NUCLEAR POWER IN A WARMING WORLD: SOLUTION OR ILLUSION?

HEARING

BEFORE THE

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING HOUSE OF REPRESENTATIVES

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NUCLEAR POWER IN A WARMING WORLD: SOLUTION OR ILLUSION?

WEDNESDAY, MARCH 12, 2008

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
Washington, DC.

The committee met, pursuant to call, at 9:05 a.m. in Room 311, Cannon House Office Building, Hon. Edward J. Markey [chairman of the committee] presiding.

Present: Representatives Markey, Herseth Sandlin, Cleaver, Hall, McNerney, Sensenbrenner, and Blackburn.

Staff present: Jonathan Phillips.

The CHAIRMAN. Good morning. This is a hearing conducted by the Select Committee on Energy Independence and Global Warming. We welcome you this morning to this very, very important hearing.

The hearing is now called to order.

Decades ago, Americans from Wall Street to Main Street rejected nuclear power. After years of construction delays, reactor shutdowns and massive cost overruns, the private sector abandoned nuclear energy. Americans nervous about the health and safety of their families and communities had few objections to seeing the nuclear construction age grind to a halt.

However, the growing threat of global warming has thrust nuclear power back into the debate. With the health of our planet on the line, some believe that all options, even those set aside long ago, merit our support. I called this hearing today to take a deeper look at whether continuing taxpayer support of nuclear power gets us closer to achieving our energy and climate goals or whether it is holding us back.

All of the available evidence suggests the prospective costs, risks and uncertainties facing the nuclear industry are higher today than they have ever been. The domestic manufacturing and human resource capacity of nuclear power has dwindled. Nuclear construction worldwide has slowed to a crawl. And the nuclear projects currently under construction are plagued by the same delays and cost overruns that have always riddled the industry.

In addition to these profound, direct problems, the collateral-damage issues—uranium mining impacts, long-term waste storage, nuclear weapons proliferation, targets for terrorism—are even greater.

The last new nuclear plant opened in 1996 in Tennessee after 22 years of construction and at a cost of $7 billion. Are delays like this acceptable in any other industry?

Florida Power & Light recently announced its plans for two new reactors at its Turkey Point facility, which it projects will cost from $12 billion to $24 billion. Could the most ambitious solar- or wind-generating station succeed if its cost projections included uncertainties of $12 billion?

Another electric utility, Progress Energy, announced yesterday that it plans to build two reactors at an estimated price of $17 billion, passing on an additional cost to customers of about $9 per month per household. Customers would begin paying this surcharge beginning in 2009, 7 years before the project would produce a single kilowatt of electricity. Can the wind industry ask for and expect to receive a 7-year cash advance from future customers?

At the Select Committee hearing last week, we witnessed the power of free markets rising to meet our energy and climate challenges. Private capital markets are moving billions of dollars into clean, renewable energy technologies, in the process creating new jobs and driving economic growth. As proof that this green revolution is taking hold, the wind industry installed over 5,200 megawatts of new generating capacity in the United States last year, about 30 percent of all new capacity installed in the United States.

Worldwide, the story is the same. The 20,000 megawatts of wind energy capacity built in 2007 was more than 10 times that of nuclear. Between now and 2016, the year in which we are likely to see the first new nuclear plant come on line in the United States, the world is projected to add 361,000 megawatts of wind. That means, in the next 10 years, as much wind-generating capacity will be installed as the total amount of nuclear capacity built worldwide over the previous half-century.

The job of Congress is not to fix problems by creating new ones or, in this case, recreating them. The innovative spirit of the American entrepreneur is forging a path forward. It is clean, it is scalable, it is distributed, it is safe, and its price is falling. These are claims that nuclear power cannot make.

Taxpayer support for the nuclear industry over the past 50 years has been massive. From 1950 through 2000, the nuclear energy industry received $145 billion in Federal subsidies in constant 1999 dollars, or over 96 percent of the total subsidies allocated to wind, solar and nuclear energy.

The American public and financial investors are responsible for putting nuclear power on mothballs. Congress must think long and hard about the wisdom of reversing that decision. Let's trust and encourage the ingenuity of the American people to solve the energy and climate challenge. The nuclear industry is not going to be the economic driver of the 21st century, but there is abundant evidence that renewable energy will.

That completes the opening statement of the Chair.

I now turn to recognize the ranking member of the committee, the gentleman from Wisconsin, Mr. Sensenbrenner.

[The prepared statement of Mr. Markey follows:]

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

"Nuclear Power in a Warming World: Solution or Illusion?"
Select Committee on Energy Independence and Global Warming
Statement of Chairman Edward J. Markey

Decades ago, Americans from Wall Street to Main Street rejected nuclear power. After years of construction delays, reactor shutdowns, and massive cost overruns, the private sector abandoned nuclear energy. Americans nervous about the health and safety of their families and communities had few objections to seeing the Nuclear Construction Age grind to a halt.

However, the growing threat of global warming has thrust nuclear power back into the debate. With the health of our planet on the line, some believe that all options—even those set aside long ago—merit our support. I called this hearing today to take a deeper look at whether continuing taxpayer support of nuclear power gets us closer to achieving our energy and climate goals, or whether it is holding us back.

All the available evidence suggests the prospective costs, risks and uncertainties facing the nuclear industry are higher today than they have ever been. The domestic manufacturing and human resource capacity of nuclear power has dwindled, nuclear construction worldwide has slowed to a crawl, and the nuclear projects currently under construction are plagued by the same delays and cost overruns that have always riddled the industry. In addition to these profound direct problems, the collateral damage issues—uranium mining impacts, long term waste storage, nuclear weapons proliferation, targets for terrorism—are even greater.

The last new U.S. nuclear plant opened in 1996 in Tennessee—after 22 years of construction and at a cost of $7 billion. Are delays like this acceptable in any other industry?

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The American public and financial investors are responsible for putting nuclear power on mothballs. Congress must think long and hard about the wisdom of reversing that decision. Let's trust and encourage the ingenuity of the American people to solve the energy and climate challenge. The nuclear industry is not going to be the economic driver of the 21st century. But there is abundant evidence that renewable energy will.

Mr. SENSENBRENNER. Thank you very much, Mr. Chairman.

Today, I will talk about the merits of nuclear energy, which is a technology that stands to produce real results in reducing greenhouse gasses.

But, first, let me be clear. I understand that nuclear technology has drawbacks too, as do renewable resources and fossil fuels. While some here today will try to sell the merits of one technology over another, I will not do that, because, in the end, Members of Congress are setting policy, not selling energy. It is the utilities and the energy producers who will sell energy and electricity in the marketplace. I believe it should be the marketplace, not regulators and policymakers, which ultimately decides what sources of energy are the most realistic for the future. It is not Congress's job to pick winners and losers, but I worry that many on this panel aim to do just that.

Nuclear power is efficient and cost-effective and, I believe, in many places, the right answer for our electricity needs, but it is not the right answer for all places.

Nuclear power is an especially useful solution for reducing greenhouse gas emissions. Mr. Alex Flint, the senior vice president of the Nuclear Energy Institute, will testify today that the 439 nuclear power plants worldwide help avoid 2.6 billion tons of CO_2 each year. That is more than three times the amount of carbon dioxide produced by all the cars in the United States in 2005. I welcome Mr. Flint's testimony and look forward to learning more about the potential that nuclear power offers the world.

Nuclear power is such a powerful greenhouse gas-reducing technology that the Nobel Peace Prize-winning U.N. International Panel on Climate Change cited nuclear power as one of the key technologies for addressing global warming in the future.

As I stated at our hearing last week, renewable energy has its own set of benefits and drawbacks and is not technically feasible for all areas of the country. But renewable energy should be an increasing part of our energy future, just like nuclear power, energy efficiency and fossil fuels. The world's energy future needs require us to maintain a diverse portfolio of energy technologies.

While some today will highlight the drawbacks of nuclear power, they do so without fully acknowledging the drawbacks of other technologies they support. For instance, a recent story in The Washington Post reported on the industrial pollution left behind by Chinese solar energy panel producers. And the New York Times reported this week that a biodiesel plant in Alabama is producing pollution as a byproduct and dumping it into a local river. Kermit the frog was right: It is not easy being green.

As I have said many times, the advancement of technology must be a part of any energy security or global warming policy. Nuclear power should be a key part of the diverse array of technologies needed for the future. Plus, nuclear power's potential for reducing greenhouse gasses can't be ignored by anyone who thinks this is a pressing priority for the world. If we are searching for realistic solutions, nuclear power can't be ignored but must be approached with a healthy skepticism to see whether that is the right thing to do at the right time, at the right place.

I have to apologize to our witnesses because, at 10 o'clock, I have to go to the Science Committee, where Bill Gates is testifying. And I do want to tell him that if he wants more high-tech visas, he had better get realistic on how to get that through the Congress.

So I thank the Chairman and yield back the balance of my time.

The CHAIRMAN. Great. The gentleman's time has expired.

The Chair recognizes the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman and Mr. Sensenbrenner.

There can be no doubt, or at least there is no doubt in my mind, that our planet is in crisis. And our constant, growing need for energy has inspired this potentially perilous situation.

However, emerging industries, such as solar and wind energy, can aid our country and others in accessing enough energy without causing potentially dangerous effects on the environment and public health.

Nuclear energy currently produces 19 percent of our Nation's electricity from 104 nuclear reactors, one of which is in my home State, not very far from my hometown, Kansas City.

Nuclear power has the ability to produce domestic energy without greenhouse gasses as a byproduct. However, if we can recall the disaster of Chernobyl and the reactor accident at Three Mile Island, we know all too well that there are potentially harmful risks and unintended consequences.

A large nuclear reactor produces around 25 to 30 tons of spent fuel annually. However, the proposed Yucca Mountain waste site, about 90 miles from Las Vegas, would only have the capacity to hold waste produced through the year 2010. Thus, this would only be a temporary solution, but it is a major risk.

Before we invest in the new production of nuclear power, we need to thoroughly examine all of the threats to public safety and the environment that it presents. We must remember that the welfare of our communities is our highest priority. We must also consider and make decisions on which energy sources will work best for our future.

I look forward to hearing the views of our witnesses this morning, as we discuss this and other ways that we can deal with this source of energy without Federal subsidies at a level that will break the bank.

I would like to thank the panel in advance for your insight and for joining us here today. Thank you very kindly.

I yield back the balance of my time.

[The prepared statement of Mr. Cleaver follows:]

U.S. Representative Emanuel Cleaver, II
5th District, Missouri
Statement for the Record
House Select Committee on Energy Independence and Global Warming Hearing
"Nuclear Power in a Warming World: Solution or Illusion?"
Wednesday, March 12, 2008

Chairman Markey, Ranking Member Sensenbrenner, other Members of the Select Committee, good morning. I would like to welcome our distinguished panel of witnesses to the hearing today.

There can be no doubt that our planet is in crisis, and our constant and growing need for energy has contributed to this situation. However, emerging industries such as solar and wind energy can aid our country and others in accessing enough energy without causing potentially dangerous effects on the environment and public health. Nuclear energy currently produces 19% of our nation's electricity, from 104 nuclear reactors (one of which is in my home state of Missouri). Nuclear power has the ability to produce domestic energy without greenhouse gases as a byproduct. However, if we can recall the disaster of Chernobyl and the reactor accident at Three Mile Island, we know that there are potentially harmful risks and byproducts of the production of nuclear power. A large nuclear reactor produces around 25 to 30 tons of spent fuel annually. However, the proposed Yucca Mountain waste site in Nevada would only have capacity to hold waste produced through the year 2010. Thus, this would only be a temporary solution, but at what risk?

Before we invest in the new production of nuclear power, we need to examine all the threats to public safety and the environment that it presents. We must remember that the welfare of our communities is our highest priority, and then we can consider which energy sources will work best for our future. I look forward to hearing the views of our witnesses this morning as we discuss this critical issue and seek to achieve safe and secure energy independence.

I thank the panel for their insight and their suggestions concerning nuclear energy and climate change, and I appreciate them taking the time to visit with our committee today.

Thank you.

The CHAIRMAN. Great. The gentleman's time has expired.

The Chair recognizes the gentlelady from Tennessee, Mrs. Blackburn.

Mrs. BLACKBURN. Thank you, Mr. Chairman. I thank you for the hearing.

And I want to welcome all of our guests.

As we know, nuclear power is a vital component to meet future energy needs and help America maintain its competitive edge. It is the most stable, least expensive and cleanest form of electric power generation available today. It is an emissions-free, domestic energy source with enough fuel stocks to last for centuries.

Nuclear energy will also be a key asset to the electric power infrastructure as the public embraces the use of electric vehicles for transportation needs and if Congress enacts a greenhouse gas reduction scheme.

Some critics maintain that nuclear energy is either too costly or that it has too poor a track record. In the past, that could have been true. But nuclear power plant construction once experienced delays and cost overruns due to licensing problems, poor project management and economic chaos of the 1970s, but Congress mitigated some of these factors in the Energy Policy Act of 2005, and the Nuclear Regulatory Commission took steps last year to drastically restructure the licensing process to ensure all major issues are settled before a company starts building a nuclear power plant and puts those billions of dollars at risk.

Further, over time and experience, the nuclear industry has vastly reduced past problems by implementing measures to manage and to contain risk, to financing and completing capital projects. And now, with modular construction, standard designs and integrated engineering and construction schedules, nuclear power plants can be built both on time and on target.

Mr. Chairman, the key to achieving American energy independence is maintaining a diversity of power generation. We cannot rely solely on a few favored energy sources. Gas, coal, renewable energy and nuclear power all should play a part in the infrastructure.

I yield back the balance of my time.

The CHAIRMAN. That is great. The gentlelady's time has expired.

The Chair recognizes the gentleman from California, Mr. McNerney.

Mr. MCNERNEY. Thank you. I would like to thank the ranking member and the Chairman for holding this timely and important hearing.

My interest today is to get a deeper understanding of the merits and the demerits of nuclear energy. I have three main concerns: the economics, the safety, and nuclear proliferation.

Safety, I believe, is an engineering issue, which reflects back on the economics. Proliferation is a political and engineering issue. So, ultimately, what I want to understand today is the economics, and so I am looking forward to your testimony. If you can elevate that to where it can be understood, I will very much appreciate your hearing today.

Thank you very much. I yield back the balance of my time.

The CHAIRMAN. Great. The gentleman's time has expired.

All time for statements by the members has expired, so we will turn to recognize our witnesses.

We are going to begin with Mr. Alex Flint. He is our opening speaker. He joins us from the Nuclear Energy Institute where he is the senior vice president of government affairs. He is also very familiar with these issues from his time as staff director of the Senate Committee on Energy and Natural Resources.

We look forward to your testimony, Mr. Flint. Whenever you are ready, please begin.

STATEMENTS OF MR. ALEX FLINT, SENIOR VICE PRESIDENT OF GOVERNMENT AFFAIRS, NUCLEAR ENERGY INSTITUTE; MS. SHARON SQUASSONI, SENIOR ASSOCIATE, NON-PROLIFERATION PROGRAM, CARNEGIE ENDOWMENT; MR. DAVID LOCHBAUM, DIRECTOR, NUCLEAR SAFETY PROJECT, UNION OF CONCERNED SCIENTISTS; MR. AMORY LOVINS, CHAIRMAN AND CHIEF SCIENTIST, ROCKY MOUNTAIN INSTITUTE

STATEMENT OF ALEX FLINT

Mr. FLINT. Chairman Markey, Ranking Member Sensenbrenner, members of the committee, thank you for the opportunity to appear before you today. I have a written statement that I ask be included in the record.

The CHAIRMAN. Without objection, it will be included in the record.

Mr. FLINT. Mr. Chairman, in preparation for this morning's hearing, I scanned through your book, "Nuclear Peril." It has been a long time since I read it. I was struck by how very different the U.S. nuclear industry is today from when you wrote your book in 1982.

It also reinforced for me the years and now decades in which you have been concerned about nuclear energy and weapons. It is with sincere appreciation of that concern that I thank you for taking the time to consider the attributes of nuclear energy, which make it so interesting and compelling as we decide how to address the challenge of climate change.

Because of rapid population and economic growth, EIA forecasts global electricity demand to nearly double between 2004 and 2030. It is extraordinarily challenging to imagine credible scenarios by which the world can double electricity production in the coming decades and concurrently reduce greenhouse gas emissions. To do so will take the successful implementation of a wide range of solutions, as Professors Pacala and Socolow made clear in their wedge analysis. To do so will require the widespread use of renewables, conservation, efficiency, carbon sequestration and nuclear energy.

That conclusion is shared by leaders and governments around the world. My written statement includes quotes and references in that regard from individuals and groups, including Yvo de Boer, the Fourth Assessment Report of the IPCC, the World Energy Council, the World Business Council for Sustainable Development, Dr. Jeffrey Sachs, and the Progressive Policy Institute.

The willingness of individuals and organizations that would not otherwise be so inclined to consider and now support the deployment of new nuclear power plants is due, in part, to the need to identify all credible ways to reduce greenhouse gas emissions. However, this reconsideration also is made possible by the extraordinarily safe and efficient operation of the existing nuclear fleet.

In 2007, the 104 reactors in the U.S. nuclear fleet operated at 92 percent of capacity. That was accomplished because of high management standards, a focus on reliability and safety, and fewer and shorter outages. It enabled nuclear power plants, which are 12 percent of installed U.S. generation capacity, to produce nearly 20 percent of the electricity generated in the United States last year.

Concurrently, production costs continued to fall last year to 1.68 cents per kilowatt hour, a record low and the 7th straight year that nuclear plants have had the lowest production cost of any major source of electricity.

Nuclear power plants generate over 70 percent of all carbon-free electricity in the United States, and prevented 681 million metric tons of carbon dioxide emissions in 2006. For perspective, the volume of greenhouse gas emissions prevented at the Nation's 104 nuclear power plants is equivalent to taking 96 percent of all passenger cars off the roads.

Our nuclear power plants are also extraordinarily safe places to work. In 2006, our lost time accident rate was 0.12 accidents per 200,000 worker hours. That is significantly safer than the 3.5 accidents per 200,000 worker hours in the manufacturing sector. It is even safer to work at a nuclear power plant than it is to work at a bank.

At a global level, 439 nuclear power plants produce 16 percent of the world's electricity while avoiding the emission of 2.6 billion metric tons of CO_2 each year. And a new build renaissance is under way. There are 34 nuclear units under construction worldwide, including seven in Russia, six in India and five in China. In the United States, we have one, the 5-year, $2.5 billion completion of TVA's Watts Bar 2.

In the United States, 17 companies or groups of companies are preparing license applications for as many as 31 new reactors. Five complete or partial applications for COLs were filed with the NRC in 2007, and another 11 to 15 are expected this year. As a result, the industry expects four to eight new U.S. plants in operation by 2016 or so, depending on a variety of factors that are provided in my written statement. A second wave could be well under construction as the first wave reaches commercial operation.

Every source of electricity has benefits and challenges. Capital costs for new nuclear plants are significant. However, when both operating and capital costs are considered, nuclear power will be competitive with other new sources of electricity.

Chairman Markey, you mentioned the Florida Power & Light Company petition for determination of need. One of the things in that petition was FP&L's finding that the addition of new nuclear capacity is economically superior versus the corresponding addition of new gas-fired combined cycle units required to provide the same power output.

At the peak of construction, a nuclear plant will employ 2,300 skilled workers. Upon completion, approximately 700 workers will be required to operate and maintain the plant. Those workers receive excellent benefits and earn pay that is, on average, 40 percent higher than wages earned by workers doing similar work in nonnuclear facilities.

The industry also is working with organized labor to develop training and other programs to provide the cadre of highly skilled workers that our future requires. NEI supports the application of Federal prevailing wage requirements, contained in the Davis-Besse Act of 1931, to loan guarantees authorized by title 17 of the Energy Policy Act of 2005.

In addition, NEI is working aggressively to revitalize the United States' nuclear manufacturing infrastructure. The global nuclear renaissance will require additional capacity for a range of products, from very small components to ultra-heavy steel forgings and castings.

Even as we work to build the next fleet of advanced reactors for electricity production, we also are developing reactors that will provide energy security and environmental benefits well beyond the traditional electric sector. One promising next-generation technology is the high-temperature gas reactor. Its unique design is well-suited to meet a wide variety of future needs, such as the production of hydrogen, drinking water, industrial process heat, and to generate electricity appropriate for the distribution systems in developing countries.

In closing, nuclear energy is the single largest source of non-carbon-emitting generation. It is a proven technology, operated at high standards, by an experienced industry that is committed to safety. It is the only energy option available today that can provide large-scale electricity, 24/7, at a competitive cost, without emitting greenhouse gasses.

Mr. Chairman, that concludes my statement. I would be glad to take any questions.

[The prepared statement of Mr. Flint follows:]

Statement of Alex Flint
Senior Vice President, Governmental Affairs
Nuclear Energy Institute

before the

Select Committee on Energy Independence and Global Warming

March 12, 2008

Chairman Markey, Ranking Member Sensenbrenner, Members of the Committee, thank you for the opportunity to testify on nuclear energy's significant role in reducing greenhouse gas emissions in today's electricity generation portfolio and the expanded role that it can play in the future.

The Nuclear Energy Institute is responsible for developing policy for the U.S. nuclear industry on generic technical, regulatory, business and other matters of industry-wide importance. More than 300 corporate and other members of NEI represent a broad spectrum of interests, including every U.S. electric utility 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.

NEI's policy statement on climate change begins with the statement that "reducing carbon emissions, while fostering sustainable development, will be a major global challenge of the 21st century."

The scope of that challenge was reinforced last week when the Administrator of the Energy Information Administration testified before Congress on the EIA's 2008 Annual Energy Outlook. The EIA forecasts growth in US electricity demand of 30 percent between 2006 and 2030. In large part, because the forecast also predicts the construction and operation of 16.4 gigawatts of new nuclear capacity, CO2 emissions are predicted to increase by a smaller, yet still challenging, 16 percent from 2006 levels.

The global forecast is even more challenging. In 2030, world population is expected to be 8.3 billion people, an increase of 23 percent from today's estimated population. In addition, strong economic growth is forecast in the developing nations. To quote EIA, "total electricity demand in the non-OECD nations is expected to grow from 2004 to 2030 at an annual rate that is nearly triple the rate of growth for electricity demand in the OECD."

Because of this rapid population and economic growth, EIA forecasts global electricity demand to nearly double between 2004 and 2030 from 16.4 trillion kilowatt-hours in 2004 to 30.4 trillion kilowatt-hours in 2030.

It is extraordinarily challenging to imagine credible scenarios by which electricity production can double in the coming decades while reducing significantly the emission of greenhouse gases from electricity generation. To do so will take the successful implementation of a wide range of solutions, as Princeton Professors Stephen Pacala and David Socolow made clear in their wedge analysis.

A credible program will require a portfolio of technologies and approaches, including the widespread use of nuclear energy, renewables, conservation, efficiency, and carbon sequestration from the use of fossil fuels. The magnitude of this challenge should not be underestimated.

That conclusion is shared by leaders and governments around the world including Yvo de Boer, Executive Secretary of the United Nations Framework Convention on Climate Change, who, in July 2007 said he had never seen a credible scenario for reducing emissions that did not include nuclear energy. Similar conclusions have been reached by the G-8 in its declaration on "Growth and Responsibility in the World Economy" issued after the June 2007 G-8 summit.

In addition to global policy leaders, the world's scientific community agrees that nuclear energy must play a significant role in meeting the dual challenges of electricity production and greenhouse gas reduction. The most recent UN scientific report on climate change, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change identifies nuclear energy as one of the "key mitigation technologies." The IPCC report says that a "robust mix" of energy sources, including nuclear energy, "will almost certainly be required to meet the growing demand for energy services, particularly in many developing countries."

Business leaders concur. The World Energy Council's 2007 Energy and Climate Change Study found that "countries with high proportions of nuclear in their systems (such as Sweden and France) had GHG emissions per head significantly lower (30-50%) than those of comparable nations, demonstrating the contribution nuclear could potentially make to dealing with climate change globally." The report recommends that "all governments should give serious consideration to the potential of nuclear power for reducing GHG emissions."

Similarly, the World Business Council for Sustainable Development's, in its *Powering a Sustainable Future,* report found that existing carbon-free technologies like nuclear energy and promising technologies including advanced nuclear energy, "...have the potential to contribute to the substantial decarbonization of the [electric] sector at acceptable cost by 2050."

In the United States, Dr. Jeffrey Sachs, the director of the Earth Institute at Columbia University has said "low-emission electricity generation will be achieved in part through niche sources such as wind and bio-fuels. Larger-scale solutions will come from nuclear and solar power."

The Progressive Policy Institute in its Progressive Energy Platform concluded "nuclear power holds great potential to be an integral part of the diversified portfolio for America. It produces no greenhouse gases, so it can help clean up the air and combat climate change. And new plant designs promise to produce power more safely and economically."

The willingness of individuals and organizations that would not otherwise be so inclined to consider and now support the deployment of new nuclear power plants, is due in part to the need to identify all credible ways to reduce greenhouse gas emissions. However, this reconsideration also is made possible by the extraordinarily safe and efficient operation of the existing nuclear fleet.

In 2007, the 104 reactors in the U.S. nuclear fleet operated at 92 percent of capacity. That was accomplished because of high management standards, a focus on reliability and safety, and fewer and shorter outages. It enabled nuclear power plants, which are 12 percent of installed US generation capacity, to produce 807 billion kilowatt-hours of electricity or nearly 20 percent of the electricity generated in the United States last year.

Concurrently, production costs continued to fall, last year to 1.68 cents per kilowatt-hour, a record low. 2007 marked the ninth straight year that the industry's average electricity production cost has been below 2.0 cents per kilowatt-hour and the seventh straight year that nuclear plants have had the lowest production costs of any major source of electricity, including coal- and natural gas-fired power plants.

We also saw capacity increase in 2007, in large part due to the restart of TVA's Browns Ferry Unit 1 last May. That 5-year, $1.8 billion project was completed on schedule and within the cost estimate.

The environmental benefit of this nuclear generation is substantial.

Nuclear power plants generate over 70 percent of all carbon-free electricity in the United States. By using nuclear power instead of fossil fuel-based plants, the US nuclear energy industry prevented 681 million metric tons of carbon dioxide emissions in 2006. For perspective, the volume of greenhouse gas emissions prevented at the nation's 104 nuclear power plants is equivalent to taking 96 percent of all passenger cars off America's roadways.

Our nuclear power plants are also extraordinarily safe places to work. In 2006, our lost-time accident rate was 0.12 accidents per 200,000 worker hours. Statistics from other industries as compiled by the Bureau of Labor Statistics show a comparable accident rate in the manufacturing sector to be 3.5 accidents per 200,000 worker hours and that it is even safer to work at a nuclear power plant that it is to work at a bank.

The nuclear industry is also one of the most heavily regulated commercial enterprises. The NRC implements a reactor oversight process for all nuclear plants that encompasses its inspection, assessment and enforcement programs. The NRC maintains at least two resident inspectors at every US nuclear power plant. These inspectors, with support from NRC regional offices and headquarters, conduct a minimum of more than 2,000 hours of baseline inspections at each site per year. Additional direct inspection is based on plant performance.

At a global level, 439 nuclear plants produce 16 percent of the world's electricity while avoiding the emission of 2.6 billion metric tons of CO_2 each year—and a new build renaissance is underway.

There are 34 nuclear units under construction worldwide including seven in Russian, six in India, and five in China. In the United States, we have one, the 5-year, $2.5 billion completion of TVA's Watts Bar 2 underway.

In the United States, 17 companies or groups of companies are preparing license applications for as many as 31 new reactors. Five complete or partial applications for construction/operating licenses (COLs) were filed with the NRC in 2007. Another 11 to 15 are expected in 2008.

Of the reactor designs being considered for deployment, two have already been certified by the NRC. An additional two were submitted to the NRC last year, and an additional one has been submitted this year. Certification means that the advanced reactor design meets all federal safety standards.

We expect the NRC's review of the new reactor COL applications to take approximately 40 months and for the first COLs to be approved in late 2010 or early 2011.

As a result, the industry expects four to eight new U.S. nuclear plants in operation by 2016 or so. The exact number will depend on many factors – forward prices in electricity markets, capital costs of all base-load electric generation technologies, commodities costs, environmental compliance costs for fossil-fueled generating capacity, natural gas prices, growth in electricity demand, availability of federal and state support for financial investment and recovery and more.

If those first plants are working to schedule, within budget estimates and without licensing difficulties, a second wave could be well under construction as the first wave reaches commercial operation.

Every source of electricity has benefits and challenges. The Members of this Committee are well aware that, although nuclear power enjoys low and stable costs of operation and is the only expandable large-scale source of emission-free electricity, capital costs for new nuclear plants are significant. However, when both operating and capital costs are considered, nuclear power will be competitive with other new sources of electricity. Further, large base-load power options are limited.

In addition to cost, new coal-fired capacity has its own challenges. Generating companies announced 28,500 megawatts of coal-fired capacity in 2006 and 2007; but 22,300 megawatts of coal-fired capacity was postponed or cancelled, largely over CO_2 emission concerns.

Natural gas supply and price volatility also limits its use as a base-load generation source. For example, Florida Power & Light Company asked the Florida Public Service Commission in October for a "determination of need" to allow the company to move forward with the development of two new reactors at its Turkey Point power plant site. In its petition, the company stated that it "has conducted an extensive review of information currently available with the industry on the expected costs of new-generation units."

The company weighed the proposed nuclear project against other alternatives. Its conclusion: "the addition of new nuclear capacity is economically superior versus the corresponding addition of new [gas-fired combined cycle] units required to provide the same power output, yielding large economic benefits to customers... Based on all the information available today, it is clearly desirable to take the steps and make the expenditures necessary to retain the option of new nuclear capacity coming on line in 2018."

The construction of those plants in the United States will have benefits beyond low-cost, clean electricity. At the peak of construction, a nuclear plant will employ 2300 skilled workers. Upon completion, approximately 700 workers will be required to operate and maintain the plant. Those workers receive excellent benefits and earn pay that is, on average, 40 percent above the wages earned by workers doing similar work in non-nuclear facilities. The plants bring increased tax revenue, economic stability, and prosperity.

Training of skilled technicians and craft personnel — such as operators, technicians, electricians, welders, pipe-fitters and other maintenance workers—is essential to sustain the highly qualified work force needed to continue efficient, reliable electricity production. To attract workers to skilled craft careers and provide appropriate training and education, the industry has participated in the formation of 10 state-based consortia and other collaborative arrangements among state governments, industry and academia. In the areas of radiation protection, operations, and maintenance, 17 industry-community college collaborative training programs have been launched in 14 states, most within the past three years, to bring younger workers into these fields.

The industry also is working with organized labor to develop training and other programs to provide the cadre of highly skilled workers that our future requires. NEI supports the application of federal prevailing wage requirements, contained in the Davis-Bacon Act of 1931 as amended, to loan guarantees authorized by Title XVII of the Energy Policy Act of 2005.

In addition, NEI is working aggressively to revitalize the United States' nuclear manufacturing infrastructure. The global nuclear renaissance will require additional capacity for a range of products from very small components to ultra-heavy steel forgings and castings. To the extent possible, we are working to see that additional global capacity established in the United States.

The potential contribution nuclear power can make to reducing forecast greenhouse gas emissions in the electricity sector in the coming decades is extraordinary. But even as we work to build the next fleet of advanced reactors for electricity production, we also are developing reactors that will provide energy security and environmental benefits well beyond the traditional electric sector role.

One promising next generation technology is the high temperature gas reactor. Its unique design is well suited to meet a wide variety of future needs such as the production of economical hydrogen, clean drinking water, industrial process heat, municipal district heating, or to generate grid appropriate electricity for the developing world.

Hydrogen can also be a valuable replacement feedstock for natural gas used in the petrochemical sector. Almost all near-term scenarios for meeting electricity demand and reducing greenhouse gas emissions in the electricity sector forecast increased use of natural gas which will drive prices even higher. Those price increases will be felt by residential consumers who will have little choice but to pay higher energy bills and also by agricultural and commercial users who we predict will increasingly move overseas in pursuit of cheaper feedstock.

While plug-in electric hybrid vehicles powered from an increasingly green grid will reduce our dependence on foreign oil in the near-term, clean, domestically produced hydrogen from advanced nuclear systems could help meet our future transportation needs.

In addition, process heat from these future reactors holds the potential to further reduce our foreign energy dependence by reducing the cost and environmental consequences of extracting oil from non-conventional sources such as tar sands and oil shale. With the availability of low cost process heat, we can once again attract investment in large energy intensive manufacturing and secure the associated, high-paying jobs for American workers.

In closing, nuclear energy is the single largest source of non-carbon emitting generation. It is a mature technology, operated at high standards by an experienced industry that is committed to safety. It is the only energy option available today that can provide large-scale electricity 24/7 at a competitive cost without emitting greenhouse gases.

The CHAIRMAN. Thank you, Mr. Flint, very much.

Our second witness is Ms. Sharon Squassoni, who has been analyzing arms control and nonproliferation issues for 20 years. She is a senior associate in the nonproliferation program at the Carnegie Endowment for International Peace. She has also served in the Nonproliferation and Political Military Bureaus in the State Department.

We welcome you. Whenever you are ready, please begin.

STATEMENT OF SHARON SQUASSONI

Ms. SQUASSONI. Good morning. Thank you, Chairman Markey and Ranking Member Sensenbrenner and other members of the committee, for inviting me to provide comments on the topic of nuclear energy expansion and its contribution to mitigating global climate change.

Chairman Markey, I would like to request permission to submit longer testimony for the record, and I will summarize my remarks here.

The CHAIRMAN. Without objection, so ordered.

Ms. SQUASSONI. Thank you.

In addition, I would like to present a few graphics on nuclear expansion, which I understand is unorthodox, but, in this case, a picture may be worth a thousand words.

Recent nuclear enthusiasm stems from several expectations: that it can help beat global climate change, meet rapidly increasing demand for electricity, combat rising costs for oil and gas, and provide energy security. The gap between expectations and reality, however, is significant. This morning, I will focus on what it will really take for nuclear energy to make a difference in terms of global climate change and why this is unlikely to happen.

As you can see on the first slide, global nuclear reactor capacity now stands at 373 gigawatts electric, or about 439 reactors. By 2030, under what I call a "realistic growth scenario," which is based on U.S. Energy Information Administration figures, that capacity could grow about 20 percent. Yet, since electricity demand is expected to almost double in that time, nuclear energy is unlikely to keep its market share, which could drop from the current 16 percent to 10 percent of worldwide electricity generation.

In the U.S. alone, according to nuclear industry estimates, a stable market share for nuclear energy would require the U.S. to build 50 nuclear reactors by 2025. At the same time, the U.S. would also be building 261 coal-fired plants, 279 natural-gas-fired plants and 73 renewables projects. This is based on, I believe, Booz Allen Hamilton information.

States' plans for nuclear energy, however, may be anything but realistic. What you are looking at now are these red dots, which are 2030 plans, the announced intentions of States for nuclear energy.

In my second scenario, what I call the "wildly optimistic" one, the total reactor capacity would reach about 700 gigawatts by 2030. This is not a projection but, rather, takes at face value what States have announced they will do. More than 20 nations have announced intentions to install nuclear capacity that do not now have nuclear power plants. More than half of these are in the Middle East.

The final scenario depicts what an expansion to 1,500 gigawatts might look like based roughly on the high-end projections for 2050 done by MIT in its 2003 study entitled, "The Future of Nuclear Power." I call this the "climate change scenario." It is a little bit more than a Pacala-Socolow wedge, which is defined as the level of growth needed to reduce carbon emissions by more than 1 billion tons per year by 2050, which equals about 1,070 gigawatts, but it is less than the Stern report on climate change estimates that nuclear energy could reduce carbon emissions between 2 billion and 6 billion tons per year. The Stern numbers were literally off the map, so I did not include them here.

For 1,500 gigawatt capacity, MIT estimated that 54 countries, which is an additional 23 compared to today, would have commercial nuclear power programs. This essentially means a fivefold increase in the number of reactors worldwide and an annual build rate of 35 reactors per year.

If we go to the next slide, you can see what this looks like. This is 2030 and, again, 2050. These are all new nuclear power states.

Then, if you go to the next slide, you will see a closer look. The darker the color, the firmer the plans are. When I say "announced intentions," some of these plants will never come to fruition.

These expansion scenarios have implications for both the front and back ends of the fuel cycle. As the next graph shows, building one nuclear wedge would require tripling uranium enrichment capacity. So that is the first green bar that you see. The orange is today's enrichment capacity, about 50 million separative work units. In the first green one, there is the climate change scenario. As you see, it gets much larger if you go to the Stern numbers.

New states could find it economically feasible to develop their own enrichment. If we go to the next slide, you will see that is current enrichment capacity. Keep going; these are 2030 plans. Then beyond climate change, you see that a lot more states could potentially be enriching. These are also a little bit lower than the MIT numbers, which estimated, I guess, that 18 countries would have enough reactor capacity to merit enrichment.

It is unlikely that these expansion rates will be achieved, however. The U.S. has just a fraction of the nuclear infrastructure it had decades ago, 2 decades ago, and other countries have not fared much better. In the last 20 years, there have been fewer than 10 new construction starts in any given year. Industrial bottlenecks are significant now, particularly in forging reactor-pressure vessels and steam generators.

The sole company with ultra-large forging capacity, Japan Steelworks, has a 2-year waiting list. When it completes its expansion in 2010, it will only produce enough forging sets for eight reactors per year. The capabilities of alternative suppliers, such as China, are unknown.

Other constraints include labor shortages, not just in engineers but also craft and construction labor, and long lead times for components and materials. Financing is another huge topic, worthy of a separate hearing. And the cost of inputs has risen significantly in recent years.

Finally, the proliferation risks of nuclear expansion are not limited just to a three-, four- or fivefold increase in the number of reactors. Some states may move forward anyway, propelled by unrealistic expectations, and could acquire uranium enrichment and plutonium separation capabilities. Such national fuel production capabilities could introduce even greater uncertainty about proliferation intentions in regions like the Middle East because of the latent nuclear weapons capability of such plants. Efforts to address both supply and demand for such sensitive capabilities need to be redoubled.

The current policy debate paints nuclear energy clean and green; advocates nuclear energy for all, even though some states with nuclear reactors could pose significant safety and proliferation concerns; and suggests that nuclear energy is a path to energy security.

At the same time, U.S. officials insist that some states forgo developing indigenous nuclear capabilities. This confused message obscures important policy considerations. If nuclear energy——

The CHAIRMAN. Could you try to summarize, please?

Ms. SQUASSONI. Last sentence.

If nuclear energy can't really make a difference in terms of global climate change, are the huge costs and risks worth it?

Thank you.

[The prepared statement of Ms. Squassoni follows:]

Congressional Testimony

The Realities of Nuclear Expansion

Sharon Squassoni
Senior Associate
Carnegie Endowment for International Peace

House Select Committee for Energy Independence and Global Warming
Washington, DC
March 12, 2008

Enthusiasm for nuclear energy has grown significantly in the last five years, prompting a flurry of policy papers, newspaper articles and magazine covers (from the *Economist* to *Fortune* to the *Bulletin of Atomic Scientists*). Although the challenges of nuclear energy haven't changed – proliferation, cost, waste, and safety – the debate is now focused on how nuclear energy can help beat global climate change. Rapidly increasing demand for electricity, rising costs of oil and gas, and concerns about energy security complete the case for the "nuclear renaissance."

The United States is taking an active role in promoting nuclear energy at home and abroad. U.S. policymakers are pursuing:

- Promotion of nuclear energy at home, including reprocessing of reactor spent fuel and subsidies for the nuclear industry;
- Promotion of global nuclear expansion, including nuclear cooperation with states like Russia and India; and
- Limits on the spread of sensitive nuclear fuel cycle technologies such as enrichment of uranium and reprocessing of spent fuel abroad for nonproliferation purposes.

U.S. federal funding for nuclear energy has increased 330% since 2001.[1] Other federal support for the nuclear industry includes loan guarantees, production tax credits, risk insurance and the 20-year extension of the Price-Anderson Act. The 2005 Energy Policy Act contained subsidies for the first six new nuclear power plants built in the United States, among other things.

More broadly, President Bush stated in May 2007 that if we're "truly interested in cleaning up the environment, or interested in renewable sources of energy, the best way to do so is through safe nuclear power." Secretary of State Rice told Congress in 2006 that the U.S.-India nuclear cooperation agreement would benefit the environment. In her words: "Nuclear energy is, after all, clean energy and providing India with an environmentally friendly energy source like nuclear energy is an important goal."[2] And the U.S. creation of the Global Nuclear Energy Partnership in 2006 also has contributed to international enthusiasm for nuclear energy.

Added to U.S. government support, prominent environmentalists such as Patrick Moore and Stewart Brand have reversed their earlier opposition to nuclear energy and now embrace it as necessary and desirable.

The result is a confused debate that paints nuclear energy "clean and green," advocates nuclear energy for all, even though some states with nuclear reactors could pose significant safety and proliferation concerns, and suggests that nuclear energy is a path to energy security, while insisting that some states rely on market mechanisms for

[1] Assistant Secretary For Nuclear Energy Dennis R. Spurgeon, "Federal Support For A Growing Nuclear Power Industry," Remarks to Platts 4th Annual Nuclear Energy Conference, February 5, 2008.
[2] "The U.S.-India Civilian Nuclear Cooperation Agreement," Secretary Condoleezza Rice, Opening Remarks Before the Senate Foreign Relations Committee, Washington, DC, April 5, 2006.

fuel supplies instead of developing their own indigenous resources and capabilities. Yet, this approach obscures important policy considerations as the United States and other countries consider nuclear investments on the order of several hundred billion dollars. A first order question is the extent to which nuclear energy can really make a difference in terms of global climate change.

The Pacala-Socolow Nuclear "Wedge"

In 2004, Princeton scientists Stephen Pacala and Robert Socolow published a "wedge analysis" for stabilizing global climate change.[3] Since fossil fuels currently emit seven billion tons of carbon/year and are projected to double that level through 2050 in the business-as-usual scenario, Pacala and Socolow considered what technologies and/or approaches might help stabilize those emissions at current levels (about 375 ppm). Seven wedges of reduced emissions (a cumulative effect of 25 billion tons through 2050, or one billion tons of carbon/year reduction at the end of that period) were postulated. One "wedge" would ultimately achieve a reduction of one billion tons per year (or 25 billion cumulative tons) by 2050.

For nuclear energy to "solve" just one-seventh of the problem – lowering emissions by one billion tons per year – an additional 700 GWe of capacity would have to be built, assuming the reactors replaced 700 GWe of modern coal-electric plants.[4] Because virtually all operating reactors will have to be retired in that time, this means building approximately 1070 reactors in 42 years, or about 25 reactors per year.

Current global reactor capacity is 373 GWe or 439 reactors worldwide. In short, one "nuclear wedge" would require almost tripling current capacity.

Mapping Nuclear Expansion[5]

The attached maps (see slide 1) depict estimates of reactor capacity growth for 2030 and 2050, according to three scenarios. The first is a "realistic growth" scenario, based on the U.S. Energy Information Administration figures for 2030.[6] The second is what states have planned for 2030, or a "wildly optimistic" scenario. The third is roughly based on the high-end projections for 2050 done by MIT in their 2003 study entitled "The Future of Nuclear Power." This 1500 GWe scenario lies between the Pacala-Socolow wedge and the Stern Review on the Economics of Climate Change estimates that nuclear

[3] S. Pacala, R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, Vol. 305, August 13, 2004.
[4] The International Panel on Fissile Materials estimates that when compared to an equivalent modern coal plant, 1 GWe of nuclear capacity operating at an average capacity factor of 90% reduces the amount of carbon released to the atmosphere by about 1.5 million metric tons annually. See IPFM, *Global Fissile Material Report 2007*, p. 87.
[5] The Nonproliferation Policy Education Center funded the development of the maps used in this testimony.
[6] Neither the U.S. Energy Information Administration nor the International Energy Agency currently provides an outlook on nuclear energy for 2050 because of the level of uncertainty (although the IEA is considering doing this), which prevents a strict comparison of the three scenarios.

energy could reduce carbon emissions between two billion and six billion tons/year (or 1800 GWe – 4500 GWe).[7]

A few caveats with respect to projecting nuclear energy expansion are necessary. Nuclear energy is undoubtedly safer and more efficient now than when it began fifty years ago, but it still faces four fundamental challenges: waste, cost, proliferation, and safety. It is an inherently risky business. Most industry executives will admit that it will only take one significant accident to plunge the "renaissance" back into the nuclear Dark Ages. Because of this, estimates are highly uncertain. For example, the U.S. Energy Information Administration does not use its computer model to estimate nuclear energy growth because, among other things, key variables such as public attitudes and government policy are difficult to quantify and project. That said, estimates tend to extrapolate electricity consumption and demand from gross domestic product (GDP) growth, make assumptions about nuclear energy's share of electricity production, and then estimate nuclear reactor capacity.

A "Realistic Growth" Scenario

The United States, France, and Japan constitute more than half of total world nuclear reactor capacity (see slide 1). Yet half of the 34 reactors now under construction are in Asia.[8] Under any scenario, nuclear power is expected to grow most in Asia, because of high Chinese and Indian growth and electricity demand.

Under the realistic growth scenario, the U.S. Energy Information Administration estimates 2030 reactor capacity at 481 GWe. The International Energy Agency (IEA) envisions greater potential for expansion, projecting a range from 414 to 679 GWe in 2030, but the higher number would require significant policy support.

With electricity consumption expected to double by 2030, nuclear energy will have a difficult time just keeping its market share – currently 16 percent of global production.[9] According to the Intergovernmental Panel on Climate Change, with no change in energy policies, "the energy mix supplied to run the global economy in the 2025-2030 time-frame will essentially remain unchanged with about 80% of the energy supply based on fossil fuels."[10] Coal now provides 59% of electricity production, followed by hydroelectric power at 39% and oil and gas together provide 25%. Renewables are just 1-2% of total electricity production.

