expected 2005.
CANDU ACR-700	Atomic Energy Company, Limited (AECL)Technologies Inc., U.S. subsidiary of AECL	753 MW HWR	Deployed outside Canada in Argentina, Romania, South Korea, China, and India.	Pre-application review scheduled to be completed by NRC, June 2004.
AP600	Westinghouse	610 MW PWR	Additional design work to be done before plant ready for construction.	Design is certified, but actual construction will be superseded by AP1000.
Simplified Boiling Water Reactor (ESBWR)	General Electric	1,380 MW BWR	Commercialization plan not likely to support deployment by 2010.	Pre-application review completion expected in early 2004. Application for design certification to be submitted mid-2005.
PBMR	British Nuclear Fuels (BNFL)	110 MW Modular pebble bed	No plan beyond completion of South African project.	Pre-application review closed September 2002 with departure of Exelon.
GT-MHR	General Atomics	288 MW Prismatic graphite	Licensed for construction in Russia.	Design certification application would begin by end of 2005.
International Reactor Innovative and Secure (IRIS) Project	Westinghouse	100 to 300 MW PWR	Plans to deploy between 2012 and 2015.	Design certification review to begin 2006.
European Pressurized Water Reactor (EPR)	Framatome-ANP	1,545 to 1,750 MW PWR	No decision on U.S. market.	Ordered for deployment in Finland.
System 80+	Westinghouse	1,300 MW PWR	Plants built in Korea. Design not planned to be marketed in United States.	Certified May 1997.
Advanced Fast Reactor; Power Reactor Innovative Small Module (AFR; PRISM)	General Electric, Argonne National Laboratory	300 to 600 MW, sodium-cooled	Began certification in the 1990s.	No action taken.

[a]Identical to Table A4-2.

Nuclear Fuel Cycle and Nuclear Waste Disposal

This study analyzes the economic costs of nuclear power contributed by the nuclear fuel cycle. It also considers two options for spent fuel disposition: (1) on-site storage followed by centralized disposal and (2) on-site storage and reprocessing, followed by centralized disposal. Recycle of mixed-oxide fuel was not considered. The front-end costs of nuclear fuel are relevant regardless of which disposition alternative is used. As shown in Table A-3, these costs amount to $3.50 to $5.50 per MWh or 5 to 12 percent of the cost of nuclear power generation. In the United States, the direct method of spent fuel disposal has been used to date, without reprocessing of spent fuel. The costs of disposal consist of on-site storage costs while awaiting permanent storage, plus a charge levied to pay for eventual permanent storage or disposal at a centralized site. The back-end costs are about $1.10 per MWh, as shown in Table A-4, which is about 2 percent of the overall LCOE. Plausible differences in fuel cycle costs are not a major factor in the economic competitiveness of nuclear power.

Table A-3: Components of Front-End Nuclear Fuel Costs, $ per kg U, 2003 Prices[a]

Process Step	Direct Outlays	Interest Cost	Total Cost
Ore Purchase	222 to 353	94 to 150	316 to 503
Conversion	40 to 94	15 to 35	55 to 129
Enrichment (per kg SWU)	606 to 951	197 to 306	804 to 1,259
Fabrication	193 to 250	54 to 69	246 to 319
Total			**1,420 to 2,209**
$ per MWh			**3.56 to 5.53**

[a]Abridged version of Table A5-1.

Table A-4: Disposal Costs, $ per MWh, 2003 Prices[a]

Fuel Cycle Component	No Reprocessing
Temporary on-site storage	0.09
Permanent disposal at Yucca Mountain	1.00
Total	1.09

[a]Identical to Table A5-2.

Nuclear Regulation

Federal Regulation 10 CFR Part 52 was adopted in the 1990s. It provides for combined construction and operation permitting and is aimed at streamlining the permitting process. The combined Part 52 license is designed to allow investors to resolve many historically important uncertainties before committing large amounts of money to a nuclear facility. This study analyzes the economic advantages that such regulatory streamlining can provide, both directly by

reducing construction delays, and indirectly by reducing the risk premium necessary to compensate investors for possible delays or cancellations due to regulatory difficulties. For example, as more new nuclear plants are built well beyond 2015, this study finds that mature designs already in operation could generate energy that could be competitive with gas-fired electricity, if the nuclear licensing period could be reduced to five years (see Table 17 above).

Nonproliferation Goals

This study reviews international arrangements aimed at preventing nuclear proliferation. Some countries have chosen direct disposal of spent nuclear fuel, while others have chosen recycling of spent fuel. In the United States, policy decisions regarding direct disposal versus recycling must be reviewed when DOE considers a second repository. By statute, DOE must report to Congress on or after January 1, 2007, but not later than January 1, 2010, on the need for a second repository. (See Sec. 161(b), P.L. Law 97-425.) The uranium extraction (UREX) process was developed as a variant of plutonium-uranium extraction (PUREX). DOE is currently conducting R&D on further recycling technologies, including pyrometallurgical processing. In the future, an innovative fuel cycle that strongly resists nuclear proliferation, such as pyrometallurgical processing, will be pursued. The President recently announced a policy to cap the deployment of new reprocessing technologies outside a select group of countries. Nevertheless, the future economic viability of nuclear power does not depend on decisions about direct disposal versus reprocessing. As Appendix A6 shows, differences in the cost of nuclear waste handling between these two alternatives is too small to materially affect the economic viability of nuclear power.