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[7] Nicholas Stern, *The Economics of Climate Change: The Stern Review*, October 2006.
[8] See World Nuclear Association figures, *World Nuclear Power Reactors 2006-08 and Uranium Requirements*, updated January 14, 2008, available at: http://www.world-nuclear.org/info/reactors.html
[8] The EIA's International Energy Outlook 2007 Reference http://www.world-nuclear.org/info/reactors.html
[9] The EIA's International Energy Outlook 2007 Reference Case Scenario states that electricity generation will rise from 16,464 billion kilowatt hours in 2004 to 30,364 billion kilowatt-hours in 2030 – almost a doubling of generation, with much of that rise coming from outside OECD states. Electricity generation from nuclear power plants worldwide is projected to increase at an average rate of 1.3 percent per year, from 2,619 billion kilowatt-hours in 2004 to 3,619 billion kilowatt-hours in 2030.
[10] Intergovernmental Panel on Climate Change, Fourth Assessment Report, Working Group III Report: Mitigation of Climate Change, 2007, p. 109.

Moreover, regions that have coal tend to use it, particularly for electricity generation, which increases greenhouse gas emissions. The IPCC has noted that "in recent years, intensified coal use has been observed for a variety of reasons in developing Asian countries, the USA and some European countries. In a number of countries, the changing relative prices of coal to natural gas have changed the dispatch order in power generation in favor of coal." Many fear that states such as China and India – both of which are not subject to Kyoto Protocol targets because they are developing states – will meet their increased demand with cheap coal. Without further policy changes, according to the International Energy Agency, the share of nuclear energy could drop to 10% of global electricity production.

"Wildly Optimistic" Growth Scenario

Although some states, such as Germany and Sweden, plan to phase out nuclear power, the trend line is moving in the opposite direction. This growth scenario does not contain projections based on electricity demand, but instead takes at face value what states have projected for themselves. The result is a total of 700 GWe global capacity (see slide 2) – two-thirds of what one nuclear wedge to affect global climate change would require. The reason these estimates are wildly optimistic is that over 20 nations have announced intentions to install nuclear reactors. Several of these – Turkey, Egypt, and Philippines – had planned for nuclear power in the past, but abandoned such plans for various reasons.

Some of these new nuclear plans are more credible than others and can be differentiated into those that have approved or funded construction, those that have clear proposals but without formal commitments, and those that are exploring nuclear energy (see slide 3).

In the Middle East, these include Iran, Israel, Jordan and Yemen, with potential interest expressed by Syria, Kuwait, and the Gulf Cooperation Council states of Saudi Arabia, Oman, United Arab Emirates, Qatar, and Bahrain. In Europe, Belarus, Turkey and Azerbaijan have announced plans, as well as Kazakhstan. In Asia, Bangladesh, Thailand, Vietnam, Malaysia, and Indonesia have announced plans, and the Philippines has also expressed interest. Venezuela has also declared it will develop nuclear power. In Africa, Morocco, Tunisia, Libya, Egypt, and Nigeria have announced plans to develop nuclear power, and Algeria and Ghana have expressed interest.[11]

More than half of all those states are in the Middle East. Although this could result in reduced carbon emissions, because Middle Eastern states use more oil for

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[11] The World Nuclear Association lists 30 nations as considering nuclear power: In Europe: Italy, Albania, Portugal, Norway, Poland, Belarus, Estonia, Latvia, Ireland, Turkey; In the Middle East and North Africa: Iran, Gulf states, Yemen, Israel, Syria, Jordan, Egypt, Tunisia, Libya, Algeria, Morocco; In central and southern Africa: Nigeria, Ghana, Namibia; In South America: Chile, Venezuela; In central and southern Asia: Azerbaijan, Georgia, Kazakhstan, Bangladesh; In SE Asia: Indonesia, the Philippines, Vietnam, Thailand, Malaysia, Australia, New Zealand.

electricity production (34%) than elsewhere, this is not where the real electricity demand is coming from.

"Climate Change" Growth Scenario

A rough approximation of where reactor capacity would expand in a climate change scenario is based on the high scenario of the 2003 MIT Study, "The Future of Nuclear Power." For 1500 GW capacity, MIT estimated that 54 countries (an additional 23) would have commercial nuclear power programs. This essentially means a five-fold increase in the numbers of reactors worldwide and an annual build rate of 35 per year. In the event that smaller-sized reactors are deployed in developing countries – which makes eminent sense – the numbers could be much higher.[12] If nuclear energy were assumed to be able to contribute a reduction of between two and six billion tons of carbon per year as outlined in the Stern Report, the resulting reactor capacity would range between 1800 GWe and 4500 GWe – increases ranging from six to ten times the current capacity.[13] This would require building between 42 and 107 reactors per year through 2050.

Impact on Uranium Enrichment

Such increases in reactor capacity would certainly have repercussions for the front and back ends of the fuel cycle. Almost 90 percent of current operating reactors use low-enriched uranium (LEU). Presently, eleven countries have commercial uranium enrichment capacity and produce between 40 and 50 million SWU. A capacity of 1070 GWe – the one "wedge" scenario – could mean tripling enrichment capacity, requiring anywhere from 11 to 22 additional enrichment plants.[14] A capacity of 1500 GWe would require quadrupling enrichment capacity (see slide 4).[15] Further, if Stern Report nuclear expansion levels are achieved, enrichment capacity would have to increase ten-fold.

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[12] The MIT study used an underlying assumption that the developed countries would continue with a modest annual increase in per capita electricity use and the developing countries would move to the 4000 kWh per person per year benchmark if at all feasible (the 4000 kWh benchmark is the dividing line between developed and advanced countries). Electricity demand was then pegged to estimated population growth. Finally, it was assumed that nuclear energy would retain or increase its current share of electricity generation. The least-off developing countries were assumed in the MIT study not to have the wherewithal for nuclear energy. A final caveat in the MIT study is that the 2050 projection is "an attempt to understand what the distribution of nuclear power deployment would be if robust growth were realized, perhaps driven by a broad commitment to reducing greenhouse gas emissions and a concurrent resolution of the various challenges confronting nuclear power's acceptance in various countries." A few countries that the MIT High 2050 case included, but we do not, are countries that currently have laws restricting nuclear energy. For example, we did not include Austria as a state that will install nuclear reactors, given its 1978 law prohibiting nuclear energy.

[13] This order of magnitude increase was impossible to plot on maps.

[14] Keystone Center for Science and Public Policy, "Nuclear Power Joint Fact-Finding," June 2007, p. 23.

[15] Calculating enrichment demand requires assumptions about reactor technologies and whether the fuel cycle is open or closed. For example, 1500 GWe light water reactors, using LEU would require 225 million SWU/year. However, 1500 GWe with MOX reactors (1 recycle) would require 189 million SWU/year, and 1500 GWe with fast, thermal reactors would require123 million SWU/year. The MIT study assumed the same proportion of light water reactors would be built, or 90%.

In assessing where new uranium enrichment capacity might develop, the MIT study assumed that 18 states would have 10 GWe reactor capacity – the point at which domestic uranium enrichment becomes competitive with LEU sold on the international market – and thus might enrich uranium. (See slide 4 for a more modest approach, with nine additional countries enriching uranium).[16]

Impact on Spent Fuel Reprocessing

A key question is whether an expansion of nuclear reactors would result in an expansion of spent fuel reprocessing. This is not necessarily the case, because decisions about whether to store fuel or reprocess it depend on several factors: existing storage capacities; fuel cycle approaches (once-through, one recycle, fast reactors) and new technologies; and cost. A shift to fast reactors that can burn or breed plutonium implies an increase in recycling, whether this is traditional reprocessing that separates out plutonium, or options under consideration now that would not separate out the plutonium.

France and Japan now commercially reprocess their spent fuel and recycle the plutonium once in mixed oxide-fuelled reactors. Russia also reprocesses a small percentage of its spent fuel. A troubling development in the last two years from a nonproliferation perspective has been the U.S. embrace of recycling spent fuel under the Global Nuclear Energy Partnership, after a policy of 30 years of not encouraging the use of plutonium in the civil nuclear fuel cycle. Whether or not the United States ultimately reprocesses or recycles fuel, other states are now more likely to view reprocessing as necessary for an advanced fuel cycle.

Constraints on Nuclear Expansion[17]

There are significant questions about whether nuclear expansion that could affect global climate change is even possible. In the United States, as the chief operating officer of Exelon recently told an industry conference, constraints include: the lack of any recent U.S. nuclear construction experience; the atrophy of U.S. nuclear manufacturing infrastructure; production bottlenecks created by an increase in worldwide demand; and an aging labor force.

Lack of construction experience translates into delays, which translate into much higher construction costs. Although reactors typically take at least four years to build, delays can increase finance costs considerably. A recent example – the construction of Okiluoto-3 in Finland – demonstrates that an 18-month delay cost 700 million Euros in a

[16] This calculation is also highly dependent on the price of uranium. For example, other estimates suggest that at a price of $200/kg, the break-even point would only be 5 GWe. See Geoffrey Rothwell, "An Evaluation of the Real Option of Starting to Build a Nuclear Power Plant in Chile in 2020," 18 October 2007, presentation to Centro de Estudios Públicos Santiago de Chile.

[17] See Mycle Schneider, with Antony Froggatt, "The World Nuclear Industry Status Report 2007," January 2008, commissioned by the Greens-EFA Group in the European Parliament, for an excellent summary of the many constraints facing nuclear expansion.

project with a fixed cost of three billion Euros.[18] In an analysis for a nuclear industry conference, the consulting firm Booz Allen Hamilton prioritized 15 different risks in new reactor construction. The most significant risks and those most likely to occur included engineering, procurement and construction performance, resource shortages and price escalation.[19]

The atrophy of nuclear manufacturing infrastructure is significant in the United States, but also worldwide. The ultra-heavy forgings for reactor pressure vessels and steam generators constitute the most significant chokepoint. Japan Steel Works (JSW) is currently the only company worldwide with the capacity to make ultra-large forgings (using 600-ton ingots) favored by new reactor designs. Other companies – such as Sfarsteel (formerly Creusot Forge) in France and Doosan Industry in South Korea – have smaller capacities. The purchase of Creusot Forge by AREVA in 2005 means that former customers of Creusot reportedly are shifting to Japan Steel Works, lengthening the two-year waiting list. According to JSW officials, it can now only produce 5.5 sets of forgings per year; this will expand to 8.5 sets in 2010. Even then, nuclear forgings at JSW compete with orders for forgings and assembly from other heavy industries, for example, oil and gas industries, which can be more profitable. China will open new plants, possibly this year, to produce ultra-heavy forgings. In the meantime, using smaller capacity forgings means more components, with more weld seams, and therefore will require more safety inspections, costing utilities more money when the reactors are shut down and not generating electricity. One AREVA estimate is that the daily cost of shutdowns (for inspections or other reasons) is $1 million.

In the United States, a significant portion of supporting industries needs to be rebuilt or recertified. In the 1980s, the United States had 400 nuclear suppliers and 900 holders of N-stamp certificates from the American Society of Mechanical Engineers.[20] Today, there are just 80 suppliers and 200 N-stamp holders. The Nuclear Energy Institute (NEI) notes that some of the decline in N-stamp holders is due to consolidation of companies, but nonetheless is encouraging firms to get recertified. In addition, certain commodities used in reactor construction may also present supply problems, such as alloy steel, concrete and nickel. The cost of these inputs, according to Moody's, has risen dramatically in recent years.

<u>Competition from other electricity and construction projects</u>

According to a 2008 Bechtel estimate, if electricity demand grows in the United States 1.5% each year and the energy mix remains the same, the United States would

[18] Mycle Schneider, "Myths and Realities on Nuclear Power in the World … and Case Studies France and Turkey," briefing for Heinrich-Böll-Foundation, Istanbul, 20-21 April 2007.

[19] Other risks included delivery delays, materials out of spec; site-related issues; safety related delays; labor productivity; NRC delays; roll-back of incentives; changes in design; late engineering; balance sheet exposure; and project financing availability. Presentation by Tom Flaherty, Booz, Allen, Hamilton to Platt's Fourth Annual Nuclear Energy Conference, Bethesda, Maryland, February 5, 2008.

[20] Jim Harding, "Seven Myths of the Nuclear Renaissance," Presented to Conference on the 50th Anniversary of the Euratom Treaty Brussels, Belgium ,March 7-8, 2007. Available at http://www.nirs.org/nukerelapse/neconomics/jimharding382007.pdf

have to build 50 nuclear reactors, 261 coal-fired plants, 279 natural-gas-fired plants and 73 renewables projects by 2025. All of these will require craft and construction labor. In addition, electricity generation projects will compete with oil infrastructure projects.

In addition, nuclear power construction competes with other large investment projects for labor and resources. Rebuilding from Hurricane Katrina and big construction projects in Texas will continue to place pressure on construction labor forces. A Bechtel executive recently stated that the U.S. faced a skilled labor shortage of 5.3 million workers in 2010, which could rise to a shortage of 14 million by 2020. Adding to this is the retirement of baby boomers, and much slower growth in the number of college graduates.[21] A typical nuclear power plant in the United States takes about 4 years to build, and requires 1400 to 2300 construction workers.

Costs and Financing

Finally, nuclear power reactors are costly to construct. Moody's estimated in October 2007 that the all-in cost of a new nuclear generating facility could range from $5000 and $6000/kw. This compares to valuations of between $2700 to $3500/kW for existing nuclear plants; $1700-$2200/kw for existing coal plants and $700-900/kw for combined cycle natural gas plants. The second least expensive option is integrated gasification combined cycle coal plants at between $3300 and $3700/kw. Even so, Moody's claims it maintains a "relatively favorable bias towards nuclear generation."[22]

Financial analysts suggest that there is certainly enough venture capital available to finance a "nuclear renaissance" but much will be determined by the level of risk. This is where governments get involved. The bottom line is that nuclear power expansion will not be possible without significant government support across the board.

Summary

For nuclear energy to contribute one of seven "wedges" of carbon emission reductions, current capacity would need to triple. This would require building 20 reactors every year for 50 years – a construction rate sustained by the United States for one decade. In the last twenty years, there have been fewer than 10 new construction starts in any given year worldwide.

A significant expansion will narrow bottlenecks in the global supply chain today that include ultra-heavy forgings, large manufactured components, engineering, craft and skilled construction labor, all exacerbated by lack of recent experience in construction, and aging labor forces. While these may not present problems for limited growth, they will certainly present problems for tripling reactor capacity.

---

[21] Brian Reilly, Principle Vice President, Bechtel, "Challenges of Construction Labor for New Builds," presentation to Fourth Annual Platt's Nuclear Energy Conference, February 5, 2008.
[22] Moody's Corporate Finance, Special Comment, "New Nuclear Generation in the United States," October 2007.

This is not to say that U.S. and global nuclear infrastructure could not expand to meet demand. However, the prospects of it doing so in the timeframe most important for global climate change are slim. One reason is that risk mitigation remains a primary concern for the industry, and this is likely to result in a "wait and see" approach. As it is, the U.S. nuclear industry continues to press the federal government for additional assistance, including delays in taxing new domestic nuclear industry until national policy objectives for nuclear manufacturing are met; establishing a nuclear work force program; and ensuring American access to other nuclear markets.[23]

Even with the requisite infrastructure, reactors can take between 10 and 15 years between a decision to build and connection to an electricity grid. Many developing states do not yet have the regulatory infrastructure to make this happen even in that time frame.

Building one "nuclear wedge" will also require a tripling of uranium enrichment capacity, and will certainly generate a debate about spent fuel reprocessing. Moving beyond the one nuclear wedge expansion to a 1500 GWe scenario, or the even more aggressive Stern Report 1800 GWe-4500 GWe scenario, it is difficult to see how such growth could be accomplished, even in 50 years. The 1500 GWe scenario would require building 35 reactors/year; 1800 GWe would require building 42/year; and 4500 GWe would require building more than two reactors per week, or 107/year. The enrichment and storage/reprocessing pressures are similarly daunting, not to mention the cost of all such capabilities.

As the demand for electricity is expected to almost double by 2030, nuclear energy will have a difficult time even keeping its 16% market share of global electricity generation. While a carbon tax will make nuclear energy more competitive, it is not likely to be strongly embraced by electric utilities in the United States, which also operate coal plants.

Finally, the proliferation risks of nuclear expansion are not limited just to a three- four-, or five-fold increase in the number of reactors. Some states may move forward anyway, propelled by unrealistic expectations, and could acquire uranium enrichment and plutonium separation capabilities under current institutions and rules. Such national fuel production capabilities could introduce even greater uncertainty about proliferation intentions in certain regions like the Middle East, because of the latent nuclear weapons capability in such plants. Efforts to address both supply and demand for such sensitive capabilities need to be redoubled.

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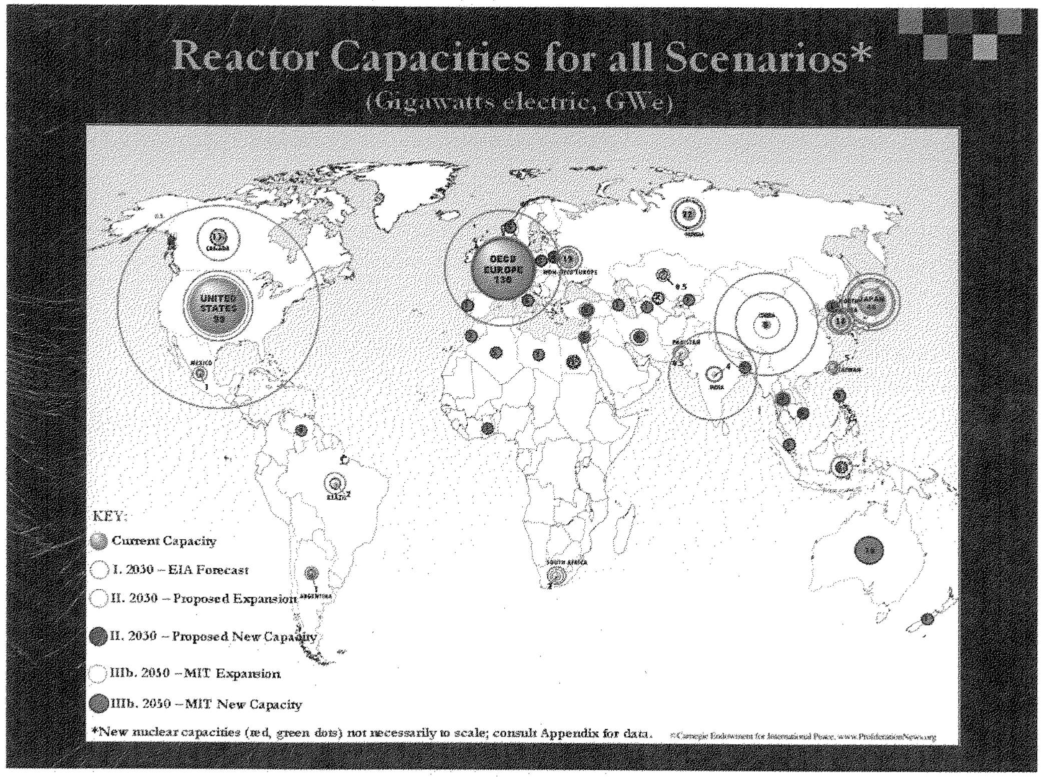
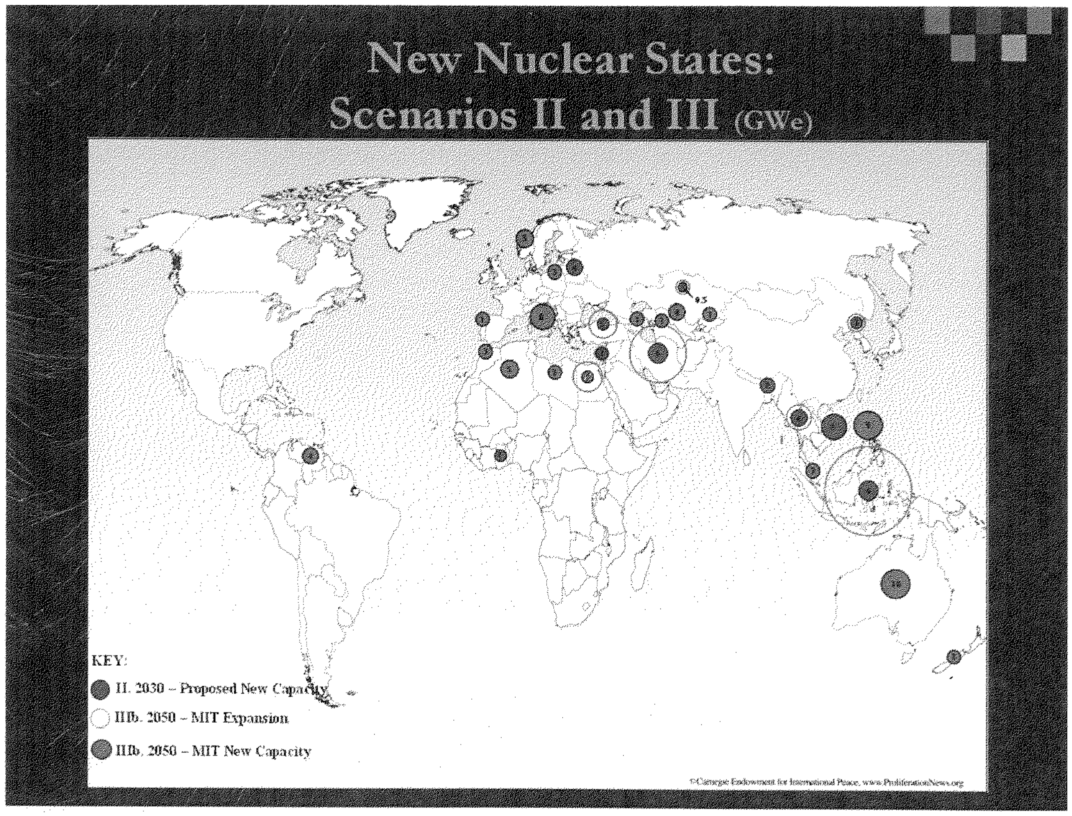
[23] See, for example, John A. Fees, President and Chief Operating Officer, BWX Technologies, Inc., "Reviving America's Industrial Base," *NEI Nuclear Policy Outlook*, October 2006, pp. 5, 8.

Appendix: Mapping Global Nuclear Expansion




New Nuclear States:
Scenarios II and III (GWe)
KEY:
II. 2030 – Proposed New Capacity
IIIb. 2050 – MIT Expansion
IIIb. 2050 – MIT New Capacity
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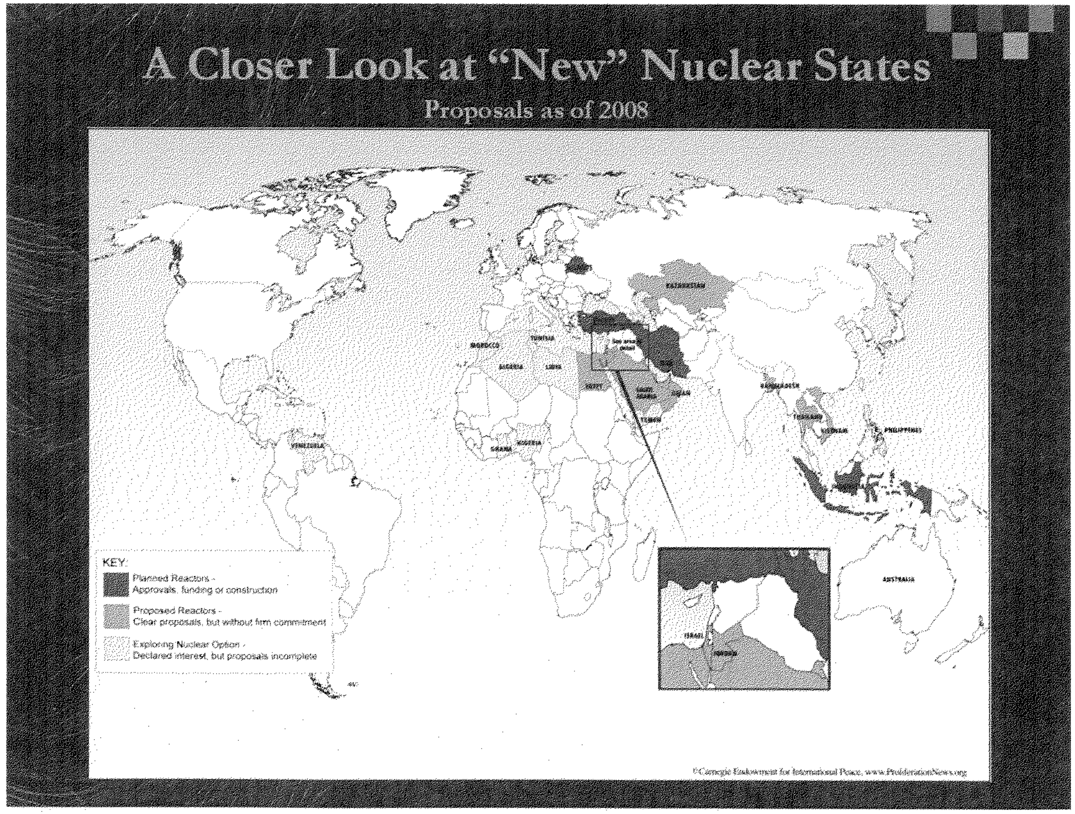
A Closer Look at "New" Nuclear States
Proposals as of 2008
KEY:
Planned Reactors - Approvals, funding or construction
Proposed Reactors - Clear proposals, but without firm commitment
Exploring Nuclear Option - Declared interest, but proposals incomplete
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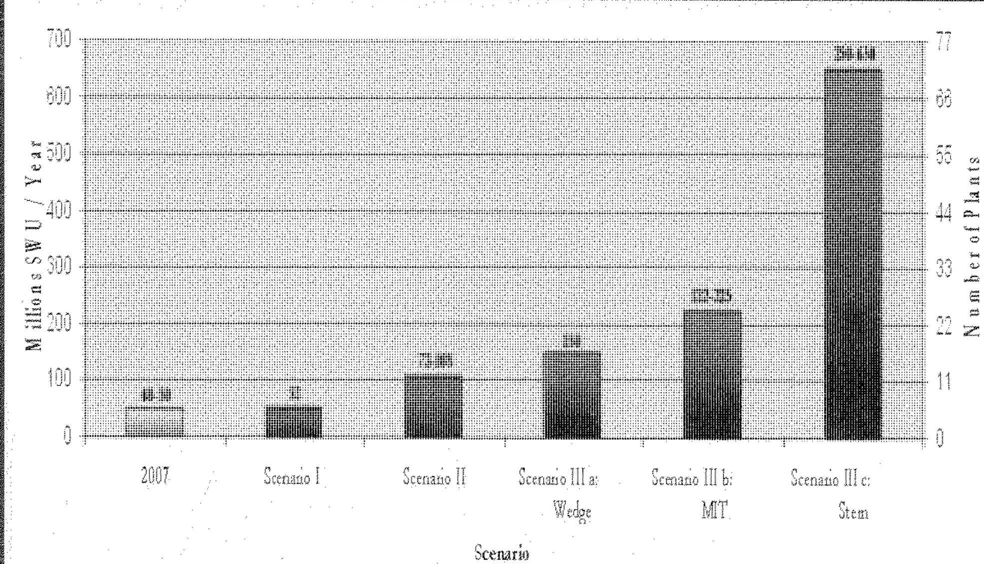
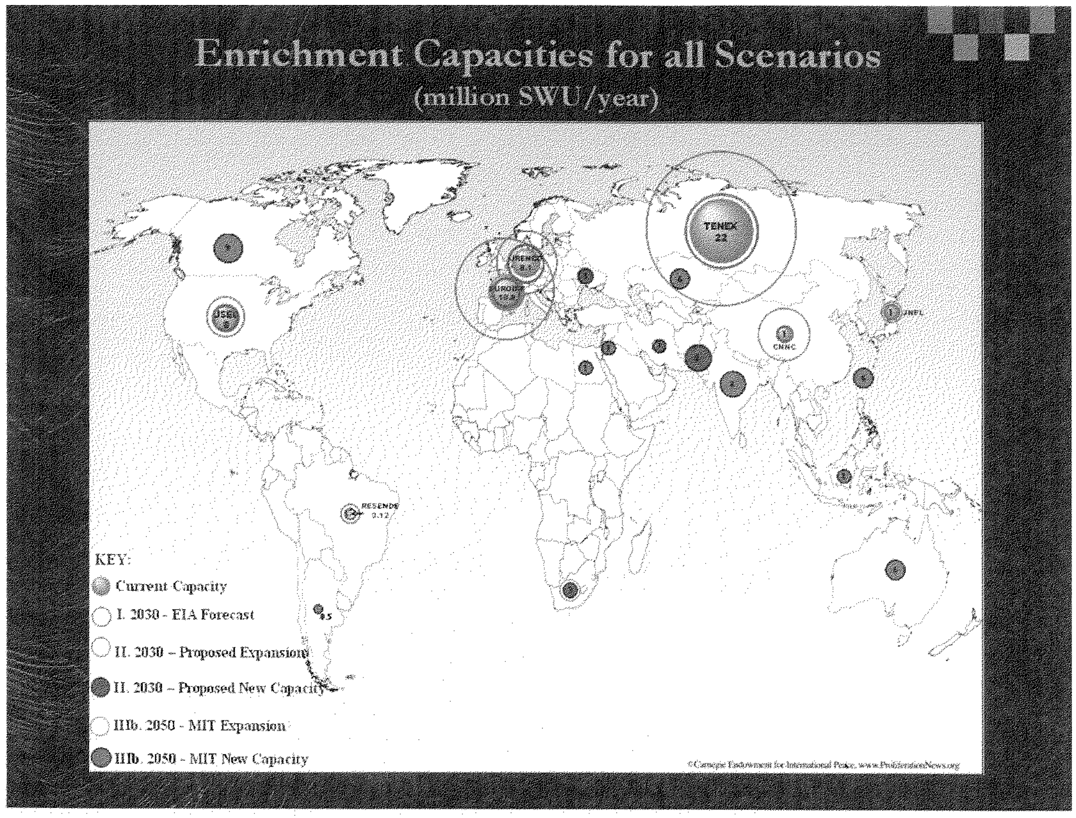
Enrichment Implications




Enrichment Capacities for all Scenarios
(million SWU/year)
TENEX
22
CNNC
JNFL
RESENDE
0.12
KEY:
Current Capacity
I. 2030 - EIA Forecast
II. 2030 – Proposed Expansion
II. 2030 – Proposed New Capacity
IIIb. 2050 - MIT Expansion
IIIb. 2050 - MIT New Capacity
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Nonproliferation Policy Education Center

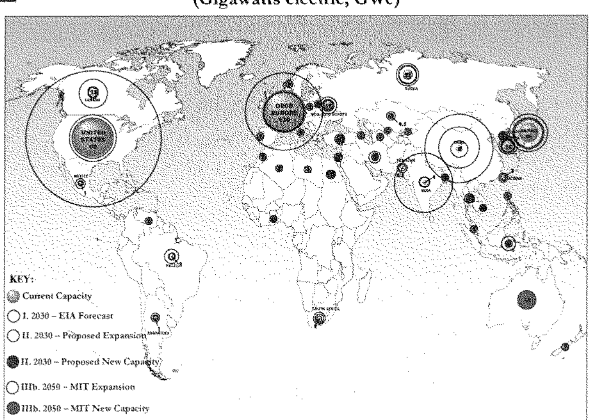
MAPPING GLOBAL NUCLEAR EXPANSION

Sharon Squassoni
Senior Associate
March 12, 2008

With Georgina Jones and Nima Gerami, research assistants

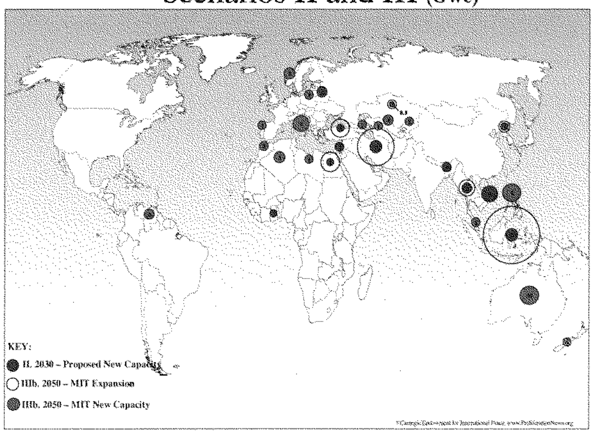
Reactor Capacities for all Scenarios*

(Gigawatts electric, GWe)



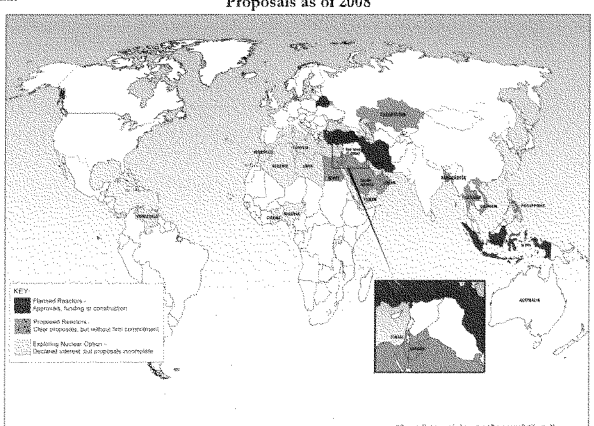
*New nuclear capacities (red, green dots) not necessarily to scale; consult Appendix for data.

New Nuclear States: Scenarios II and III (GWe)

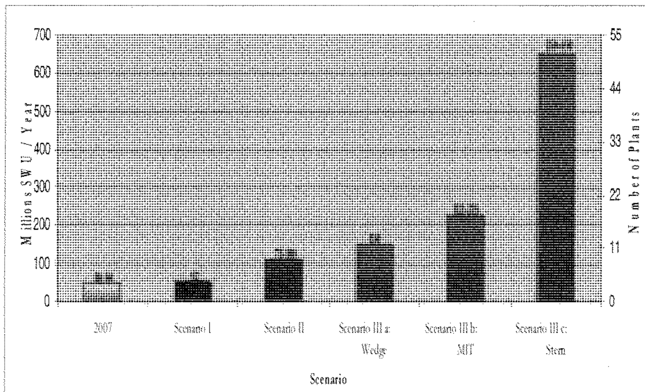


A Closer Look at "New" Nuclear States

Proposals as of 2008



Enrichment Implications*



*See separate Appendix for details. Numbers are rough approximation.

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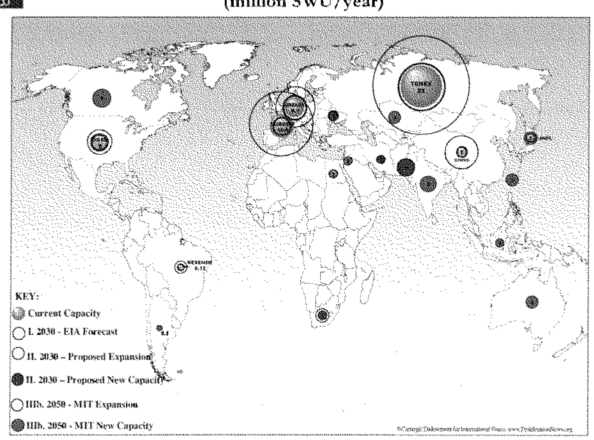
Enrichment Capacities for all Scenarios
(million SWU/year)



The CHAIRMAN. Thank you so much.

Our next witness is Mr. David Lochbaum. He is the director of the Nuclear Safety Project for the Union of Concerned Scientists, where he leads the efforts to ensure the safety of nuclear power in the United States. Mr. Lochbaum has more than 17 years of experience in commercial nuclear power plant startup, testing, operations, licensing, software development, training, and design engineering.

We welcome you, sir. Whenever you are ready, please begin.

STATEMENT OF DAVID LOCHBAUM

Mr. LOCHBAUM. Thank you, Mr. Chairman and members of the committee. I appreciate this opportunity to present our views.

I have submitted a written statement that I request be entered into the record.

The CHAIRMAN. Without objection, so ordered.

Mr. LOCHBAUM. 253 nuclear power reactors have been ordered in the United States. 28 percent were cancelled before construction even began. Another 20 percent were cancelled after construction began. So about half of the reactors ordered never generated a single watt of electricity.

But what about the other half? 11 percent of the reactors ordered shut down prematurely due to unfavorable economics. 14 percent of the reactors ordered are operating today but have had to shut down for at least a year to restore safety levels. Only 27 percent of the reactors ordered are operating today without having experienced a year-plus safety restoration outage.

The NRC anticipates 33 nuclear reactor applications in the near term. Running the calendar forward 55 years could yield the following retrospective: 33 nuclear reactors ordered, nine reactors cancelled before construction began, seven reactors cancelled after construction began, four reactors shut down due to economics, four reactors operating despite 1-or-more-year-plus outages, nine reactors operating without a year-plus outage.

Does past performance predict the future? Yes, when the underlying causes and behavior patterns are firmly in place, as if set in concrete.

Nearly 30 years ago, during the 97th Congress, the House held a hearing on construction problems caused by poor quality control. Chairman Udall posed four questions: How did these quality assurance failings occur? Why did the failings go undetected so long by the owners and the NRC? What is being done to minimize the likelihood of future failings? How can we be sure that completed plants have been constructed in accordance with NRC's regulations?

The answer to the first question is mismanagement by plant owners, a recurring theme in nuclear power plant problems since that hearing. Mismanagement shut down all of TVA's nuclear plants in the 1980s, it shut down eight reactors for over a year in the late 1990s, shut down Davis-Besse for over 2 years earlier in this decade, and caused the current problems at the Palo Verde plant in Arizona.

The answer to question two is mismanagement by the plant owners, coupled by ineffective oversight by the NRC. The companion theme in nuclear plant problems since that hearing has been ineffective oversight by the NRC. The GAO reported in 1997, quote, "NRC is not effectively overseeing the plants that have problems. NRC enforcement actions are too late to be effective," end quote. Seven years later, almost to the day, GAO updated its conclusion: Quote, "NRC should have but did not identify or prevent the vessel head corrosion at Davis-Besse because both its inspections at the plant and its assessments of the operator's performance yielded inaccurate and incomplete information on plant safety conditions," end quote.

The names and the dates change, but the underlying pattern of mismanagement, coupled with ineffective NRC oversight, remains the same.

The answer to question three is that quality assurance failings during nuclear plant construction were minimized when we stopped constructing nuclear power plants. The problem was never solved; it just became moot.

The answer to question four is that no such assurance exists. In 2000, the NRC reported hundreds of design errors at operating plants—prima facie evidence that the completed reactors did not meet NRC's regulations. 70 percent of those design errors dated back to original construction that were not detected.

More recently, there are signs that the nuclear industry cannot even renovate its existing plants. Consider the two reactors at Quad Cities, licensed in 1972. 29 years later, the NRC approved increasing its power level by 20 percent. Within 3 weeks, the unit 2 reactor was shut down due to repair leaks caused by vibrations from the hot-air steam flows. During restart, vibrations broke a drain line off a steam pipe. Weeks later, the reactor had to be shut down again when vibrations damaged the steam dryer. The owner reported, quote, "The root cause of the steam dryer failure was determined to be a lack of industry experience and knowledge of flow-induced vibration dryer failures," end quote.

If the nuclear industry is inexperienced and knowledge-challenged about their old reactors, how can they have sufficient knowledge and experience to tinker with new ones?

The Energy Bill of 2005 contains billions of dollars of subsidies to jumpstart a moribund nuclear industry to help address global warming. Nuclear power plant owners are protected when their mismanagement causes a reactor under construction to be cancelled, a reactor under construction to take longer and cost more, or an operating reactor to melt down. But how are Americans protected from global warming when their mismanagement causes nuclear power plant "solutions" to come up empty? Clearly, Americans deserve protection against the nuclear industry defaulting on its global warming pledges, especially since so many of our tax dollars are subsidizing those pledges.

The best protection would be a zealously aggressive regulator enforcing safety regulations. The NRC is not that regulator.

The NRC needs to take three steps toward becoming that regulator: institute safety culture surveys of its workforce every 2 years and make the results available; fill senior manager vacancies from a pool that includes external candidates; institute a rotation plan in which middle-level managers are rotated to other Federal agencies and middle managers from those agencies come to work at the NRC.

If the NRC is not reformed, nuclear power will be more of an illusion than a solution to global warming.

Thank you.

[The prepared statement of Mr. Lochbaum follows:]

Union of Concerned Scientists

Citizens and Scientists for Environmental Solutions

TESTIMONY SUBMITTED BY

DAVID A. LOCHBAUM

DIRECTOR, NUCLEAR SAFETY PROJECT

TO THE SELECT COMMITTEE ON

ENERGY INDEPENDENCE AND GLOBAL WARMING

UNITED STATES HOUSE OF REPRESENTATIVES

MARCH 12, 2008

Mr. Chairman and members of the Subcommittee, on behalf of the Union of Concerned Scientists (UCS), I appreciate this opportunity to present our views on nuclear power's past, present, and future.

My name is David Lochbaum. After obtaining a degree in nuclear engineering from the University of Tennessee in 1979, I worked for over 17 years in the nuclear power industry, mostly at operating reactors in Georgia, Alabama, Mississippi, Kansas, New Jersey, Pennsylvania, New York, Ohio and Connecticut. I joined UCS in October 1996 and am the Director of the Nuclear Safety Project. Almost from its inception in May 1969, UCS has worked to enhance nuclear power plant safety and security. UCS is neither an opponent nor a supporter of nuclear power–our perspective is that of a safety and security advocate.

Global warming is UCS's foremost concern. If we fail to do the right thing about global warming, then solving other problems becomes moot. UCS recently re-examined nuclear power's role in combating global warming. We concluded that an expansion of nuclear power could help curb global warming because nuclear power plants do not emit global warming gases during operation and the emissions during the nuclear fuel cycle and plant construction are relatively modest.

Unfortunately, history has repeatedly shown that the safety and security risks of this nuclear curb are both significant and sustained. Those advocating a nuclear revival should recall the famous words of George Santayana: *Those who cannot learn from history are doomed to repeat it.* Here is the nuclear power history we risk repeating:[1]

[1] Data Sources: United States Council on Energy Awareness, "Historical Profile of U.S. Nuclear Power Development," 1993 Edition; United States Nuclear Regulatory Commission, "2006-2007 Information Digest," NUREG-1350 Vol. 18, August 2006; and Union of Concerned Scientists, "Walking a Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages," September 2006.

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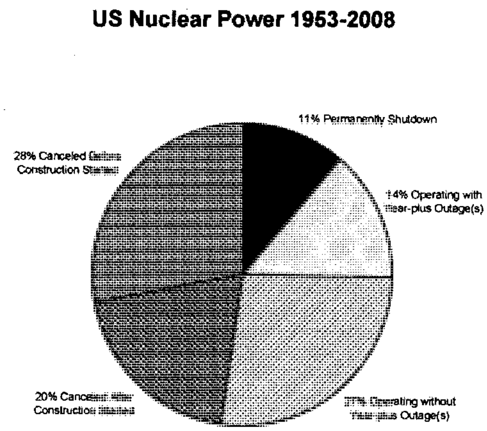
U.S. Nuclear Power Reactors, 1953-2008

253	nuclear power reactors ordered
71	reactors canceled before construction started
182	construction permits or limited work authorizations issued
50	reactors canceled after construction started
132	operating licenses issued
28	reactors permanently shut down before the end of their 40-year operating licenses expired (including one meltdown)
104	reactors operating
36	reactors operating despite having experienced one or more year-plus outages
68	reactors operating having never experienced a year-plus outage
0	inherently safe reactors operating



The last entry in the table–which indicates that none of the operating reactors are inherently safe–may appear to be a snide editorial comment, but is not. Because the reactors are inherently dangerous, their risk must be properly managed. The history of nuclear power in the United States is fraught with mismanagement of that risk. This has resulted in reactors that were canceled before ever operating, permanently shut down before the end of their operating licenses, and temporarily shut down for over a year to restore safety levels. This mismanagement of these inherently dangerous reactors made nuclear power less safe and more costly than necessary.

While it has been several decades since the last nuclear power reactor was ordered in the United States, the nuclear industry did not use that time to design inherently safe reactors, or even reactors that are vastly safer than those operating today. It is for this reason that the 2005 Energy Bill extended federal liability protection for nuclear power reactors via the Price-Anderson Act, as amended. Because the new reactor designs do not provide inherent or significantly enhanced safety, they are as vulnerable to mismanagement as are current reactors.

Nor did the nuclear industry and the NRC use the past several decades to improve management and oversight performance and thus exorcise safety problems caused by mismanagement. (Attachment 1 contains a sampling of mismanagement case studies including the current one involving the Palo Verde Unit 3 nuclear reactor in Arizona.) The nuclear industry itself believes that mismanagement can be as big a problem in the future as it has been in the past. It is for this reason that the 2005 Energy Bill provided federal loan guarantees to new reactors, protecting investors in the event that reactors under construction default on debt payments.

During the 97th Congress, the House Subcommittee on Energy and the Environment of the Committee on Interior and Insular Affairs held an oversight hearing on November 19, 1981, titled "Quality Assurance in Nuclear Powerplant Construction." Chairman Morris K. Udall summarized construction problems caused by poor quality control at the Diablo Canyon (CA), South Texas Project (TX), and Zimmer (OH) nuclear plants and posed four questions:

1. How did these quality assurance failings occur?

2. Why did these failings go so long undetected by the owner utilities and the NRC?

3. What is being done to minimize the likelihood of future failings of this kind?

4. How are we to be sure that completed plants have in fact been constructed in accordance with the Commission's regulations?

As the case studies in attachment 1 indicate, the answer to the first question is "mismanagement by the plant owners." The recurring theme in nuclear plant problems since 1981 has been mismanagement. Mismangement shut down all of TVA's operating nuclear plants for many years in the mid 1980s and early 1990s. Mismanagement shut down the Salem (NJ), Millstone (CT), Clinton (IL), Crystal River Unit 3 (FL) and DC Cook (MI) reactors for over one year in the late 1990s. Mismanagement shut down Davis-Besse (OH) for over two years in the early part of this decade. Mismanagement caused the current problems at Palo Verde (AZ).