Hydrogen

This study reviews the prospects of hydrogen as a transportation fuel that would reduce U. S. dependence on foreign oil and could have potentially large environmental benefits. Mass production costs need to be reduced by roughly one-half to two-thirds to achieve widespread adoption of hydrogen vehicles. The environmental benefits of hydrogen would be tempered to the extent that fossil fuels, with their attendant carbon emissions, were used to produce the hydrogen. Carbon emissions from oil would then simply be replaced by emissions from fossil-fuel power generation or steam methane reforming. Nuclear energy, on the other hand, would provide a pollution-free input to hydrogen production. A hydrogen economy, accompanied by more stringent control of carbon emissions, could greatly expand the demand for nuclear power.

Energy Security

This study considers the energy security benefits of nuclear power as a potential source of hydrogen to replace oil in the transportation sector and more generally as a substitute for gas-generated electricity. Energy security has been analyzed primarily in connection with oil and the political instability of the Middle East. A direct link to electricity is limited by the small amount of electricity produced using oil. However, nuclear energy could help ease oil security concerns if hydrogen is cogenerated for transportation. Currently, the United States imports about 4 percent of its natural gas consumption in the form of liquefied natural gas (LNG), but that percentage could grow if many new gas-fired electricity generating plants are built and if North

American gas production expands only sluggishly. As international trade in LNG becomes more extensive and the United States imports increase, this energy security linkage could become more important, if nuclear electricity substitutes directly for gas-generated electricity.

This study considers potential supply and demand shocks from environmental, national security, and other risks affecting choices among electricity generation technologies. Maintaining some nuclear capacity now could avoid a costly and lengthy adjustment of gearing up a nuclear industry that might otherwise be in a run-down condition. This study uses a decision-making model to develop a numerical example of a portfolio of fossil and nuclear electrical generating capacity. In this example, 25 percent of new capacity would be nuclear. Further research is needed to refine this analysis.

The Future of Nuclear Power

AN INTERDISCIPLINARY MIT STUDY

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Executive Summary

STUDY CONTEXT

Over the next 50 years, unless patterns change dramatically, energy production and use will contribute to global warming through large-scale greenhouse gas emissions — hundreds of billions of tonnes of carbon in the form of carbon dioxide. Nuclear power could be one option for reducing carbon emissions. At present, however, this is unlikely: nuclear power faces stagnation and decline.

This study analyzes what would be required to retain nuclear power as a significant option for reducing greenhouse gas emissions and meeting growing needs for electricity supply. Our analysis is guided by a global growth scenario that would expand current worldwide nuclear generating capacity almost threefold, to 1000 billion watts, by the year 2050. Such a deployment would avoid 1.8 billion tonnes of carbon emissions annually from coal plants, about 25% of the increment in carbon emissions otherwise expected in a business-as-usual scenario. This study also recommends changes in government policy and industrial practice needed in the relatively near term to retain an option for such an outcome.

We did not analyze other options for reducing carbon emissions — renewable energy sources, carbon sequestration, and increased energy efficiency — and therefore reach no conclusions about priorities among these efforts and nuclear power. In our judgment, it would be a mistake to exclude any of these four options at this time.

STUDY FINDINGS

For a large expansion of nuclear power to succeed, four critical problems must be overcome:

- Cost. In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs, and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage.
- Safety. Modern reactor designs can achieve a very low risk of serious accidents, but "best practices" in construction and operation are essential. We know little about the safety of the overall fuel cycle, beyond reactor operation.
- Waste. Geological disposal is technically feasible but execution is yet to be demonstrated or certain. A convincing case has not been made that the long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs. Improvement in the open, once through fuel cycle may offer waste management benefits as large as those claimed for the more expensive closed fuel cycles.
- Proliferation. The current international safeguards regime is inadequate to meet the security challenges of the expanded nuclear deployment contemplated in the global growth scenario. The reprocessing system now used in Europe, Japan, and Russia that involves separation and recycling of plutonium presents unwarranted proliferation risks.

We conclude that, over at least the next 50 years, the best choice to meet these challenges is the open, once-through fuel cycle. We judge that there are adequate uranium resources available at reasonable cost to support this choice under a global growth scenario.

Public acceptance will also be critical to expansion of nuclear power. Our survey results show that the public does not yet see nuclear power as a way to address global warming, suggesting that further public education may be necessary.

SELECTED RECOMMENDATIONS

- We support the Department of Energy (DOE) 2010 initiative to reduce costs through new design certification, site banking, and combined construction and operation licenses.
- The government should also share "first mover" costs for a limited number of power plants that represent safety-enhancing evolutionary reactor design. We propose a production tax credit for up to $200/kWe of the plant's construction cost. This mechanism creates a strong incentive to complete and operate the plant and the mechanism is extendable to other carbon-free technologies. The government actions we recommend aim to challenge the industry to demonstrate the cost reductions claimed for new reactor construction, with industry assuming the risks and benefits beyond first- mover costs.
- Federal or state portfolio standards should include incremental nuclear power capacity as a carbon free source.
- The DOE should broaden its long-term waste R&D program, to include improved engineered barriers, investigation of alternative geological environments, and deep bore hole disposal. A system of central facilities to store spent fuel for many decades prior to geologic disposal should be an integral part of the waste management strategy. The U.S. should encourage greater harmonization of international standards and regulations for waste transportation, storage, and disposal.
- The International Atomic Energy Agency should have authority to inspect all suspect facilities (implement the Additional Protocol) and should develop a worldwide system for materials protection, control, and accountability that goes beyond accounting, reporting, and periodic inspections. The U.S. should monitor and influence developments in a broad range of enrichment technologies.
- The DOE R&D program should be realigned to focus on the open, once-through fuel cycle. It should also conduct an international uranium resource assessment; establish a large *nuclear system analysis, modeling, and simulation project*, including collection of engineering data, to assess alternative nuclear fuel cycle deployments relative to the four critical challenges; and halt development and demonstration of advanced fuel cycles or reactors until the results of the nuclear system analysis project are available.