As the case studies indicate, the answer to question 2 is "mismanagement by the plant owners and ineffective oversight by the NRC." The companion theme in nuclear plant problems since 1981 has been ineffective oversight by the NRC. An evaluation by the General Accounting Office (GAO) of NRC's oversight of the Millstone, Salem, and Cooper (NE) nuclear plants concluded:[2]

NRC is Not Effectively Overseeing the Plants That Have Problems
and
NRC is Not Getting Licensees to Fix Deficiencies in a Timely Manner
and
NRC Enforcement Actions Are Too Late to Be Effective

Seven years later, almost to the day, the GAO reported on its assessment of NRC's oversight of the Davis-Besse nuclear plant concluded:[3]

> *NRC should have but did identify or prevent the vessel head corrosion at Davis-Besse because both its inspections at the plant and its assessments of the operator's performance yielded inaccurate and incomplete information on plant safety conditions.*
> and

[2] US General Accounting Office, 1997. "Nuclear Regulation: Preventing Problem Plants Requires More Effective NRC Action," GAO/RCED-97-145. Pages 10 and 14. May.
[3] US General Accounting Office, 2004. "Nuclear Regulation: NRC Needs to More Aggressively and Comprehensively Resolve Issues Related to the Davis-Besse Nuclear Power Plant's Shutdown," GAO-04-415.

NRC's process for deciding whether Davis-Besse could delay its shutdown to inspect for nozzle cracking lacks credibility because the guidance NRC used was not intended for making such a decision and the basis for the decision was not fully documented.

The names and dates may change, but the underlying pattern of mismanagement coupled with ineffective oversight stays the same.

The answer to question 3 is that the likelihood of quality assurance failings during nuclear plant construction was minimized when we stopped constructing nuclear power plants. No nuclear power plant construction efforts were initiated after this hearing and the last of those underway at the time of the hearing saw the Watts Bar Unit 1 reactor begin operating in 1996. We never solved the problem, it simply became moot.

The answer to question 4 is that no such assurance exists, as irrefutably demonstrated by the NRC's report on its efforts responding to design errors exposed at Millstone (CT).[4] Figure 1 from the NRC's report shows that hundreds of design errors–*prima facie* evidence that completed plants did not meet NRC's regulations–reported annually, a high number given that only slightly over 100 nuclear power reactors are operating. Figure 10 from the NRC's report revealed that 70 percent of the hundreds of design errors dated back to original construction. Figure 10 also revealed that whatever remedies promised to Congress as a result of the 1981 hearing were either not implemented or not implemented effectively. More than 10 percent of the design errors were introduced by "plant modifications," changes to the plants generally made after they began operating.

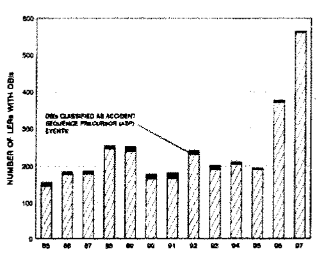


Figure 1 Trend of design basis issues reported for 1985–1997

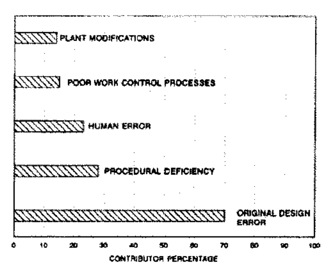


Figure 10 Causes of design-basis issues for 1997

[4] Nuclear Regulatory Commission, 2000. "Causes and Significance of Design-Basis Issues at U.S. Nuclear Power Plants," NUREG-1275, Vol. 14. November. Available in NRC's online ADAMS library under accession no. ML003773633.

But what does nuclear power's past 55 years have to say about nuclear power's future? The NRC anticipates receiving applications to construct and operate 33 nuclear power reactors through 2010.[5] If this happens, running the calendar 55 years forward to 2063 could yield the following "retrospective:"

New U.S. Nuclear Power Reactors, 2008-2063?

33	nuclear power reactors ordered
9	reactors canceled before construction started
24	combined operating licenses issued
7	reactors canceled after construction started
17	reactors placed into operation
4	reactors permanently shut down before the end of their 40-year operating licenses expired
13	reactors operating
4	reactors operating despite having experienced on or more year-plus outage(s)
9	reactors operating without having experienced a year-plus outage(s)
0	inherently safe reactors operating

If the nuclear revival turns out to be merely a nuclear re-run, the multi-billion dollar investment in 33 nuclear power reactor solutions to the global warming dilemma would result in 13 operating reactors, only 9 of which would have avoided year-plus outage(s) to restore deficient safety levels.

There are ample signs that neither the nuclear industry nor the NRC has taken the steps needed to prevent a nuclear re-run. While no new nuclear reactors have been constructed in the United States in decades, modifications to existing nuclear reactors have occurred in recent years. The fact that the nuclear industry, and its regulator, cannot renovate a small portion of a nuclear power reactor without compromising safety provides zero confidence that they will be able to design, build, and operate new reactors any better. A very abridged list of many recent modifications gone awry:

> **Quad Cities (IL)**: The Atomic Energy Commission issued operating licenses for the two reactors in December 1972. Twenty-nine years later, the NRC approved amendments to the licenses that increased the maximum power level of the reactors by 20 percent. In March 2002, the Unit 2 reactor was operated at the uprated power level for the first time. Within about three weeks, the reactor had to be shut down to repair leaks in the turbine control system caused by vibrations from the higher steam flow rates. As the reactor was being restarted after these repairs, vibrations broke a drain line off one of the major steam pipes. There had been earlier warnings about excessive vibrations because when–of all things–a vibration monitor shook itself loose from the piping and fell to the floor. Workers patched the broken drain lines and restarted the reactor without having corrected the vibration problems. Within weeks, the reactor had to shut down again when vibrations damaged a large metal component called the steam dryer located above the reactor core. The reactor's owner reported:

[5] Nuclear Regulatory Commission webpage http://www.nrc.gov/reactors/new-licensing/new-licensing-files/expected-new-rx-applications.pdf, February 27, 2008.

The root cause of the steam dryer failure was determined to be a lack of industry experience and knowledge of flow-induced vibration dryer failures.[6]

The inexperience and incomplete knowledge did not end when the broken steam dryer was repaired. Excessive vibrations later damaged two safety relief valves for the Unit 1 reactor. The Quad Cities reactors started up in the 1970s. If the nuclear industry is inexperienced and knowledge-challenged three decades later about how these reactors work, why would any reasonable person believe the industry would possess sufficient experience and knowledge to tinker with new reactors?

Palo Verde (AZ) and Waterford (LA): In fall 2004 and spring 2005, workers at the Palo Verde Unit 3 reactor and Waterford reactor replaced the electric heaters inside the pressurizers. Due to failure of the replacement heaters, Palo Verde Unit 3 had be shut down several times over the next few months. The faulty replacements had to be replaced at Waterford even sooner. The NRC reported:

The vendor subsequently inspected the failed heaters from the Palo Verde and Waterford plants and determined that the heaters had been incorrectly fabricated with a longer heating element than the licensees' design specification.[7]

There's scant evidence to suggest performance with new reactors will be the same as in the past, yet alone to believe it will be better. At an April 17, 2007, Commission briefing on new reactors, I asked how the NRC intended to train its existing staff and its many new hires on nuclear plant construction oversight, an activity not performed by the NRC in over a decade. I expected to hear about the role of the NRC's Technical Training Center in Tennessee. Instead, all I heard about was on-the-job training: Joe will tell Mary who will tell Ludwig who will pass it along to Brendan and Alexa. It would be insanity, if it wasn't pre-planned and deliberate.

More troubling is NRC's fixation or obsession with schedule rather than quality. The NRC Commissioners' testimony before Congress, pledges before industry, and interviews for media exclusively focus on their plans to approve new reactor licenses within 24 months. How does NRC plan to meet its set-in-stone schedules? By farming out its safety review work to private industry.[8] That's quite simply outrageous and unacceptable. As Congressman Edward Markey quite correctly pointed out in his September 24, 2007, letter to NRC Chairman Dale Klein:

If Congress has intended to allow private companies to regulate private companies in the extraordinary sensitive nuclear sector, we would not have established the NRC.

Neither the nuclear industry nor the NRC can provide sufficient evidence to prove that mismanagement and ineffective oversight problems have been properly addressed.

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[6] Union of Concerned Scientists, 2004. "Snap, Crackle & Pop: The BWR Power Uprate Experiment." July 9. Available online at http://www.ucsusa.org/clean_energy/nuclear_safety/snap-crackle-pop-experimental-power-uprates-at-boiling-water-reactors.html

[7] Nuclear Regulatory Commission, 2006. "Design Deficiency in Pressurizer Heaters for Pressurized-Water Reactors," Information Notice No. 2006-04. February 13. Available online at http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2006/in200604.pdf

[8] Washington Business Journal, 2007. "Firm's Rockville site to handle contract on nuclear plant analysis." September 17.

The Energy Bill of 2005 contains billions of dollars of taxpayer subsidies intended to jump start a moribund nuclear power industry under the thin guise of helping to address global warming. The subsidies come in the form of loan guarantees to cover debts when nuclear plants are canceled during construction, cost containment measures to cover construction taking longer than planned, and liability protection to cover offsite damages and deaths due to a nuclear reactor disaster. Nuclear power reactor owners are thus protected if their mismanagement causes a reactor under construction to be canceled, a reactor under construction to take longer and cost more to reach completion, or a reactor under operation to melt down, but how are Americans protected from global warming when this mismanagement results in nuclear power's "solutions" coming up empty?

Clearly, the American public deserves protection against the nuclear industry defaulting on its global warming pledges, especially since so many of their tax dollars are underwriting the industry's pledges. The best public protection would be a zealously aggressive regulator that consistently and effectively enforced federal safety regulations. Such a regulator would prevent the significant degradation that doomed the Zimmer (OH) and Shoreham (NY) plants, prematurely shut down the Rancho Seco (CA) and Fort St. Vrain (CO) reactors, and caused low safety/high cost operations at Millstone (CT), Davis-Besse (OH), and Palo Verde (AZ). These and numerous other shortfalls show that enough is not being done to minimize the safety risks of nuclear power today, and that the NRC is not the regulator it needs to be to manage the risks of tomorrow.

Consider the event widely deemed to be the closest near-miss since the 1979 meltdown at Three Mile Island–the March 2002 discovery of a football-sized hole in the reactor vessel at Davis-Besse. The NRC expended nearly 7,000 person-hours[9] examining things it could have done to prevent this near-miss. That self-assessment resulted in 49 recommendations on process changes to prevent future near-misses. Ninety-four percent of those recommendations involved ways the NRC could better enforce existing federal regulations. In other words, the underlying regulations were sufficient to have prevented the Davis-Besse near-miss had the NRC merely enforced them. NRC's lack of enforcement was contributed to seriously degraded safety levels at dozens of nuclear power reactors in the US. For decades, the NRC has been a poor enforcer of federal safety regulations. If accused of being an effective regulator, the NRC could not be convicted.

If NRC's performance deficiencies are not rectified, the future of nuclear power will be less safe and more costly than necessary. One need not gaze into a crystal ball to divine this outlook, looking into the rear-view mirror at Zimmer (OH), Watts Bar (TN), Millstone (CT), and Davis-Besse (OH) is enough.

Luckily, the key to successful reforms at the NRC is also readily visible in that rear-view mirror. The mismanagement that created the problems at Watts Bar, Millstone, and Davis-Besse were resolved by bringing in new managers. Not by pruning senior managers and bumping everyone else up one rung on the ladder; but by bringing in senior managers who could set high performance standards and institute the policies and practices needed to attain and then sustain those standards.

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[9] By comparison, the NRC expended an average of only 5,003 person-hours inspecting safety at each nuclear plant site in fiscal year 2002. (source: NRC SECY-07-0069 dated April 6, 2007). An effective regulator would spent more effort ensuing safety than explaining its shortcomings.

Beset by the same mismanagement woes that infested these reactors, NRC waits for attrition to remove its senior managers, bumps everyone else up on rung on the ladder and hires new people at ground-level entry positions. This process sustains the status quo at NRC and explains why it continues to do a poor job enforcing its own regulatory standards.[10]

The NRC must take three immediate towards becoming the enforcer of federal safety regulations the American public deserves:

1. Institute safety culture surveys of the NRC work force every two years and make the survey results publicly available.

2. When NRC senior manager vacancies from a pool that includes external candidates.

3. Initiate a rotation plan in which NRC mid-level managers work for approximate one year periods at other federal agencies (i.e., DOE, EPA, NASA, FEMA, etc.) and mid-level managers from those agencies work at the NRC, for about a year. In this way, NRC managers would learn new management skills, and the NRC would receive input on regulatory and safety management approaches from other agencies.

This hearing is titled "Nuclear Power in a Warming World: Solution or Illusion?"

If the NRC is not reformed, even existing reactors may not operate long into the future and new reactors are unlikely to make a meaningful contribution to global warming. Thus, if the NRC is not reformed, UCS believes that nuclear power will be more of an illusion than a solution.

Attachments:

1) Case Studies of Nuclear Reactor Mismanagement

2) Executive summary from UCS's December 2007 report *Nuclear Power in a Warming World.* The full report is available online at
http://ucsusa.org/global_warming/solutions/nuclearandclimate.html

3) Curriculum vitae

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[10] The recent debacle over Wackenhut security guards sleeping at Exelon's Peach Bottom nuclear plant vividly illustrates the NRC's fundamental problem. Subsequent investigations revealed that Wackenhut, Exelon, and Peach Bottom all knew about the problem for months before a TV reporter exposed it. The sleeping guards have been fired. Wackenut lost its contract at Peach Bottom and all other Exelon nuclear plant sites. Exelon brought in new managers to govern security at Peach Bottom. But no one at NRC lost a job or even received a finger-shaking scolding for the agency's culpability in the debacle.

Attachment 1 – Case Studies of Nuclear Reactor Mismanagement

CANCELED AFTER CONSTRUCTION STARTED

Zimmer (OH): The Atomic Energy Commission issued a construction permit in October 1972. In September 1978, the US General Accounting Office issued a report criticizing NRC's inspection program for reactors under construction. In January 1979, a private investigator reported safety defects. NRC investigated and in July 1980 cited the company for sloppy paperwork but found its work to be otherwise sound. In December 1980, the Government Accountability Project initiated a follow-up probe into the safety defects identified by the private investigator. NRC conceded in August 1981 that its first investigation into safety concerns was inadequate and fined the company $200,000 in November 1981 for poor quality control. In June 1982, the US House held hearings on construction problems at Zimmer and the U.S. Attorney confirmed it was investigating reports that quality assurance inspectors at the plant were being harassed and intimidated. In December 1982, Congressman Morris Udall stated that NRC misled the public about conditions at Zimmer by "*squelching NRC documents critical of the plant.*" In August 1983, an independent consulting firm hired by the company reported that the problems caused by "*a total management breakdown*" could be fixed. On January 21, 1984, the company announced that Zimmer would be converted to a coal-fired generating station. The cost of this 'nuclear' plant was over $1 billion in 1980 dollars.[11]

Shoreham (NY): The Atomic Energy Commission issued a construction permit in April 1973. The reactor's original cost was estimated to be $65 million (1970 dollars). By May 1974 after one year of construction, the estimated cost had increased to $695 million. The estimated cost neared $1 billion by the end of 1976. Approximately $100 million of the cost increase was due to the need to re-design and re-build the GE Mark II containment when the NRC revised requirements in 1975. An audit by New York State in 1984 concluded that the company failed to properly schedule and monitor construction work, resulting in the waste of almost 10 million man-hours, about one-third of the labor invested in the plant. In March 1984, cost over-runs forced the company to halt dividend payments and lay-off nearly 1,000 workers. In May 1988, the company and the state agreed to permanently close the $5.5 billion reactor that never really operated.[12]

Midland (MI): The Atomic Energy Commission issued a construction permit in December 1972. At the time, the cost of the two-reactor plant was estimated at $776 million. In July 1978, engineers discovered that the building housing the emergency diesel generators was sinking into the soil. In December 1979, the NRC halted all safety-related work at the site due to the soil settlement problems. The estimated cost of the plant was revised to $3.1 billion. In April 1983, the NRC ordered a complete inspection of work performed to date due to widespread and recurring quality control problems. In October 1983, the company halted construction and laid off 1,000 workers due to confusion over blueprints. The following month, one of the reactors was canceled. In May 1984, the company proposed capping the cost to the ratepayers from the $4.1 billion nuclear plant at $3.5 billion. The offer was

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[11] Cincinnati Enquirer, 1984. "Zimmer: Conversion to Coal, A Chronology, 1968-1984." January 22.

[12] Associated Press, 1988. "Chronology of LILCO History." May 26, and Kinsey Wilson, 1992. "Lights out for Shoreham." *Bulletin of the Atomic Scientists*. June.

rejected because even that cap was projected to increase electricity prices by 75 percent. In July 1984, the company canceled the second unit.[13]

Washington Nuclear Plant Units 4 & 5 (WA): The NRC issued construction permits for Units 4 and 5 in April and February 1978, respectively. The company notified the NRC in February 1982 that it was canceling the two reactors with 24 percent and 15 percent of the construction completed, respectively. On July 25, 1983, the company announced it was defaulting on loan payments for $2.25 billion debt for Units 4 and 5.[14]

PREMATURELY SHUT DOWN

Rancho Seco (CA): The Atomic Energy Commission issued a construction permit in October 1968 and an operating license in August 1974. The reactor exhibited a checkered operating history. In April 1989, the Institute of Nuclear Power Operations (INPO) reported to the company's Board of Directors that *"the history of governance and the present governance situation, if unchanged, portend a continuing pattern of performance problems."* In June 1989, the majority of votes in a public referendum were to permanently close the reactor. On June 7, 1989, the reactor was permanently shut down.[15]

Fort St. Vrain (CO): The Atomic Energy Commission issued an operating license in December 1973. The reactor exhibited a checkered operating history before being permanently shut down in August 1989. The reactor had been shut down for nearly two years between June 23, 1984, and April 11, 1986, to restore safety levels. Over its abbreviated operating history, the reactor's top performing month resulted in a 73 percent capacity factor.[16]

Yankee Rowe (MA): The Atomic Energy Commission issued a construction permit in November 1957 and an operating license in July 1960. In 1990, the reactor became the first pressurized water reactor in the United States to initiate a process to extend the original 40-year operating license for an additional 20-year period. On June 5, 1991, UCS petitioned the NRC to order the reactor to be immediately shut down due to unresolved concerns about weakening of the reactor vessel caused by embrittlement. The NRC denied the UCS petition 21 days later. Six New England congressmen formally asked the NRC Commission to review the NRC staff's decision. On July 31, 1991, the Commission affirmed the staff's denial of the UCS petition and authorized reactor operation until April 15, 1992, while the embrittlement concerns were resolved. On October 1, 1991, the NRC staff reversed itself and recommended that the reactor be immediately shut down due to rector vessel embrittlement concerns. The

[13] *Saginaw News*, 1984. "Consumer Power Co.'s Midland Nuclear Plant has gone through many changes through the years. Here's a chronology of the plant's troubled history." July 17.
[14] R. L. Ferguson, 1982. Letter to William J. Dircks, Executive Director for Operations, Nuclear Regulatory Commission, "Termination of Supply System Nuclear Projects 4 and 5." Ferguson was managing director of the Washington Public Power Supply System. February 1; and Tamar Lewin, 1983. "Power group says it cannot pay off $2.25 billion debt," *New York Times*. July 26.
[15] Zack T. Pate, 1989. Letter to the Sacramento Municipal Utility District Board of Directors. Zack Pate was president of the Institute of Nuclear Power Operations. April 4; and Sacramento Municipal Utility District, 2006. License Termination Plan, Rev. 0. April.
[16] D. A. Copinger and D. L. Moses, 2004. "Fort Saint Vrain Gas Cooled Reactor Operational Experience," NUREG/CR-6839. D. A. Copinger and D. L. Moses work at the Oak Ridge National Laboratory. January; and Nuclear News, 1989. "Fort St. Vrain Has Generated Its Last Electricity." September.

company voluntarily shut down the reactor that same day.[17] In February 1992, the company informed the NRC that it would not be restarting the reactor.

OPERATING REACTORS THAT HAVE EXPERIENCED ONE OR MORE YEAR-PLUS OUTAGES

Millstone Units 2 & 3 (CT): The Atomic Energy Commission issued construction permits for Units 2 and 3 in December 1970 and August 1974 respectively. The NRC issued operating licenses for Units 2 and 3 in September 1975 and January 1986, respectively. Unit 2 was shut down for over three years between February 20, 1996, and May 11, 1999, to restore safety levels. Unit 3 was shut down for over 2 years between March 30, 1996, and July 1, 1998, to restore safety levels. Two researchers at the Yale School of Management examined the Millstone outages and concluded:

> *Executive management treated cost containment and safety related outlays in nuclear plant operations as tradeoffs and deliberately chose the low-cost/low-safety option. That is, they were far from incompetent in choosing an option that contained an inherent risk of NRC shutdown.*[18]

Davis-Besse (OH): The Atomic Energy Commission issued a construction permit in March 1971 and the NRC issued an operating license in April 1977. The reactor was shut down for one and a half years between June 9, 1985, and December 24, 1986, to restore safety levels. The NRC reported the cause of the problems was "*the licensee's lack of attention to detail in the care of plant equipment. The licensee has a history of performing troubleshooting, maintenance and testing of equipment, and of evaluating operating experience related to equipment in a superficial manner and, as a result, the root causes of problems are not always found and corrected.*"[19] The reactor was shut down for more than two years between February 16, 2002, and March 16, 2004, to restore safety levels. The company told the NRC that the cause of the problems was "*There was a focus on production established by management, combined with taking minimum actions to meet regulatory requirements, that resulted in the acceptance of degraded conditions.*"[20]

OPERATING REACTORS THAT HAVE NEVER EXPERIENCED A YEAR-PLUS OUTAGE

Watts Bar (TN): The Atomic Energy Commission issued a construction permit in January 1973 and the NRC issued an operating license in February 1996 (not a typo, it really took the Tennessee Valley Authority nearly a quarter century to construct this nuclear reactor with its 40-year operating lifetime). The delays were caused, in large part, by management's failure to control the quality of construction work activities. On December 19, 1985, TVA's Nuclear Safety Review Staff reported to the NRC's Commissioners about eleven problem areas, finding that the common thread was non-compliance with the federal quality assurance regulations embodied in 10 CFR Part 50, Appendix B. On January 3, 1986, the NRC asked

[17] *Boston Globe*, 1991. "Chronology of Yankee Rowe." October 2.
[18] Paul W. MacAvoy and Jean W. Rosenthal, 2001. "The Strategic Destruction of Northeast Utilities." Yale School of Management. April.
[19] Hugh L. Thompson Jr., 1985. Letter to Toledo Edison Company, "Loss of Main and Auxiliary Feedwater Event at the Davis-Besse Nuclear Plant on June 9, 1985 NUREG-1154." Hugh L. Thompson Jr. was director – division of licensing for the Nuclear Regulatory Commission. July 26.
[20] FirstEnergy Nuclear Operating Company, 2002. Presentation slides to Nuclear Regulatory Commission, "Management and Human Performance Root Causes." August 15.

TVA to respond, under oath, whether these requirements were being met. TVA replied affirmatively on March 20, 1986, with a follow-up on June 5, 1986. In March 1988, NRC determined that the senior manager at TVA "*knowingly and willfully made a material false statement in his March 20, 1986, and his June 5, 1986, letters to the NRC regarding the meeting of the requirements of 10 CFR 50, Appendix B, at TVA's WBN* [Watts Bar nuclear]."[21]

Shearon Harris (NC): The NRC issued a construction permit in January 1978 and an operating license in January 1987.When construction began in 1978, the estimated cost for the four reactors planned at the site was $1.4 billion. Units 2, 3, and 4 were canceled in the early 1980s and Unit 1 went into operation at a cost of $3.9 billion.[22] The NRC's construction appraisal team inspection (CATI) identified two major problems: "*(1) lack of verification of piping and pipe support/restraint location to original design requirements and (2) lack of an ongoing program to effectively identify and resolve hardware clearance problems early in the construction process. Both of these concerns involve practices that could result in extensive inspection, analyses, and rework efforts very late in the construction schedule.*"[23]

Palo Verde Unit 3 (AZ): The NRC issued a construction permit in May 1976 and an operating license in November 1987. For the past two years, the reactor has been rated by the NRC as the worst safety performers in the United States. The new managers, brought in to undo the damage that warranted that low rating, explained to the NRC Commissioners last July how the reactor got into that situation:

> *Our high plant performance combined with high performance assessments, although positive at the time, contributed to complacency and an environment that camouflaged our growing weakness in personal accountability and a higher tolerance for incomplete root cause analysis; encouraged an attitude of pride, reduced our focus on continuous improvement and established a mind set that we were good enough to handle all issues as they occurred.*[24]

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[21] Nuclear Regulatory Commission Office of Investigations, 1988. "Report of Investigation – Watts Bar Nuclear Plant: Possible Willful Attempt by TVA Management to Mislead the NRC," Case No. 2-87-002S. October 11.
[22] United States Nuclear Regulatory Commission, "2006-2007 Information Digest," NUREG-1350 Vol. 18, August 2006; and Associated Press, April 14, 1988.
[23] Nuclear Regulatory Commission, 1985. "Discrepancies Between As-Built Construction Drawings and Equipment Installations," Information Notice No. 85-66. August 7.
[24] Nuclear Regulatory Commission, 2007. Transcript, "Briefing on Palo Verde Nuclear Generating Station," page 5, line 17 through page 6, line 1. July 24.

Executive Summary

Findings and Recommendations in Brief

Global warming demands a profound transformation in the ways we generate and consume energy. Because nuclear power results in few global warming emissions, an increase in nuclear power could help reduce global warming—but it could also increase the threats to human safety and security. The risks include a massive release of radiation due to a power plant meltdown or terrorist attack, and the death of hundreds of thousands due to the detonation of a nuclear weapon made with materials obtained from a civilian nuclear power system. Minimizing these risks is simply pragmatic: nothing will affect the public acceptability of nuclear power as much as a serious nuclear accident, a terrorist strike on a reactor or spent fuel pool, or the terrorist detonation of a nuclear weapon made from stolen nuclear reactor materials.

The report finds that:

1. The United States has strong nuclear power safety standards, but serious safety problems continue to arise at U.S. nuclear power plants because the Nuclear Regulatory Commission (NRC) is not adequately enforcing the existing standards. The NRC's poor safety culture is the biggest barrier to consistently effective oversight, and Congress should require the NRC to bring in managers from outside the agency to rectify this problem.
2. While the United States has one of the world's most well-developed regulatory systems for protection of nuclear facilities against sabotage and attack, current security standards are inadequate to defend against credible threats. Congress should give the responsibility for identifying credible threats and ensuring that security is adequate to the Department of Homeland Security rather than the NRC.
3. The extent to which an expansion of nuclear power increases the risk that more nations or terrorists will acquire nuclear weapons depends largely on whether reprocessing is included in the fuel cycle, and whether uranium enrichment comes under effective international control. A global prohibition on reprocessing, and international ownership of all enrichment facilities, would greatly reduce these risks. The United States should reinstate a ban on reprocessing U.S. spent fuel and take the lead in forging an indefinite global moratorium on reprocessing. The administration should also pursue a regime to place all uranium enrichment facilities under international control.
4. Over the next 50 years, interim storage of spent fuel in dry casks is economically viable and secure, if hardened against attack. In the longer term, a geologic repository would provide the stability needed to isolate the spent fuel from the environment. It is critical to identify and overcome technical and political barriers to licensing a permanent repository, and the Department of Energy should identify and begin to characterize potential sites other than Yucca Mountain.
5. Of all the new reactor designs being seriously considered for deployment in the United States, only one—the Evolutionary Power Reactor—appears to have the potential to be significantly safer and more secure than today's reactors. To eliminate any financial incentives for reactor vendors to reduce safety margins, and to make safer reactors competitive in the United States, the NRC should require new U.S. reactors to be significantly safer than current reactors.
6. The proposed Global Nuclear Energy Partnership (GNEP) plan offers no waste disposal benefits and would increase the risks of nuclear proliferation and terrorism. It should be dropped.

Since its founding in 1969, the Union of Concerned Scientists (UCS) has worked to make nuclear power safer and more secure. We have long sought to minimize the risk that nations and terrorists would acquire nuclear weapons materials from nuclear power facilities. This report shows that nuclear power continues to pose serious risks that are unique among the energy options being considered for reducing global warming emissions. The future risks of nuclear energy will depend in large part on whether governments, industry, and international bodies undertake a serious effort to address these risks—including the steps outlined here—before plunging headlong into a rapid expansion of nuclear energy worldwide. In particular, the risks will increase—perhaps substantially—if reprocessing becomes part of the fuel cycle in the United States and expands worldwide.

The risks posed by climate change may turn out to be so grave that the United States and the world cannot afford to rule out nuclear power as a major contributor to addressing global warming. However, it may also turn out that nuclear power cannot be deployed worldwide on the scale needed to make a significant dent in emissions without resulting in unacceptably high safety and security risks. Resolving these questions is beyond the scope of this report, but the information provided here will help inform a necessary discussion of the risks of various energy technologies that can address global warming.

Global warming is a profound threat to both humanity and the natural world, and one of the most serious challenges humankind has ever faced. We are obligated by our fundamental responsibility to future generations and our shared role as stewards of this planet to confront climate change in an effective and timely manner. Scientists are acutely aware that the window for reducing global warming emissions to reasonably safe levels is closing quickly. Several recent analyses have concluded that, to avoid dangerous climate change, the United States and other indusrrialized nations will need to reduce emissions at least 80 percent by mid-century, compared with 2000 levels—and that national and international policies must be in place within the next 5 to 10 years to achieve this ambitious outcome.

Thus a profound transformation of the ways in which we generate and consume energy must begin now, and the urgency of this situation demands that we consider all possible options for minimizing climate change. However, in examining each option we must take into account its environmental and public health impacts, its potential impact on national and international security, the time required for deployment, and the costs.

Nuclear power plants do not produce global warming emissions when they operate, and the emissions associated with the nuclear fuel cycle and plant construction are quite modest (and will fall further if industry and transportarion rely less on fossil fuels). Thus an expansion of nuclear power could help curb global warming. However, such an expansion could also worsen the threats to human safety and security from radioactive releases and wider access to materials that can be used to make nuclear weapons.

This report assesses the risks posed by nuclear power and proposes ways to minimize them. In particular, it considers (1) the risk of reactor accidents and how to improve government oversight of reactor safety; (2) the threat of sabotage and terrorist attacks on reactors and associated facilities, and how to improve security; (3) the potential for expanded nuclear power facilities to allow nations and terrorist groups to acquire nuclear weapons more easily, and what the United States can do to minimize those possibilities; and (4) how best to deal with the radioactive waste from U.S. power plants. This report also examines new designs for reactors and other nuclear power facilities, and considers to what extent these plants would entail fewer risks than today's designs.

Key Findings and Recommendations

1. Ensuring the Safety of Nuclear Power

The United States has strong nuclear power safety standards, but serious safety problems continue to arise at U.S. nuclear power plants because the Nuclear Regulatory Commission (NRC) is not adequately enforcing those standards.

Findings

Safety problems remain despite a lack of serious accidents.

A serious nuclear power accident has not occurred in the United States since 1979, when the Three Mile Island reactor in Pennsylvania experienced a partial core meltdown. However, the absence of serious accidents does not necessarily indicate that safety measures and oversight are adequate. Since 1979, there have been 35 instances in which individual reactors have shut down to restore safety standards, and the owner has taken a year or more to address dozens or even hundreds of equipment impairments that had accumulated over a period of years. The most recent such shutdown occurred in 2002. These year-plus closures indicate that the NRC has been doing a poor job of regulating the safety of power reactors. An effective regulator would be neither unaware nor passively tolerant of safety problems so extensive that a year or more is needed to fix them.

The most significant barrier to consistently effective NRC oversight is a poor "safety culture" at the agency itself.

The poor safety culture at the NRC manifests itself in several ways. The agency has failed to implement its own findings on how to avoid safety problems at U.S. reactors. It has failed to enforce its own regulations, with the result that safety problems have remained unresolved for years at reactors that have continued to operate. And it has inappropriately emphasized adhering to schedules rather than ensuring safety. A significant number of NRC staff members have reported feeling unable to raise safety concerns without fear of retaliation, and a large percentage of those staff members say they have suffered harassment or intimidation.

The NRC's recent curtailment of the public's right to participate in reactor licensing proceedings shuts the door to an important means of enhancing safety.

Public input has long played an important role in the NRC's process for licensing power plants. The NRC itself has identified numerous examples where public participation has improved safety. Despite this, the NRC recently removed the public's right to discovery and cross-examination during hearings on renewals of existing power plant licenses and applications for new ones, precluding meaningful public participation.

The NRC's policy on the safety of new reactors is an obstacle to ensuring better designs.

NRC policy stipulates that advanced reactors need provide only the same level of protection against accidents as today's generation of reactors, hampering the development of safer ones.

The NRC's budget is inadequate.

Congress continues to pressure the NRC to cut its budget, so it spends fewer resources on overseeing safety. The NRC does not have enough funding to fulfill its mandate to ensure safety while also responding to applications to extend the licenses of existing reactors and license new ones.

The Price-Anderson Act lessens incentives to improve safety.

The act, just renewed for another 20 years, severely limits the liability of owners for accidents at nuclear power plants. This protection lessens the financial incentives for reactor vendors to increase safety measures, and for owners to improve operating standards.

Recommendations

- To ensure that the NRC develops a strong safety culture as soon as possible and sustains it, Congress should require the NRC to bring in managers from outside the agency to establish such a culture, and evaluate them on whether they do so.
- The NRC should fully restore the public's right to discovery and cross-examination before and during hearings on changes to existing power plant licenses and applications for new ones.
- To ensure that any new nuclear plants are significantly safer than existing ones, the NRC should require that new reactors have features designed to prevent severe accidents, and to mitigate them if they occur. These design features should reduce reliance on operator interventions in the event of an accident, which are inherently less dependable than built-in measures.
- Congress should ensure that the NRC has enough resources to provide robust oversight of nuclear reactor safety, and to meet its goals for responding to requests from reactor owners in a timely manner without compromising safety.
- Congress should eliminate Price-Anderson liability protection—or substantially raise the liability limit—for new U.S. nuclear power plants, to remove financial disincentives for reactor designers and owners to improve safety.

2. Defending against Sabotage and Terrorist Attacks

While the United States has one of the world's most well-developed regulatory systems for protecting nuclear facilities against sabotage and attack, today's security standards are inadequate to defend against credible threats.

Findings

Sabotage of a nuclear reactor could result in a large release of radiation.

If a team of well-trained terrorists forcibly entered a nuclear power plant, it could disable safety systems within a matter of minutes, and do enough damage to cause a meltdown of the core, failure of the containment structure, and a large release of radiation. Such an attack could contaminate large regions for thousands of years, producing higher cancer rates and billions of dollars in associated costs.

Spent fuel pools are highly vulnerable to terrorist attack.

Unlike reactors, the pools used to store spent fuel at reactor sites are not protected by containment buildings, and thus are attractive targets for terrorist attacks. Such attacks could lead to the release of large amounts of dangerous radioactive materials into the environment.

The NRC gives less consideration to attacks and deliberate acts of sabotage than it does to accidents.

This lack of attention is manifested in emergency plans that do not take terrorist attacks into account, the agency's refusal to consider terrorist attacks as part of the environmental assessments during licensing proceedings, and its failure to adequately address the risk of an attack on spent fuel pools at reactor sites.

NRC assumptions about potential attackers are unrealistically modest.

The NRC's Design Basis Threat (DBT) defines the size and abilities of a group that might attack a nuclear facility, and against which an owner must be able to defend. Although not publicly available, before 9/11 the DBT was widely known to consist of three attackers armed with nothing more sophisticated than handheld automatic rifles, and working with a single insider whose role was limited to providing information about the facility and its defenses. The DBT has been upgraded post-9/11, but it still does not reflect real-world threats. For example, it excludes the possibility that terrorist groups would use rocket-propelled grenades—a weapon widely used by insurgents around the world.

The DBT is unduly influenced by industry perspectives and pressure.

The NRC would ideally base the DBT solely on plausible threats to nuclear facilities. However, in practice, the agency's desire to avoid imposing high security costs on the nuclear industry also affects its security requirements.

There is no assurance that reactors can be defended against terrorist attacks.

The NRC stages mock attacks to determine if plant owners can defend their reactors against DBT-level attacks. Test results reveal poor performance, and the integrity of the tests themselves is in question. The federal government is responsible for defending against attacks more severe than the DBT, but it has no mechanism for ensuring that it can provide such protection.

Recommendations

- The NRC should treat the risks of deliberate sabotage and attacks on par with the risks of accidents, and require all environmental reviews during licensing to consider such threats. The agency should also require and test emergency plans for defending against severe acts of sabotage and terrorist attacks as well as accidents.
- The NRC should require that spent fuel at reactor sites be moved from storage pools to dry casks when it has cooled enough to do so (within six years), and that dry casks be protected by earthen or gravel ramparts to minimize their vulnerability to terrorist attack.
- The Department of Homeland Security (DHS) should set the DBT. It should assess the credible threats to nuclear facilities, determine the level of security needed to protect against those threats, and assign responsibility for countering each type of threat to either industry or the federal government. To conduct its independent assessments, the DHS would need full-time staff with the necessary expertise. It would also need to address the internal problems that have hampered its past performance. The NRC would ensure that the nuclear industry complies with DHS requirements. The DHS should ensure that the government has enough resources to fulfill its responsibilities to protect nuclear facilities against credible threats as assigned by the DHS.
- The government should evaluate its ability to protect the public from attacks above the DBT level by periodically conducting tests that simulate an actual attack. The DHS should serve as an independent evaluator of such tests, analogous to the role performed by the Federal Emergency Management Agency during biennial exercises of emergency plans for nuclear plants.
- The government should establish a federally administered program for licensing private nuclear security guards that would require them to successfully complete a federally run training course and undergo periodic recertification.

3. Preventing Nuclear Proliferation and Nuclear Terrorism

The extent to which an expansion of nuclear power would raise the risk that more nations or terrorists will acquire nuclear weapons depends largely on two factors: whether reprocessing is included in the fuel cycle, and whether uranium enrichment comes under effective international control. A global prohibition on reprocessing, and international ownership of all enrichment facilities, would greatly reduce these risks.

Findings

An expansion of nuclear power could—but need not—make it more likely that more nations will acquire nuclear weapons. In any event, it is only one factor of many that will affect this outcome.

Many states that do not now have nuclear weapons already have the technical ability to produce them, should they decide to do so. In other countries without such a capability, nuclear power facilities could aid a nuclear weapons program—in some cases significantly. However, the political incentives for a nation to acquire nuclear weapons are the most significant factor, and there is little the United States or international community can do to prevent a determined nation from eventually acquiring such weapons.

The nuclear facilities that present the greatest proliferation risk are those that can be used to produce the materials needed to make nuclear weapons—plutonium and highly enriched uranium (HEU).

Reprocessing plants extract plutonium from used reactor fuel, while uranium enrichment facilities that make low-enriched uranium for reactor fuel can be used to make HEU.

An expansion of nuclear power could—but need not—make it more likely that terrorists will acquire nuclear weapons.

In any event, other sources of nuclear weapons and weapons materials exist. Because it is difficult and expensive to produce the fissile materials needed for nuclear weapons, terrorists are almost certainly unable to do so themselves. However, several countries have large military stockpiles of plutonium and HEU, or civil stockpiles of plutonium, which terrorists could steal and use to produce nuclear weapons. Terrorists could also steal a nuclear weapon, or purchase one that has been stolen.

The degree to which an expansion of nuclear power would increase the risk of nuclear terrorism depends largely on whether reprocessing is part of the fuel cycle—internationally or in the United States.

Reprocessing changes plutonium from a form in which it is highly radioactive and nearly impossible to steal to one in which it is not radioactive and could be stolen surreptitiously by an insider or taken by force during routine transportation. Building more facilities for reprocessing spent fuel and making plutonium-based reactor fuel would provide terrorists with more potential sources of plutonium, and perhaps with greater ease of access. U.S. nuclear power does not now pose a risk that terrorists will acquire material for nuclear weapons. However, the U.S. reprocessing program now being pursued by the administration would change that.

None of the proposed new reprocessing technologies would provide meaningful protection against nuclear terrorism or proliferation.

No reprocessing technology can be made as secure as directly disposing of used nuclear fuel.

Strict international controls on uranium enrichment facilities will be needed to minimize the proliferation risks associated with expanded nuclear power.

Such controls should not discriminate between nations that have nuclear weapons and those that do not.

Recommendations

- The United States should reinstate a ban on reprocessing U.S. spent fuel, and actively discourage other nations from pursuing reprocessing. The security risks associated with current and near-term reprocessing technologies are too great.
- The United States should take the lead in forging an indefinite global moratorium on operating existing reprocessing plants and building or starting up new ones. Reprocessing is not necessary for any current nuclear energy program, and the security risks associated with running reprocessing plants and stockpiling plutonium are unacceptable in today's threat environment, and are likely to remain so for the foreseeable future. A U.S. moratorium will facilitate a global moratorium.
- The administration should pursue a regime—overseen by the International Atomic Energy Agency—to internationalize all uranium enrichment facilities and to safeguard such facilities. To make such a regime attractive to nations without those facilities, it would need to be non-discriminatory, and thus cover all existing enrichment plants.

- The administration should work to complete a comprehensive Fissile Material Cutoff Treaty that prohibits the production of plutonium for any purpose—military or civil—and that institutionalizes and verifies the reprocessing moratorium.

4. Ensuring the Safe Disposal of Nuclear Waste

Over the next 50 years, interim storage of spent fuel in dry casks is economically viable and secure. However, identifying and overcoming the technical and political barriers to licensing a permanent U.S. geologic repository for nuclear waste is critical.

Findings

A permanent geologic repository is the preferred method for disposal of nuclear waste.

An underground geologic repository—if properly sited and constructed—can adequately protect the public and environment from radioactive waste for tens of thousands of years. However, a repository location must be chosen based on a high degree of scientific and technical consensus. Such a consensus does not now exist on the proposed Yucca Mountain facility in Nevada.

Reprocessing offers no advantages for nuclear waste disposal.

Reprocessing spent fuel to extract plutonium and uranium would not allow a geologic repository to accommodate more nuclear waste, as the repository would also have to accept high-level waste from reprocessing. Reprocessing would also increase the amount of material needing disposal in other engineered waste facilities.

There is no immediate need to begin operating a permanent repository.

Interim storage of spent fuel in dry casks at reactor sites hardened against attack is an economically viable and secure option for at least 50 years. However, such dry casks are not adequately protected today, and should be strengthened against attack, such as by surrounding them with an earthen berm.

Recommendations

- The United States should drop its plans to begin a reprocessing program.
- The federal government should take possession of spent fuel at reactor sites and upgrade the security of onsite storage facilities.
- Because licensing a permanent repository may take a decade or more, especially if Yucca Mountain is found unsuitable, the Department of Energy should identify and begin to characterize other potential sites.

5. Evaluating New Reactor Designs

Of all new reactor designs under consideration in the United States, at this time only one—the Evolutionary Power Reactor, which was designed to comply with more stringent European requirements—appears to have the potential to be significantly safer and more secure against attack than today's reactors. However, U.S. plant owners will have no financial incentive to build such reactors unless the NRC strengthens U.S. standards and requires that new reactors be significantly safer than today's reactors.

The administration's proposed Global Nuclear Energy Partnership (GNEP)—which would entail reprocessing U.S. spent fuel and building large numbers of new fast burner reactors to use plutonium-based fuel—offers no waste disposal benefits and would increase the risks of nuclear proliferation and terrorism.

Findings

Of all the new reactor designs, only one—the Evolutionary Power Reactor (EPR)—appears to have the potential to be significantly less vulnerable to severe accidents than today's reactors.

The Pebble Bed Modular Reactor has several attractive safety features, but outstanding safety issues must be resolved to determine whether it is likely to be safer than existing reactors. Other designs either offer no potential for significant safety improvements, or are too early in the design phase to allow informed judgment.

Of all the new reactor designs, only one—the EPR—appears to have the potential to be significantly less vulnerable to attack than today's reactors.

However, this may only remain the case if the NRC requires that new reactors be able to withstand the impact of a commercial aircraft, thus ensuring that U.S. EPRs will include the double containment structure that is part of EPRs built in Europe.

No technical fix—such as those incorporated in new reprocessing technologies—can remove the proliferation risks associated with nuclear fuel cycles that include reprocessing and the use of plutonium-based fuel.

Once separated from highly radioactive fission products, the plutonium is vulnerable to theft or diversion. New reprocessing technologies under consideration will leave the plutonium in a mixture with other elements, but these are not radioactive enough to provide theft resistance, and a nation seeking nuclear weapons could readily separate the plutonium from these elements by chemical means.

The proposed GNEP system of fast burner reactors will not result in more efficient use of waste repositories.

While the proposed GNEP system could, in principle, significantly reduce the amount of heat-producing actinides that would need disposal in a geologic repository, thus allowing it to accept more waste, this potential cannot be realized in practice. As the National Academy of Sciences and the U.S. Department of Energy have found, reducing the actinides by a meaningful amount would require operating a large system of nuclear facilities over a period of centuries, and cost hundreds of billions of dollars more than disposing of spent fuel directly.

Recommendations

- The NRC should require that new reactor designs be safer than existing reactors. Otherwise, designs with greater safety margins will lose out in the marketplace to designs that cut costs by reducing safety.
- Forthcoming NRC regulations that will require owners to integrate security measures into reactor designs if they are "practicable" should specify that the NRC—not reactor owners—will determine which measures meet that criterion.
- The NRC should require that new reactors be able to withstand the impact of a commercial aircraft.
- The United States should reinstate a ban on reprocessing U.S. spent fuel, and actively discourage other nations from pursuing reprocessing.
- The United States should eliminate its programs to develop and deploy fast reactors.

David A. Lochbaum

Experience Summary

10/96 to date *Nuclear Safety Engineer, Union of Concerned Scientists*

Responsible for directing UCS's nuclear safety program, for monitoring developments in the nuclear industry, for serving as the organization's spokesperson on nuclear safety issues, and for initiating action to correct safety concerns.

11/87 to 09/96 *Senior Consultant, Enercon Services, Inc.*

Responsible for developing the conceptual design package for the alternate decay heat removal system, for closing out partially implemented modifications, reducing the backlog of engineering items, and providing training on design and licensing bases issues at the Perry Nuclear Power Plant.

Responsible for developing a topical report on the station blackout licensing bases for the Connecticut Yankee plant.

Responsible for vertical slice assessment of the spent fuel pit cooling system and for confirmation of licensing commitment implementation at the Salem Generating Station.

Responsible for developing the primary containment isolation devices design basis document, reviewing the emergency diesel generators design basis document, resolving design document open items, and updating design basis documents for the James A. FitzPatrick Nuclear Power Plant.

Responsible for the design review of balance of plant systems and generating engineering calculations to support the Power Uprate Program for the Susquehanna Steam Electric Station.

Responsible for developing the reactor engineer training program, revising reactor engineering technical and surveillance procedures and providing power manuevering recommendations at the Hope Creek Generating Station.

Responsible for supporting the lead BWR/6 Technical Specification Improvement Program and preparing licensing submittals for the Grand Gulf Nuclear Station.

03/87 to 08/87 *System Engineer, General Technical Services*

Responsible for reviewing the design of the condensate, feedwater and raw service systems for safe shutdown and restart capabilities for the Browns Ferry Nuclear Plant.

08/83 to 02/87 *Senior Engineer, Enercon Services, Inc.*

Responsible for performing startup and surveillance testing, developing core monitoring software, developing the reactor engineer training program, and supervising the reactor engineers and Shift Technical Advisors at the Grand Gulf Nuclear Station.

Experience Summary (continued)

10/81 to 08/83 *Reactor Engineer / Shift Technical Advisor, Tennessee Valley Authority*

Responsible for performing core management functions, administering the nuclear engineer training program, maintaining ASME Section XI program for the core spray and CRD systems, and covering STA shifts at the Browns Ferry Nuclear Plant.

06/81 to 10/81 *BWR Instructor, General Electric Company*

Responsible for developing administrative procedures for the Independent Safety Engineering Group (ISEG) at the Grand Gulf Nuclear Station.

01/80 to 06/81 *Reactor Engineer / Shift Technical Advisor, Tennessee Valley Authority*

Responsible for directing refueling floor activities, performing core management functions, maintaining ASME Section XI program for the RHR system, providing power maneuvering recommendations and covering STA shifts at the Browns Ferry Nuclear Plant.

06/79 to 12/79 *Junior Engineer, Georgia Power Company*

Responsible for completing pre-operational testing of the radwaste solidification systems and developing design change packages for modifications to the liquid radwaste systems at the Edwin I. Hatch Nuclear Plant.

Education

June 1979 Bachelor of Science in Nuclear Engineering, The University of Tennessee at Knoxville

May 1980 Certification, Interim Shift Technical Advisor, TVA Browns Ferry Nuclear Plant

April 1982 Certification, Shift Technical Advisor, TVA Browns Ferry Nuclear Plant

Professional Affiliations

Member, American Nuclear Society (since 1978).

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(202) 223-6162 fax

The CHAIRMAN. Thank you, Mr. Lochbaum, very much.

Our final witness is Mr. Amory Lovins, who is chairman and chief scientist of the Rocky Mountain Institute and chairman emeritus of Fiberforge, Incorporated. Mr. Lovins has published 29 books and hundreds of papers, and advises governments and major firms worldwide on advanced energy and resource efficiency.

We are honored to have you with us here today, Mr. Lovins. Whenever you are ready, please begin.

STATEMENT OF AMORY LOVINS

Mr. LOVINS. Thank you, Mr. Chairman and distinguished committee members. I appreciate this opportunity to share with the committee some recent analysis of whether we need nuclear power, especially to protect the climate.

And I request that my written submission be included in the record.

The CHAIRMAN. Without objection, so ordered.

Mr. LOVINS. Thank you.

I will summarize why nuclear power is not needed for any civilian purpose, how and why it is being dramatically outcompeted in the global marketplace by no-carbon and low-carbon electrical resources that deliver far more climate solution per dollar far faster, and why nuclear expansion would inhibit climate protection, energy security and reliably powering prosperity. Even if nuclear power could attract private risk capital, it could not in principle deliver its claimed climate and security benefits, but because it is uneconomic and unnecessary, we need not inquire into its other attributes.

Far from undergoing a renaissance, nuclear power is conspicuously failing in the marketplace for the same forgotten reason it failed previously: It costs too much, and it bears too much financial risk to attract private risk capital, despite Federal subsidies now approaching or exceeding its total cost.

What is beating nuclear power at other central thermal plants? Micropower—that is, cogeneration plus distributed renewables—now produces a sixth of the world's total electricity, more than nuclear, at least a third of the world's new electricity, and from a sixth to over half of all electricity in a dozen industrial countries. The U.S. lags, with about 4 percent. Negawatts, electricity saved by using it more efficiently or timely, are about as big worldwide as micropower and cost even less.

In 2006, nuclear power added less capacity than photovoltaics added, one-tenth what wind power added, and 30 to 41 times less than micropower added. Its output growth was one-sixth of micropower's.

Distributed renewables won $56 billion of private risk capital. Nuclear, as usual, got zero. Only central planners buy it. China's distributed renewable capacity reached seven times its nuclear capacity and is growing seven times faster.

Micropower has such huge potential that just the full economic use of electric efficiency, zero-carbon waste-heat cogeneration and wind power, with no other renewables, could provide roughly 13 to 15 times nuclear power's current share of U.S. electric generation without significant land use, reliability or other constraints, at much lower cost and with millions of good new jobs.

Distributed generators are generally more dependable than centralized ones because their many small units will not all fail at once and can bypass the grid where nearly all power failures originate. Variable renewable resources—sun and wind—even in large amounts, need less backup than we have already bought and built to manage the intermittence of big thermal plants, especially nuclear plants, many of which can fail simultaneously, unpredictably and for long periods.

The Nuclear Energy Institute says 78 percent of the new coal plants announced in the past couple of years got cancelled. I expect announced nuclear projects to do worse because they cost more. They have attracted no private risk capital, despite U.S. taxpayer subsidies that can now total about $13 billion per new nuclear plant, roughly its entire cost, which exceeds the market cap of any U.S. utility, save one.

The smart money, led by Warren Buffet, is now heading for the exit, spooked by steeply rising nuclear costs, disappointments in the flagship Finnish project, competition by ever-cheaper micropower negawatts, and the credit crunch. The U.S. can have only about as many new nuclear plants as taxpayers are forced to buy. Heroic efforts at near or over 100 percent subsidization will continue to elicit the same response as defibrillating a corpse: It will jump, but it won't revive.

That is good for climate protection, because nuclear power is so expensive that it buys roughly one and a half to 11 or more times less carbon reduction per dollar than competing no-carbon technologies or even fossil fuel cogeneration in factories and buildings.

As the graph in my prefiled testimony's Annex E explains—or as the graphs explain, I should say—nuclear plants cost so much more than competing climate solutions that spending a dollar on nuclear, instead of on efficient end use, worsens global warming more than spending the same dollar on new coal power. It is, therefore, time to get on with judicious investments that yield the most energy services and the most climate protection per dollar and per year.

The straightest path to American energy security and to a richer, fairer, cooler and safer world is to let all ways to save or produce energy compete fairly at honest prices, regardless of their type, technology, size, location and ownership. That is pretty much the opposite of the Federal energy policy we have.

Thank you, sir.

[The prepared statement of Mr. Lovins follows:]

Invited testimony to the Select Committee on Energy Independence and Global Warming
United States House of Representatives, Washington, DC
Hearing on "Nuclear Power in a Warming World: Solution or Illusion?"
Cannon HOB 311, 12 March 2008

Amory B. Lovins, Chairman and Chief Scientist
Rocky Mountain Institute
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Why expanding nuclear power would reduce and retard climate protection and energy security... but can't survive free-market capitalism

I appreciate this opportunity to share with the Committee some recent analysis of whether we need nuclear power, especially to protect the climate.[1] I'll summarize why nuclear power isn't needed for any civilian purpose[2]; how and why it's being dramatically outcompeted in the global marketplace by no- and low-carbon electrical resources that deliver far more climate solution per dollar, far faster; and why nuclear expansion would *inhibit* climate protection, energy security, and reliably powering prosperity. Even if nuclear power could attract private risk capital, it could not in principle deliver its claimed climate and security benefits. But because it's uneconomic and unnecessary, we needn't inquire into its other attributes.

Far from undergoing a renaissance, nuclear power is conspicuously failing in the marketplace, for the same forgotten reason it failed previously: it costs too much and it bears too much financial risk to attract private risk capital, despite federal subsidies now approaching or exceeding its total cost.

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[1] My curriculum vitae is Annex A and my Federal contract/grant disclosure is Annex B. The analysis summarized here is set out in several papers based both on 2004 (Annexes C and D) and on the latest, even stronger, data presented in Annex E, which is the best starting-point. Details and documentation supporting Annex E's summary will be posted shortly at www.rmi.org as a preprint of a major peer-reviewed scholarly article.

[2] A case can be made for nuclear naval propulsion (submarines and carriers), where strategic and operational needs trump economics. Recent claims that nuclear propulsion is also worthwhile for medium surface combatants rely on Navy analyses that improperly assume a zero real discount rate; at even a minimal 3% real discount rate (OMB rules require at least 3% and probably 7%), the breakeven oil price required is a large multiple of the $60/bbl claimed on the House floor last December. Both the JASON senior scientific advisory group to the Secretary of Defense and a Defense Science Board Task Force on military energy strategy on which I recently served (www.acq.osd.mil/dsb/reports/2008-02-ESTF.pdb) pointedly declined to endorse either this naval propulsion concept or the similarly uneconomic—and, for energy security, counterproductive—notion of installing small nuclear power plants on military bases.

Fortunately, its decentralized competitors don't have these problems. Despite much smaller subsidies and often tall barriers, the low- and no-carbon distributed resources dismissed by the nuclear industry as uneconomic, impractical, and trivial are actually producing more electricity worldwide than nuclear, are growing tens of times faster, and have tens of times nuclear's market share. Specifically, "micropower"—cogeneration plus distributed renewables—now produces a sixth of the world's total electricity (more than nuclear), at least a third of the world's new electricity, and from one-sixth to more than half of all electricity in a dozen industrial countries (the U.S. lags with just 4%). "Negawatts"—electricity saved by using it more efficiently or timely—are about as big worldwide as micropower and cost even less.

In 2006, nuclear power added less capacity than photovoltaics added, one-tenth what windpower added, and 30–41 times less than micropower added; its output growth was one-sixth of micropower's. Distributed renewables won $56 billion of private risk capital; nuclear, as usual, got zero—only central planners buy it. China's distributed renewable capacity reached seven times its nuclear capacity and grew seven times faster. These trends are accelerating, especially in developing countries, which have more scope and more need for both micropower and negawatts.

Millions of small resources can be collectively huge, much as networked PCs now provide most of the world's computing capacity. Distributed ways to make or save electricity can spread like PCs and cellphones, not like constructing cathedrals. Capital embraces them. They're quick, agile, rapidly evolving, ever cheaper, and independent of foreign inputs—just the opposite of nuclear power. Moreover, they have such huge potential that just the full economic use of electric efficiency, zero-carbon waste-heat cogeneration, and windpower—with no other renewables—could provide ~13–15× nuclear power's current share of U.S. electric generation, without significant land-use, reliability, or other constraints, and with millions of good new jobs.

Distributed generators are generally more dependable than centralized ones because their many small units won't all fail at once and can bypass the grid, where nearly all power failures originate.[3] Variable renewable resources (sun and wind), even in large amounts, need less backup than we've already bought and built to manage the intermittence of big thermal plants—especially nuclear plants, many of which can fail simultaneously, unpredictably, and for long periods.

The Nuclear Energy Institute says 78% of the new coal plants announced in 2006–07 got cancelled. I expect announced nuclear projects to do worse because they cost more. They've attracted no private risk capital despite U.S. taxpayer subsidies that can now total about $13 billion per new nuclear plant—roughly its entire cost, which exceeds the market cap of any U.S. utility save one. The smart money, led by Warren Buffet, is now heading for the exits, spooked by steeply rising nuclear costs, disappointments in the flagship Finnish project, competition by ever-cheaper micropower and negawatts, and the credit crunch. The U.S. can have only about as many new nuclear plants as taxpayers are forced to buy. Heroic efforts at near- or over-100% subsidization will continue to elicit the same response as defibrillating a corpse: it will jump, but it won't revive.

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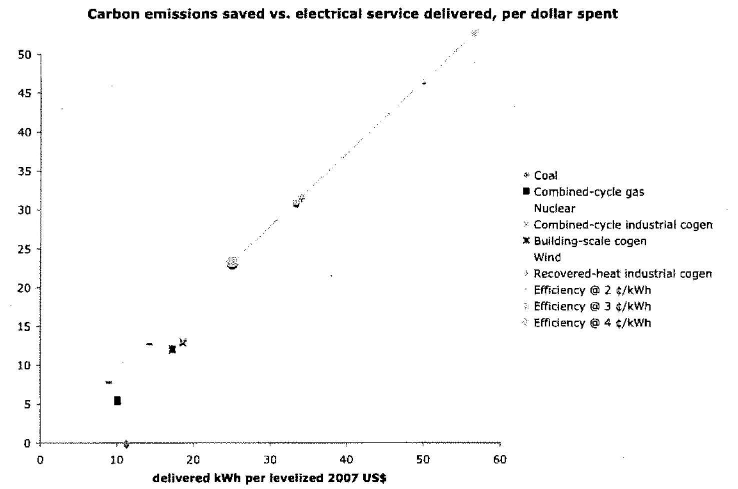
[3] For fundamental reasons described in my 1982 DoD study *Brittle Power: Energy Strategy for National Security*, www.rmi.org/sitepages/pid114.php, reliable, affordable power supplies must come from efficiently used, diverse, dispersed, mainly renewable resources sited at or near the customer.. The Feb 08 DSB report cited in the previous note strongly reinforces that message. My Senate Energy Committee testimony of 7 Mar 06 provides an overview of the elements of national energy security at www.rmi.org/images/PDFs/Energy/E06-02_SenateTestimony.pdf.

That's good for climate protection, because nuclear power is so expensive that it buys ~1.5–11+ times less carbon reduction per dollar than competing no-carbon technologies (efficient use, renewables, recovered-heat cogeneration)—or fossil-fueled cogeneration in factories and buildings (adjusted for its modest carbon emissions). This graph, derived in Annex E, summarizes the typical empirical costs today of producing or saving electricity at your meter:



The horizontal axis shows how much new electrical service you get per dollar: cheaper is toward the right. The vertical axis shows how much carbon you save per dollar: more climate-friendly is toward the top. Many "negawatts" are way off the upper-right corner of the chart. Conversely, the least helpful options are toward the lower left corner. Among those losers, nuclear emits less carbon—almost none in operation—than coal power, but it *costs* so much more than competing climate solutions that spending a dollar on nuclear instead of on efficient end-use worsens global warming more than spending the same dollar on new coal power.

Wishing for a nuclear revival will not make it so. After a half-century, nuclear power has irrefutably proven its inability to compete in the marketplace. It's time to get on with judicious investments that yield the most energy services and climate protection per dollar and per year.

The capital markets are now injecting a welcome realism long absent from Federal policy. The straightest path to American energy security and to a richer, fairer, cooler, safer world is to let all ways to save or produce energy compete fairly, at honest prices, regardless of their type, technology, size, location, and ownership. That's pretty much the opposite of the Federal energy policy we have.

3

Annex A: Curriculum vitae of Amory B. Lovins

Birth: 13 November 1947, in Washington DC
Marriage: L. Hunter Lovins 1979–99, Judy Hill Lovins 2007–

Course of Studies and Professional Career:
1964–1967: Undergraduate, Harvard College
1967–1969: Advanced Student, Magdalen College, Oxford
1968– : Consultant to industry and government in ~30 sectors and ~50 countries, chiefly on advanced energy and resource efficiency, integrative design, implementation, strategy, and public policy; clients include scores of major firms; recently redesigned >$30b worth of superefficient facilities
1969–1971: Junior Research Fellow, Merton College, Oxford (MA by Special Resolution, 1971)
1978: Regents' Lecturer in Energy and Resources, University of California at Berkeley
1979–2007: Honorary doctorates of nine US and UK universities
1979: Distinguished Visiting Scholar, University of Oklahoma
1980: Regents' Lecturer in Economics, University of California at Riverside
1980–81: Energy Research Advisory Board, U.S. Department of Energy
1981– : Cofounder, CEO (2002–07), Chairman and Chief Scientist (2007–), Rocky Mountain Institute (independent, nonpartisan, entrepreneurial nonprofit; creates abundance by design; www.rmi.org)
1982: Henry R. Luce Visiting Professor of Environmental Studies, Dartmouth College
1982: Distinguished Visiting Professor of Environmental Design, University of Colorado
1986–92: Cofounder/director, E SOURCE; 1992–99: Board member/Principal Technical Consultant
1999: Oikos Visiting Professor, Business School, University of St. Gallen (Switzerland)
1999–2007: Cofounder and Chairman, Hypercar, Inc. (now Fiberforge Corporation, www.fiberforge.com); Director and Chairman Emeritus, 2007–
1999–2001 and 2006–08: Defense Science Board Task Forces on energy, U.S. Department of Defense
2002: Visiting Lecturer, College of Environmental Engineering, Peking University
2007: MAP/Ming Visiting Professor, School of Engineering, Stanford University

Main Awards:
1982: Mitchell Prize (2nd place)
1983: Right Livelihood Award ("Alternative Nobel Prize")
1984: Fellow, American Association for the Advancement of Science
1988: Fellow, World Academy of Arts and Sciences
1989: Delphi Prize of the Onassis Foundation
1993: Nissan Prize (ISATA); MacArthur Fellow
1997: Heinz Award for the Environment
1999: Lindbergh Award
1999: World Technology Award
2000: Happold Medal of the U.K. Construction Industry Council; *Time* "Hero for the Planet"
2001: Shingo Prize (Research)
2005–6: Benjamin Franklin Medal, Royal Society of Arts (London) (Life Fellow 2007)
2006: Jean Meyer Award
2007: Blue Planet Prize; Volvo Prize; Hon. member, American Institute of Architects; Foreign Member, Royal Swedish Academy of Engineering Sciences; Hon. Senior Fellow, Design Futures Council; *Popular Mechanics* Breakthrough Leadership Award; *Time International* "Hero of the Environment"

29 books and hundreds of papers; the three most recent books are:
- *Natural Capitalism: Creating the Next Industrial Revolution* (with sr. author P.G. Hawken & L.H. Lovins), Little Brown (Boston), 1999 (>12 translations), www.natcap.org
- *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (with six coauthors), Rocky Mountain Institute (Snowmass, Colorado), 2001 (*Economist* book of the year), Japan Energy Conservation Center (Tokyo), 2005, www.smallisprofitable.org

- *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security* (with E.K. Datta, O.-E. Bustnes, J.G. Koomey, & N.J. Glasgow), Rocky Mountain Institute for DoD *et al.*, 2004, www.oilendgame.com

Annex B: Statement of Federal grants and contracts received by myself or by my organization in the current or previous two fiscal years

During 2006–08 I served on the Defense Science Board Task Force on DoD Energy Strategy, cochaired by former SECDEF Dr. James Schlesinger and GEN Mike Carns (USAF Ret.). This service as a Special Government Employee (as I understand it) was noncontractual and uncompensated, but RMI was reimbursed for most of my travel expenses. Since the Task Force's report was briefed to DSB more than a year ago and was released to the public on 13 Feb 08 (www.acq.osd.mil/dsb/reports/2008-02-ESTF.pdb), I presume that my SGE service to DoD has ended., though I received no official notice of entering or leaving SEG status.

For the fiscal year ended 30 Sep 06, my nonprofit employer, Rocky Mountain Institute, held and some of my colleagues partly used a $50,000 contract to support policy research and development on military energy efficiency for the Office of the Secretary of Defense.

I am not currently aware of any other Federal grants or contracts received by Rocky Mountain Institute or by myself during the current or the previous two fiscal years. However, on receiving the Committee's inquiry on this point on 7 Mar 2008, I asked RMI's CFO to research it in case, for example, I might have given a lecture (for which RMI would have been paid) to some Federal entity, as I sometimes do *pro bono*. I shall advise the Committee of any information received.

Annex C: "Mighty mice," from *Nuclear Engineering International*, December 2005, Rocky Mountain Institute Publication #E05-15, www.rmi.org/images/PDFs/Energy/E05-15_MightyMice.pdf,

This article sought to explain to the nuclear industry who its competitors are. The yellow box at the upper right corner of the first page cites an exchange with a critic from the World Nuclear Association.

Annex D: "Nuclear power: Economics and climate-protection potential," Rocky Mountain Institute Publication #E05-14, 6 January 2006, www.rmi.org/images/PDFs/Energy/E05-14_NukePwrEcon.pdf

This more technical paper details and documents the analysis in Annex C. Both are based on the 2004 data then available. Those data are posted at www.rmi.org/sitepages/pid256.php#E05-04, to which 2006–07 updates will shortly be posted. An independent renewable-energy database with very similar figures (but slightly higher due to a wider definition of small hydro) is at www.ren21.net.

Annex E: "Forget nuclear," prepublication draft, *RMI Solutions* (www.rmi.org), Spring 2008; final version to be posted shortly at www.rmi.org, Publications, Energy, Nuclear Energy, and in RMI's Newsletter section, and provided to Committee staff as soon as available

This relatively nontechnical article, currently being edited for the RMI newsletter and hence subject to minor change, draws on a much fuller and heavily documented peer-reviewed analysis to be published in September 2008 by the Royal Swedish Academy of Sciences' journal *Ambio*. A preprint will be posted by permission in spring 2008. The cost analysis in Annex E is updated from that in Annexes C and D chiefly in the following respects:

- The 2004 costs are updated to reflect the best 2006–07 empirical U.S. cost data from industry. Thus we retained the MIT nuclear and combined-cycle costs but added the June 2007 Keystone Center nuclear analysis and more recent estimates from utilities and leading financial houses. We refreshed coal-plant cost escalation with MIT Coal Study and industry estimates. We used the empirical capacity-weighted median windpower prices for 2004–05 US installations (equal to the 1991–2006 average), sensitivity-tested through 2006, and their average O&M costs, plus the mean of nine recent studies of windpower firming and integration costs, all as compiled by Lawrence Berkeley National Laboratory.
- We used the GDP Implicit Price Deflator (1.09) to convert all 2004 $ to 2007 $.
- We added a nominal 0.1¢/kWh cost to the onsite generators as a proxy for any excess of backup costs over distributed benefits to the utility (the actual value may well be negative in most cases), and added similar minor costs for some other resources for which they hadn't previously been explicitly shown.
- We continued to use deliberately low delivery costs for central stations, favoring them over distributed resources.
- We showed an illustrative cost range for electric end-use efficiency. For comparison, national-average program costs are around 2¢/kWh; hundreds of utility programs in industry and commercial buildings have cost less than 1¢/kWh; and the best practitioners routinely achieve costs at or below that level—often even less than zero.

The CHAIRMAN. I thank you very much, Mr. Lovins.

The Chair will now recognize for a round of questions the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

Again, I thank all of you.

The issue of safety is extremely important in my community. We are not far from one of the nuclear facilities, one of the 104, in our community. We are clearly aware of the two significant accidents that have happened in the nuclear facilities.

This would go to any of you. If you were giving information to the 1.7 million people in our metropolitan area, what would you say that you believe would assure them of the safety of such a facility?

Mr. FLINT. If I can take that question, Congressman, I would tell you that the track record of the U.S. nuclear power plants is that they are exceptionally safe and that the safety is improving, and that the metrics by which the NRC tracks that—and there are a variety of metrics, be they from the Bureau of Labor Statistics, worker injury statistics that were in my statement, or be they the NRC's metrics where they track unplanned shutdowns and other issues—are all trending very positively.

And so those plants are absolutely safe. They are safe from a perspective of their physical operations, from the way in which the professional staff operates those plants and from the security. In every manner, those plants are currently very safe.

Mr. CLEAVER. Yes, I mean, I listened in your statement, and I appreciate the information you provided with regard to the safety, you know, that it is as safe as working in a bank. But, you know, airplane travel is far, far safer than driving an automobile. The issue, though, is that there is a possibility of surviving an automobile accident. Surviving an airplane accident is dramatically lower. And so, you know, people are thinking one event at a nuclear facility, a major event, could be just devastating. And so people are afraid all over the country, which is part of the reason.

Part of the reason, of course, is the cost, the Federal subsidy, which is something we would be concerned about. But also, I am not sure that there are a lot of electeds around the country who are willing to stand up and say to a community, "We are going to build a new facility." I mean, you can say that electeds do not have courage or whatever, but the truth of the matter is people are afraid.

Mr. FLINT. Congressman, we deal with that issue frequently. It is a question of helping people understand real versus perceived risks.

I will tell you that, currently, some of the greatest support new nuclear power plants have for construction in this country comes from the elected officials whose districts include those plants and whose communities include those plants. Frankly, our polling shows that people who live nearby nuclear power plants, who are familiar with them, who know people who work at the plants so that they have those personal relationships and where they can talk to people, their neighbors, actually are some of the strongest supporters of nuclear power.

So I agree with you, we have a perception problem. When we are given the opportunity and we sit down with people over a period of time and they grow to trust us and they grow to trust the people who work at and who operate those plants, those perceptions change over time.

Mr. CLEAVER. That may happen. But the other issue that we all would have to deal with, as it relates to a community, is that the waste is primarily unconverted uranium. When you say "unconverted uranium" in the climate today, there is then going to be the discussion about, you know, what if this is somehow used or falls in the hands of those who would want to harm people in this country?

And where do we store the waste? What area in the country is open and joyful about receiving the waste?

Mr. FLINT. Congressman, you, having a nuclear power plant near your district, are well aware of the political difficulties associated with storing used fuel on site.

Ideally, the Nuclear Waste Policy Act, which requires the DOE to pick up used fuel beginning in 1998, over a decade ago, would be operative. Unfortunately, it is not. As a result, we store used fuel on site, be it in pools or dry casks. We do it very safely. That fuel is handled in a way in which it is protective of the health and environment. It is secure.

Mr. CLEAVER. But we can't continue to do that at each site.

Mr. FLINT. Sir, you are absolutely correct. And the Government's failure to move used fuel is extremely frustrating, particularly to politicians to whom utilities have made promises that used fuel will be moved.

However, in the absence of DOE meeting its obligations, the utilities are responding very constructively to dealing with the used fuel on site, and it is currently stored safely and securely. It is not an ideal situation, but I can assure you it is very protective of health and safety.

Mr. CLEAVER. Thank you, Mr. Flint.

Thank you, Mr. Chairman.

The CHAIRMAN. The gentleman's time has expired.

The Chair recognizes the gentlelady from South Dakota, Ms. Herseth Sandlin.

Or I could ask questions and come back to the gentlelady?

Great. Thank you.

The Chair will recognize himself for a round of questions.

Mr. Lovins, you heard the argument made by Mr. Flint from the Nuclear Energy Institute. This is a stark difference of opinion in terms of the economics of nuclear in our country. He is contending that nuclear is on the rebound, it has had a revival, it is about to produce perhaps four to eight completed nuclear power plants by the year 2016, and that the prospects beyond that are very rosy, indeed.

How do you analyze the prospects as you have just heard Mr. Flint present them to the committee here today?

Mr. LOVINS. I am very puzzled. The motto in our shop is, "In God we trust; all others bring data," so I look at the numbers. I do not see any private investment in new nuclear plants. It has never been bid into a competitive market. It has never been bought in what is normally—in the current generation, of what is normally considered a free-market transaction anywhere in the world. And the competitors that the nuclear industry dismisses as uneconomic, impractical and trivial are producing more electricity today than nuclear is, growing tens of times faster, and it has tens of times nuclear's market share.

So I fear the nuclear industry lives in a sort of "Alice in Wonderland" world in which nuclear merits every kind of subsidy and support because it is supposedly indispensable, while it actually has only about a 2 percent market share in the world's new electric capacity, and its competitors—micropower and negawatts—are beating all central plants.

The CHAIRMAN. Now, again, when you say "negawatts," what do you mean by—you mean N-E-G, negative watts?

Mr. LOVINS. Correct.

The CHAIRMAN. What do you mean by that?

Mr. LOVINS. And "N" for "Nellie."

Negawatts are saved electricity, saved through either efficient end use or a demand response. And although they are not nearly as well measured as megawatts, they do appear to be having about the same annual capacity effect in the world, maybe even bigger, as micropower has.

The CHAIRMAN. I want to go over to Mr. Flint and have him respond to what you are saying. I think I hear you saying that there is no private-sector investment in nuclear power, that there is no market right now for private money to be placed into the nuclear power market. Is that correct?

Mr. LOVINS. Yes, sir, despite Federal subsidies now approaching or exceeding new nuclear plants' U.S. cost.

Now, I find this really remarkable because, normally, if you lay out that lavish a trough, some pigs will arrive. But I do not see them arriving, because the private capital market believes, in my view, that the reward is not greater than the financial cost of risk.

The CHAIRMAN. Let me go over to Mr. Flint then.

How do you respond to what Mr. Lovins just said? He says there is no private capital going into nuclear power.

Mr. FLINT. Well, Mr. Chairman, I appreciate the opportunity to address the issue.

I am confronted with a situation in which many people have proposed that nuclear power receives a variety of different levels of subsidies. I have tried on occasion to duplicate the math, and I can't make some of those numbers work.

And so I went off and I looked at two different sources. And, if you like, I can make these available for the record. I have the June 2006 issue of Science and Technology, which is the publication of the National Academies. There is an article in there entitled "Real Numbers: The U.S. Energy Subsidy Scorecard," by Mr. Bezdek and Mr. Wendling of the Management Information Services. And they compare the subsidization rates of all energy technologies in the United States.

And let me read one of their conclusions: "Considerable disparity exists between the level of incentives received by different energy sources and their current contribution to the U.S. energy mix. Although oil has received roughly its proportionate share of energy subsidies, nuclear energy, natural gas and coal may have been undersubsidized. And renewable energy, especially solar, may have received a disproportionately large share of Federal energy incentives."

Now, that is sort of an aggregate assessment. There are two issues—and Mr. Lochbaum mentioned them in his statement—with which I am particularly familiar, so I would like to focus on those two things.

The Energy Policy Act of 2005 reauthorized Price Anderson in title 6. In title 17, it had a loan guarantee program for innovative technologies. Frequently, Price Anderson and the loan guarantee title are considered significant subsidies for the nuclear energy industry.

So I brought with me CBO's score of the Conference Report on the 2006 Energy Policy Act. CBO, of course, keeps track of how much legislation costs. Title 6, which includes Price Anderson reauthorization, is not even on the detail table attached to that score because it does not score.

Title 17, for loan guarantees, does warrant a notation in the score. In particular, CBO estimated that it would score $100 million in outlays, and outlays only, in 2006. From that point on, there is a set of zeros that reach out to the end of the chart, because CBO estimates that the loan guarantee program's cost will be fully paid by the recipients of the loans.

So I have to base my analysis on something, and, in this case, I base it on CBO's assessment. I think——

The CHAIRMAN. Are there loan guarantees in that bill for solar and wind?

Mr. FLINT. Yes, sir. Title 17 applies to—and I actually have it with me, but it will take a minute to dig out—"Innovative Technologies that Reduce or Sequester Greenhouse Gas Emissions," I believe is the title. It is not nuclear-specific. So it is any technology that meets those requirements.

I think part of the reason we get into these discussions about the subsidization rates for nuclear in particular is because people like Mr. Lovins and I can disagree on some of the fundamental issues, like what is the score of the loan guarantee title and what is the score of Price Anderson. When I turn to independent analyses, I run into things like this article and issues in Science and Technology that indicate that nuclear power is subsidized at a rate less than other technologies.

The CHAIRMAN. Let me go back over to you then, Mr. Lovins. You have heard this contention.

Mr. LOVINS. Yes.

The CHAIRMAN. Can you provide further analysis?

Mr. LOVINS. Well, I did not hear an answer to your question, Mr. Chairman. What I did hear was some selective quotation.

I, actually, have also relied on the CBO findings that there is a well-above-50-percent default risk on nuclear loan guarantees. My understanding is that the $18.5 billion latest nuclear loan guarantee allocation occurs in a committee conference report, not in the actual legislative language, so that it evades CBO scoring.

However, I thought your question was about the absence of private capital investment, and I believe that is correct. This is simply not an attractive option. Again, I would contrast it with just distributed renewables, let alone cogeneration, having received $56 billion of worldwide private risk capital in 2006 alone. If you add cogen, the total would be well over $100 billion, compared to zero for nuclear. And that trend continues.

I was also very puzzled by Mr. Flint's remarks about nuclear's being competitive with other sources of electricity. The average 1999 through 2006 wind power price in the United States was 3.5 U.S. cents per kilowatt hour net of production tax credit, which has a levelized value of about .9 cents. This is all in 2006 levelized dollars.

And even if you firm the wind power and even if you count the uptick in price to 4.9 average cents in 2006, because largely of a shortage of turbines because of the booming market, it is still hard to get much over a nickel a kilowatt hour. That is approximately a third of any plausible nuclear busbar cost on the margin.

Mr. FLINT. Mr. Chairman, may I?

The CHAIRMAN. Please.

Mr. FLINT. This is a continuing dialogue, clearly. He cited a CBO analysis that showed a 50 percent default rate on a loan guarantee program for nuclear power. There was such a CBO analysis. It was for a loan guarantee program that was considered in the Energy Policy Act of 2003 on the floor of the U.S. Senate. That provision did not pass the Senate. It has not become law. The operative document is the CBO analysis of the 2005 energy policy, a conference report which is the law. As you can imagine, it frustrates me significantly to have to be able to track every CBO analysis of nuclear-related provisions regardless of whether they became law or not. In this case I can tell you that the operative analysis shows that the loan guarantee title does not score.

The CHAIRMAN. And the reason it does not score, why is that, Mr. Flint? How can there be a $40 billion loan guarantee program and have it not score and yet have the same agency, just a couple of years before, project that there would be a 50 percent default rate? That doesn't make any sense. How can you respect an agency that projects a 50 percent default rate, says there is $40 billion at risk, and then scores for all of the subsequent years the risk to taxpayers as zero? That makes no sense.

Mr. FLINT. Actually, Mr. Chairman, when you read the two provisions and you realize that CBO was scoring two different proposed laws, it does make a lot of sense. The provisions were written very differently. The 2005 provision is written in accordance with the Federal Credit Reform Act which requires that the cost of the loan guarantees be paid in advance so that any cost that will be associated with those loans have to be paid by the project sponsors. They will write a check to the Federal Government to cover the total cost of the loan guarantee. As a result, because they are being paid in advance for the cost of the loans, the loan guarantee program in Title 17 does not score. I mean, I would request that I be able to submit this.

The CHAIRMAN. And we would welcome that for the record.

[The information follows:]

* * * * **COMMITTEE INSERT** * * * *

The CHAIRMAN. Mr. Lovins, do you have any comment on this? This a very perplexing concept here that all of this taxpayer money can be at risk, and yet it is not scored in any way in terms of an obligation the taxpayers have assumed.

Mr. LOVINS. Mr. Chairman, in principle the project sponsors are supposed to put up what amounts to an insurance premium against default. My understanding is that it is up to the Department of Energy to determine what is an adequate premium, and that the industry expects that this Department of Energy will set a very low premium because otherwise the conditions would be unacceptable to the industry. I don't think any fundamental risk conditions have changed except that probably the risk has increased.

And in a longer paper that I will submit for the record, you will find a remarkable history in which the Department of Energy initially proposed relatively responsible rules for its very generous loan guarantees under the 2005 act, but then progressively relaxed the rules under intense pressure from the nuclear and financial industries so that the loan guarantees are now strippable. They are 100 percent of 80 percent debt financing.

The sponsor is supposed to put up what DOE considers, without any criteria, to be a significant equity stake. But the sponsors don't seem to be willing to do that, so I assume DOE's judgment of what is a significant equity stake will be appropriately relaxed. And DOE even put in language in its final decision saying that it may even choose to subordinate Federal debt to private debt. So the financial industry got everything it wanted and yet is still unwilling to invest.

The CHAIRMAN. My time has expired. The Chair recognizes the gentlelady from South Dakota, Ms. Herseth Sandlin.

Ms. HERSETH SANDLIN. Thank you, Mr. Chairman, and thank you for having this hearing. I find the discussion very interesting, and in some ways similar to an issue that I have worked very hard on in the Congress. And that is the issue of biofuels development. And I am not comparing nuclear energy to biofuels, but the debate here in trying to get the facts right and the ongoing discussion about whether or not there is information based on either older technologies or information that has been around since the 1970s that really has evolved in a way that we have to address this in light of new technologies, in light of other new developments and in light of priorities that have changed from a policy perspective on what is the greater risk that we face, either within the country for national security purposes or worldwide as it relates to climate change.

And so I am very interested, as I think the Chairman is, and others will be, to continue—whether we get some of the information that is being cited here on both sides of the argument—to try to figure out what the facts are today and some of the arguments and the reputations of those arguments.

But I am interested a little bit in terms of this discussion of sort of the private capital investment, whether there is an absence of it, what the reasons may be for that. And a lot of what we have done in the Select Committee is taken testimony in other hearings as it relates to the experience of Europe with its cap-and-trade system.

And so I would be interested in hearing from any of our witnesses today about what you know of the experience in Europe as it relates to nuclear energy development prior to and since they adopted a cap-and-trade system, and whether or not that has affected private capital investment and the levels of that investment in European countries that are looking at—that either had historically nuclear energy in their portfolio or looking at that as a possibility as it relates to the requirements of their cap-and-trade system.

Mr. LOVINS. Perhaps I could take that because I am very active in Europe. There have been no such nuclear purchases in Europe. The one that I expect Mr. Flint would tell you about, although he might find other aspects of it embarrassing, is the Finish project which was bought by the Finish equivalence of TVA. That is, it is a nonprofit customer-based consortium. It has long-term power purchase contracts passed through to customers. And it got a lot of very well below-free-market financing from German and French parastatals, which appears to many of us to be illegal, but the Commission hasn't yet said so. The plant after 28 months of construction was 24 months behind schedule and roughly $2 billion over budget, which was not what was supposed to be demonstrated. So this has spooked a lot of folks who were thinking otherwise.

Now, the British Government has lately reversed its previous white paper and proposed to build replacements for its aging and retiring nuclear reactors and believes this can be done in the private market without subsidy. No other country has achieved that, so many of us will be interested to see how it can be pulled off. The main method of doing it so far appears to be that the government, like the French Government, has announced a willingness to intervene in carbon markets to raise carbon prices high enough for nuclear to compete. I don't think this will work, however, because higher carbon prices will equally advantage efficiency renewables and largely advantage co-gen as well. In other words, the competitors will do about as well as nuclear will out of higher carbon prices.

The other British intervention proposed is basically to continue policies that discriminate against things like wind power of which they have an immense resource. They don't call it that. They say they are favoring wind power, but that has not so far been the practical effect.

I think the most interesting case to watch will be France. They get 78 percent of their electricity from nuclear and it is widely considered the world leader in that regard. What is not often said is the program was so costly that it required costly taxpayer bailouts of both the largely state-owned national utility and the nuclear construction firm. So France today is using about a tenth less fossil fuel than in 1973, which isn't a big difference. It has a large and sometimes unsellable nuclear surplus. And to try to sell the surplus it has intensively promoted electric heating, which a quarter of French houses have but it is very expensive. And they are having to restart some inefficient old oil-fired plants to cope with the winter peak load that their electric heating promotion created, so it has made quite a mess of the electricity system.

And having been engaged in the policy discussions in France from the beginning when the Cabinet was split down the middle, I can tell you that France is very rich in renewable energy, is starting to figure that out and, as in most of Europe, there is serious policy discussion going on that is shifting very rapidly toward renewables. You will find this in the latest European Union climate policy which is very strong on efficiency and renewables and not on nuclear.

Ms. HERSETH SANDLIN. Mr. Flint.

Mr. FLINT. Congresswoman, if I might, before you arrived I told the Chairman that I was struck by the changes in the nuclear industry since 1982 when he wrote a book about nuclear power and nuclear weapons, and I think some of those changes are important to keep in mind. Clearly, there have been nuclear power plants that have had a multitude of problems with cost overruns and design changes and many of them eventually not being completed and operating.

We have learned a great deal from that experience. And the way in which we hope to build nuclear power plants in the United States now is dramatically different than we did prior to that time. From 1960 through the 1970s and the early 1980s the U.S. nuclear industry rapidly advanced in this country. We scaled up the size of reactors from several hundred megawatts to over a thousand megawatts. Designs were evolving, plants went under construction without completed designs, we had problems with engineering and construction contracts, we built them in an era in which interest rates went to 18 percent as the economy slowed in the late 1970s and many utilities decided they didn't need the electricity, so they stretched out the plants of their own design. Or their own business needs caused them to stretch out the plants, the capital costs went up. We had a variety of issues that we have learned from.

Now as we look around the world and we see 34 nuclear reactors under construction, we do have problems with cost and schedule in Finland, but we have learned a great deal from reactors under construction in China and Japan. The new EPR that is under construction in France is not having the same issues that we had with plants under construction in Finland. We hope to bring to the United States some of the best regulatory financial as well as design characteristics of plants being built around the world.

We have a different licensing process in the United States, this one-step licensing process. We have modularized construction techniques that we intend to use. My expectation is that you are going to see nuclear power plants built here much more cautiously on the one hand by the utilities doing their analysis in advance, and on the other hand incorporating best-in-class capabilities from reactors around the world. This may be one place where it is an advantage that the United States is not the world leader.

The CHAIRMAN. The gentlelady's time has expired, but we will go to another round as well if you would like.

The Chair will recognize himself again. Again, I want to go back to this $40 billion loan guarantee program and it not being scored. And it is my understanding that the reason that CBO didn't score it is that it was put into report language rather than into the actual appropriations language itself. And by circumventing that analysis, it is able to create a false impression that it doesn't really cost any money or put the American taxpayer at risk if there is a default. And I think that very devious technique is something that gives a misimpression to the American people about the risk in the same way that subprime loans, in the way in which they were scored, gave a very grave misimpression to the American public as to the amount of risk that was being run.

Mr. Flint.

Mr. FLINT. Mr. Chairman, let me make sure I am very precise about what I say. The 2005 Energy Policy Act, which includes the authority for Title 17 loan guarantees, did not score. And that is the CBO document that I was referring to. You are now referring to the 2008 Energy and Water appropriations bill. That bill includes two provisions. It includes bill language authorizing the loan guarantee program to go forward. In fact, that language has no cap on the volume of loans that may be issued. That language does not score comparable to the 2005 Energy Policy Act, because it uses the authorities in the 2005 Energy Policy Act. An unlimited loan volume does not score.

The CHAIRMAN. But again, Mr. Flint, that is ridiculous.

Mr. FLINT. Mr. Chairman——

The CHAIRMAN. No, that is an absurd conclusion. That is the same thing that the banking regulators were doing in not properly weighing the risk of subprime loans. And the more you had, of course, and the more diversified the risk was, the lower the risk was to the American consumer; when in fact, it was only increasing it by breaking it up into these little sub-bits. So, again, this is just phony accounting.

In looking at the whole history of nuclear power, Mr. Lochbaum went through the history of cancellations. We have got this Florida case where Florida Power & Light has two nuclear reactors that are now going to cost up to $24 billion. And, again, all of this is part of an illusion that is sought to be created by the nuclear industry and abetted by those at CBO, I guess, or the crafty legislators who are able to avoid having it counted as any potential risk for the American taxpayer.

But the reality is that looking at the past, looking at what is happening in Finland right now, looking at what is happening to Florida Power & Light, which is seeing an explosion in the risk to its ratepayers, and, if it qualifies for loan guarantees, there is a real mess on the hands of the American taxpayer.

Mr. Lovins, let me go back to you.

Mr. LOVINS. It seems to me the fundamental point here is not whether CBO was prevented from scoring by the way the legislation was enacted, but why should a mature industry that claims to be robustly competitive require loan guarantees or any other subsidies. And of course we have competing experts here. I happen to think since my institute did the first real scoring of Federal energy subsidies back in the 1980s that Doug Koplow has emerged as the most careful independent student of this subject, and I think his numbers are careful and transparent. And I would prefer them to the ones Mr. Flint cited.

But it seems to me however big the subsidies are, they shouldn't be needed. And I find it very telling that the leading financial houses make quite clear they are not willing to assume the risks that they wish to impose on the public, and neither are the utilities. It is also clear that in the roughly half of the United States where investors bear their own risks and have no rate barriers to impose them on because those States have restructured their electric systems, nuclear plants are especially unlikely to be built. But what we are going to see, I think, in places that do have the traditional rate-of-return regulation is considerable sticker shock.

If you take a nuclear capital cost pretty near the low end of Moody's range, that would correspond to a busbar levelized cost of about $0.16 a kilowatt hour in year 2007 dollars. But that means the first-year revenue requirements is about a $0.26 a kilowatt hour rate and that rate shock I think will reverberate considerably.

The CHAIRMAN. Well, if the taxpayer has to pick up the tab, of course it will.

Mr. Flint, in your testimony you said you expect between four and eight new reactors to be in operation in the U.S. by 2016, with the possibility of a second wave of additional reactors, as long as the first wave is on schedule and on budget.

Last week the EIA projected that by 2030 the United States would add 16.4 gigawatts of new nuclear generation capacity, which translates into roughly 15 or 16 new reactors. But according to Ms. Squassoni's testimony, the nuclear industry would have to build 50 new nuclear reactors in the United States by the year 2025 just to maintain its current share of the U.S. electricity market.

Do you agree with EIA's projection that even with the current financial incentives in place, the nuclear industry is going to dramatically lose, not gain, in its share of the U.S. electricity market in the next couple of decades?

Mr. FLINT. Mr. Chairman, my statement has a number of issues that are going to consider whether or not the second wave of new nuclear power plants gets built. And I am trying to turn to that section right now. They have to do with a variety of issues that utilities will face. What is the cost of competing technologies, what are the costs associated with carbon, what is the economic growth, what are the electricity demands in their region of the country, what are the costs of nuclear built power plants as they get built? There are many variables thereafter that significantly influence what happens with that second wave. We are quite confident of this initial estimate of four to eight plants in the 2016 time frame. The issues beyond 2015, for me to make a particularly accurate prediction, there are simply too many business——

The CHAIRMAN. I appreciate that, but I think it is important for us because we are talking about climate change. That is our objective here. Are you confident that the 42 to 46 reactors needed to maintain the share of the market which the nuclear industry has today, can be built in the United States by 2025?

Mr. FLINT. Maybe I can answer the question more broadly. We are well aware of the challenges that are presented by the wedge analysis and whether or not nuclear can respond globally and build the number of plants necessary. Back-of-the-envelope calculations, you are talking 200 gigawatts of new electric generation in a decade in order to support the rates of growth that you see in the

Socolow analysis. That did occur in the 1980s. We saw that sort of growth worldwide. Now, today we do not have the manufacturing infrastructure, we do not have enough skilled labor to be able to do that. The market has contracted in the following decade.

The CHAIRMAN. So is it fair to say, then, that the nuclear power industry, given the financial uncertainties, is not going to be able to grow in a manner that would be needed for it to accomplish the sort of expanded vision by Socolow?

Mr. FLINT. No, sir.

The CHAIRMAN. No matter how much U.S. Federal Government subsidies are there for the industry?

Mr. FLINT. No, sir, it wouldn't. What you could say is the marketplace has responded by contracting capability in that regard.

The CHAIRMAN. No, what I am saying to you is—and I just need you to deal with the numbers—you need 42 to 46 new nuclear power plants by 2025 to maintain your current share of the electricity market. You are projecting 4 to 8 by 2016. Are you saying that somewhere between 40 and 45 new nuclear power plants are going to be built from 2016 to 2025; is that what you are saying?

Mr. FLINT. Mr. Chairman, there are a number of variables that will affect how——

The CHAIRMAN. I understand that. We know that we are going to have approximately 365,000 megawatts of wind by then, over 100,000 megawatts of wind in the United States by 2016. We are here talking about between four and eight nuclear power plants by 2016. So as we are making our plans here to solve the global warming problem, we want to hear from you that you are confident and your industry is confident that it can build 45 nuclear power plants by the year 2025.

Mr. FLINT. Mr. Chairman, there are analyses done by very reputable organizations such as the Electric Power Research Institute that predict construction in excess of that much nuclear capacity in the United States. The EPRI PRISM analysis predicts 64 gigawatts of new power by 2036. We are in the process of——

The CHAIRMAN. Again, even by 2036 that would only keep you at where you are today, at 19 percent in terms of a total percentage of the marketplace. Is there any reason to believe that you are going to actually see an increase, an increase in the percentage of electricity that is generated by nuclear power by 2016, by 2025, by 2035?

Mr. FLINT. If you let me give you a complete sentence as an answer.

The CHAIRMAN. Okay, please.

Mr. FLINT. We are doing a very—as we call it, a cold-blooded analysis so that we are neither overly optimistic nor overly pessimistic about exactly what rates of new nuclear industry can support. We are in the process of developing new manufacturing capability, of building training centers for the skilled workforce. We are working with State legislators on a——

The CHAIRMAN. That is not an answer. We can see where wind is going, we can see where solar is going. We have blinders on when it comes to the nuclear industry, even with these massive multibillion-dollar subsidies. So that is the real problem that we have right now, Mr. Flint. We are trying to predict a future looking at the reality of the marketplace, which is a renewable and a negawatt, an efficiency marketplace. And you want us to basically continue to go back to the American taxpayer to get loan guarantees for an industry that the industry itself can't garner investment from the private sector.

Let me just stop there for a second. I want to give the gentlelady from South Dakota another round.

Ms. HERSETH SANDLIN. Well, I appreciate that. I know we've got a pending vote, so I will just reserve my right to submit questions in writing for the panelists to pursue some of what both Mr. Flint and Mr. Lovins were responding to in my previous questions as it relates to the ability to meet some of these projections; what the renewables are, but what the projected demands are, to be able to determine whether or not as we develop the renewables either here, as some of the European countries are developing their renewables further and the tax incentives and government policies that go along to facilitating that, just whether or not that is going to be sufficient to meet all the projections and demands.

So I appreciate the opportunity for another round, but I think I will reserve the right to submit them in writing.

The CHAIRMAN. I thank the gentlelady. And the Chair will recognize himself once again.

Again, I have to go back, Mr. Flint, to your testimony where you say that the potential contribution nuclear power can make to reducing projected greenhouse gas emissions in the electricity sector in coming decades is "extraordinary." That is the word you use.

Mr. FLINT. Yes.

The CHAIRMAN. And yet you then turn and say that you are doing a cold-blooded analysis of whether or not that is possible. So there is kind of a public representation that the opportunities are extraordinary, but when you are asked a specific question about a quantity of electricity that the industry is willing to represent that it will build, we don't hear that number. All we hear is between four and eight, which is a pretty wide variation between now and 2016. And beyond that we don't hear any specific numbers.

Whereas the renewable electricity industry, the energy efficiency sector, can give us quantifiable amounts of electricity produced or saved that we can rely upon going forward in our fight against climate change. And that is the dilemma that we have with the nuclear industry right now.

Mr. FLINT. Mr. Chairman, I can understand your frustration. But recognize that we are trying to ensure that we meet the expectations that are established. I will give you some specifics. I have 17 utility companies that have announced plans to build 31 new nuclear reactors. That is significant. Those companies are spending real money in pursuit of those license applications.

To give you a back-of-the-envelope estimate, a license application process at the NRC costs about $100 million. Recall the nuclear industry, we pay not only our own costs of submitting a license application, we also pay 90 percent of NRC's annual budget. We pay them. And the NRC budget for 2009 is a little over $1 billion. So utility companies are now spending very real money in the development of these nuclear reactors.

I can't tell you exactly what year certain reactors will come on line. Largely it is dependent upon whether electricity growth in certain regions is at 7 percent or 4 percent or whether it goes to 0 percent. But I can tell you that independent analyses, like the EPRI analysis, anticipate 64 gigawatts of new generation by 2036. That is an extraordinary contribution to greenhouse gas emission avoidance.

The CHAIRMAN. Let me go to you, Ms. Squassoni. At this point many people think that there is a small probability that the Yucca Mountain site to store all the nuclear waste in the United States will never be opened. Have you looked at the question of how many Yucca Mountains we would need to store the waste that all of these new hypothetical reactors will generate?

Ms. SQUASSONI. Thank you. Yes, I have, although people more expert than I say it is a little misleading to use that as a figure, because the limits for Yucca have been legislated at 75 metric tons and there is a big debate about whether it could hold more. In part, the calculation of the kinds of spent fuel that will be generated depends on what you think that future nuclear fuel cycle will look like: Is it just lightwater reactors or are you going to reprocess? Will we have fast breeder reactors?

And so I will rely on some other people's data—if I can see this here. A scenario of 700 gigawatts would require, according to the NRDC, 14 Yuccas. That is at the 70,000-metric ton limit. If you go to a one nuclear wedge, you would require one Yucca every 3.5 years or 20 Yuccas. And if you go to the MIT 2050 scenario, you would require about 30 Yucca Mountains.

The CHAIRMAN. Let me ask you this, Ms. Squassoni. Do you think that the nuclear industry can ramp-up the way it did in the 1970s and 1980s? Is that possible in this new era as Mr. Flint talks about a nuclear renaissance? Can we expect to see dozens of new nuclear power plants come on line over a 20-year period?

Ms. SQUASSONI. Well, I think there are a lot of factors, as Alex Flint has mentioned. I think you have to keep in mind that in the 1970s and 1980s, the period of greatest growth, we had a large nuclear infrastructure. We don't have that anymore, particularly in—I forget the figures—just in terms of the supporting industries.

For example in the 1980s, the U.S. had 400 nuclear suppliers and 900 holders of N-stamp certificates. That is, nuclear qualified. Now we only have 80 suppliers and 200 N-stamp holders, so we have a much much smaller percentage.

The CHAIRMAN. Let me ask, in your testimony you cite some of the industry bottlenecks that pose a challenge to the nuclear industry, such as the fact that there is only one company in the world that can make the specialized metal forgings needed to build new reactors. That company has a 2-year long wait list, and, even when it scales up, will still only be able to produce material sufficient for eight reactors a year.

But you also cite the MIT nuclear study which says that for nuclear energy to play its projected climate role that there would have to be a fivefold increase in the number of reactors worldwide and an annual build rate of 35 per year. How can this and other projections for a significant expansion of nuclear energy be reconciled? What would it take, for example, to bring the global specialized metal forging capacity up to 35 reactors per year?

Ms. SQUASSONI. I think there is a gap between the expectations and what can be accomplished in the next 10 years. Obviously, countries can develop specialized forging capabilities over time. I would say that the information provided to me by Japan Steel Works—I asked, Well, why does everyone come to you? And they said, Well, because we have 30 years of experience, including Russian companies and entities.

The CHAIRMAN. So what would it take to just double the capacity, Ms. Squassoni?

Ms. SQUASSONI. Well, you have to keep in mind that JSW I think provides about 30—or not 100 percent of the forgings. It depends on what reactors will be built. But it is significantly greater than——

The CHAIRMAN. In order to not even do 35 power plants per year, let us just say 17 power plants per year across the world, what would it take to double that capacity? What kind of investment is necessary in order to provide the materials?

Ms. SQUASSONI. I would have to get back to you on that.

The CHAIRMAN. If you would do that for the record, I would very much appreciate it.

[The information follows:]

* * * * **COMMITTEE INSERT** * * * *

The CHAIRMAN. Let me go over to you, then, Mr. Lochbaum. You haven't had a chance to comment on what you have been hearing. Can you take any one of these points and comment upon it?

Mr. LOCHBAUM. I joined the nuclear industry in 1979 after the Three Mile accident, so I have an alibi for that. But that was during the expansion, the great expansion of nuclear power in the United States. And looking back on that, we ramped-up too quickly. For example, the Nuclear Regulatory Commission didn't have enough staff to do the reviews of the reactors in the pipeline. They had interns, summer interns that were reviewing the safety applications that resulted in problems like the Connecticut Yankee final safety analysis report having the Millstone final safety analysis report incorporated, without catching the fact that it was a totally different reactor.

I worked at Grand Gulf. I recall your comments around the time of Grand Gulf's licensing, calling it Grand Goof. I worked at Grand Gulf. We messed that up very badly. The original license for Grand Gulf was for another plant. We didn't catch that. We submitted it to the Nuclear Regulatory Commission and they didn't catch it. So the problems with ramping-up haven't been dealt with.

I noticed your comments in September of last year about the Nuclear Regulatory Commission's plans to meet the 24-month review time for new reactors. The NRC plans to do that by farming out the work to private industry. That is totally unacceptable. That shows that the NRC is focused on schedule. Not on quality. It hasn't learned a lesson of the past. It seems like it is destined to repeat that mistake rather than avoid it. So I don't see any optimism at all for believing that the future will be any different than the past, except for the fact that we have fewer excuses for repeating that mistake, since we know about them now.

The CHAIRMAN. My time has expired. The Chair recognizes the gentleman from New York State, Mr. Hall.

Mr. HALL. Thank you, Mr. Chairman. I am sorry, due to the vote to adjourn, I was unable to hear your oral testimony, but I did have a chance to review it. And let me just state, first of all, as one who represents the 19th District in New York where we currently have the second and third units at Indian Point awaiting relicensing proceedings with the NRC at a time that they are leaking strontium and tritium from the spent-fuel cooling ponds into the groundwater and into the Hudson River, and when there have been a series of unscheduled outages caused by anything from an exploding transformer to river debris washing up into the water intake and clogging it, and the folks in Rockland County who do emergency management finding out about that transformer fire in particular by seeing a puff of smoke across the river, rather than by getting a call as the procedure is supposed to be. There are many people in my district who are nervous in particular about this plant.

So to me there are a couple of issues. One regarding whether we should be investing our short precious resources in nuclear as opposed to renewables, which I think, given the same massive—and depending on whose numbers you look at, it is easily over $100 billion from the birth of the industry, some would say $145 billion, $150 billion and all kinds of subsidies—and insurance by the taxpayer. The only industry to my knowledge that has been unable to get insurance against a catastrophic accident, and therefore the utilities required that the government provide taxpayer-backed insurance. And the average taxpayer didn't even know this.

So there is a question overall in terms of whether nuclear power, commercial nuclear power can stand on its own two feet if it had to compete on a level playing field against various other sources.

But then there arises the question of whether one should relicense a plant in the area that probably shouldn't have been built in the first place. And certainly I don't think a utility today would apply to build a new nuclear plant in Westchester County, in an area where 8 percent of the population lives within a 15-mile radius of the plant. You look at where applications are going. They are generally going for more remote locations, for good reason.

We also know that Mohammed Atta flew over the New York area several times on commercial flights, checking out targets. And one of his notes that was found in his possessions after 9/11 included a comment about a nuclear plant that was presumed to have been Indian Point that he flew over as a potential target.

At any rate I would just like to ask all of you, I guess one question to start with, and I may be out of time by then, thanks to my talking so much, but I asked our first panel last year when the Chairman called a security panel with Jim Woolsey, our former CIA chief, and Steven Haas from the Council on Foreign Relations, and Admiral McGinn and folks who were involved in the security end of this.

If we ramp-up the kind of increase in nuclear power across the world—and I know that there are companies. In fact, this President has authorized sales of, for instance to India, of nuclear technology and materials and even waived, if I remember correctly, certain provisions of the Nonproliferation Treaty to be able to do so.

What I asked that panel a year ago I ask you again: When we are increasing the transit by ship and by rail and by truck of many thousands of shipments all over the world, including in this country, of enriched fuel on its way to a plant and of spent fuel on its way to a repository, whether such a repository actually exists for a long-term basis or if it is a temporary one, are we not making eventually the explosion of a dirty bomb virtually a certainty?

Feel free to go first.

Mr. FLINT. Congressman, it is important to recognize there have been 24,000 international shipments, or around the world they are having 24,000 shipments of nuclear material to date. Those shipments are handled safely and securely and will continue to be done in such a manner.

Mr. HALL. Thank you.

Ms. SQUASSONI. I think both Reuters and Nucleonics Week have reported recently that States are getting jittery about these kinds of transfers, mostly even in just the fresh fuel. I think if you see the kind of expansion for the global climate change levels, you are talking about a lot of nuclear material in transit, much more than we have seen now. And so I think that does—I don't know if it makes it a certainty, but I think it does increase the risk. Thank you.

Mr. LOVINS. I don't think one needs to imagine airplane crash scenarios, which I wrote about in a Pentagon study in 1981, to be concerned about particularly nearsighted nuclear plants with their gigacurie inventories being a terrorist target. Most of the existing plants can be caused to melt down by interventions that would take readily available devices that can generally be operated from outside the site boundary and would cause the safety systems to fail.

Mr. HALL. Thank you. My time has expired. And I just wanted to comment, if I may, Mr. Chairman, that the 20-some-thousand shipments of nuclear material around the world, I presume a good number of them were before the rise of Islamic terror, terrorists and groups that we have seen in the last several years. And I also assume that that number would have to be drastically increased in order to reach the level of total nuclear output worldwide that is being considered.

So with that, I thank the Chairman and yield back.

The CHAIRMAN. I thank the gentleman, and the Chair will recognize himself for another round of questions.

Let me go back to you again Mr. Lovins, then I can go back to Mr. Flint. And I want to focus on this Florida Power & Light decision to build two reactors that could cost upwards of $24 billion. Why would Florida Power & Light, Mr. Lovins, want to build two reactors that couldn't possibly generate any more than perhaps 2,500 megawatts and be willing to run the risk of having it cost them $24 billion? What is in the mind of Florida Power & Light or any utility that moves in that direction?

Mr. LOVINS. Having worked in the utility industry for several decades, I must say that what must be in their minds is a rare phenomenon and typically does not survive encounters with the capital market.

The longer paper I will submit for the record is replete with statements by the bond rating agencies and others in the industry, and indeed by utility executives very knowledgeable in this field, that they would not contemplate such an investment or they think it is unlikely or imprudent. So I must presume that whoever made that statement must not know very much about cost-effective alternatives.

I think we are likely to have 100 gigawatts of wind power installed in this country before we have our first gigawatt of new nuclear, if ever.

It was interesting thinking about the four to eight plants Mr. Flint mentioned when the NRC expects 33 applications. Now, perhaps there is a difference between a plant and a unit, but it sounds kind of like the funnel that Mr. Lochbaum talked about, going from announcements to actualities.

The Nuclear Energy Institute has noted the cancellation already of about three-quarters of the announced coal plants. I expect somewhere between that and all of the nuclear announcements will lead to nothing. And the global nuclear industry projects that in the 5 years 2006 through 2010, it is going to build about 17 gigawatts of capacity of which, by the way, most all or more than all is expected to be offset by retirements meanwhile, which we haven't discussed here. But basically the bulk of the fleet is old. The average age is 24 years. And it will gradually go away.

Now, compare 17 gigawatts over 5 years with the current construction rate just of Micro-Power let alone negawatts. Micro-Power today is adding 17 gigawatts about every 15 weeks.

The CHAIRMAN. Why don't you redefine for the audience what Micro-Power is?

Mr. LOVINS. Micro-Power is cogeneration plus renewables minus big hydro. Well, Micro-Power is adding 17 gigawatts about every 15 weeks. In other words, times faster than the nuclear industry has projected. Gross additions, not net of retirements. I don't know what part of that number anyone who takes the market seriously doesn't understand.

The CHAIRMAN. Thank you. Let me go back to you again, Mr. Flint. It seems like an astounding amount of money, $24 billion for two reactors, given the fact that, as Mr. Lovins says, there is likely to be 100,000 megawatts of wind by 2016 across the country. So Florida Power & Light, it is known as a company that believes in wind power, solar power, other renewables in other parts of the country. But here it is willing to risk ratepayer, and I guess taxpayer, dollars up to the tune of $24 billion. It just doesn't seem economical. It seems to be completely out of sync with what is going on in the whole rest of the national and international marketplace.

Mr. FLINT. Well, Mr. Chairman, the reality is it is not out of sync, you are absolutely right. Florida Power & Light I believe is the largest wind utility in the United States, very familiar with the economics of wind going forward. But let me read you a little bit more from their determination of need petition. It said that the company, quote, has conducted an extensive review of information currently available within the industry on the expected cost of new generation nuclear units.

Quote, the addition of new nuclear capacity is economically superior versus the corresponding addition of new gas-fired combined cycle units required to provide the same power output, yielding large direct economic benefits to customers. Based on all the information available today it is clearly desirable to take the steps and make the expenditures necessary to retain the option of new nuclear capacity coming on line in 2018, end quote.

Mr. Chairman, the reality is that we are seeing significant increases in the cost of all types of baseload generation. What we say is that nuclear power will be competitive. We have costs that are rising as concrete and steel and labor costs rise, but those are the same pressures that coal and gas-fired plants are being subject to. The cost of natural gas is going up and one can only speculate as to the future of coal in whatever the regulatory environment will be.

The CHAIRMAN. Go back to Mr. Lovins. You just heard the Florida Power & Light justification for two nuclear power plants costing $24 billion. What is your comment?

Mr. LOVINS. Or more precisely, for retaining the option value, which is very different from actually ordering a plant and putting cash on the barrel head to pay for it.

I would differ in several respects with Mr. Flint's remarks. The Cambridge Energy Research Associates construction industry—or excuse me, construction cost index for U.S. power plants in the 3 years ending third quarter 2007 for North America showed a 2.31 times year 2000 cost for all main types of power plants, but 1.79 times for non-nuclear types; that is, nuclear suffering uniquely rapid cost escalation. This shows up very clearly not just in the nuclear numbers from the Keystone study last June, which were so devastating that the industry, and specifically NEI, misrepresents the results or ignores them, but also in actual comparisons.

And I think Mr. Flint is incorrect to say that the right comparison—or to imply the right comparison is with other baseload central thermal plants, coal or gas. Those are not the real competitors. It is all central plants that are getting absolutely walloped in the marketplace by Micro-Power and negawatts. And the very competitors that the nuclear industry refuses to accept as important are eating its lunch.

The CHAIRMAN. Thank you.

Let me go to you, Ms. Squassoni. And let us talk about the nuclear power plants that are being proposed for Egypt, for other countries around the world that could pose nonproliferation threats to our country and to the rest of the world.

Give us a little bit of detail as you are looking at what is now projected in terms of plutonium, uranium, nuclear materials, spreading to country after country, especially in the Middle East.

Ms. SQUASSONI. I think you have to start with the context that over 27 countries have announced intentions to install nuclear capacity. And because they don't have nuclear power plants now, they lack the infrastructure, not just—I mean regulatory, legal——

The CHAIRMAN. So which countries frighten you the most from a nonproliferation perspective Ms. Squassoni?

Ms. SQUASSONI. Yemen.

The CHAIRMAN. Keep going.

Ms. SQUASSONI. I have to get out my map here. I think part of the proliferation concern, it is not just—you know, nonproliferation advocates tend to be painted as non-nuclear. It is not a question of non-nuclear. But when you have what nuclear power plants will do in these countries, it will give them expertise, it will give them a scientific and technological basis. And in the current state of the nonproliferation regime where we have been completely unsuccessful in discouraging other countries from developing enrichment or reprocessing plants, these countries will then have a further excuse, if you will, for developing the entire fuel cycle.

Now, is that cost effective? No. But that doesn't happen to be stopping Iran, for one.

The CHAIRMAN. So the risk we run, obviously, is that if nuclear becomes this global solution and they are constructed in Yemen, in Egypt, in Saudi Arabia, in other countries——

Ms. SQUASSONI. United Arab Emirates. I mean I don't want to paint the—it is not that these individual countries in the Middle East themselves might pose a problem, but they are certainly looking at their options as the probability that Iran can't be discouraged from its nuclear program. They are certainly looking at their options and thinking, well, we will develop our own nuclear infrastructure to keep our options open.

The CHAIRMAN. And that is the problem that I think I hear out of this testimony today. That Mr. Flint is not willing to project that by 2025 the nuclear industry can meet a production level that is perhaps upwards of 45 new nuclear power plants and keep it at the same level in the United States of its percentage of electricity generation as it has today. And to meet the problem globally we have to watch nuclear power plants be built in countries that don't have regulatory systems or security systems in place that would give people confidence that the price we are paying in increased climate protection is not completely counteracted by a collapse of our nuclear global nonproliferation regime. And that is a real price that I think the whole world has to understand.

Let me turn and recognize again the gentleman from New York, Mr. Hall.

Mr. HALL. Thank you Mr. Chairman. I just have a couple of quick questions before I have to go vote.

Mr. Flint, I just wanted to refer to a comment that Admiral McGinn made in his testimony before this committee that the experience of the Navy with naval reactors has been very, very positive, unquote. And this is often brought up as a point that safety can be achieved to a much higher degree. And I think that as we all know, the Navy is not a for-profit business. They have sailors down in the submarine close to the reactor, and it is in their interest, and they spare no expense and cut no corners.

And if it were decided by—I mean, this is a societal decision I think we are talking about. We need to as a country decide what mix of different sources of power we are going to use. But in order to gain the degree of confidence of safety that would generate broad public support, do you personally or do you think the industry would take kindly to the idea of being nationalized as opposed to being a for-profit bunch of utilities that operate in different plants?

Mr. FLINT. Congressman, if I may, I would like to answer that in part and take part of that as a question for the record. First, the U.S. utility industry is not interested in being nationalized. The reason I would like to take part of that as a question for the record is that Admiral Skip Bowman who previously ran the nuclear reactor program is now the president and CEO of the Nuclear Energy Institute and he might like the opportunity to address that question directly, particularly the issues associated with naval reactors and its application to the civilian sector.

And so if I may take that part as a question for the record, I would be delighted to get back to you.

Mr. HALL. Thank you.

[The information follows:]

* * * * **COMMITTEE INSERT** * * * *

Mr. HALL. And just one more for you, Mr. Flint. A couple of times in your testimony you reference clean—the benefits of clean energy from nuclear power. I am just curious why you would describe as clean a technology which produces cancer-producing radioactive isotopes that remain radioactive for hundreds of thousands of years.

When we look back at King Tut 7,000 years ago, or whenever that was, it is pretty hard to imagine that we will actually be able to isolate the longer-lived radioactive products of the fission process for the length of time that they need to be isolated and protect people that need to be shielded from them.

I mean there have been books written about this that speculate about a nuclear priesthood that will design some kind of symbolism or language that can be read by future civilizations and might come across our repository so that they know not to go in there and get too close to it.

I mean, that is the level of—now, also we don't have a control planet, by the way. The fact that I have in my own family and friends half a dozen people who are either just recently deceased of cancer or fighting off some kind of cancer. Who happen to live in the immediate area of Indian Point, for instance, is something that we will never know if there is a connection because there is also PCBs and pesticides and all these other things in this one environment, this whole Earth that we have.

There is no control planet, and then a planet that we can see what the effects would be. But I contend that it is not clean and it is actually fraudulent advertising to say that it is. Your response?

Mr. FLINT. Congressman, the issue of what to say with somebody who lives near a power plant and gets cancer is always very difficult when you are sitting directly with somebody, as you do with your constituents from time to time. In different settings, though, it is appropriate to recall that 40 percent of the population will get cancer during its lifetime from other causes, okay. The issue really is, does nuclear power result in any incremental increase in cancer?

And let us look at radiation for just a moment. Currently we anticipate that a new disposal standard for Yucca Mountain will be issued that will contemplate a million-year disposal requirement for Yucca Mountain. We estimate that DOE will come up with models that will show at what rate radionuclides from Yucca

Mountain might migrate through the environment and be released out to the environment and might get close enough to the surface to be brought up in plants and water and other things like that.

Mr. HALL. Excuse me, my time has expired, so I just wanted to ask you—I gather that all these great lengths that you are going to to try to keep it isolated would imply that in fact the waste is not clean?

Mr. FLINT. Congressman, I would imply that the doses of radiation that people receive from the civilian nuclear industry in this country are minuscule compared to background and other sources of radiation. The net benefit is the issue at hand. So, for example, when somebody goes in for an MRI and receives a fair amount of radiation, the amount of radiation they receive from a nuclear power plant is inconsequential in comparison, and the benefits of the clean electricity generated from that nuclear power plant are tremendous.

The CHAIRMAN. I hate to say this, the gentleman's time has expired. We have a very important roll call on the House floor. We have been constantly interrupted. I missed one or two, so I could keep the hearing going. I am going to ask each one of you to give us 30 seconds, what you want us to remember about the nuclear power industry as we are going forward. Begin with you, Mr. Flint.

Mr. FLINT. Mr. Chairman, climate change is one of the great challenges facing this country. I see no scenario by which we can possibly achieve reductions in greenhouse gas emissions while we meet the electricity demands of our country, estimated to grow at 30 percent between now and 2030, without a significant increase in the amount of nuclear power that we have. The industry is preparing to respond to that, and we will be able to respond to that challenge.

The CHAIRMAN. Thank you. Ms. Squassoni.

Ms. SQUASSONI. Thank you. The kinds of nuclear expansion that would be needed to affect global climate change are huge and unrealistic and incredibly costly, and moreover they carry with them proliferation risk that I don't think the United States and the international community yet have begun to really combat.

The CHAIRMAN. Thank you. Mr. Lochbaum.

Mr. LOCHBAUM. We have 104 nuclear power reactors in the United States today. We may build some in the future, we may not. We don't know. But we are going to have nuclear power in our future for a few decades. The best protection the American public has against that risk is an effective nuclear regulator. We don't have that today. We need that as soon as we can get it.

The CHAIRMAN. Thank you. Mr. Lovins.

Mr. LOVINS. Nuclear power is continuing to drive an incurable attack of market forces just by heroic efforts to revive it with subsidies. But even though it is being massively outcompeted by larger, faster, cheaper options, Micro-Power negawatts, it has claimed to produce climate benefits. That claim is simply false. Because nuclear is so expensive that if the same money were spent instead on Micro-Power negawatts, we would get 1½ to 11 times more carbon saving per dollar, and we would get it sooner.

The CHAIRMAN. Thank you, Mr. Lovins.

We thank each of you. I think this was a very important panel for us to have. There are still questions I think that the Members of the committee who could not attend would like to pose to you in writing. We would appreciate written responses in a timely fashion.

With that and the thanks of the committee, this hearing is adjourned.

[Whereupon, at 11:05 a.m., the committee was adjourned.]

Sharon Squassoni
Senior Associate
Carnegie Endowment for International Peace
April 10, 2008

To: Select Committee on Energy Independence and Global Warming
Subject: Responses to Questions Submitted for the Record, March 27, 2008 after Hearing on "Nuclear Energy and Global Warming: Solution or Illusion?" on March 12, 2008

Question 1: The International Atomic Energy Agency is the international entity responsible for oversight of the world's nuclear programs. The United States is a party to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)? To your knowledge does the United States uphold this treaty?

The United States signed the NPT in 1968 as a nuclear weapon state (defined in the treaty as a state that tested a nuclear weapon or other nuclear explosive device prior to January 1, 1967). Its obligations under the NPT therefore include the following:

- Article I obligates nuclear weapon states party to the treaty not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear weapon state to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices.
- Article III obligates all parties not to provide (a) source or special fissionable material, or (b) equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear weapon state for peaceful purposes, unless the source or special fissionable material shall be subject to safeguards.
- Article IV.2 obligates all parties to the treaty to facilitate the fullest possible exchange of equipment, materials and scientific and technological information

for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear weapon states party to the treaty, with due consideration for the needs of the developing areas of the world.

- Article VI obligates all parties to pursue negotiations in good faith on effective measures relating to the cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

The United States has led nuclear nonproliferation efforts globally for over forty years. Many of the NPT obligations are mirrored in U.S. law, notably the 1954 Atomic Energy Act, as amended. In particular, the obligation to ensure that nuclear exports to non-nuclear weapon states are subject to safeguards is a condition of nuclear supply under Section 123 a. of the Atomic Energy Act. The United States has also long promoted peaceful nuclear cooperation with states party to the NPT, per Article IV.2.

There are two areas of U.S. obligations under the NPT which, in my view, bear increased scrutiny. The first is the potential for U.S. civilian nuclear cooperation with India to cross into gray areas of treaty interpretation and the second is the extent to which the current Administration has pursued "good faith" negotiations on measures relating to the cessation of the nuclear arms race.

U.S.-India Nuclear Cooperation Agreement

In 2005, President Bush entered into an agreement with India – a state that has refused to sign the NPT, tested nuclear weapons in 1974 and 1998, and yet is considered under the NPT and under U.S. law to be a non-nuclear weapon state – to cooperate on peaceful nuclear energy. This decision reversed a thirty-year policy of not engaging in nuclear trade with countries that refused to join the NPT and accept comprehensive, full-scope safeguards on all nuclear material on their territory. In fact, the 1978 Nuclear Nonproliferation Act, and the creation of the Nuclear Suppliers Group in 1975, was in direct response to the 1974 Indian test.

In December 2006, the 109th Congress passed P.L. 109-401, known as the Henry J. Hyde Act, which authorized the President to submit a nuclear cooperation agreement with India (known as a Section 123 agreement) to Congress that would not meet all of the requirements under the 1954 Atomic Energy Act, as amended (including from full-scope safeguards). That 123 agreement, which was signed in 2007 but has not yet been submitted to the Congress, contains provisions that allow the United States and India to cooperate on sensitive nuclear technology. Before such cooperation, the 123 agreement would need to be amended and, presumably, approved by Congress. However, among the 23 U.S. peaceful nuclear cooperation agreements currently in force, only one allows for cooperation in such areas – an amended agreement with Australia. In that case, amendment was considered necessary for transfer of Australian enrichment technology (SILEX) to the United States, not the other way around. For many years, the United States has pursued a policy of not cooperating in such sensitive technologies. Thus, the signed U.S.-India agreement is a marked departure from the norm.

Cooperation in sensitive nuclear technology could include, in principle, uranium enrichment and spent fuel reprocessing. These two technologies, which are used to make and recycle fuel for civil nuclear power reactors, can also be used to produce fissile material for nuclear weapons. India has not placed all of its fissile material production facilities under international safeguards as part of its 2006 plan to separate civilian and military facilities. Uranium enrichment and plutonium separation plants will continue to operate outside of international inspections to produce fissile material for nuclear weapons. Even though any exports related to enrichment or reprocessing from the United States to India would be required to be under International Atomic Energy Agency (IAEA) safeguards, such safeguards are only applied to nuclear material, equipment, and facilities. They cannot and are not designed to monitor the transfer of technological know-how. Therefore, I would argue that if the United States engages in sensitive nuclear technology cooperation that involves the potential transfer of technological know-how to India, such activities could violate the U.S. obligation under Article I of the NPT "not in any way to assist, encourage, or induce any non-nuclear weapon state to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices." There is no way of preventing the transfer of knowledge from safeguarded to unsafeguarded – and thus nuclear weapons-related – facilities.[1]

Other, broader arguments that the offer of U.S. nuclear cooperation to India, which has not signed the NPT, has assisted, encouraged or induced India to manufacture nuclear weapons are persuasive. Lifting the ban on uranium exports to India will free domestic, unsafeguarded uranium to be used for military purposes; India's domestic uranium shortage has for years caused its civil power reactors to operate at lower capacities than desired. Reporting requirements under the Hyde Act seek to explore just how much uranium imports could assist India's nuclear weapons program. More broadly however, lifting the long-time export bans is a *de facto* recognition of India's nuclear weapons status. Secretary of State Rice stated for the record in April 2006 that "India has nuclear weapons and we must deal with this fact in a realistic, pragmatic manner." She added that "we do not recognize India as a nuclear weapon state or seek to legitimize India's nuclear weapons program." Other officials' statements, however, appear to confer legitimacy. Under Secretary of State Nicholas Burns told reporters on March 2, 2006, that "It's not a perfect deal in the sense that we haven't captured 100 percent of India's nuclear program. That's because India is a nuclear

[1] For a longer analysis, please see a copy of a memo I authored while at the Congressional Research Service, provided on the following website: http://markey.house.gov/docs/defense/CRS%20Memo%20on%20US-India%20Nuke%20Deal.pdf

weapons power, and India will preserve part of its nuclear industry to service its nuclear weapons program."

Good Faith Negotiations on Disarmament

There is no question that the United States has made significant strides in the last ten to fifteen years in drawing down its nuclear weapons stockpiles. Much of the supporting evidence can be found in U.S. official statements made within the context of the NPT Review conference cycle (on the State Department's website). However, there is considerable debate on the nature of the legal obligation Article VI of the NPT confers upon NPT parties. A convincing case can be made that the Bush Administration has largely failed to pursue *negotiations in good faith on effective measures* relating to cessation of the nuclear arms race at an early date. Some of the supporting evidence includes:

- Abrogation of the 1972 ABM Treaty
- Conclusion of the Moscow Treaty on strategic arms, which includes neither verification, nor enduring reductions
- Rejection of the verifiability of a treaty that would ban the production of fissile material for weapons (commonly known as FMCT)
- Rejection of the Biological and Toxin Weapons Convention Verification Protocol
- Disavowal of 13 steps toward disarmament agreed upon in Final Document of the 2000 NPT Review Conference

Other evidence cited by critics include certain aspects of the Nuclear Posture Review and nuclear weapons programs such as the Reliable Replacement Warhead. By and large, the Bush Administration has rejected treaty-based approaches in favor of ad-hoc approaches toward reducing the threat of nuclear weapons. Although Article VI of the NPT does not require the conclusion of a treaty, but rather negotiations, it is difficult to see how the nuclear arms race might eventually be halted without legally binding obligations.

Question 2: On page 8 of your testimony, you state, "The atrophy of nuclear manufacturing infrastructure is significant in the United States, but also world wide." Could this problem be solved, with a well defined nuclear regulatory environment which would make it profitable for companies to invest in the nuclear manufacturing infrastructure? If the global market demand for new nuclear plants shifts out, wouldn't the supply of goods to produce these plants also increase?

It is difficult to see how a better-defined nuclear regulatory environment could make it profitable for companies to invest in nuclear manufacturing infrastructure. The Energy Reorganization Act of 1974 split the functions of the Atomic Energy Commission between what is now the Department of Energy, which is responsible for the development and production of nuclear weapons, promotion of nuclear power, and other energy-related work, and assigned the Nuclear Regulatory Commission regulatory work. According to the NRC's strategic plan, its mission is to "license and regulate the Nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment." As such, it would not be within the NRC's purview to make it more profitable for companies in the nuclear industry to invest in manufacturing infrastructure.

There have been cases in the past where agencies of the U.S. government (e.g., the Department of Defense) have provided seed money for industries to collaborate in developing manufacturing infrastructure – the example of Sematech in the 1980s comes to mind. Critics generally view these efforts as attempts at creating an industrial policy.

Private companies obviously do respond to market forces; the prospect for greater profitability will prompt manufacturers to invest in capabilities that will improve their ability to provide goods in short supply. As I noted later in my testimony, "This is not to say that U.S. and global nuclear infrastructure could not expand to meet demand. However, the prospects of it doing so in the timeframe most important for global climate change are slim. One reason is that risk mitigation remains a primary concern for the industry, and this is likely to result in a 'wait and see' approach. As it is, the U.S. nuclear industry continues to press the federal government for additional assistance, including delays in taxing new domestic nuclear industry until national policy objectives for nuclear manufacturing are met; establishing a nuclear work force program; and ensuring American access to other nuclear markets.[2]

Even with significant subsidies, however, the nuclear industry recognizes that a major accident could dampen expansion of nuclear energy. This recognition affects risk assessments and could dampen enthusiasm for major infrastructure investment.

It is noteworthy that Japan Steel Works, which has a waiting list of customer orders over two years long, is only expanding its capacity from 5.5 to 8.5 reactor forging sets per year by 2010. JSW could be hedging its bets that competitors in France, China, South Korea and perhaps the Czech Republic will expand their own capabilities. Or, it could simply be implementing an incremental approach to expansion. Either way, it is not motivated purely by profit.

One factor limiting the easing of key supply bottlenecks like heavy forging is that industries in many countries are no longer involved in heavy manufacturing. This is particularly true in the United States. Another factor is how long it will take to put in place capabilities that will make a difference. The lag time between recognition of a gap, implementing measures to expand supply, and the production of that supply, will vary across resources. For example, although some efforts are already underway to mitigate labor shortages, industry estimates suggest that the nuclear industry will require between 10,000 and 40,000 new workers through 2014.

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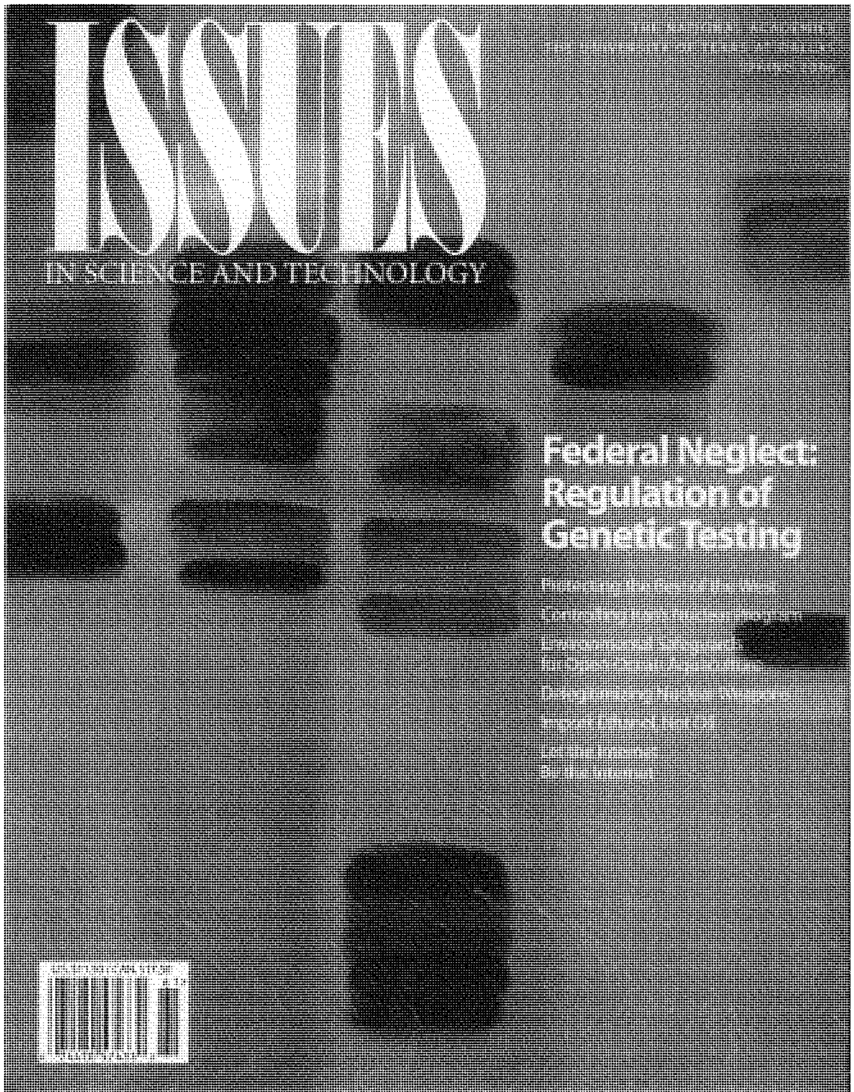
[2] See, for example, John A. Fees, President and Chief Operating Officer, BWX Technologies, Inc., "Reviving America's Industrial Base," *NEI Nuclear Policy Outlook*, October 2006, pp. 5, 8.


ISSUES
IN SCIENCE AND TECHNOLOGY
Federal Neglect: Regulation of Genetic Testing

REAL NUMBERS

ROGER H. BEZDEK
ROBERT M. WENDLING

The U.S. Energy Subsidy Scorecard

In his State of the Union address on January 31, 2006, President Bush called for more research on alternative energy technologies to help wean the country from its oil dependence. The proposal was not surprising: After all, R&D investment has long been a staple of government efforts to deal with national challenges.

Yet despite its prominent role in the national debate, R&D has constituted a relatively small share of overall government investment in the energy sector since 1950. According to our analysis, the federal government invested $644 billion (in 2003 dollars) in efforts to promote and support energy development between 1950 and 2003. Of this, only $60.6 billion or 18.7% went for R&D. It was dwarfed by tax incentives (43.7%).

Indeed, our analysis makes clear that there are diverse ways in which the federal government has supported (and can support) energy development. In addition to R&D and tax policy, it has used regulatory policy (exemption from regulations and payment by the federal government of the costs of regulating the technology), disbursements (direct financial subsidies such as grants), government services (federal assistance provided without direct charge), and market activity (direct federal involvement in the marketplace).

SURPRISES ABOUND. TAX SUBSIDIES OUTPACE R&D SPENDING. SOLAR R&D IS WELL FUNDED. OIL PRODUCTION IS THE BIG WINNER. COAL RECEIVES ALMOST AS MUCH IN TAX SUBSIDIES AS IT DOES FOR R&D. NUCLEAR POWER RECEIVES MUCH LESS THAN COAL FOR R&D.

We found that R&D funds were of primary importance to nuclear, solar, and geothermal energy. Tax incentives comprised 87% of subsidies for natural gas. Federal market activities made up 75% of the subsidies for hydroelectric power. Tax incentives and R&D support each provided about one-third of the subsidies for coal.

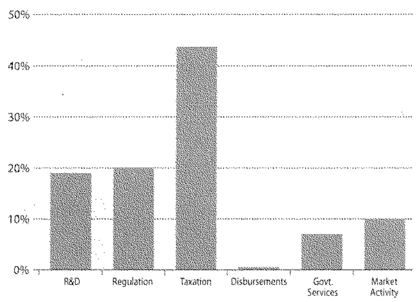
As for future policy, there appears to be an emerging consensus that expanded support for renewable energy technologies is warranted. We found that although the government is often criticized for its failure to support renewable energy, federal investment has actually been rather generous, especially in light of the small contribution that renewable sources have made to overall energy production. As the country maps out its energy plan, we recommend that federal officials pay particular attention to renewable energy investments that will lead to market success and a larger share of total supply.

Roger H. Bezdek (rbezdek@misi-net.com) is president of Management Information Services, Inc., (MISI), an economic research firm in Washington, D.C. Robert Wendling is vice president of MISI.

The power of tax incentives

Policies that allowed energy companies to forego paying taxes dwarfed all other kinds of federal incentives for energy development. Tax policy accounted for $281.3 billion of total federal investments between 1950 and 2003, with the oil industry receiving $155.4 billion and the natural gas industry $75.6 billion.

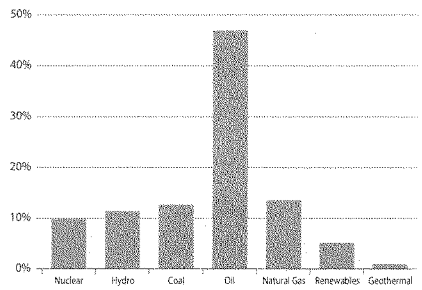
Distribution of Federal Energy Incentives by Type, 1950-2003



The dominance of oil

The conventional wisdom that the oil industry has been the major beneficiary of federal financial largess is correct. Oil accounted for nearly half ($302 billion) of all federal support between 1950 and 2003.

Distribution of Federal Energy Incentives among Energy Sources, 1950-2003

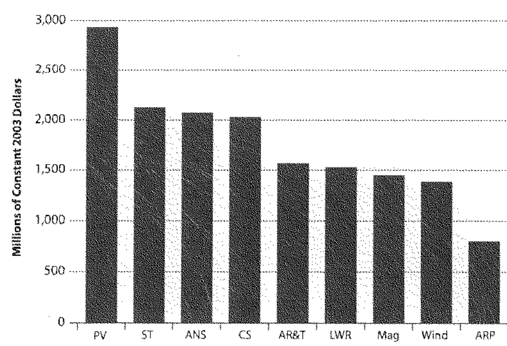


Renewable energy not neglected

The perception that the renewable industry has been historically shortchanged is open to debate. Since 1950, renewable energy (solar, hydropower, and geothermal) has received the second largest subsidy—$111 billion (17%), compared to $63 billion for nuclear power, $81 billion for coal, and $87 billion for natural gas.

LEGEND: PV: Photovoltaic (renewable); ST: Solar Thermal (renewable); ANS: Advanced Nuclear Systems; CS: Combustion Systems (coal); AR&T: Advanced Research and Technology (coal); LWR: Light Water Reactor (nuclear); Mag: Magnetohydrodynamics (coal); Wind: Wind Energy Systems (renewable); ARP: Advanced Radioisotope Power Systems (nuclear).

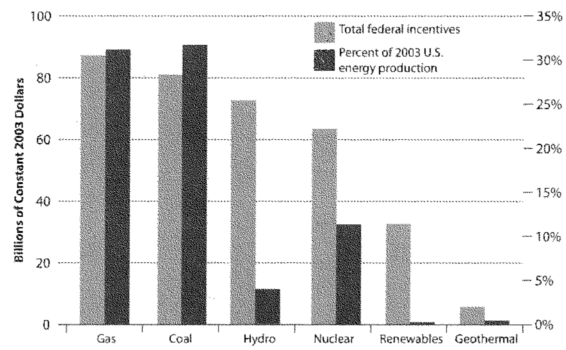
Federal R&D Expenses for Selected Technologies, 1976-2003



Cost/benefit mismatch

Considerable disparity exists between the level of incentives received by different energy sources and their current contribution to the U.S. energy mix. Although oil has received roughly its proportionate share of energy subsidies, nuclear energy, natural gas, and coal may have been undersubsidized, and renewable energy, especially solar, may have received a disproportionately large share of federal energy incentives.

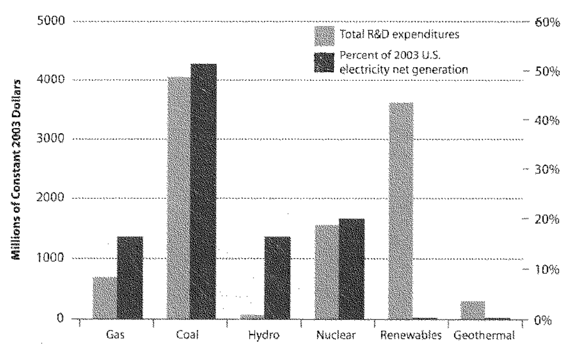
Federal Energy Incentives through 2003 Compared to Share of 2003 U.S. Energy Production



Skewed R&D expenditures

Recent federal R&D expenditures bear little relevance to the contributions of various energy sources to the total energy mix. For example, renewable sources excluding hydro produce little energy or electricity but received $3.7 billion in R&D funds between 1994 and 2003, whereas coal, which provides about one-third of U.S. energy requirements and generates more than half of the nation's electricity, received just slightly more in R&D money ($3.9 billion). Nuclear energy, which provided 10% of the nation's energy and 20% of its electricity, was also underfunded, receiving $1.6 billion in R&D funds.

Federal R&D Energy Expenditures, 1994-2003, Compared to 2003 U.S. Electricity Production



Source of all graphs: Management Information Services, Inc.

CONGRESSIONAL BUDGET OFFICE
U.S. Congress
Washington, DC 20515

Douglas Holtz-Eakin, Director

July 27, 2005

Honorable Joe Barton
Chairman
Committee on Energy
and Commerce
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

Based on a preliminary review of the July 27, 2005, conference agreement for H.R. 6, the Energy Policy Act of 2005, CBO estimates that enactment would increase direct spending by $2.2 billion over the 2006-2010 period and by $1.6 billion over the 2006-2015 period. CBO and the Joint Committee on Taxation estimate that the legislation would reduce revenues by $7.9 billion over the 2005-2010 period and by $12.3 billion over the 2005-2015 period. The estimated direct spending and revenue effects of the act are summarized below. A table with additional details is enclosed.

	By Fiscal Year, in Millions of Dollars											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Estimated Budget Authority	0	141	745	607	511	279	-63	-105	-153	-165	-159	1,638
Estimated Outlays	0	231	615	606	490	298	-44	-106	-154	-166	-160	1,610
Estimated Revenues	40	-588	-1,827	-2,069	-1,645	-1,787	-1,321	-840	-686	-611	-971	-12,305

SOURCES: CBO and Joint Committee on Taxation.

In addition, implementing H.R. 6 would affect spending subject to appropriation action. CBO has not completed an estimate of the potential discretionary costs of the legislation.

Honorable Joe Barton
Page 2

The conference agreement for H.R. 6 contains several preemptions of state authority, which are defined as intergovernmental mandates by the Unfunded Mandates Reform Act (UMRA). CBO estimates, however, that the total cost of complying with the intergovernmental mandates would not exceed the annual threshold established in that act ($62 million in 2005, adjusted annually for inflation).

H.R. 6 contains numerous mandates as defined in UMRA that would affect the private sector. Based on our review of the act, CBO expects that the mandates contained in the legislation's titles on ethanol and motor fuels (title XV), nuclear energy (title VI), electricity (title XII), and energy efficiency (title I) would have the greatest impact on private-sector entities. CBO estimates that the aggregate cost of private-sector mandates in the legislation would exceed the annual threshold established in UMRA ($123 million in 2005, adjusted annually for inflation).

If you wish further details on this estimate, we will be pleased to provide them. The CBO staff contact is Lisa Cash Driskill.

Sincerely,

Douglas Holtz-Eakin
Director

Enclosure: Table of Direct Spending and Revenue Effects by Title

cc: Honorable John D. Dingell
Ranking Member

Identical letter sent to the Honorable Pete V. Domenici.

July 27, 2005

ESTIMATED IMPACT OF THE CONFERENCE AGREEMENT FOR H.R. 6 ON DIRECT SPENDING AND REVENUES

	By Fiscal Year, in Millions of Dollars												
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2005-2010	2005-2015
CHANGES IN DIRECT SPENDING													
Title I - Energy Efficiency													
Estimated Budget Authority	0	0	301	307	314	320	327	334	341	348	355	1,242	2,947
Estimated Outlays	0	0	256	306	313	319	326	333	340	347	354	1,194	2,894
Title II - Renewable Energy													
Estimated Budget Authority	0	7	7	7	7	7	2	2	2	2	2	35	45
Estimated Outlays	0	7	7	7	7	7	2	2	2	2	2	35	45
Title III - Oil and Gas													
Coastal Impact Assistance													
Budget Authority	0	0	250	250	250	250	0	0	0	0	0	1,000	1,000
Estimated Outlays	0	0	250	250	250	250	0	0	0	0	0	1,000	1,000
Other Provisions													
Estimated Budget Authority	0	33	38	45	50	52	46	38	41	38	36	218	417
Estimated Outlays	0	23	33	45	50	52	46	38	41	38	36	203	402
Subtotal, Title III													
Estimated Budget Authority	0	33	288	295	300	302	46	38	41	38	36	1,218	1,417
Estimated Outlays	0	23	283	295	300	302	46	38	41	38	36	1,203	1,402
Title IV - Coal Provisions													
Estimated Budget Authority	0	1	1	1	1	1	1	1	1	1	1	5	10
Estimated Outlays	0	1	1	1	1	1	1	1	1	1	1	5	10
Title IX - Research and Development													
Budget Authority	0	0	50	50	50	50	50	50	50	50	50	200	450
Estimated Outlays	0	0	10	30	50	50	50	50	50	50	50	140	390
Title XII - Electricity													
Electric Reliability Standards													
Estimated Budget Authority	0	100	102	104	106	108	110	113	115	117	120	520	1,095
Estimated Outlays	0	100	102	104	106	108	110	113	115	117	120	520	1,095
Third-party Financing of Power Marketing Administration Transmission Projects													
Estimated Budget Authority	0	0	50	0	50	0	0	0	0	0	0	100	100
Estimated Outlays	0	0	10	20	30	20	20	0	0	0	0	80	100
Subtotal, Title XII													
Estimated Budget Authority	0	100	152	104	156	108	110	113	115	117	120	620	1,195
Estimated Outlays	0	100	112	124	136	128	130	113	115	117	120	600	1,195

Continued

July 27, 2005

ESTIMATED IMPACT OF THE CONFERENCE AGREEMENT FOR H.R. 6 ON DIRECT SPENDING AND REVENUES
Continued

	By Fiscal Year, in Millions of Dollars												
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2005-2010	2005-2015
CHANGES IN DIRECT SPENDING (Continued)													
Title XIII - Tax													
Estimated Budget Authority	0	0	-7	-24	-6	0	0	0	0	0	0	-37	-37
Estimated Outlays	0	0	-7	-24	-6	0	0	0	0	0	0	-37	-37
Title XV - Ethanol and Motor Fuels													
Estimated Budget Authority	0	0	-47	-133	-311	-509	-599	-643	-703	-721	-723	-1,000	-4,389
Estimated Outlays	0	0	-47	-133	-311	-509	-599	-643	-703	-721	-723	-1,000	-4,389
Title XVII - Incentives for Innovative Technologies													
Estimated Budget Authority	0	0	0	0	0	0	0	0	0	0	0	0	0
Estimated Outlays	0	100	0	0	0	0	0	0	0	0	0	100	100
Total, Direct Spending													
Estimated Budget Authority	0	141	745	607	511	279	-63	-105	-153	-165	-159	2,283	1,638
Estimated Outlays	0	231	615	606	490	298	-44	-106	-154	-166	-160	2,240	1,610
CHANGES IN REVENUES													
Title XII - Electricity													
Estimated Revenues	0	75	77	78	80	81	83	84	86	87	89	391	820
Title XIII - Tax [a]													
Estimated Revenues	40	-663	-1,865	-1,931	-1,286	-1,207	-1,162	-924	-772	-698	-1,060	-6,915	-11,525
Title XV - Ethanol and Motor Fuels													
Estimated Revenues	0	0	-39	-216	-439	-661	-242	0	0	0	0	-1,355	-1,597
Total Changes in Revenues	40	-588	-1,827	-2,069	-1,645	-1,787	-1,321	-840	-686	-611	-971	-7,876	-12,305

NOTE: Numbers may not add up to totals because of rounding.

a. Estimate supplied by the Joint Committee on Taxation.

Nuclear power: economics and climate-protection potential

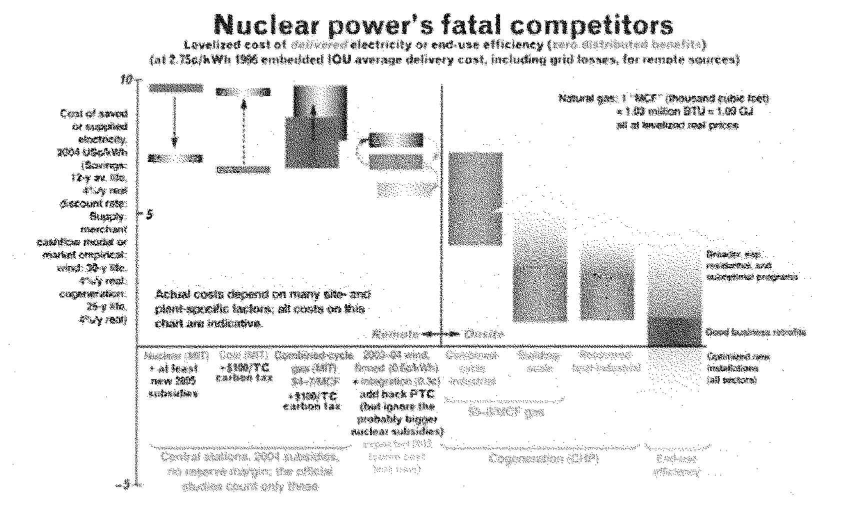
AMORY B. LOVINS, CEO, ROCKY MOUNTAIN INSTITUTE, WWW.RMI.ORG

11 September 2005, updated 6 January 2006

Abstract

Nuclear power is often described as a big, fast, and vital energy option—the only practical and proven source big and fast enough to do much to abate climate change. Yet industry and government data tell the opposite story. Nuclear power worldwide has less installed capacity and generates less electricity than its decentralized no- and low-carbon competitors—one-third renewables (excluding big hydroelectric dams), two-thirds fossil-fueled combined-heat-and power. In 2004, these rivals added nearly three times as much output and six times as much capacity as nuclear power added; by 2010, industry forecasts this sixfold ratio to widen to 136–184 as nuclear orders fade, then nuclear capacity gradually disappears as aging reactors retire. These comparisons don't count more efficient use of electricity, which isn't being tracked, but efficiency gains *plus* decentralized sources now add at least ten times as much capacity per year as nuclear power.

All the meager nuclear orders nowadays come from centrally planned electricity systems, because despite strong official support and greatly increased U.S. subsidies, nuclear power's bad economics make it unfinanceable in the private capital market. Official studies compare new nuclear plants only with coal- or gas-fired central stations. But all three kinds of central stations are uncompetitive with windpower and some other renewables, combined-heat-and power (cogeneration), and efficient use of electricity, all compared on a consistent accounting basis:



Efforts to make nuclear plants appear competitive with central coal or gas plants by enlarging nuclear subsidies or taxing carbon dioxide (CO_2) emissions are futile, because windpower and some other renewables, cogeneration, and technologies for wringing more work from each kilowatt-hour will still win in the marketplace—by margins far too great for new reactor technologies or further-streamlined siting and regulation to overcome, even in principle.

Empirical data also confirm that these competing technologies not only are being deployed an order of magnitude faster than nuclear power, but ultimately can become far bigger. In the U.S., for example, full deployment of these very cost-effective competitors (conservatively excluding all renewables except windpower, and all cogeneration that uses fresh fuel rather than recovered waste heat) could provide ~13–15 times nuclear power's current 20% share of electric generation—all without significant land-use, reliability, or other constraints. The claim that "we need all energy options" has no analytic basis and is clearly not true; nor can we afford all options. In practice, keeping nuclear power alive means diverting private and public investment from the cheaper market winners—cogeneration, renewables, and efficiency—to the costlier market loser.

Nuclear power is an inherently limited way to protect the climate, because it makes electricity, whose generation releases only two-fifths of U.S. CO_2 emissions; it must run steadily rather than varying widely with loads as many power plants must; and its units are too big for many smaller countries or rural users. But nuclear power is a still less helpful climate solution because it's about the slowest option to deploy (in capacity or annual output added per year)—as observed market behavior confirms—and the most costly. Its higher cost than competitors, per unit of net CO_2 displaced, means that every dollar invested in nuclear expansion will *worsen* climate change by buying less solution per dollar. Specifically, every $0.10 spent to buy a single new nuclear kilowatt-hour (roughly its delivered cost, including its 2004 subsidies, according to the authoritative 2003 MIT study's findings expressed in 2004 $) could instead have bought 1.2 to 1.7 kWh of windpower ("firmed" to be available whenever desired), 0.9 to 1.7+ kWh of gas-fired industrial or ~2.2–6.5+ kWh of building-scale cogeneration (adjusted for their CO_2 emissions), 2.4–8.9 kWh of waste-heat cogeneration burning no incremental fuel (more if credited for burning less fuel), or from several to 10+ kWh of electrical savings from more efficient use. In this sense of "opportunity cost"—any investment foregoes other outcomes that could have been bought with the same money—nuclear power is far *more* carbon-intensive than a coal plant.

For these reasons, expanding nuclear power would both reduce and retard the desired decrease in CO_2 emissions. Claims that more nuclear plants are needed to protect Earth's climate cannot withstand documented analysis nor be reconciled with actual market choices. If you worry about climate change, it is essential to buy the fastest and most effective climate solutions. Nuclear power is just the opposite. Claimed broad "green" support for nuclear expansion, if real (which it's not), would therefore be unsound and counterproductive. And efforts to "revive" this moribund technology, already killed by market competition, can only waste time and money.

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Nuclear power: economics and climate-protection potential[1]

AMORY B. LOVINS, CEO, ROCKY MOUNTAIN INSTITUTE, WWW.RMI.ORG

11 September 2005, updated 6 January 2006

The race is to the fleet

National energy policy currently rests on and reinforces an illusion. Ingenious advocates conjure up a vision of a vibrant nuclear power industry poised for rapid growth, with no serious rivals in sight, and with a supposedly vital role in mitigating the threat of climate change.[2] A credulous press accepts this supposed new reality and creates an echo-box to amplify it. Some politicians and opinion leaders endorse it. Yet industry data reveal the opposite: a once significant but now dying industry already fading from the marketplace (Figs. 1–2, pp. 2–3), overtaken and humbled by swifter rivals. In 2004 alone, Spain and Germany each added as much wind capacity—two billion watts (GW)—as nuclear power is adding worldwide in each year of this decade.[3] Around 2005–2006, nuclear construction starts may add less capacity than solar cells. And in the year 2010, nuclear power is projected by the International Atomic Energy Agency to add 136–184× less net capacity than the decentralized electricity industries project their technologies will add.[4]

That astonishing ratio will increase further, not only because micropower is growing so fast from a base that's already bigger than nuclear power, but also because the aging of nuclear plants is about to send global installed nuclear capacity into a long decline. Mycle Schneider and Antony Froggatt[5] have shown that the world's average reactor is 21 years old, as is the average of the 107 units already permanently retired. Their analysis of reactor demographics found that if the reactors now operating run for 40 years (32 under German law), then during the next decade, 80 more will retire than are planned to start up; in the following decade, 197; in the following, 106; and so on until they're all gone around 2050. Even if China built 30 GW of nuclear plants by 2020, it'd replace only a tenth of the overall worldwide retirements. No other nation contemplates anywhere such an ambitious effort, and even China seems unlikely to complete that proposed addition as its power market becomes more competitive and its polity more transparent: nuclear power today is a Treasury-financed state monopoly whose power sales are guaranteed.

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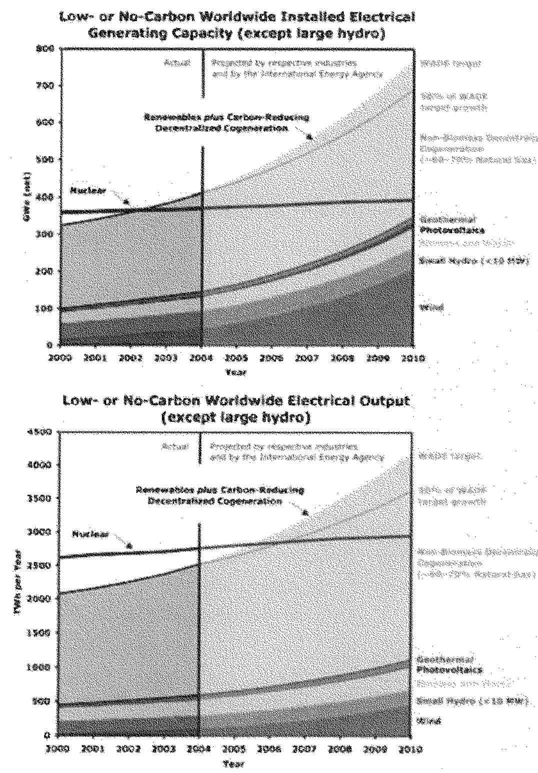
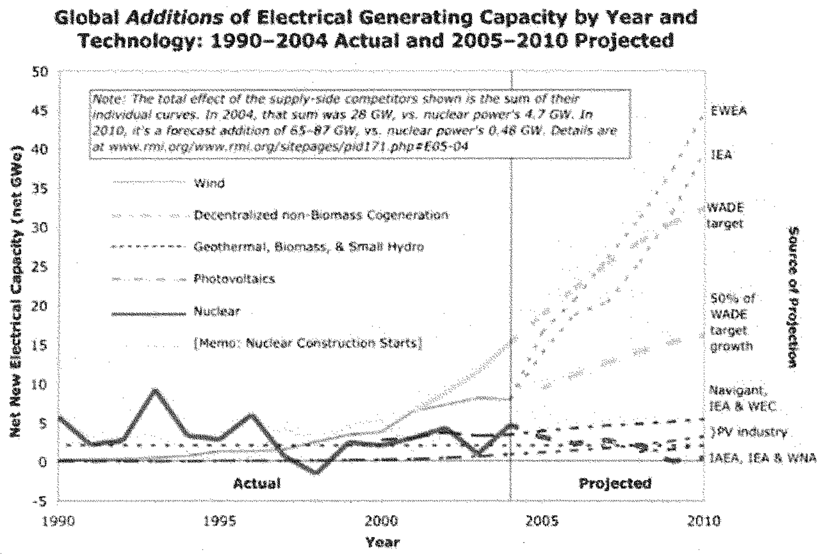
[1] This paper is adapted, slightly updated, and reorganized from the author's "Nuclear power: economic fundamentals and potential role in climate change mitigation," submitted 31 August 2005 to the California Energy Commission in support of the author's 16 Aug. 2005 invited testimony to CEC's Committee Workshop on Issues Concerning Nuclear Power (Integrated Policy Report 2005, docket 04-IEP-1J): www.rmi.org/sitepages/pid171.php#E05-09.
[2] For least-cost solutions, see A.B. Lovins, "More Profit With Less Carbon," *Sci. Amer.* **293**(III):74–83 (Sept. 2005), www.sciam.com/media/pdf/Lovinsforweb.pdf and www.rmi.org/sitepages/pid173.php#C05-05. A broader list, equating nominal nuclear growth with modest efficiency gains, is S. Pacala & R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* **305**:968–972 (2004).
[3] The Spanish government just raised its wind target from 13 GW in 2010 to 20 GW in 2011 (15% of total capacity).
[4] RMI analysis graphed in Figs. 1–2 (p. 2) and documented in a methodological note, spreadsheet, and references at www.rmi.org/sitepages/pid171.php#E05-04. Dr. Eric Martinot (ex-LBNL, now at Tsinghua University) has independently reached similar conclusions: *Renewables 2005: Global Status Report*, Nov. 2005, www.ren21.net.
[5] M. Schneider & A. Froggatt, "On the Way Out," *Nucl. Eng. Intl.*, June 2005, pp. 36–38; *The World Nuclear Industry Status Report 2004*, www.greens-efa.org/pdf/documents/greensefa_documents_106_en.pdf, Dec. 2004.

Fig. 1. Worldwide, low- and no-carbon decentralized sources of electricity surpassed nuclear power in capacity in 2002 and in annual output in 2005. In 2004, they added 5.9× as much capacity and 2.9× as much annual output as nuclear power added. (Output lags capacity by 3 y because nuclear plants typically run more hours per year than windpower and solar power — though other renewables, like the fossil-fueled cogeneration shown, have high average capacity factors. Large hydro, over 10 MWe, isn't shown in these graphs nor included in this paper's analysis.) The post-2004 forecasts or projections shown are industry's, and are imprecise but qualitatively clear. The E.U. aims to get 12% of its energy and ~21% of electricity from renewables by 2010, when the European Wind Energy Association projects 75 GW of installed European windpower. China targets decentralized renewables to grow from 37 GW in 2004 to 60 GW, a tenth of total capacity, in 2010. Two-thirds of the decentralized non-nuclear capacity shown is fossil-fueled co- or trigeneration (making power + heat + cooling); its total appears to be conservatively low (e.g., *no steam turbines outside China), and it is ~60–70% gas-fired, so its overall carbon intensity is probably less than half that of the separate power stations and boilers (or furnaces) that it has displaced; the normal range would be ~30–80% less carbon.*



Thus the global nuclear enterprise has been definitively eclipsed by its decentralized competitors, even though they received 24× smaller U.S. federal subsidies per kWh in FY1984[6] and are often barred from linking fairly with the grid. The runaway nature of the competitors' market victory is evident from Fig. 2 (the first derivative of the upper graph in Fig. 1), showing global *additions* of electric generating capacity by year and by technology, all derived from the same industry data.

Fig. 2. Nuclear power's allegedly "small, slow" decentralized low- and no-carbon supply-side competitors are growing far faster, and are taking off rapidly while nuclear additions fade. Note also the light dotted line of nuclear construction starts, a leading indicator. (It stops in 2004 because future plans are uncertain; due to lead times, this won't affect 2010 completions.)



Moreover, these striking graphs show only the supply side. Electric end-use efficiency may well have *saved* even more electricity and carbon. Most countries don't track it, so it can't be rigorously plotted on the same graph, but clearly it's a large and expanding resource. As one rough indication, the 1.98% drop in U.S. electric intensity in 2003 (whatever its causes) would correspond, at constant load factor, to saving 13.8 GW_p—6.3× U.S. utilities' declared 2.2 GW_p from demand-side management—and the 2004 intensity drop of 2.30% would have saved >16 GW_p (plus 1 GW_p/y from utility load management actually exercised). The U.S. uses only one-fourth of the world's electricity, so it's hard to imagine that global savings don't rival or exceed global

[6] See the detailed analysis in RMI Publications #CS85-7 and –22 (hard copy orderable from www.rmi.org). FY1984 federal energy subsidies exceeded $50b/y. Per unit of energy or savings delivered, they varied by nearly 200-fold between more and less favored technologies. Electricity got 65%—48× as much per kWh as efficiency. Subsidies may be larger and more lopsided today, especially after the 2005 Energy Policy Act. See Doug Koplow's invaluable http://earthtrack.net/earthtrack/index.asp?page_id=177&catid=66 and his new Nov. 2005 estimate (note 63 below).

additions of distributed generating capacity (24 GW in 2003, 28 GW in 2004).[7] Thus these *total* global additions must exceed annual nuclear capacity growth by upwards of tenfold.

Together, then, *the low- or no-carbon supply- and demand-side resource deployments actually occurring in the global marketplace are already bigger than nuclear power and are growing an order of magnitude faster. This is no accident. It simply reflects nuclear power's fundamental uncompetitiveness*—the attribute that, more than any other, makes new nuclear plants unfinanceable in the private capital market.[8] Indeed, the trickle of orders observed worldwide all come from centrally planned electricity systems: nuclear plants aren't bid into auctions nor chosen by an open decision process.[9] But the key question is...uncompetitive compared to what?

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[7] The focus of nearly all EIA data (probably >99%) on the supply side—which provided only 22% of the increase in U.S. energy services during 1996–2005—creates a dangerous "blind spot" that helps make U.S. energy policy in 2005 eerily similar to that of the early 1980s. President Reagan then sought, with modest success, to boost centralized supply expansions with subsidies and siting preëmption. But thanks to Ford/Carter policies, reinforced by the 1979 second oil price shock, the market was quietly producing a gusher of efficiency. For a time, these two trains, one using less energy and the other producing more, sped down the same track in opposite directions. In 1984–85, they met head-on. That almighty trainwreck glutted supplies, crashed prices, and bankrupted suppliers. Efficiency was among the victims too: attention wandered, and Americans, having spent twenty years learning how to save energy, spent the next twenty years forgetting. Soon we may see this very bad movie all over again. Persistently high and jittery oil prices are eliciting major vehicle and biofuel innovations. Micropower is booming. Primary-energy and electric intensities have respectively been falling 2.3 and 1.5%/y since 1996, providing 78% of the increase in delivered energy services. The statistical invisibility of that 78% of the action to policymakers and investors risks repeating, on a larger scale, the ~$100b of losses recently incurred by merchant combined-cycle-plant construction to meet imaginary demand (inferred from a misinterpretation of California's 2000–01 power crisis—see www.rmi.org/images/other/Energy/E01-20_CwealthClub.pdf—plus the Western Fuels Association-funded lie, spread then and now by Mark Mills and Peter Huber, that information technology is a huge and rapidly growing electricity-guzzler; *cf.* http://enduse.lbl.gov/Projects/InfoTech.html). Most of those merchant builders are now deservedly bankrupt. Yet the basic lessons of this episode, like the broader mid-1980s energy-market crash, remain seemingly unlearned. Markets do work. Demand does respond to price. Supply and demand do equilibrate. Small, fast technologies—mass-produced modules with inherently short lead times, deployable by diverse market actors without specialized institutions—can reach customers before big, slow ones can, grabbing revenue streams from energy suppliers. In the early 1980s, efficiency won the race for revenue; today, it's efficiency plus micropower—both far cheaper, more attractive, and with more mature market channels than in the early 1980s. Then, federal policy drove efficiency gains; today, the drivers are smart corporate decisions and state policies. Different details can yield nearly identical results, because these powerful forces continue to operate whether we perceive them or not. In this decade as in the 1980s, those who believe they are helping the nuclear, coal, and hydrocarbon industries may prove to be their worst enemies, while those whom some in those industries might consider their foes may turn out to have done the most to try to save them from federally sponsored disaster. The main hope of averting a mid-1980s-like crash lies in investors' prudence and in the more balanced data, policies, and investment habits fostered by states with policy frameworks based on market processes, not desired outcomes.

[8] S. Kidd (Head of Strategy & Research, World Nuclear Association), "How can new nuclear power plants be financed?," *Nucl. Eng. Intl.* News, 1 Sept. 2005, www.neimagazine.com/story.asp?storyCode=2030770, concludes that despite strong support from the U.S. and other national governments, "financing new nuclear build in the financial markets will prove very challenging." This is due as much to painful experience as to prospective analysis: as Mark Twain put it, "A cat which sits on a hot stove lid will not do so again, but neither will it sit on a cold one."

[9] P. Bradford, "Nuclear Power's Prospects in the Power Markets of the 21st Century," 2005, Nonproliferation Education Center, www.npec-web.org/projects/Essay050131NPTBradfordNuclearPowersProspects.pdf. The Finnish Parliament's recent choice of a nuclear plant doesn't contradict this claim—the secretively handled supporting study used favorable assumptions (*e.g.* 5%/y real discount rate, €1,794/kW capital cost including interest during construction); modern decentralized supply- and demand-side competitors weren't seriously considered; the buyer was a tax-exempt TVA-like nonprofit entity with captive customers, economically equivalent to a long-term power-purchase contract, with no private capital at risk; the plant was mainly financed by 2.6%/y loans provided under unprecedent-

Comparing nuclear power with all *its main competitors—not just the costliest ones*

Standard studies compare a new nuclear plant only with a central power plant burning coal or natural gas. They conclude that new nuclear plants' marked disadvantage in total cost might be overcome if their construction became far cheaper, or if construction and operation were even more heavily subsidized, or if carbon were heavily taxed, or if (as nuclear advocates prefer) all of these changes occurred. *But those central thermal power plants are all the wrong competitors. None* of them can compete with windpower (and some other renewables), let alone with two far cheaper resources: cogeneration of heat and power, and efficient use of electricity. The MIT study (note 57), like every other widely quoted study of nuclear economics, *simply didn't examine these competitors*[10] on the grounds of insufficient time and funding. Thus the distinguished authors' "judgment" that nuclear power merits continued subsidy and support, because we'll supposedly need all energy options, is only their personal opinion unsupported by analysis. The author has verified this widely overlooked interpretation with three of the MIT study's leaders.

To illuminate why the standard studies' consistent omission of non-central-plant alternatives matters, Fig. 3 summarizes the findings of a fair, conservative, simple, and transparent analysis comparing new nuclear plants with an expanded range of widely and abundantly available competitors, all expressed on the same accounting basis—real levelized[11] cost (over a lifetime appropriate for each technology) per *delivered* kilowatt-hour. The methodology and assumptions are in the Appendix on pp. 18–25. Like Fig. 1–2's industry projections for various technologies, one can quibble about many details of the numbers, but their qualitative import is incontrovertible: as the Italian proverb says, *L'aritmetica non è opinione* (arithmetic is not an opinion).

The left side of Fig. 3 first shows the MIT study's nuclear results and its potential "unproven but plausible" nuclear cost reductions under "optimistic" assumptions. Those cost reductions would be a very ambitious outcome for the levels of subsidy and compliant regulation added by the federal Energy Policy Act of 2005. On the contrary, Standard & Poor's has concluded[12] that the Act's nuclear provisions probably won't much reduce nuclear developers' market cost of capital, because most of the key nuclear risks that concern the capital market remain unaddressed. (The bleak competitive prospects for nuclear power revealed by the rest of the graph should deter investment even more, but S&P probably didn't consider that.)

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ed arrangements by German and French parastatals to support those nations' vendors Siemens and Areva (a deal now under legal challenge before the European Commission as an illegal subsidy); and the plant itself, a reported ~€1,875–2,000/kW turnkey bid in 2003 (then worth ~$2,500/kWe in 2004 $), is clearly a loss-leader bid by desperate vendors: an identical unit proposed for France is reportedly expected to cost at least 25% more. Finland's Dec. 2005 energy policy omits nuclear (www.neimagazine.com/story.asp?sectionCode=132&storyCode=2032999).

[10] The MIT study's Executive Summary states: "We did not analyze other [*i.e.*, non-central-plant] 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." However, the study's authors drew such a conclusion in the very next sentence: "In our judgment, it would be a mistake to exclude any of these four options at this time." The key issue, of course, is what "exclude" means in practice. Hardly anyone is suggesting that nuclear power not be allowed, on principle, to be offered in the marketplace. Rather, the question is whether it should be given further subsidies and other advantages (as Congress just did) to try to keep it alive despite its manifest inability to compete unaided. Such assistance inevitably comes at competitors' expense.

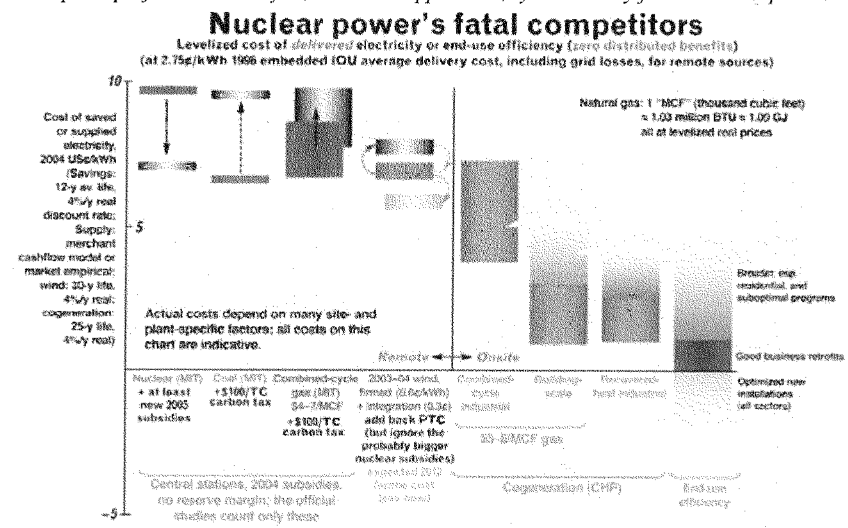
[11] A stream of annual levelized costs has the same present value as an actual time-varying stream of costs.

[12] *Nucl. Eng. Intl.* News, "Energy Policy Act 2005 has limited credit implications: S&P," 18 August 2005, www.neimagazine.com/story.asp?sc=2030540&ac=7969460. See also Kidd, note 8.

Next from the left, Fig. 3 shows the MIT study's conclusions about central coal and gas plants. Heavy carbon taxes ($100 per tonne of carbon) could raise new-coal-electric costs nearly to current new-nuclear costs, based on the 2004 levels of subsidies baked into the numbers shown for both. Alternatively, a very generous interpretation of the effects of the new nuclear support legislation could help new nuclear plants to approach the current market prices of coal-fired electricity. Gas combined-cycle plants would be less affected by carbon taxes, due to their higher thermal efficiency and gas's lower carbon content, but are likelier to see higher fuel prices.

The intended effect of the 2005 Energy Policy Act provisions favoring nuclear construction, plus a very high carbon tax, would be to try to reverse nuclear power's current market disadvantage *vs.* its central-plant competitors. But the rest of Fig. 3 suggests that the immense lobbying efforts that have gone and will continue to go into trying to interchange the relative costs of these three central-plant options will prove futile, because *all three are grossly uneconomic* compared with decentralized supply-side and demand-side competitors, shown on a consistent accounting basis.

Fig. 3. The canonical 2003 MIT study, whose results continue to look conservative, says a new nuclear plant would produce electricity for about 7.0¢/kWh (2004 $). Adding the cost of delivery to the customers (at least 2.75¢/kWh) raises this busbar cost to 9.8¢ per delivered *kWh. The decentralized competitors' delivered costs shown are typically observed for well-executed U.S. marketplace projects. The analysis, detailed on pp. 18–25, systematically favors nuclear power.*



This comparison is conservative in many ways, including:

- The large pre-2005 subsidies to nuclear power and other central stations are baked into the costs graphed, but the Production Tax Credit for windpower (in 2004 $, 1.84¢/kWh for ten years—see note 64 below) is optionally backed out. Most independent students estimate nuclear subsidies' value at well above wind's PTC (see p. 20).[13] Indeed, that PTC was meant to offset the larger permanent subsidies to central-plant competitors. Now that nuclear power has been given its own PTC, this effort to level at least part of the playing-field has again been re-tilted.

- Windpower is assumed to incur a 0.9¢/kWh firming and integration cost (generally well above actual), but no corresponding reserve-margin or spinning-reserve cost is counted for nuclear or other central plants, although their large unit size makes them tend to fail in larger chunks and their forced outages often last longer. *Every* source of electricity is intermittent, differing only in why they fail, how often, how long, and how predictably.
- Marginal costs of delivering power from all the remote sources are understated by using nine-year-old average embedded historic costs—and for investor-owned utilities (IOUs), which generally have denser loads than the quarter of U.S. demand that they don't serve.
- Other than heat recovery by cogeneration, *none* of the 207 "distributed benefits" documented in RMI's *Economist* 2002 book of the year *Small Is Profitable* is counted—yet they typically increase the economic value of distributed resources (supply- *and* demand-side) by an order of magnitude, swamping all the cost differences shown.[14]
- The case made by the static cost comparisons shown—with short-term projections only for nuclear and windpower—becomes far stronger when one considers cost *trends*. For fundamental and durable reasons, as discussed on pp. 20–22 for windpower, efficiency and renewables are getting rapidly cheaper.[15] (Page 21 also notes that some wind projects *today* have half the lowest cost assumed here.) The end-use efficiency potential, too, gets ever bigger and cheaper as new and improved technologies, offshore and high-volume manufacturing, competition, streamlined delivery, and (above all) integrative design outpace the depletion of potential savings.[16] The speed of and further scope for all these competitors' improvements far exceeds any plausible improvements for nuclear power.

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[13] "Energy Subsidies in the European Union: A brief overview," European Environment Agency (Copenhagen), 2004, http://reports.eea.eu.int/technical_report_2004_1/en/Energy_FINAL_web.pdf, notes that during the first 15 years' industrial development, the U.S. subsidized nuclear power ~30× as heavily as windpower per kWh produced. UNDP estimates that only ~8% of the past 30 years' world energy R&D subsidies went to *all* renewables combined.

[14] A.B. Lovins *et al.*, *Small Is Profitable*, RMI, 2002, www.smallisprofitable.org, fully documents these "distributed benefits." The biggest come from financial economics—lower risk with small fast modules, avoided fuel-price volatility risk (worth ~1–2¢/kWh for windpower), etc.—and the next biggest from electrical engineering.

[15] See slides 9–10 in the .PPT at www.rmi.org/sitepages/pid171.php#E05-09. Some argue that onshore wind has very limited potential because of siting conflicts (in the U.K., a leading nuclear advocate, Sir Bernard Inghams, reportedly boasted he had fomented two-thirds of these: P. Toynbee, *Guardian*, 23 Aug. 2003). Yet this objection seems unsound because most lower-48-states onshore wind resources are on very low-value land whose few residents are generally eager for such projects: Native American Reservations just in the Dakotas have ~300 GW of high-class windpower potential, and nearly all High Plains farmers and ranchers welcome the royalties. People who think onshore sites will be very limited then extrapolate from odd cases like the Cape Cod windpower controversy to argue that offshore wind is equally likely to be blocked by siting conflicts. It seems more plausible that offshore siting issues—coastal visibility, navigation and fishing compatibility, cable and structural cost, marine engineering—will be offset by free land and by stronger, steadier wind regimes (less surface roughness, hence lower gustiness).

[16] For example, Jim Rogers PE notes that in *nominal* dollars, compact fluorescent lamps cost >$20 in 1983, $2–5 in 2003 (with ~1b/y volume); electronic T-8 lighting ballasts, >$80 in 1990, <$20 in 2003 (while producing 30% more light per watt); industrial variable-speed drives, ~60–70% cheaper since 1990; window air conditioners, 54% cheaper and 13% more efficient than in 1993; low-emissivity window coatings, ~75% cheaper than five years ago; and direct/indirect luminaires have gone from a premium to the cheapest option. Meanwhile, the biggest New England lighting retrofitter has halved the normal contractor price through more streamlined delivery. EPRI's VP Clark Gellings agrees the "negawatt" resource is becoming cheaper and bigger (personal comm., 4 July 2005).

Fig. 3 shows a huge gap between the cost of delivered electricity from new central plants and the cost of delivered or saved electricity from just the three categories of decentralized resources included—not counting the many other renewables now succeeding in the market (Figs. 1–2).[17] That gap is so big that *nothing can save nuclear power from its dismal economics*. Not regulatory change: the U.S. industry has already enjoyed a regulatory system of its own design for a quarter-century with zero orders. Not new kinds of reactors: if the nuclear steam supply system were *free*, the rest of the plant would still cost too much. Not carbon taxes: they'd help efficiency and renewables equally and cogeneration at least half as much. Not hydrogen: nuclear energy is a hopelessly costly way to split water.[18] And not the roughly $13 billion of new nuclear subsidies just added: history teaches us that markets ultimately prevail. Indeed, history also suggests that whenever a President makes nuclear power the centerpiece of energy policy and tries to smooth its way, the resulting relaxation of market discipline ultimately harms its prospects.[19]

Comparative speed

Although nuclear power is clearly the costliest resource in Fig. 3, might it have other advantages that from a public policy perspective could justify paying a premium for it? Clearly freedom from carbon emissions[20] isn't sufficient, because renewables and end-use efficiency provide the same attribute at much lower cost, and cogeneration does so partially; a fossil-fueled cogenerator that saves, for example, half as much carbon per kWh and costs half as much per kWh as a zero-carbon resource thereby saves carbon at the same cost per ton. But might the comparative *speed*

[17] This slate seems bound to expand, probably dramatically, as basic innovation accelerates—*e.g.*, cheap 65%-efficient quantum-dot photovoltaics, cheap PV concentrators (www.sunengy.com), or using ultralight fuel-cell cars as plug-in power plants when parked. The latter option (typically using hydrogen reformed from natural gas), which the author proposed in the early 1990s, would give the U.S. light-vehicle fleet an order of magnitude more generating capacity than is now on the grid: A.B. Lovins & D.R. Cramer, "Hypercars®, Hydrogen, and the Automotive Transition," *Intl. J. Veh. Design* **35(1/2)**:50–85 (2004), www.rmi.org/images/other/Trans/T05-01_HypercarH2AutoTrans.pdf, and note 18.

[18] This is as true of nuclear heat for thermolysis of water as of nuclear electricity for electrolysis: A.B. Lovins, "Twenty Hydrogen Myths," 2003, www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf.

[19] Bradford, note 9.

[20] Neither nuclear power nor any other electrical resource is wholly carbon-free when embodied energy is counted, though most end-use efficiency comes very close. Nuclear plants' cement and steel intensity, plus uranium enrichment energy, actually make the net-energy issue worth exploring. Dr. John Price and the author did so with the best literature available in 1977 (*Non-Nuclear Futures*, Ballinger [Cambridge MA], Part Two), and concluded that nuclear plants using high-grade uranium ore and low-energy methods of decommissioning and waste management have an order-of-magnitude favorable net energy yield individually. However, that analysis also showed, by a closed-form analytic solution, that the rapid nuclear growth forecast then (and proposed now by advocates of nuclear solutions to climate change) would cause a negative net energy balance *for the collective nuclear enterprise* until the growth leveled off. This thesis has recently been revived and the individual-plant analysis updated by J.W.S. van Leeuwen & P. Smith, www.oprit.rug.nl/deenen/Chap_2_Energy_Production_and_Fuel_costs_rev6.PDF, 6 Aug. 2005 (see also www.world-nuclear.org/info/inf11.htm). Pending review, the author expresses no opinion of their work, but notes that the results will be quite sensitive to the ore-grade, enrichment-technology, and end-of-life assumptions. It would also be useful to follow up on another potential climate impact of nuclear power—concerns that ^{85}Kr released by reprocessing could ionize the atmosphere (W.L. Boeck, D.T. Shaw, & B. Vonnegut, *Bull. Am. Meterol. Soc.* **56**:527 (1975); R.G. Harrison & H.M. ApSimon, *Atmos. Electr.* **28**(4):637–648 (1994)), or possibly help to form ultrafine aerosols (R.H. Harrison & K.S. Carslaw, *Revs. Geophys.* **41**(3):1012 (2003); K.S. Carslaw, R.G. Harrison, & J. Kirkby, *Science* **298**:1732–1737 (2002)), enough to affect nimbus rainfall (such as the Asian monsoon) or other important processes. Collapsing nuclear growth has moderated this concern, but it persists, and direct observational tests seem difficult due to uncontrolled variables.

of deploying these various resources at scale, and the total scale that they can ultimately achieve, offer nuclear power such an advantage?

Figs. 1–2 (pp. 2–3) show that in 2004, when U.S. windpower additions were artificially depressed, decentralized low- and no-carbon generation worldwide nonetheless outpaced nuclear power by nearly sixfold in annual capacity additions and nearly threefold in annual output additions, and was pulling away rapidly. This occurred at a substantial scale, four times that of U.S. nuclear power—adding 28 GW to the 2003 global decentralized-generation base of ~383 GW—and was achieved despite nuclear power's generally higher subsidies per kWh (with modest exceptions, notably in Germany) and its far easier access to the grid. This speed disparity, probably more than doubled by efficient use (pp. 3–4), reflects the decentralized competitors' basic advantages, such as short lead times, modularity, economics of mass production, usually mild siting issues (excepting such pathological cases as Cape Cod wind), and the inherently greater speed of technologies that are deployable by many and diverse market actors without needing complex regulatory processes, challengingly large enterprises, or unique institutions. As either nuclear power or its decentralized supply- and demand-side competitors grow, it's hard to imagine how this balance of speed could ever shift in favor of nuclear power—the quintessentially big, long-lead-time, delay-prone, lumpy, complex, and contentious technology, and one that a single major accident or terrorist attack could scuttle virtually everywhere.

Of course *every* technology has its own hassles, obstacles, barriers, and hence risk of slow or no ultimate implementation at scale. Peter Schwartz says that bizarre local rules let a neighbor's objections block his installing photovoltaics on his roof. Efficiency has numerous obstacles—~60–80 market failures, each convertible to a business opportunity[21]—that leave most of it not yet bought. But efficiency's obstacles are being overcome sufficiently to have sustained an unprecedented 1.5%/y average decline in U.S. electric intensity since 1996, even though electricity is the form of energy most heavily subsidized and most prone to split incentives, is seldom priced on the margin, and is sold by distributors which in 48 states are rewarded for selling more kWh and penalized for selling fewer kWh. (The overall U.S. rate of decrease in primary energy intensity was 2.3%/y during 1996–2004, most of it believed to be due to more efficient use.) Such firms as DuPont, IBM, and STMicroelectronics routinely cut their energy intensity by 6%/y, and word of the resulting juicy profits is spreading.[22] In contrast, nuclear power, despite every form of advantage an enthusiastic federal government can provide, has fulfilled no U.S. orders since 1973, and now has a tenth the capacity that was then officially forecast. The key question about "dry hole risk" thus seems to be whether nuclear power, or the diverse portfolio of competing options already far outstripping it in the global marketplace, has the greater risk of badly underfulfilling expectations at scale. Based on actual market behavior and fundamental technological attributes, no *analytic* basis is evident on which nuclear power could satisfy this concern. (The contrary is claimed—by those who also erroneously claim that the decentralized competitors, though necessary and desirable, are *currently* far smaller and slower than nuclear.) An illuminating illustration of the speed of a diverse portfolio of short-lead-time technologies installed by diverse actors in an open market occurred in California during 1982–85, when

[21] This taxonomy is at pp. 11–20 of A.B. & L.H. Lovins, *Climate: Making Sense* and *Making Money*, RMI, 1997, www.rmi.org/images/other/Climate/C97-13_ClimateMSMM.pdf.
[22] *E.g.*, www.pewclimate.org/companies_leading_the_way_belc/company_profiles/index.cfm, www.cool-companies.org/homepage.cfm, and sporadic reports in *RMI Solutions* newsletter, www.rmi.org.

resource acquisitions were fairly across-the-board and the playing field was (by historical standards) relatively level as between supply- and demand-side investments. In those few years, with none of the climate or supply-adequacy concerns that motivate many actors today, the three investor-owned utilities' solicitations elicited (compared with a 37-GW peak load in 1984):

- 23 GW (62% of load) of contracted-for electric end-use efficiency to be installed over the following decade
- 13 GW (35%) of contracted-for new generating capacity, mostly renewable
- 8 GW (22%) of additional new generating capacity on firm offer, plus
- a further 9 GW (25%) of new generating offers arriving *each year*

These contracts and offers totaled 144% of the 1984 peak load, exceeding forecast load growth through the end of the implementation period. Had bidding not been suspended in April 1985 because of the resulting power glut, another year or so of acquisitions at that pace could have displaced every thermal station in California—which in hindsight could have been valuable.[23] This examples suggests that the big risk of creating a level playing-field is not a dangerous paucity but rather an awkward surplus of decentralized alternatives.

Comparative size of the practically and economically exploitable resource base

How about the ultimate potential *size* of the competing resources? Is it true, as nuclear advocates often claim, that only nuclear power is big enough to take on such gigantic tasks as powering an advanced industrial economy and displacing carbon emissions? Clearly not.[24] Just add these up:

- At less than the delivered cost of just *running* a nuclear plant, even if building it cost nothing, potential U.S. electricity savings range from 2–3× (EPRI) to 4× (RMI) nuclear power's 20% U.S. electricity-market share (2004), according to the bottom-up assessments summarized in those organizations' joint *Scientific American* article (note 74).

[23] Similarly, during 1979–85, the U.S. ordered more new capacity from small hydro and windpower than from coal and nuclear plants, excluding their cancellations, which totaled more than 100 GW—despite nuclear's ~24× greater FY1984 subsidy per kWh and far greater interconnection obstacles as mentioned on p. 7 above and in note 13.
[24] A favorite tactic of nuclear advocates (*e.g.*, M. Hoffert *et al.*, "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet," *Science* **298**:981 (2002)) is to dismiss end-use efficiency (as desirable but small) without analysis, reject each supply alternative separately as impractical at an enormous scale, and never add up the diverse portfolio of competitors—which *together*, using each to do what it does best, could stabilize climate and support ambitious global development goals (see note 35). Hoffert *et al.* present not a reasoned strategy or portfolio analysis but a wish-list of technologies they do or don't like, with no economics and no totals. But comparing ¢/kWh would reveal nuclear power's huge opportunity costs, as noted on pp. 14–15 below. Hoffert *et al.* would reject as inadequate all of the climate-safe, profitable, market-winning energy options whose R&D succeeded, and substitute the speculative, uneconomic, failed technologies that 30 years' experience has winnowed out. Such time-travel would take us back 30-odd years, to just before the first oil shock, when nuclear fusion (on earth, not appropriately sited 150 million km away), pie-in-the-sky (solar power satellites whose assumed cheap photovoltaics would deliver cheaper power from your rooftop), and fast breeder reactors (which proved proliferative, uneconomic, sterile, and probably unsafe) were widely touted. But despite vast public investments, these all failed investors' economic giggle test. Reviving the 1970s' cramped logic is a public disservice. Hoffert *et al.*'s seductive polemic masquerading as analysis seeks to divert attention and funding from winners to losers. If it misled non-expert policymakers, then more decades of tragically misallocated time and R&D resources (J.P. Holdren *et al.*, *Energy Research and Development for the Challenges of the Twenty-First Century*, PCAST, Washington DC, 1997, www.ostp.gov/Energy/index.html; D.M. Kammen & G.F. Nemot, "Real Numbers," *Issues in Sci. & Technol.*, pp. 84–88, Fall 2005) would probably make the climate problem truly insoluble.

- Cogeneration potential in industry and buildings is very large if regulators allow it. Lawrence Berkeley National Laboratory[25] preliminarily found waste-heat cogeneration alone to have a technical potential nearly as large as today's U.S. nuclear capacity, though cost and feasibility are very site-specific.
- Windpower's U.S. potential on readily available rural land—equivalent to a few of the larger Dakota counties—is at least twice national electrical usage.[26] China's Meteorological Administration similarly found 2 TW of practical windpower potential, more than China's total electricity usage.[27] European experience confirms that windpower's intermittence even at penetrations of at least ~14% for Germany[28] or 30% for West Denmark[29] would be manageable at modest cost if renewables are properly dispersed, diversified, forecasted, and integrated with the existing grid and demand response.[30] LBL-58450 notes that 2014 resource plans include 20% wind for SDG&E and 15% for Nevada Power—neither near a limiting value. Intermittence does require attention and proper engineering, but it's neither a serious issue nor unique to renewables: the grid is already designed for sudden loss of big blocks of capacity, *e.g.* from transmission or even

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[25] O. Bailey & E. Worrell, "Clean Energy Technologies: A Preliminary Inventory of the Potential for Electricity Generation," LBNL-57451, April 2005, http://repositories.cdlib.org/lbnl/LBNL-57451/; ~2.5 GW has been installed.
[26] D.L. Elliott, L.L. Wendell, & G.L. Gower, *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, PNL-7789, Pacific Northwest Laboratory (Richland WA), Aug. 1991, www.nrel.gov/wind/wind_potential.html, estimated the Dakotas' Class III+ wind potential, net of environmental and land-use exclusions (50% of forest area, 30% of agricultural and 10% of range lands, 20% of mixed ag/range lands, 10% of barren lands, and 100% of urban, wetlands, and parks and wilderness areas), at 2,240 TWh/y, equivalent to 58% of total U.S. 2002 net generation. But they assumed 750-kW turbines with 50-m hub height, 25% efficiency, and 25% losses. Today's 2–5 MW turbines have hub heights up to 100 m, efficiencies are up to the mid-40s of percent and rising, and losses have been at least halved. These turbine improvements, and improved wind prospecting and measurement, combine with the unexpectedly improved wind regime lately found at greater hub heights: C.L. Archer & M.Z. Jacobson, "Spatial and Temporal Distribution of U.S. Winds and Wind Power at 80 m Derived from Measurements," *J. Geophys. Res.* **108**(D9):4289–4309 (2003). Together, these factors appear to have increased the U.S. wind potential assessed in 1991 by a factor of at least two, including for windy lands in the Dakotas; yet NREL doesn't yet seem to have published an updated wind resource assessment comparable to the 14-year-old PNL-7789.
[27] CREIA reports the industry belief that China's 20-GW 2020 windpower target could be exceeded by twofold (thereby surpassing its ambitious 32-plant nuclear-additions goal): "China has potential to be world's biggest wind energy market by 2020," 6 Nov. 2005, www.ewea.org/documents/051106WF12Chinalaunchrelease.pdf. In Nov. 2005, China's leaders set a goal to raise total renewables from 2004's 7% (half big hydro) to 15% of all energy, and in Dec. 2005, they're expected to raise the 2020 windpower goal to 30 GW (E. Martinot, pers. comm., 4 Dec. 2005). Most observers would consider it more plausible that China will add 30 GW of wind than 32 nuclear plants by 2020.
[28] See European Wind Energy Association brief of 10 May 2005, "German Energy Agency Dena study demonstrates that large scale integration of wind energy in the electricity system is technically and economically feasible," www.ewea.org/documents/0510_EWEA_BWE_VDMA_dena_briefing.pdf. Collaborators on this study included the major German grid operators E.ON Netz, RWE Netz, and Vattenfall Transmission.
[29] European Wind Energy Association, "Wind Power Technology: Operation, Commercial Developments, Wind Projects, and Distribution," ~2004, www.ewea.org/documents/factsheet_technology2.pdf.
[30] Windpower today, in an average wind year, generates the equivalent of 19–20% of Denmark's electricity use and 25–30% of that of three German *Länder* (>50% in some whole months in Schleswig-Holstein), and on windy days with light loads, over 100% of the load in certain regions, particularly in West Denmark, North Germany, and northern Spain. For more detailed treatments of integrating intermittent resources into the grid, see *Small Is Profitable*, note 14, pp. 193–200, and J. C. Smith, E.A. DeMeo, B. Parsons, & M. Milligan, "Wind Power Impacts on Electric Power System Operating Costs: Summary and Perspective on Work to Date," NREL CP-500-35946, www.nrel.gov/docs/fy04osti/35946.pdf. Loadshape correlation matters: U.K. wind capacity factors average higher in the high-load than the low-load quarters (G. Sinden, "Wind Power and the he UK Wind Resource," www.eci.ox.ac.uk/renewables/ukwind), and highest—~2/3—at peak load (www.bwea.com/ref/stop.html).

nuclear-plant[31] outages. Whenever renewable penetration levels of supposed concern have been approached in practice, they've faded over the hazy theoretical horizon—which also continues to recede as distributed intelligence gradually permeates the grid.

- Other renewable sources of electricity are also collectively very large indeed—small hydro, biomass power (especially cogen), geothermal, ocean waves, currents, solar-thermal, and photovoltaics (which NREL's Dr. Garry Rumbles expects will get to or below ~5¢/kWh delivered, within at most a few nuclear-plant lead times). These sources and windpower also tend to be statistically complementary, working well under different weather conditions. All renewables collectively, plus solar technologies that indirectly displace electric loads (daylighting, solar water heating, passive heating and cooling), clearly have a practical economic potential many times U.S. electricity consumption, *i.e.* at least an order of magnitude greater than nuclear power provides today.
- Even at such a scale, land-use concerns are unfounded for a diversified renewable portfolio. For example, a rather inefficient PV array covering half of a sunny area 100×100 miles could meet all annual U.S. electricity needs.[32] In practice, of course, PVs would be building-integrated, rooftop-retrofitted, and built into parking-lot shades, alongside highways, etc. to avoid marginal land-use and to make the power near the load.[33] Specious claims persist comparing (say) the footprint of a nuclear reactor or power station with the [generally miscalculated] land area of which some fraction—from about half for PVs to a few percent for wind turbines—is physically occupied by renewable energy and infrastructure. But ever since the International Institute for Applied Systems Analysis's 1977 *Energy in a Finite World*, it's been well known that *properly including the relevant fuel cycles*, land intensity is quite similar for solar, coal, and nuclear power. An update might even show a modest land advantage to solar.
- A sizeable literature shows that old canards about poor net energy yield from wind and PV technologies are invalid; they generally use very old (or originally grossly erroneous) data on materials intensity. Even some more careful recent papers, such as Prof. Per Peterson's, show materials intensities for windpower far above those found by a detailed lifecycle assessment based on actual projects[34] reflecting recent technological refinement.
- Renewables have a very large potential on a global scale. Even under restrictive solar power assumptions, the International Energy Agency's *World Energy Outlook 2004* (pp. 229–232) foresees a potential of ~30,000 TWh/y in 2030—roughly 2030 world demand.
- Most importantly, a cost-effective *combination* of efficient use with decentralized (or even just decentralized renewable) supply is ample to achieve strong climate-stabilization and global development goals, even using technologies quite inferior to today's.[35]

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[31] As of 15 Nov. 2005, the latest completed *major* outage (≥12 days at zero power)—planned or forced—among U.S. operating nuclear units averaged 36 days and occurred an average of 17 months after the previous such event: www.nei.org/documents/NuclearPerformanceMonthly.pdf, downloaded 2 Dec. 2005. See also note 49 below.
[32] J.A. Turner, "A Realizable Renewable Energy Future," *Science* **285**:687 (1999).
[33] U.S. rooftops in 2025 could accommodate up to 710 GW_p of PVs, net of orientation, HVAC equipment, and shading: Navigant Consulting, Sept. 2004, www.ef.org/documents/EF-Final-Final2.pdf.
[34] Danish Wind Turbine Mfrs. Assn. "The Energy Balance of Modern Wind Turbines," *Wind Power Note,* No. 16, Dec. 1997, www.windpower.org/media(444,1033)/The_energy_balance_of_modern_wind_turbines%2C_1997.pdf. R.H. Williams (Princeton) and the author have separately calculated that a gram of silicon in thin-film photovoltaics can produce more energy over the normal operating life than can a gram of uranium in a light-water reactor.
[35] A.B. & L.H. Lovins, F. Krause, & W. Bach, *Least-Cost Energy: Solving the CO_2 Problem*, Brick House (Andover MA), 1981; A.B. Lovins, "Least-Cost Climatic Stabilization," *Ann. Rev. En.* **16**:433–531 (1991); F. Krause, *Energy*

For all these reasons, a portfolio of least-cost investments in efficient use and in decentralized generation will beat nuclear power in cost *and* speed *and* size by a large and rising margin. This isn't hypothetical; it's what today's marketplace is proving decisively. To be sure, all technologies have a nonzero non-completion risk (at a given site and over all sites); all have implementation hassles. But observed market behavior proves that this risk has been far smaller so far for the competitive portfolio than for nuclear power. Why should this reverse at larger scale?

Indeed, there is good historical reason to believe that nuclear power's perceived problems and actual capital costs tend to increase as it expands. At the height of U.S. nuclear growth, the more coal or (especially) nuclear plants were built or being built, the more they cost in constant steam-plant $/kW. (Later costs closely tracked the coal curve but far overshot the nuclear curve.) Statistical testing[36] suggested a causality that's bad news for nuclear power.[37] It could be even more troublesome at the scale that the nuclear enterprise would need to achieve to make much of a dent in climate change. Dr. Tom Cochran has estimated[38] that adding 700 nuclear GWe worldwide—roughly twice today's nuclear capacity—and running it for 2050–2100 would:

- add ~1,200 nuclear plants (if they lasted 40 years);
- require 15 new enrichment plants (each 8 million SWU/y);
- create 0.97 million tonnes of spent fuel, requiring 14 Yucca Mountains, and containing ~1 million kg—hundreds of thousands of bombs' worth—of plutonium…or

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Policy in the Greenhouse, Intl. Project for Sustainable Energy Paths, 1989– , www.ipsep.org; D.W. Aitken, "Transitioning to a Renewable Energy Future," International Solar Energy Society, 2003, http://whitepaper.ises.org.

[36] The hypothesis was proposed by I.C. Bupp, J.-C. Derian, M.-P. Donsimoni, & R. Treitel, "The Economics of Nuclear Power," *Technol. Rev.* 77(4):15–25 (1975); refined by W.E. Mooz, *A Second Cost Analysis of Light Water Reactor Power Plants*, RAND (Santa Monica), R-2504-RC, 1979; and confirmed, in collaboration with Vince Taylor, by C. Komanoff, *Power Plant Cost Escalation: Nuclear and Coal Capital Costs, Regulations, and Economics*, Komanoff Energy Associates (NY), 1981, whose regression results are graphed as a supply curve in slide 30 at www.rmi.org/sitepages/pid171php#E05-09. For the original version of that graph, plus further discussion and historical perspective, see A.B. Lovins, "The Origins of the Nuclear Power Fiasco," pp. 7–34 in J. Byrne & D. Rich, eds., *The Politics of Energy Research and Development* (*Energy Policy Studies*, Vol. 3), Transaction Books (New Brunswick, USA, & Oxford, UK), 1986, RMI Publ. #E86-29; also Krause (ref. 35), Vol. II, Part 3E, 1994.

[37] Normally if people think an activity is hazardous, the market tends to signal that perception through insurance premia, tort liability, and regulatory internalization of societal costs. This used to work fairly well for coal plants, chiefly through the Clean Air Act. But for nuclear plants, unique liability-limiting laws and an unresponsive regulatory system largely suppress these signals. Moreover, the more plants there are, the more pollution or other perceived hazard they'll cause, and the more probably they'll have an incident you'll hear and care about. As rising public concerns work through the political and regulatory processes, they increase pressure for each plant to become cleaner and safer so that their collective burden doesn't increase. Meanwhile, returns to investment in plants' cleanliness and safety tend to diminish. One would therefore expect the real cost of each plant to rise geometrically with the number of plants built. That is precisely what we observe, explaining 93% of real cost escalation for U.S. nuclear and 68% for coal plants commissioned during 1971–78; no other explanation better fitting the data has been proposed. This inferred causality would hurt nuclear power. For a coal plant, the perceived irritation is real and directly sensible: you can see it, smell it, and wipe it off the windowsill. But for a nuclear plant, the perceived hazard is insensible and ineffably abstract. If someone, even someone you consider highly credible, announces that the risk of a meltdown or a successful terrorist attack has just been greatly reduced, you can still feel that it's too big and you don't like it: you may care more about big consequences than allegedly small probabilities. Thus the investments that this societal process can require of a coal plant are reasonably bounded, while for a nuclear plant they are unpredictable and nearly open-ended. Efforts to dismiss or suppress such concerns don't make them go away, but only make them pop out elsewhere, like squeezing a balloon. And this is not a uniquely U.S. phenomenon. Similar real cost escalation has occurred across all major nuclear-power countries: see the graphs in Lovins (1986), note 36.

[38] At the 22 June 2005 Board meeting of Natural Resources Defense Council (personal comm., 30 June 2005).

- require 50 new reprocessing plants (each 800 TSF/y with a 40-y operating life) to extract that plutonium under, one hopes, stringent international safeguards;
- require ~$1–2 trillion of investment; and yet
- cut the global average temperature rise by just 0.2°C.

Similarly daunting numbers were published in 1988 by RMI researchers Dr. Bill Keepin and Greg Kats.[39] They showed that under the demand-growth assumptions then popular, building a 1-GW reactor every 1–3 days through 2025 couldn't reverse CO_2 growth, so nuclear power "cannot significantly contribute to abating greenhouse warming, except possibly in scenarios of low energy growth for which the problem is already largely ameliorated by efficiency improvement." Since 1988, the economic and logistical logic of non-nuclear investments has become far more compelling; Dr. Cochran has simply reminded us of the impracticality of relying on one dominant and slow option rather than on a diverse and well-balanced portfolio of quicker options.

Implications for climate protection

Does this mean that abating climate change (to the major extent it's caused by fossil-fuel CO_2) is hopeless because of the sheer scale of the carbon substitution required? No; rather, it means that:

- much, indeed most, of the carbon displacement should come from end-use efficiency, because that's both profitable—cheaper than the energy it saves—and fast to deploy;
- end-use efficiency should save not just coal but also oil—especially in transportation[40], which in the U.S. in 2003 emitted 82% as much CO_2 as power generation: indeed, since power generation emits only 39% of U.S. and 40% of world CO_2[41], *across-the-board energy efficiency addresses 2.5 times as much CO_2 emission as an electricity-only focus*;
- supply-side carbon displacements should come from a diverse portfolio[42] of short-lead-time, mass-producible, widely applicable, benign, readily sited resources that can be adopted by many actors without complex institutions or cumbersome procedures; and
- the total portfolio of carbon displacements should be both *fast* in collective deployment (MW/y—or, more precisely, TWh/y per y) and *effective* (carbon displaced per dollar).

This last point highlights perhaps the most troublesome unheralded drawback of nuclear power. Buying a costlier option, like nuclear power, instead of a cheaper one, like the competitors

[39] "Greenhouse warming: Comparative analysis of nuclear and efficiency abatement strategies," *En. Pol.* **16**(6):538–561 (Dec. 1988).
[40] The displacement of oil-fired power stations has already been done and can't be done again. In the U.S., <3% of electricity is oil-fired (and only a tenth of that oil is distillate—nine-tenths is gooey bottom-of-the-barrel residual oil), while <2% of oil makes electricity. Worldwide, these figures are only around 7%. The only consistent U.S. holdout, Hawai'i, is shifting markedly toward renewable acquisitions now that its main utility has figured out how advantageous they can be. Moreover, outside such rare condensing-plant situations, most oil-fired power plants are relatively small, run variably or intermittently, and on small grids—not a suitable target for displacement by nuclear plants, which both for technical and for economic reasons must run as steadily as possible. Fortunately, *all* U.S. oil use can be saved or displaced at much lower cost than buying it—even at half today's oil price, and even if its externalities are all worth zero—via the business-led strategy detailed by RMI's Pentagon-cosponsored 2004 study *Winning the Oil Endgame* (www.oilendgame.com). Its implementation is now beginning and shows much promise.
[41] USEIA, *Ann. En. Rev. 2004*, p. 341, data for 2003 (the most recent available), www.eia.doe.gov.
[42] The strategic advantages of a diversified portfolio are unquestioned. This does not mean, however, that every option merits a place in the portfolio purely for the sake of diversity, any more than a financial portfolio should include bad investments just because they're on the market. Diversification is good, but it must be intelligent.

shown in Fig. 3, *displaces less carbon per dollar spent*. This opportunity cost is an unavoidable consequence of not following the least-cost investment sequence: the order of *economic* priority is also the order of *environmental* priority. For example, based on the indicative costs in Fig. 3, and neglecting the energy embodied in manufacturing and supporting the technologies (or, equivalently, assuming that they all have similar embodied energy intensity per dollar[43]), we could displace coal-fired electricity's carbon emissions by spending ten cents to deliver roughly:

- 1.0 kWh of nuclear electricity at 2004 subsidy levels and costs, or
- 1.2–1.7 kWh of dispatchable windpower at no to 2004 subsidies and 2004–2012 costs, or
- 0.9–1.7+ kWh of gas-fired industrial cogeneration or ~2.2–6.5+ kWh of building-scale cogeneration (both adjusted for their carbon emissions[44]), or
- 2.4–8.9 kWh of waste-heat cogeneration burning no incremental fuel (more if credited for burning less fuel), or
- from several to 10+ kWh of end-use efficiency.

The ratio of net carbon savings per dollar to that of nuclear power—the reciprocal of their relative costs of saved or supplied energy—is their ratio of effectiveness in climate protection per dollar. This comparison reveals that *nuclear power saves as little as half as much carbon per dollar as windpower and traditional cogeneration, half to a ninth as much as innovative cogeneration, and as little as a tenth as much carbon per dollar as end-use efficiency.* Or as Keepin and Kats arrestingly put it, based on their reasonable 1988 estimate that efficiency would save ~7× as much carbon per dollar as nuclear power, "*every $100 invested in nuclear power would effecttively release an additional tonne of carbon into the atmosphere*"—so, counting this opportunity cost, "the effective carbon intensity of nuclear power is nearly six times *greater* than the direct carbon intensity of coal fired power." Whatever the exact ratio, this finding is qualitatively robust even if nuclear power becomes as cheap as its advocates claim it can, but its competitors don't. Recall also that this paper has used assumptions systematically favoring nuclear power, and didn't count nuclear power's old and new U.S. subsidies—preliminarily estimated[45] to total ~4.2–8.2¢/kWh, or roughly two-thirds of new plants' apparent total marginal busbar cost.

Alongside the economic priority of carbon displaced per dollar, one must consider physical speed of deployment: if nuclear investments are also inherently *slower* to deploy, as we discussed on pp. 8–10 above, then they don't only *reduce* but also *retard* carbon displacement. Thus **if climate matters, then we must buy the most solution per dollar and per year spent. Empirically, on the criteria of both cost *and* speed, nuclear power seems about the least**

[43] This is a valid first-order assumption because energy markets are in reasonable equilibrium. The only reason net energy analysis received much attention—around 1975 when the author helped to write its "generally accepted accounting practice"—was that severe disequilibria then made it possible, though not common, for a project to make money but lose energy. That is no longer true. However, any technology with very high materials or process-energy intensity merits a corresponding degree of suspicion about its net energy balance. Modern corn ethanol, which has a modestly favorable net energy yield but unimpressive economics without subsidy, is a case in point.
[44] The reciprocal of the delivered cost of 3.78–7.28¢/kWh (for a range of 28–64 MWe unit size and $5–8/MCF gas price) yields a gross 1.4–2.6 kWh/$0.10. However, this technology does emit fossil carbon in its operation. If, as a conservative approximation, the carbon emission is 3× less per kWh than for the coal-fired power plant and the fossil-fueled boiler displaced (4× is often achievable and is not an upper limit), then the carbon-reducing effect of a gas-fired CCGT cogeneration kWh is only about two-thirds as big as windpower's, or ~0.9–1.7 kWh/$0.10.
[45] Koplow, note 63 below, as of 8 November 2005. Further study seems more likely to raise than lower these figures.

effective climate-stabilizing option on offer. The case for new nuclear build as a method of climate protection is therefore purely rhetorical and cannot withstand analytic scrutiny.

Conclusions

This widening gap between market reality and nuclear theology raises some pointed policy questions. Why divert further public resources from market winners to the market loser?[46] Why pay a premium to incur nuclear power's uniquely disagreeable problems? (No other energy technology spreads do-it-yourself-kits and innocent disguises for making weapons of mass destruction[47], nor creates terrorist targets[48] or potential for mishaps that can devastate a region, nor creates wastes so hazardous, nor is unable to restart for days after an unexpected shutdown.[49]) Why incur the opportunity cost of buying a costlier option that both saves less carbon per dollar and is slower per megawatt to deploy? And if, unsupported by analysis, you think "we need everything," how will you avoid acting like a Chinese-restaurant diner who orders one item from each section of the menu because it all sounds tasty, spends his money on a small bowl of shark's-fin soup and other delicacies, can't afford rice, and goes away hungry?

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[46] Nuclear plant vendors probably got far less 2004 revenue than renewable power equipment vendors' ~$30b.

[47] A.B. & L.H. Lovins & L. Ross, "Nuclear Power and Nuclear Bombs," *Foreign Affairs*, Summer 1980, www.foreignaffairs.org/19800601faessay8147/amory-b-lovins-l-hunter-lovins-leonard-ross/nuclear-power-and-nuclear-bombs.html; A.B. Lovins, "Nuclear Weapons and Power-Reactor Plutonium," *Nature* **283**:817–823, 28 Feb. 1980, www.rmi.org/images/other/Security/S80-01_NucWeaponsAndPluto.pdf; V. Gilinsky, H.W. Hubbard, & M. Miller, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors," 2004, www.npec-web.org/projects/NPECLWRREPORTFINALII10-22-2004.pdf. Note also that the higher enrichment of pebble-bed reactor fuel (>90% of the way to highly enriched bomb-grade uranium in terms of separative work) makes this type of reactor particularly proliferative by encouraging the wide development and deployment of cheaper enrichment technologies like centrifuges. The combination of centrifuges' concealability and modularity with ^{235}U bombs' simplicity and lack of need for prior testing (thus defeating the "timely warning" criterion fundamental to nonproliferation strategy) makes this an especially dangerous development. That's quite aside from the other daunting issues described in J. Harding's 2004 ESKOM paper at www.rmi.org/sitepages/pid171php#E05-10 and the dismal economic picture now starting to emerge (www.neimagazine.com/story.asp?storyCode=2030985; S. Thomas, "The Economic Impact of the Proposed Demonstration Plant for the Pebble Bed Modular Reactor Design," Aug. 2005, www.psiru.org/reports/2005-09-E-PBMR.pdf; www.noseweek.co.za, Dec. 2005).

[48] *E.g.*, F.N. von Hippel, "Revisiting Nuclear Power Plant Safety," *Science* **291**:201 (2003); A.B. & L.H. Lovins, *Brittle Power: Energy Strategy for National Security*, Brick House (Andover MA), 1981, out of print but reposted at www.rmi.org/sitepages/pid1011.php. Crashing a large airplane at high speed into a reactor, though it has been threatened, is likely but not necessary to breach its containment, and is not even the most plausible threat. Neither is a concerted paramilitary attack aimed at taking over the control room. Rather, using readily available and inconspicuously portable standoff weapons, often from outside the security perimeter, a small group or even an individual could cause many an existing light-water reactor to melt down uncontrollably if the attack were properly designed by a technically trained person (analogous to the structural engineer(s) who planned the 9/11 airplane attack on the World Trade Center) using publicly available information.

[49] After the Northeast blackout on the afternoon of 14 August 2003, the nine scrammed U.S. nuclear units achieved 0% output on the 15th, 0.3% on the 16th, 5.8% on the 17th, 38.4% on the 18th, 55.2% on the 19th, and 66.8% on the 20th. That's two and a half days to restore 6% power, five-plus days to half-power, and two-thirds power after six and a half days. The units lost an average of 97.5% of their capacity for the first 3 days, 82% for 5, 59% for 7, and 54% for 12 days (www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2003/index.html)—hardly a reliable resource. Such an inability to restart promptly after a major grid outage (and hence not just nucleate restart but restore the gross supply/demand balance to permit restart altogether) makes nuclear plants least available when they are most needed—a sort of "anti-peaker" attribute. This present security issue, like nuclear plants' potential for national- or world-scale shutdown in case of a serious accident or attack, has received curiously little notice; yet milder windpower failures, confined to a relatively small region, are claimed to be an insurmountable problem.

A popular euphemism holds that we must "keep nuclear energy on the table." What exactly does this mean? Continued massive R&D investments for a "mature" technology that has taken the lion's share of energy R&D for decades (39% in OECD during 1991–2001, and 59% in the United States during 1948–98)? Ever bigger taxpayer subsidies to divert investment away from the successful competitors?[50] Heroic life-support measures? Where will such efforts stop? We've been trying to make nuclear power cost-effective for a half-century. Are we there yet? When will we be? How will we know? And would nuclear advocates simply agree to desubsidize the entire energy sector, so all options can compete on a level playing field?

The Energy Policy Act of 2005 is festooned with lavish subsidies and regulatory shortcuts for favored technologies that can't compete unaided.[51] Nuclear expansion, for example, gets ~$13 billion in new gifts from the taxpayer:[52] 80% loan guarantees (if appropriated), ~$3 billion in dubious "R&D," 50% licensing-cost subsidies, $2 billion of public insurance against any legal or regulatory delays, a 1.8¢/kWh increase in operating subsidies for the first 8 y and 6 GW (equivalent to a capital subsidy of ~$842/kW—roughly two-fifths of likely capital cost)[53], a new $1.3-billion tax break for decommissioning funds, and liability for mishaps capped at $10.9 billion (and largely evadable through shell companies). The industry already enjoyed Treasury payments to operators as a penalty for late acceptance of nuclear waste (which there's no place to put nor obvious prospect of one), free offsite security, and almost no substantive public participation in or judicial review of licensing.[54] The total new subsidies approximate the entire capital cost of six big new nuclear plants. Taxpayers have assumed nearly all the costs and risks they didn't already bear; the promoters will pocket any upside, yet are unwilling to risk any material amount of their own capita, despite ~$569 billion of FY2004 revenue and $694 billion of market capitalization (if they were a country, they'd rank as the world's #13 economy).[55] Yes, this boost may yield slight twitches from the moribund nuclear industry—but no authentic revival.

Lord Keynes said, "If a thing is not worth doing, it is not worth doing well." Nuclear power has already died of an incurable attack of market forces, with no credible prospect of revival. Current efforts to deny this reality will only waste money, further distort markets, and reduce and retard carbon dioxide displacement. Cheaper, faster, abundant decentralized alternatives are now empirically larger, are being bought an order of magnitude faster in GW/y, and offer far greater

[50] C. Komanoff's 1992 study *Fiscal Fission*, www.earthtrack.net/documents.asp?docUrl=FiscalFission.pdf, found that during 1950–90, the U.S. put ≥$0.5 trillion into nuclear power, which produced electricity for at least 9¢/kWh, twice the contemporaneous cost of equivalent fossil-fueled electricity.
[51] Nuclear power isn't the only beneficiary of this latest burst of Congressional largesse. Coal gasification, for example, is also richly aided even though a large-scale program, worthy of the defunct Synfuels Corporation, would yield 8–10 times less gas than efficient use could save, and would cost 4–5 times as much per unit (*WTOE*, note 40).
[52] This estimate by Public Citizen, in undiscounted nominal dollars, rests on specific assumptions, chiefly about loan guarantees not yet appropriated. However, it may also be low, partly because Congress "scores" tax expenditures only over the next ten years, while many subsidies last longer. Koplow (note 63 below) implies far higher figures.
[53] Assuming a 4%/y real discount rate, ignoring ramp-up, and discounting back to the first year of full-power operation. The 2005 present value is ~$640/kW. *Cf.* EIA's earlier "Analysis of Five Selected Tax Provisions of the Conference Energy Bill of 2003," Feb. 2004, http://tonto.eia.doe.gov/FTPROOT/service/sroiaf(2004)01.pdf.
[54] The NRC, which shows every sign of capture by the industry it is supposed to regulate, has made clear its unwillingness to consider the most serious outstanding issues, including credible terrorist attacks, even though in nearly half of tests, guards have proven unable to repel small groups of mock attackers whose capabilities and tactics were severely constrained (www.nci.org/nci-ht.htm).
[55] D. Koplow, "NuSubsidies Nuclear Consortium," www.earthtrack.net/documents.asp?docUrl=NNC_Overview.ppt.

ultimate potential. Since nuclear power is therefore unnecessary and uneconomic, we needn't debate whether it's safe. And the more concerned you are about climate change, the more vital it is to invest judiciously, not indiscriminately—best buys first, not the more the merrier.

A state government committed to market-based, least-cost energy policies could do much to correct the distortions introduced by misguided federal policies. State energy taxes might even be designed to offset federal energy subsidies, technology-by-technology, to create a "subsidy-free zone."[56] This should have a salutary effect on energy cost, security, environmental impacts, and broad economic benefits. Just talking seriously about it and analyzing its consequences could help to focus attention on the differences between current federal energy policy and sound free-market principles. Such a state could become the first jurisdiction in the world to allow all ways to save or produce energy to compete fairly and at honest prices, regardless of which kind they are, what technology they use, how big they are, or who owns them. Who could be against that?

Appendix: Analysis Underlying Fig. 3 (p. 6)

Fig. 3 (p. 6) graphs the following levelized costs in 2004 US$, documented next. All have only about one significant figure, not the three shown here for calculational clarity. In summary:

- Nuclear (see p. 19): 7.02¢/kWh busbar cost (MIT study at 40 y, 0.85 capacity factor) + 2.75¢/kWh delivery cost = 9.77¢/kWh; successive sensitivity tests for cost reductions: MIT study's 5.76¢/kWh for –25% construction cost, 5.55¢/kWh for 5→4 y construction time, 5.34¢/kWh for reducing O&M cost to 1.36¢/kWh, and 4.40¢/kWh for zero risk premium *vs.* coal and gas plants, all + 2.75¢/kWh delivery cost = combined minimum delivered cost 7.15¢/kWh, *i.e.*, ~2.6¢/kWh "cheaper" than expected for a 2003 order
- Coal (p. 21): MIT study's 4.40¢/kWh busbar cost (at $1.26/million BTU coal) + 2.75¢ delivery cost = 7.15¢/kWh; $100/tonne carbon tax or equivalent would raise this, per MIT study, to 6.91 + 2.75 = 9.66¢/kWh (p. 22)
- Combined-cycle gas (p. 21): MIT study's 3.98–5.86¢/kWh at levelized real gas prices of $3.95– $7.04 per thousand cubic feet ["MCF"], + 2.75¢/kWh delivery cost = 6.73–8.61¢/kWh; illustrative $100/tonne carbon tax or equivalent raises this (p. 22) to 7.78–9.77¢/kWh
- Wind (pp. 21–22): 3.0–3.5¢/kWh busbar + 0.6¢/kWh firming + 0.3¢/kWh integration + 2.75¢/kWh delivery cost = 6.65–7.15¢/kWh; optionally add back levelized after-tax Production Tax Credit (0.86¢/kWh, note 64) = 7.51–8.01¢/kWh; optionally subtract 1.0¢/kWh for cost reduction that DOE and industry expect by 2012 (already surpassed by some projects) = 6.51–7.01¢/kWh without or 5.65–6.15¢/kWh with PTC
- Cogeneration (p. 22) at levelized real gas prices of $5–8/MCF: combined-cycle industrial 3.78–7.28¢/kWh at 28–64 MWe; recovered-heat industrial 1.1–2.6, perhaps up to 4, ¢/kWh; building-scale ~1–3¢/kWh well-optimized, or up to ~7¢/kWh with standard design

[56] One might at first suppose that federal preëmption could prevent this, but states' powers to devise and enforce their own tax regimes for their own purposes should trump the notion that only the federal government can use fiscal instruments to influence energy choices. For example, states now have widely differing levels and structures of automobile and gasoline taxes, yet aren't preëmpted by the federal authority to set car efficiency standards.

- End-use efficiency (societal cost, see pp. 23–25): ~0–1¢/kWh for well-designed and -executed retrofits in commercial/industrial sectors; <0 for optimized new installations in all sectors; up to ~5¢/kWh for suboptimal business programs or broad all-sectors programs

General methodology: All costs are in 2004 US$ unless otherwise stated. For central plants, we use the 2003 MIT nuclear study's merchant cashflow model with its ~5%/y implicit real discount rate and all its other assumptions[57]; the MIT analysis uses engineering economics with no risk adjustment, a conventional approach that favors nuclear power. For decentralized competitors, such as windpower (mainly in Class V–VI sites, levelized at 4%/y over 30 y), we use observed costs or higher. Similarly, for gas-fired industrial cogeneration, the basis is a set of proprietary empirical data for five commercial projects that a leading developer considers typical and amply profitable; for building-based cogeneration and trigeneration (coproduction of electricity with useful heating and cooling), we draw on a wider range of anecdotal in-house and reported experience, reflecting costs' sensitivity to site-specific design details. All cogeneration costs are levelized at 4%/y real over 25 y. Costs of electric end-use efficiency are drawn from a wide range of data (pp. 23–25), converted as fully as possible to a conservatively assumed 12-y average service life and levelized at a 4%/y real discount rate. Fig. 3 shows the potential for lower nuclear costs and for the expected reduction in windpower costs by 2012 (one nuclear lead time away), but doesn't otherwise reflect future costs, which tend to favor non-nuclear options.

Location: To compare resources fairly, regardless of their scale and their distance from the retail customer, the levelized busbar costs of remote resources (central nuclear, coal, and gas plants plus windpower) is converted into *delivered* costs at the retail meter by adding a uniform nominal delivery cost. Absent a recent national assessment of marginal delivery cost, reflecting the costs and losses of new transmission and distribution capacity, we adopt as a conservatively low benchmark the 1996 embedded-average-historic real delivery cost of U.S. investor-owned utilities in 1996, namely 2.75¢/kWh, derived from their published financials (in the USEIA *Electricity Annual*) in RMI calculations published in 2002.[58] A realistic marginal cost for delivery would be site-specific but generally higher: *e.g.*, *Small Is Profitable* (p. 219) notes that PG&E's average grid cost some years ago was ~8% above the national average but that this large utility's maximum marginal grid cost was 5.5× the national average. The delivery-cost adder does not apply to resources that are already onsite, namely cogeneration and end-use efficiency.

New nuclear plant: We adopt the analysis of the 2003 MIT study *The Future of Nuclear Power* for a nominal light-water reactor of the various advanced types now on offer. For a 40-y life and 0.85 average capacity factor, that study found a levelized busbar cost of 6.7¢/kWh (2002 $), which we convert to 7.0¢/kWh in 2004 $ using the 1.0471 GDP implicit price deflator. The MIT study makes a strong case that its assumed overnight cost of $2,000/kW (2002 $) or $2,094/kW (2004 $) is realistic and may well be conservative. (For example, it's less than the ~$2,200/kW apparent overnight turnkey cost of the new Finnish plant, which shows every sign of being built at a substantial loss, especially at today's higher commodity prices.) The weaker analytic basis of the University of Chicago 2004 study, which adopted overnight costs of $1,232 to $1,847/kW,

[57] J. Deutsch & E.J. Moniz (Co-Chairs), *The Future of Nuclear Power*, MIT, 2003, http://web.mit.edu/nuclearpower/.
[58] A.B. Lovins *et al.*, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, 2002, www.smallisprofitable.org, at pp. 217–219.

reflects industry hopes but not global experience. The World Nuclear Association's "authoritative" compilation of others' estimates of nuclear cost[59] adds no new reason to believe its vigorous claim of $1,000–1,400/kW "achievable now." That's because all its sources simply recycle industry estimates—except the independent MIT team, whose closely reasoned $2,000/kW base case WNA rejects (while nonetheless citing the MIT study as authority for its own contrary findings). WNA understandably prefers to assume cheap money equivalent to public financing of nuclear plants, but within an increasingly privatized sector in a largely market-based global economy, that's clearly inconsistent with market principles and realities.

Capacity factors averaging 0.9 have lately and commendably been achieved by the U.S. reactor fleet, but the MIT study notes this is unrepresentative of experience with mature programs in other industrial countries (the global average is ~0.75) and doesn't seem realistic over 40 y; we use the MIT study's 0.85. Our 40-y lifetime, the MIT study's upper bound, is also unsupported by convincing experience and may well prove overly generous.[60] Neither of these assumptions, though, is important to the outcome, which depends largely on nuclear plants' capital cost and cost of money. Those who wish to bet that the MIT study's capital costs are 40-odd to 100% too high should put their money where their mouths are. They're conspicuously failing to do so, and if they did, their financial ratings could reasonably be expected to suffer.

New coal and gas central plants: We similarly adopt the MIT study's busbar costs of 4.4¢/kWh for pulverized-coal plants and 4.0–5.9¢/kWh for combined-cycle gas plants (both in 2004 $), using a utility natural-gas price levelized at $4–7/MCF.[61]

Windpower: Windpower's empirical busbar costs vary widely: wind energy varies as the cube of windspeed, so a 10% stronger wind contains 33% more energy.[62] It is not generally true, as economic theorists might suppose, that the best sites have been exploited first; rather, siting tends to be determined substantially by local utility policies, buyback prices, and transmission capacity. For example, the Dakotas' world-class wind sites stand virtually unexploited because lignite-plant operators bar transmission access and FERC has not yet intervened to promote competition.

For windpower's busbar costs, this paper conservatively adopts a range of 3.0–3.5¢/kWh, conventionally assuming 30-y operating life, and including the Production Tax Credit (PTC), which Fig. 3 offers the option of adding back (but without adding back nuclear power's probably larger

[59] World Nuclear Association, "The New Economics of Nuclear Power," www.world-nuclear.org/economics.htm, 1 Dec. 2005. The best rebuttal to this redux's claim of robustly competitive new nuclear plants is the industry's insistence on more subsidies and its unwillingness to bid turnkey projects at anywhere near the claimed costs.
[60] Higher figures, such as the 60-y life implied by some recent NRC license extensions, seem unlikely to be empirically validated, but if they were, that wouldn't materially alter this paper's conclusions.
[61] Henry Hub front-month prices were around $6–8/MCF from November 2004 through July 2005; at the end of August 2005, as Henry Hub reopened after Hurricane Katrina, its June 2007 contracts were priced at $8.55/MCF in nominal dollars. EIA's *Annual Energy Outlook 2005* (Jan. 2005) forecasted that power plants will pay in 2025 an average of $5.58/million BTU for gas (2004 $, *not* levelized), nearly one-fourth below $7/MCF. One needn't guess at the long-term gas price; constant-price forward gas can be bought today in the futures and options markets.
[62] In 2000, NREL noted a 1.8¢/kWh lower production cost for a Class VI than for a Class IV site, but expected better designs to shrink this difference to 0.6¢/kWh by 2010: "Technology Profile for Wind," www.nrel.gov/analysis/power_databook/docs/pdf/db_chapter02_wind.pdf.

2004 subsidies[63]). This cost range exceeds the lowest wind energy contract price in 2003, FPL's 2.9¢/kWh including PTC. The 3.0–3.5¢/kWh range also brackets the historic capacity-weighted average cost of 3.37¢/kWh (2004 $) observed for >2.7 GW of U.S. wind projects commissioned in 1999–2005; the lowest observed cost is only 1.5¢/kWh, and the highest, excluding one outlier, 5.8¢/kWh.[64] Further confirming reasonableness, LBNL-58540 (*id.*) found that Western utilities' resource plans use levelized costs as low as 2.3¢/kWh in a good site, also including PTC.

In 2005, nominal wind-turbine costs spiked from ~$1,000/kW to ~$1,250/kW for three reasons: a weaker dollar (the erratic PTC long ago made the U.S. cede wind-turbine manufacturing dominance to Europe), higher steel prices, and a spot shortage of turbines (the world's major makers are booked over a year ahead). That shortage was due to the U.S. installation bust in 2004 and resurgence in 2005–6, both caused by the perennial unpredictability of Congress's brief PTC renewals; the latest of its three expirations, from December 2003 to October 2004, delayed ~1 GW of projects. However, these factors do not appear to reflect equilibrium market behavior—the PTC was just renewed for three years, bringing some short-term stability to market development—and the first two causes, especially steel prices, would also raise nuclear costs.

The 2005 wind-turbine price spike occurs against a background of downward-trending real costs due to production volume, big players like GE, installation and operating experience, and improving technology. Windpower's real capital costs have historically fallen by 12–18% per doubling of installed capacity, which worldwide averaged 28%/y growth (a 2.5-y doubling time) in 1999–2004. Rising hub heights increase wind capture more than had been expected (thus expanding the whole wind resource and its competitiveness); have markedly increased efficiencies; have boosted typical capacity factors to ~0.30–0.35 (again very sensitive to site); and can achieve CF ~0.45 in many good offshore sites. R&D is also yielding turbines optimized for lower-windspeed sites, which are much more widespread and often closer to load centers. Availability varies by model and manufacturer but is typically ~0.95–0.98 and rising. The combination of these factors led DOE to project in 2001 that nominal windpower costs in Class VI to Class IV sites will respectively fall from 2.4–3.0¢/kWh in 2010 to 2.2–2.7¢/kWh in 2020.[65] As the new LBL empirical data confirm, some of this progress has already occurred. The ~1¢/kWh cost decrease that DOE and the industry currently expect from ~2003 to ~2012 is approximately shown as a sensitivity test in Fig. 3 (p. 6), but its result still exceeds likely long-term windpower costs. Indeed, LBNL's database of actual projects shows some *already* costing less than DOE's lowest expectation for 2010, which is sooner than a nuclear plant ordered today can be built.

For dispatchability comparable to central stations', we add to all wind costs a firming cost of 0.6¢/kWh (the BPA wind-firming tariff), and to be extra-conservative (note 30), an additional

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[63] The most authoritative independent U.S. expert estimates pre-2005 federal nuclear subsidies had a levelized 2004-$ value of 0.79–4.2¢/kWh, and preliminarily estimates that the Energy Policy Act of 2005 added another ~3.4–4.0¢/kWh for at least the next 6 GW: D. Koplow, "Nuclear Power in the U.S.: Still Not Viable Without Subsidies," 8 Nov. 2005, www.earthtrack.net/earthtrack/library/NuclearSubsidies2005_NPRI.pdf.

[64] M. Bolinger & R. Wiser, "Balancing Cost and Risk: The Treatment of Renewable Energy in Western Utility Resource Plans," LBNL-58540, Aug. 2005, http://eetd.lbl.gov/ea/ems/reports/58450.pdf, at p. 27. EIA's *Annual Energy Outlook 2005* adopts 4.5–6¢ (2003 $) levelized over 20 y without PTC. On this basis, PTC has a levelized value of ~1.1–1.2¢; we levelize at 4%/y for 30 y, after-tax as LBNL-58540 recommends, to yield a PTC of 0.86¢/kWh in 2004 $. EIA's 4.5–6¢/kWh would be ~2.4–3.5¢/kWh on our accounting basis, *vs.* our 3.0–3.5¢.

[65] Cited at end of "Technology Profile for Wind," note 62.

0.3¢/kWh for integration, which BPA's firming tariff already includes. The generally lower ranges (including a firming and integration cost of roughly zero for hydro-rich California) cited in Table EP-5 of LBL-58450 and in NREL CP-500-35946 (note 30) suggest both these values are excessive, especially in combination. Mature firming markets, even at large scale, should indeed get substantially cheaper, especially with demand-response "virtual peaker" contracts. The extra 0.3¢/kWh might instead pay for adding transmission to some remote sites where coal or lignite developers monopolize transmission capacity that wind could more cheaply utilize. In general, it does not appear that the best lower-48 U.S. windpower resources are more remote from load centers than are suitable sites for big nuclear and coal plants, although historically the major transmission lines have been built to link load centers with the latter, not the former.

Cogeneration: Tom Casten, Chairman and CEO of Primary Energy, LLC (a leading cogeneration developer with ~0.9 GW of operating U.S. projects), has generously shared proprietary data on five projects he considers typical and profitable, assuming 10%/y weighted-average cost of capital (~200 basis points above the utility average he cites) and 25-y amortization.[66] We have parameterized levelized real natural-gas costs as $5–8/MCF—conservatively assumed to be $1/MCF higher than central plants' gas cost—so his actual gas-fired combined-cycle cogeneration project costs imply net levelized electricity costs of 3.78–7.28¢/kWh at 28–64 MWe. This credits any avoided capital cost of duplicate boiler facilities and associated O&M, as well as the useful thermal energy produced (*i.e.*, what it would otherwise have cost to produce with a conventional boiler). To protect proprietary data, Casten's recovered-heat ("recycled-energy") data are also for a blend of three actual projects in the 60–160 MWe size range, all using heat that was previously being thrown away. That heat is worth more than the applicable capital and O&M costs, so these projects book an average net annual profit of $5.8–19.3 million, including return of and on capital, *before* valuing of the 517 GWh/y that the average project generates. Dividing those figures would indicate a notional negative cost of electricity (–2.1 to –4.7¢/kWh), but Fig. 3 instead graphs their actual all-in electricity price (+1.1 to +2.6¢/kWh), with possible variation up to 4¢/kWh in less favorable cases. The building-scale cogeneration costs shown are for very well-designed projects integrated with end-use efficiency and load management, and where appropriate, use very efficient absorption chillers or desiccants or both to replace vapor-compression chillers. More conventional designs, such as those considered in a recent proprietary RMI study of five 4.0–5.5 MWe prospects in California, deliver at a typical net cost around 4.8–5.7¢/kWh, within Fig. 3's shaded upper range of up to 7¢/kWh.

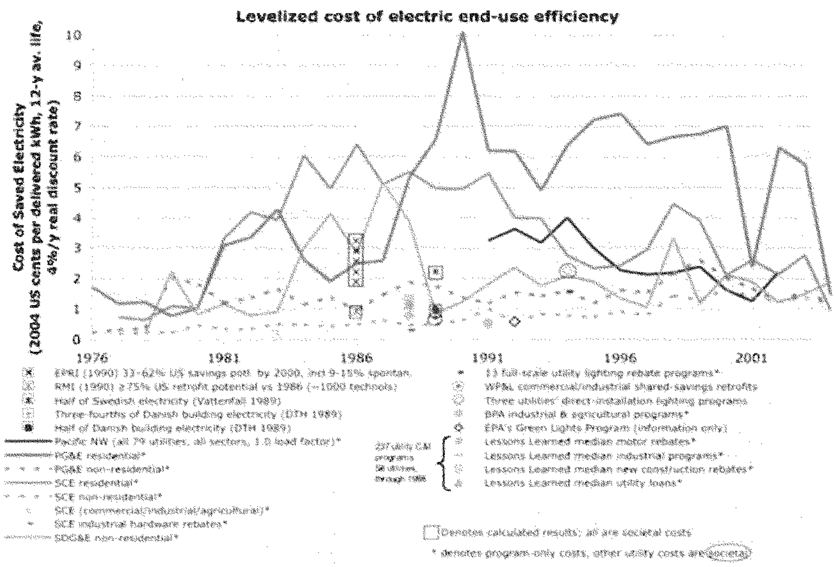
Central-plant sensitivity testing: We adopt the MIT study's conclusion that the nuclear busbar cost of 7.0¢ (2004 $) could fall to 5.8¢ if nuclear capital cost declined 25%, to 5.6¢ if construction speeded up from the assumed "optimistic" 5 y to 4 y, to 5.3¢/kWh if O&M costs fell to 1.36¢/kWh, and to 4.6¢ if the capital market attached zero risk premium to nuclear *vis-à-vis* other central-station projects. (This is within WNA's claimed range, but still barely matches coal, let alone beats the decentralized competitors.) We also adopt the MIT study's finding that each $50 of carbon tax, or equivalent trading price, per tonne of carbon (TC) emitted raises the 40-y coal-electricity price by 1.3¢/kWh and the combined-cycle gas-electricity price by 0.5¢/kWh. The MIT study tests for a carbon pricing range of $50–200/TC. Based on a broader view of the role of end-use efficiency and decentralized supply-side competitors, an equilibrium value of

[66] T. Casten and S. Richards PE (Primary Energy, LLC), personal communications, 12 and 15 August 2005.

even \$100/TC seems implausibly high, and a long-run market-clearing price in a comprehensive and efficient market seems more likely to range from negative to single digits,[67] but for conservatism, Fig. 3 sensitivity-tests an illustrative carbon tax of \$100/TC.

End-use efficiency: A detailed treatment of this complex subject is well beyond the scope of this paper, but Fig. 4 summarizes some key data. This graph compares the levelized cost of saving a kWh (normalized as nearly as possible to a uniform accounting basis) from a variety of utility program evaluation findings and from bottom-up engineering studies of efficiency potential.

Fig. 4. Costs of saved electricity from some evaluated utility programs and some empirically based detailed engineering studies of national end-use efficiency potential.



The main primary or secondary data sources are diverse but representative.[68] Asterisked program-only costs are typically about half of total societal real resource costs (customers pay the rest). The best results shown are existence proofs of what is possible. Key implications include:

[67] Consistent with a value <\$50/TC, on 7 April 2005 the California PUC adopted the final imputed costs for CO_2 emissions to be used by the utilities as the "greenhouse gas adder" in long-term planning and procurement: a net present value of \$8/2000 lb CO_2, based on a cost of \$5 per ton CO_2 in the near term, \$12.50 by 2008, and \$17.50 by 2013 (CPUC Decision 05-04-024, Conclusion of Law 7). To convert from \$/ton CO_2 to \$/ton C, divide by 0.27.

[68] S. Nadel, *Lessons Learned: A Review of Utility Experience with Conservation and Load Management Programs for Commercial and Industrial Customers*, NYSERDA #90–8 (Albany), American Council for an Energy-Efficient Economy Publ. #U901 (1990), www.aceee.org/store/proddetail.cfm?CFID=237174&CFTOKEN=57381814&ItemID=237&CategoryID=7; A.B. Lovins, "Negawatts: Twelve transitions, eight improvements and one distraction," *En. Pol.* **24**(4):331–343 (1996), RMI Publ. #U96-11, www.rmi.org/images/other/Energy/U96-11_Negawatts12-8-1.pdf; A.B. Lovins, "Apples,

- Program costs tend to decline with experience, as shown by the recent evaluations for the three California investor-owned utilities[69] and the aggregate of the 79 Pacific Northwest utilities evaluated by the Northwest Power Planning Council.[70] California has generally mild climates, high building and appliance efficiency standards, and a long DSM history, so other sites lacking those attributes should tend to have bigger potential at lower costs.
- Broad programs, especially those emphasizing the relatively costlier and higher-transaction-cost measures common in the residential sector (notably home shell retrofits), tend to cost a few ¢/kWh. In striking contrast, many programs targeting commercial and industrial savings cost much less, and the best ones cost less than 1¢/kWh. Potential savings in these sectors are so large that the data support ~1¢/kWh or lower societal cost for savings ~20% of total use, with higher or lower costs plausible depending on assumptions.
- Very detailed bottom-up analyses for Danish buildings[71] and for all electricity uses in Sweden[72] and the United States[73], and EPRI's moderately detailed estimate of U.S. potential savings[74], show very large technical-potential savings (~40–75+%) at total soci-

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Oranges, and Horned Toads," *El. J.* 7(4):29–49 (1994), available through www.sciencedirect/com or as RMI Publ. #U94-16; A.B. Lovins. "Letter to Professor Paul. L. Joskow, Department of Economics, MIT," 12 Jan. 1992, RMI Publ. #U93-2; A.B. Lovins. "Report to Minister for Industry and Economic Planning on matters pertaining to Victorian Energy Policy" [Australia], 30 Nov. 1990, RMI Publ. #U91-5.

[69] C. Rogers, M. Messenger, & S. Bender, *Funding And Savings For Energy Efficiency Programs For Program Years 2000 Through 2004.* Staff report for California Energy Commission, July 2005, www.fypower.org/pdf/CEC_Trends2000-04.pdf, updated 1976–2004, M. Messenger & C. Rogers (CEC), pers. comms., Nov.–Dec. 2005. Evaluation protocols have evolved over the period graphed, but have been modern and stable since the mid-'90s; earlier evaluations may have been self-reported or less conservatively and completely included certain factors.

[70] Northwest Power Planning Council, "Utility Conservation Achievements Reports: 2004 Survey," www.nwcouncil.org/energy/rtf/consreport/2004/Default.asp, and "Utility Conservation Achievements Reports: 2002 Survey," www.nwcouncil.org/energy/rtf/consreport/2002/Default.asp.

[71] J.S. Nørgård, a leading expert at the Danish Technical University (DTH/Lyngby), showed in detail how half the electricity in Danish late-1980s buildings could be saved at an average cost of 0.6¢/kWh, or three-fourths at 1.3¢/kWh (1986 $): *Husholdninger og Energi*, Polyteknisk Forlag, København, 1979, updated and summarized in his "Low Electricity Appliances—Options for the Future," at pp. 125–172 in T.B. Johansson, B. Bodlund, & R.H. Williams, eds., *Electricity: Efficient End Use and New Generation Technologies and Their Planning Implications* (Lund U. Press, 1989).

[72] B. Bodlund *et al.*, "The Challenge of Choices," in Johansson *et al.*, *id.*, 1989, showed for Vattenfall, the Swedish State Power Board, how to save half of Swedish electricity at 78% lower cost than making more (*i.e.*, at an average cost of 1.6¢/kWh in ~1986 $). Sweden, like Denmark, is already quite energy-efficient. Vattenfall's CEO ordered removed from the paper the usual disclaimer saying it didn't represent the organization's official view.

[73] E SOURCE (Boulder CO), *Technology Atlas* series (five volumes and numerous supplements, 1999–), www.esource.com, subscription products by various authors, condensing six volumes by the author's COMPETITEK team at Rocky Mountain Institute, 1986–92. Those encyclopedic works, totaling 2,509 dense pages cited to 5,135 sourcenotes, assessed empirical cost and performance for ~1,000 technologies; showed how to combine them into optimal packages; remain the most detailed assessment to date of the potential for electric end-use efficiency; and found that upwards of three-fourths of U.S. electricity (*vs.* 1986 frozen efficiency) could be saved at an average cost of ~0.6¢/kWh (1986 $). The basic findings are summarized in A.B. Lovins, "Least-Cost Climatic Stabilization," note 35, referencing similar sectoral findings by other analysts. The RMI analyses excluded fuel-switching lifestyle changes, load management, technological progress beyond the late 1980s, and some technical options. How much of the indicated potential actually gets captured is a policy and marketing variable, but some utilities have in fact captured 70–90+% of particular efficiency markets in months to years through skillful marketing, suggesting that most of the national technical potential could actually be captured over a few decades.

[74] EPRI, *Efficient Electricity Use: Estimates of Maximum Energy Savings*, CU-6746, 1990, summarized in A.P. Fickett, C.W. Gellings, & A.B. Lovins, "Efficient Use of Electricity," *Sci. Am.* **263**(3):64–74 (Sept. 1990). EPRI estimated that full application of late-1980s techniques to the expected 2000 U.S. economy could save (almost all cost-effectively) ~24–44% of U.S. electricity, not including a further 8.6% expected to occur spontaneously by then,

etal costs similar to or below today's broad-based utility program costs, although these studies used 1980s technologies that generally cost more and saved less than today's.
- Few if any of the programs shown use truly modern technologies, and probably none uses modern integrative design techniques that typically "tunnel through the cost barrier" to achieve very large industrial, commercial, and residential kWh savings at *negative* marginal cost in most new installations[75] and some retrofits.[76]

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A student of nuclear power since the 1960s, Mr. Lovins has consulted for scores of utilities worldwide, many of them nuclear operators. In 1986–92 he led the world's most detailed examination of electric efficiency potential. He served in 1980–81 on USDOE's senior advisory board and in 1999–2001 on a Defense Science Board panel on the energy efficiency of military platforms. It may be of historic interest that his high-school experimental-physics research received national awards from Westinghouse, General Electric, the American Nuclear Society, and Dr. Glenn T. Seaborg, then Chairman of the U.S. Atomic Energy Commission. At that time, he and Dr. Seaborg both thought nuclear power sounded like a good idea.

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nor a further 6.5% likely to be saved by utilities' planned efficiency programs. The total potential saving found by EPRI was thus ~39–59%. These findings are compared with RMI's (see previous note) by E. Hirst, "Possible Effects of Electric-Utility DSM Programs, 1990 to 2010," ORNL/CON-312, Oak Ridge National Laboratory, Feb. 1991. Hirst's and the author's comparisons, summarized in the 1991 *Ann. Rev. En.* article, note 35, showed that most of the difference came from EPRI's assuming a drivepower saving 3× smaller and 5× costlier than EPRI found in our joint 1990 article (Fickett *et al.*, *op. cit. supra*), and from a simple methodological difference: EPRI excluded, but RMI included, credit for maintenance costs saved by customers, so commercial lighting savings cost 1.2¢/kWh in the EPRI but –1.4¢/kWh in the RMI supply curves. Normalizing for these non-substantive differences makes the two curves nearly identical. The remaining differences—believed to be due to the modernity, thoroughness of characterization, and disaggregation of the measures analyzed—are less important than the EPRI/RMI consensus that cost-effective potential savings are many times larger than utilities, even in California, currently plan to capture. This was further confirmed by PG&E's "ACT^2" experiment, which the author co-founded and co-steered in the 1990s (with A.H. Rosenfeld, Ralph Cavanagh, and Carl Weinberg), but whose striking integrative-design successes are not yet reflected in California's codes or its utilities' programs.

[75] See *e.g.* P.G. Hawken, A.B. Lovins, & L.H. Lovins, *Natural Capitalism*, Little Brown (Boston), 1999, summarized in *Harv. Bus. Rev.*, May–June 1999, pp. 145–158, both free downloads at www.natcap.org; A.B. Lovins, "Energy efficiency—taxonomic overview," *Encyc. of Energy* **2**:382–401, Elsevier, 2004, RMI Publ. #E04-02, www.rmi.org/images/other/Energy/E04-02_EnergyEffTax.pdf; and other sources in the bibliography to the author's paper, ref. 2. A detailed methodological discussion, clarifying common misconceptions about the costs of utility programs and technical efficiency gains, is A.B. Lovins, "Apples, Oranges, and Horned Toads," *El. J.*, n. 68.

[76] For example, A.B. Lovins, "The Super-Efficient Passive Building Frontier," *ASHRAE J.*, June 1995, pp. 79–81, www.rmi.org/images/other/Energy/E95-28_SuperEffBldgFrontier.pdf, describes how to save three-fourths of the electricity used by a ~200,000-ft^2 curtainwall office tower near Chicago, at a retrofit cost slightly below that of the normally required 20-year routine renovation that saves no energy. Comfort and value would also improve greatly.

Forget nuclear

AMORY B. LOVINS AND IMRAN SHEIKH
RMI Solutions prepublication draft 11 March 2008, subject to further editing

Nuclear power, we're told, is a vibrant industry that's dramatically reviving because it's proven, necessary, competitive, reliable, safe, secure, widely used, increasingly popular, and carbon-free—a perfect replacement for carbon-spewing coal power. New nuclear plants thus sound vital for climate protection, energy security, and powering a growing economy.

There's a catch, though: the private capital market isn't investing in new nuclear plants, and without financing, capitalist utilities aren't buying. The few purchases, nearly all in Asia, are all made by central planners with a draw on the public purse. In the US, even government subsidies comparable to new nuclear power's total cost have failed to entice Wall Street.

The private capital market is unenthusiastic because it sees financial risks outweighing rewards. Capitalists' unwillingness to risk their own money suggests the public story is flawed. In fact, as we'll see, it's steadily diverging from observed market behavior. Nuclear power, far from reviving, is collapsing because it's so uneconomic that one needn't even debate whether it's clean and safe. Moreover, nobody needs its modest potential contribution, it weakens electric reliability and national security, and it *worsens* climate change compared to better buys.

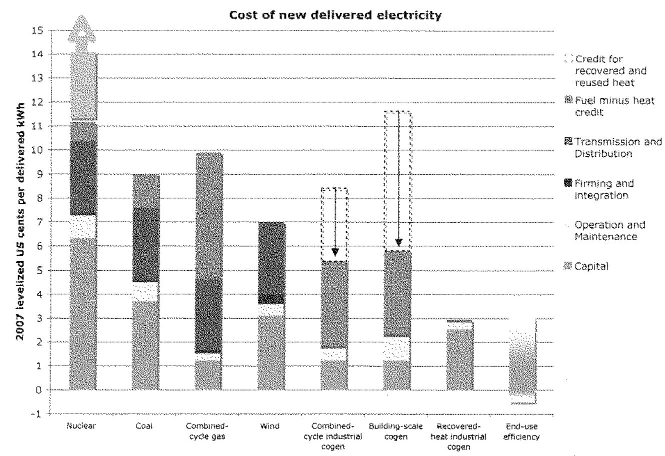
The more decisively new nuclear power is humbled in the marketplace by swifter and cheaper rivals, the more vigorously its advocates claim it has no rivals—that its indispensability justifies intensive support. But in fact, the low- or no-carbon competitors dismissed as uneconomic, trivial, and impractical actually produce more electricity, are growing tens of times faster worldwide and seven times faster in China, and have tens of times nuclear power's market share.

This nontechnical summary article compares new nuclear plants' with competitors' costs, market success, deployment speed, reliability, and adequacy. It explains why taxpayer subsidies that approach or exceed 100% of new US nuclear plants' entire cost are failing to attract investors, who instead favor climate-protecting competitors with lower costs and financial risks. And comparing all options' ability to protect the earth's climate and enhance energy security reveals why nuclear power couldn't deliver those benefits even if it could find free-market buyers.

Uncompetitive costs

The world's 439 operating nuclear plants face such challenges as safety, terrorist vulnerability, waste disposal, and proliferation of nuclear weapons. New plants would face very similar issues. But few new plants will be built if they can't attract private capital, so let's start with cost.

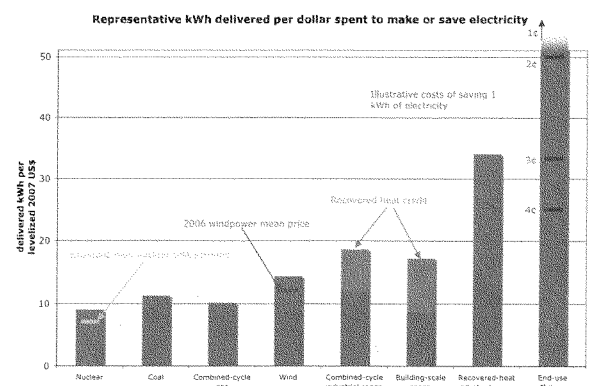
The Economist wrote in 2001 that "Nuclear power, once claimed to be too cheap to meter, is now too costly to matter"—cheap to run but very expensive to build. Its total costs exceed those of other common power plants (coal, gas, big windfarms), and far exceed the costs of the even cheaper competitors described below. In the past few years, nuclear power's capital costs, promised to fall, have instead soared, and even its low fuel costs look set to rise by severalfold. By 2007, as this empirical graph shows, nuclear was the costliest option among all main competitors, whether using MIT's authoritative but now low 2003 cost assessment, the Keystone Center's mid-2007 update (pink bar), or later and even higher industry estimates (pink arrow):



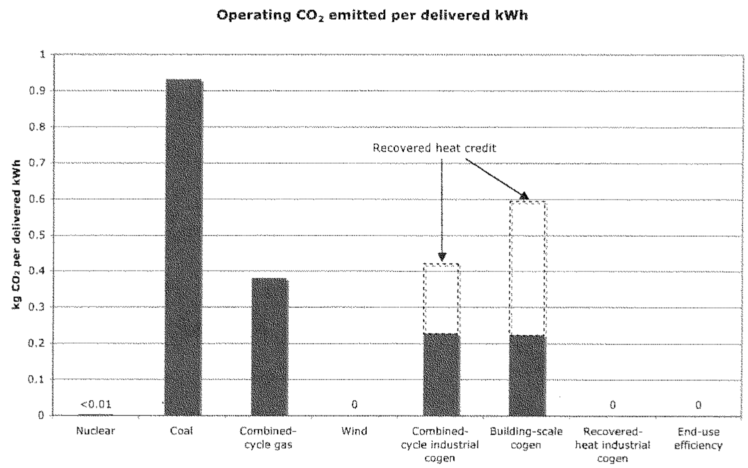
Climate savior or climate handicap?

But wouldn't new nuclear plants justify even their high costs by displacing coal-fired power and thus protecting the earth's climate? After all, nuclear plants' operations emit almost no carbon: making their fuel uses less than one percent as much electricity as they produce, and the energy to make their construction materials isn't very different than competitors'. But while uranium can indeed displace coal, it does so less cost-effectively and rapidly than competitors.

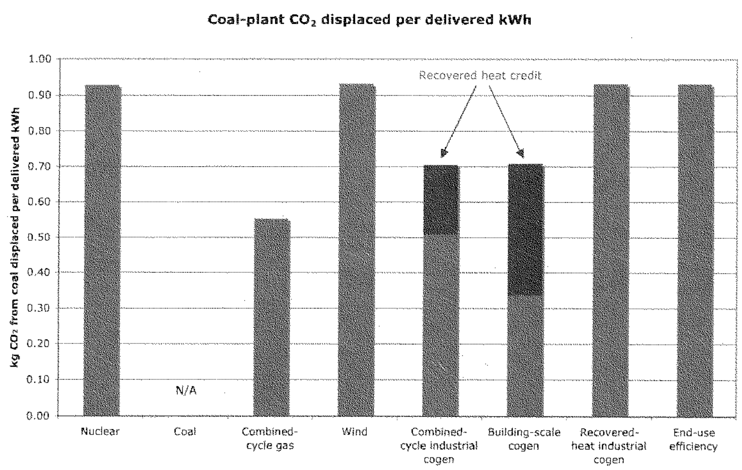
The same dollar can't buy two different things at the same time. Therefore every dollar spent on a new nuclear plant foregoes buying *more* carbon displacement sooner from cheaper and faster low- or no-carbon options. Converting the graph above from cost (cents per kilowatt-hour) to cost-effectiveness (kilowatt-hours per dollar) yields this graph:



Various sources of electrical services emit very different amounts of carbon, coal most of all:



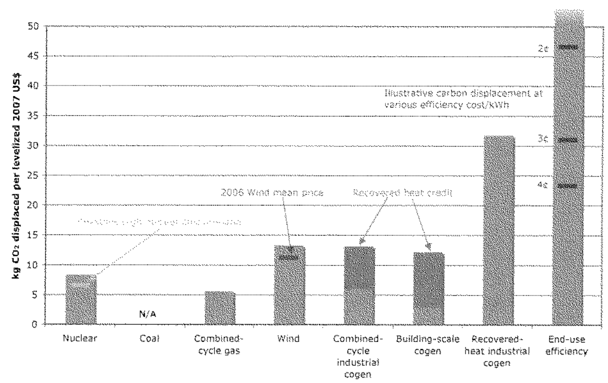
The carbon displaced by shifting from coal-fired electricity to another resource is simply the difference between their respective carbon emissions per kilowatt-hour:



Nuclear looks like an effective way to displace carbon, but it's also very costly, so it delivers fewer kWh per *dollar* than do other resources that displace similar amounts of carbon per kWh.

Thus when we multiply the coal-plant carbon displaced per kWh times the kWh delivered per dollar, we get the net climate benefit of spending a dollar in different ways:

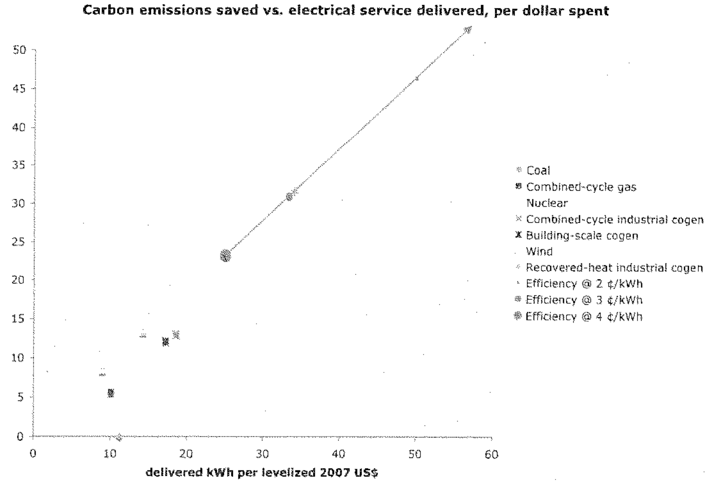
Coal-fired CO_2 emissions displaced per dollar spent on electrical services



This analysis shows that nuclear is the least cost-effective carbon-saver per dollar, other than (if nuclear costs stabilize) a combined-cycle power plant burning very expensive natural gas.

Another way to represent these findings would be to combine effectiveness in both powering the economy *and* protecting the climate. Coal power is cheaper than nuclear but emits copious carbon; combined-cycle gas power plants are intermediate in both cost and carbon. But moving toward the upper right of the following summary graph, toward better buys than any central thermal plant, both delivers more services per dollar *and* saves more carbon per dollar:

Carbon emissions saved vs. electrical service delivered, per dollar spent



Scoring by the vertical axis (climate protection per dollar), we see that making and delivering new nuclear power displaces 1.5–11× less carbon per dollar than negawatts or micropower. That is, *every dollar spent on new nuclear power produces 1.5–11× less climate solution than spending the same dollar on its cheaper competitors.* If climate is a problem, we must invest judiciously, not indiscriminately, to buy the most solution per dollar and the most solution per year —best buys first, not the more the merrier, and (as we'll see) *fastest* buys first.

Which power sources are reliable?

Another reason to buy nuclear power could be to provide reliable power—the lifeblood of modern economies. At first glance this looks like a strong argument, because US nuclear reliability has improved so impressively that the average plant generates each year about 90% of its theoretical potential. Yet it also shuts down for 39 days every 17 months for refueling and maintenance, and sometimes unexpectedly. The world's largest nuclear plant, a 7-reactor complex supplying 6–7% of Japan's total electricity, remains closed after 2006 earthquake damage.

The average US fossil-fueled power plant fails about 8% of the time, but nuclear power can be even less dependable because many plants can fail at once. A major drought, accident, or attack, or an episode like the falsified safety data that led Japanese regulators to close all 17 of Tokyo Electric's reactors for months to years, could shut down many nuclear plants at once. Worse, nuclear plants must instantly shut down in a power failure, as nine perfectly operating US units did in the August 2003 Northeast blackout. But suddenly stopped reactors can't be quickly restarted, so the average capacity lost was 97.5% over the first three days, 62.5% for five days, and 53.2% for twelve days. Canadian reactors' restart was even rougher, threatening Toronto with grid collapse for days. This inherent nuclear-physics attribute makes nuclear plants "antipeakers"—guaranteed unavailable when most needed—as Florida rediscovered on 26 February 2008 when two reactors couldn't promptly restart after a blackout.

The giant transmission lines that highly concentrated nuclear plants require are also vulnerable to lightning, ice storms, rifle bullets, and other interruptions. The bigger our power plants and power lines get, the more frequent and widespread regional blackouts will become (just as suppressing forest fires causes monster blazes when fire suppression fails). Because 98–99% of power failures start in the grid, highly reliable power must come from efficiently used, diverse, dispersed resources sited at or near the customer, And if supply interruptions are also of concern, then supply should shift to renewables that can't be cut off.

To be sure, all sources of electricity sometimes fail, differing only in why, how often, how much, for how long, and how predictably. Even the most reliable giant plants are intermittent: they fail unexpectedly in billion-watt chunks, often for long periods, so utilities must install ~15% "reserve margin." Yet a portfolio of many smaller units would be unlikely to fail all at once, and collectively they can be especially reliable if they're of different kinds and in different places.

The sun doesn't always shine on a given solar panel, nor does the wind always spin a given turbine. Yet if properly engineered, both windpower—whose global potential is 35 times world electricity use—and solar energy—as much of which falls on the earth's surface every ~70 minutes as humankind uses in a year—can deliver reliable power. Variable renewable resources become collectively reliable when diversified in type and location, forecasted in output, and integrated with steady renewables (geothermal, small hydro, biomass, etc.), with existing fueled plants, and with customer demand. In general, reliable power supplies with large wind and solar fractions require *less* backup or storage capacity than utilities *have already bought* to cope with big thermal stations' intermittence.

Of more than 200 international studies through 2006, not one found significant costs or technical obstacles to reliably integrating large variable supplies into the grid. Experience confirms these analyses. Denmark today is over one-fifth and Germany one-tenth wind-powered. Without significant integration costs or problems, some 20–30%-windpowered regions of those countries and of Spain get more windpower in windy periods than their total usage. Solar power, too, is strongest on hot afternoons when it's most needed. Eight recent US utility studies found that high windpower fractions would incur backup and integration costs equivalent to just 1–15% of windpower's 1999–2006 US average price, which is one-third that of new nuclear power.

Rising nuclear costs, soaring subsidies, dwindling competitive prospects

In past decades, nuclear plants' ruinous cost overruns were variously split between ratepayers and shareholders. But as power markets became more competitive and decisions more transparent, restructured markets in about half the US shifted all the risk to investors. Now, as the credit crunch deepens investors' skittishness, the smart money is starting to head for the exits. In early 2008, Warren Buffet cancelled his Idaho reactor because "it does not make economic sense," a South Carolina proposal collapsed, and financial risk drove the capacity-short City of Austin out of the NRG project. What spooked these prospective buyers?

First, the industry's Finnish flagship project led by France's top builder, after 28 months' construction, had gone at least 24 months behind schedule and $2 billion over budget, plus an estimated ~$4 billion in extra customer costs. Construction costs worldwide have risen far faster for nuclear than non-nuclear plants, due not just to soaring steel, copper, and cement prices but also to weakened global infrastructure for making, building, managing, and operating reactors.

These trends make investors doubt the industry's cost forecasts. New designs and smarter construction, it was claimed, would bring in new plants at or below the lowest costs US builders had ever achieved. In 2005, the industry said capital costs (in 2007 $) would fall to ~$1,240–1,360/kW. But in 2004, a careful and independent MIT team estimated $2,308/kW, which realistic free-market financing costs could nearly double. In mid-2007, an industry-dominated Keystone Center study found total costs including financing had risen to $3,600–4,000/kW (the pink bar in the first graph above)—so high that the industry ignored or misrepresented the report. Costs keep escalating: in late 2007, Moody's estimated ~$5,000 to ~$6,000/kW and big utilities estimated ~$4,300 to ~$7,000/kW. That's "on the order of…$13 to $14 billion for a two-unit plant," said a utility chairman—more than the market cap of every US electric company but one.

High, and highly uncertain, costs now make financing prohibitively costly for free-market nuclear plants. But even regulated utilities would face sticker shock: new nuclear electricity that might cost upwards of 16¢/kWh "levelized" over decades would cost 27¢/kWh in the first year's operation—triple today's price, and even costlier than rooftop solar power.

Lacking investors, nuclear promoters have turned back to taxpayers, who already bear most accident risks, have no meaningful say in licensing, insure operators against legal or regulatory delays, and subsidize existing nuclear plants by ~0.9–4.6¢/kWh. In 2005, desperate for orders, the politically potent industry got those subsidies raised to ~4.6–8.9¢/kWh for new plants, or ~60–90% of their entire projected power cost. Wall Street still demurred. In 2007, the industry won relaxed government rules that made its 100% loan guarantees even more valuable—worth, one utility's data revealed, about $13 billion for a single new plant. But rising costs had meanwhile made the $4 billion of 2005 loan guarantees scarcely sufficient for one plant, so Congress raised taxpayers' guarantees to $18.5 billion (enough for several plants), and will be asked for another $30+ billion this year. The Congressional Budget Office considers defaults likely. The benefiting firms unwilling to bear that risk, now transferred to taxpayers, had total FY2004 revenues of $569 billion and enterprise values of $1.25 trillion, making them collectively the world's 13^{th}-biggest economy—bigger than the world's 112 poorest nations combined.

With Wall Street still skeptical that nuclear power is as robustly competitive as claimed, the Nuclear Energy Institute is discreetly starting to damp down the rosy expectations it created. It now says US nuclear orders will come not in a tidal wave but in two little ripples—a mere 5–8 units coming online in 2015–16, then more if those are on time and within budget. In 2006– 07, NEI ominously noted, 78% of announced coal plants got cancelled. Many signs suggest that nuclear ambitions may suffer a similar fate. In today's capital market, governments can have only about as many nuclear plants as they're willing to pay for. Ever more heroic subsidies will elicit roughly the same response as defibrillating a corpse: it will jump, but it won't revive.

The invisible revolution

While nuclear power struggles in vain to attract private capital, investors have switched in droves to cheaper, less risky competitors. The very alternatives that the nuclear industry derides as infeasible and unimportant actually surpassed nuclear's global capacity in 2002 and its electricity output in 2006. Nuclear power now holds a mere sliver of global markets—about 2% of capacity additions and nearer 1% of new electrical services—while decentralized generators have captured at least a third of the total market for new electric generating capacity.

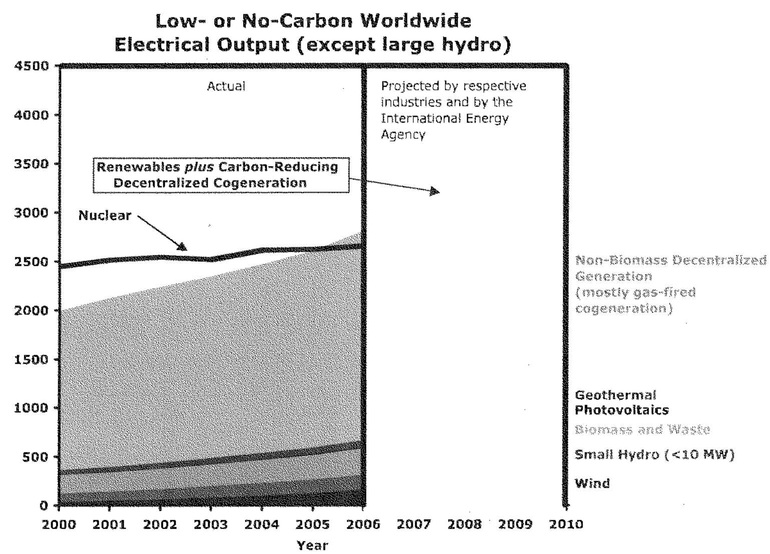
Half of what *The Economist* calls "micropower" makes electricity in factories or buildings, and usually cogenerates useful heat too, mostly from gas and saving over half the carbon. The other half comes from distributed renewable sources—all renewable sources of electricity except big hydro dams. Another, even cheaper competitor to nuclear is "negawatts"—saving electricity by using it more efficiently or at smarter times. Despite subsidies generally smaller than nuclear's, and many tall barriers to fair market entry and competition, these decentralized resources have lately turned in stunning global market performance:

- In 2005, micropower added 13 times as much electricity and 10 times as much capacity as nuclear power added (or 14 times as much capacity including onsite standby and peaking generators that can generally be run when needed). A fifth of the world's new electricity and a sixth of its total electricity came from micropower. So did from a sixth to more than half the electricity in a dozen industrial nations (the US lagged with 4%).
- In 2006, nuclear power added less capacity than photovoltaics added, one-tenth what windpower added, and 30–41 times less than micropower added. Nuclear added only one-sixth as much annual electricity production as micropower. Distributed renewables won $56 billion of private risk capital; nuclear, as usual, got zero. China's distributed renewable capacity reached seven times its nuclear capacity and grew seven times faster.
- In 2007, for which data on cogeneration aren't yet available, distributed renewables grew another ~15% to ~237 GW of global capacity—65% of nuclear's. Global nuclear capacity grew ~2.5 GW, while windpower alone added 3.2 GW in China, 3.5 GW in Spain (now 10% wind-powered), 5.2 GW in the US (~30% of total capacity additions), and 20

GW worldwide. A nuclear kilowatt produces three times the annual electricity of a wind kilowatt, but wind added eight times more kilowatts.

- The nuclear industry projects that in the five years 2006–2010 it'll build 17 GW (most, all, or more expected to be offset by nuclear retirements)—yet micropower today is adding 17 GW about every 15 *weeks*, or 18 times faster.

Micropower's actual and industry-projected electricity production is running away from nuclear's, not even counting the roughly comparable additional growth in negawatts:



The nuclear industry still believes its only serious competitors are big coal and gas plants. But the marketplace has already abandoned that battleground for two others: central plants *vs.* micropower, and megawatts *vs.* negawatts. By beating *all* central stations, micropower and negawatts together provide about half the world's new electrical services.

In this broader competitive landscape, high carbon prices or taxes can't save nuclear power from its fate. If nuclear did compete only with coal, then far-above-market carbon prices might save it; but coal isn't the competitor to beat. Higher carbon prices will advantage all other zero-carbon resources—renewables, recovered-heat cogeneration, and negawatts—as much as nuclear, and will partly advantage fossil-fueled but low-carbon cogeneration too.

Many smalls can make a big

Just as computing has largely switched from central mainframes to networked PCs, and telephony from central exchanges to distributed packet-switching, so can small power stations run a big economy. Despite their small individual size, micropower generators and electrical savings are already adding up to huge totals, just like the small individual pieces of electrical demand. Small, quickly built units also have far smaller financial risks than big, slow ones. Micropower's 207 kinds of financial-economics and electrical-engineering benefits can indeed make it about ten times more valuable (www.smallisprofitable.org) than current prices, or the cost comparisons above, imply. Most of the same benefits apply to negawatts.

Small, quickly built units are also faster to deploy for a given total effect than a few big, slowly built units. Widely accessible choices that sell like cellphones and PCs can add up to more, sooner, than ponderous plants that get built like cathedrals. California proved this with quarter-century-old technology in 1982–85 by letting all ways to make or save electricity compete on a fairly level playing-field. In just three years, utilities bought or were firmly offered decentralized resources totaling 143% of total statewide demand—creating a glut that forced a halt to the bidding. Today's technologies are far better and cheaper.

Negawatts can also be deployed quickly. Just in 2006, the U.S. cut its electricity use per dollar of real GDP by 3% and its primary energy intensity by 4% while GDP grew only 3%, so total energy, oil, and coal use *fell* while electricity use rose only 0.1%. This occurred even though 48 states rewarded utilities for selling more electricity and penalized them for cutting customers' bills. That perverse incentive is now starting to be reversed by a fast-spreading reform, called "decoupling and shared savings," that aligns utility with customer interests, benefiting both and greatly speeding savings.

Over decades, negawatts and micropower can shoulder the entire burden of powering the economy. The US negawatt potential cheaper than just running an existing nuclear plant is calculated by the utilities' think-tank to be two to three times, and by RMI to be at least four times, nuclear power's 19% US market share. Cogeneration in factories can make as much US electricity as nuclear does, plus more in buildings, which use 69% of US electricity. Windpower in acceptable US sites can cost-effectively produce at least twice the nation's total electricity use, and other renewables can make even more without significant land-use, variability, or other constraints. Rather, it's nuclear power whose challenges—decade-long project cycles, difficult siting, and (above all) unattractiveness to private capitalists—limit its potential contribution. And it's nuclear power that compromises energy independence: the US must import key parts from Japan or France, which must in turn import uranium.

Despite decades of intense effort, neither of those leading nuclear nations has made atomic power a commercial success. Nuclear plants drove Tokyo electric prices so high that as soon as big customers were allowed to choose their supplier, one-third fled to cheaper cogenerators. France's vaunted 78%-nuclear electricity proved so costly that it required taxpayer bailouts of its largely state-owned national utility and nuclear builder. France uses only one-tenth less fossil fuel today than in 1973, has a large and sometimes unsellable nuclear surplus, and is even restarting inefficient old oil-fired plants to cope with the winter peak load created by its imperative to try to absorb that surplus by promoting electric heat, which just one-fourth of French homes use, because it's too expensive.

Nuclear power does, however, have one critical link with security. President Bush rightly identifies the spread of nuclear weapons as the gravest threat to America. Yet that proliferation is largely driven and greatly facilitated by nuclear power's handy provision of do-it-yourself bomb kits in innocent-looking civilian disguise (especially with nuclear-fuel reprocessing, an uneconomic activity the President hopes to revive). Acknowledging nuclear power's market failure and moving on to secure, least-cost energy options for global development would unmask and penalize proliferators by making bomb ingredients harder to get, more conspicuous to try to get, and politically costlier to be caught trying to get. This would make proliferation far more difficult, and easier to detect timely by focusing scarce intelligence resources on needles, not haystacks.

In short, nuclear power's less attractive features—such as proliferation, long-lived radioactive wastes, potentially serious accidents or terrorist attacks, and need for a vulnerably concentrated electric grid—are not a minor counterweight to big economic advantages, but a gratuitous supplement to major economic *dis*advantages. And far from protecting the climate, nuclear investments would reduce and retard the climate solutions that are routing them in the market.

In a 1988 *Energy Policy* paper, RMI researchers Dr. Bill Keepin and Greg Kats arrestingly noted—based on estimates that using electricity efficiently could save ~7× as much carbon per dollar as nuclear power—that *"every $100 invested in nuclear power would effectively release an additional tonne of carbon into the atmosphere"* compared to better buys. Twenty years later, that estimate remains valid. Buying new nuclear power instead of coal-fired electricity would save carbon if those were the only two choices, but they're not. Efficiency is so much cheaper than either that buying 1¢/kWh efficiency instead of new nuclear power *saves* about eight times more carbon per dollar than would have been *released* if the same money had instead bought new *coal*-fired electricity! That is, spending a dollar on nuclear instead of on efficiency makes global warming worse than spending that dollar on new coal power rather than not spending it at all.

Conclusions

So why do otherwise well-informed people still consider nuclear power a key element of a sound climate strategy? Not because that belief withstands analytic scrutiny; rather, it seems, because of a superficially attractive story, an immensely powerful and effective lobby, a new generation who forgot or never knew why nuclear power failed previously, sympathetic leaders of nearly all main governments, deeply rooted habits and rules that favor giant power plants over distributed solutions and enlarged supply over efficient use, the market winners' absence from many official databases (which often count only big plants owned by utilities), and lazy reportage by an unduly credulous press. One needn't invoke undue influence—nuclear vendors happen to own CBS, NBC, CNBC, MSNBC, and dozens of TV stations—to discern widely deficient energy journalism.

Isn't it time we forgot about nuclear power? Informed capitalists have. Politicians and pundits should too. After more than half a century and a half-trillion dollars of public subsidies, it still can't make its way in the market. If we accept that verdict, however reluctantly, we can at last get on with the best buys first: proven and ample ways to save more carbon per dollar, faster, more surely, more securely, and with wider consensus. As often before, the biggest key to a sound climate and security strategy is to take market economics seriously.

Mr. Lovins, a physicist, is cofounder, Chairman, and Chief Scientist of Rocky Mountain Institute (www.rmi.org), where Mr. Sheikh, an engineer, is a Research Analyst. Mr. Lovins has consulted for scores of electric utilities, many of them nuclear operators. The authors are grateful to their colleagues Dr. Joel Swisher PE and Dr. Alex Markevich for insightful comments, to many cited and uncited sources for research help. A technical paper preprinted at **TK URL** from the September 2008 *Ambio* (Royal Swedish Academy of Sciences) supports this summary with full details and documentation. RMI's annual compilation of global micropower data from industrial and governmental sources is being updated through 2006, and often through 2007, at www.rmi.org/sitepages/pid256.php#E05-04.

Mighty mice

The most powerful force resisting new nuclear may be a legion of small, fast and simple microgeneration and efficiency projects. ***By Amory B Lovins***

Two men on a wild and barren plain suddenly spy a huge bear charging towards them. One man immediately starts putting on his running shoes. "How futile!" the other exclaims, "you'll never outrun that bear!" His companion drily replies: "I don't need to outrun the bear."

In any race, it's vital to understand whom you need to outrun and what it takes to win. Yet an incomplete picture of the competitive landscape may be the nuclear industry's greatest impediment to sound strategic planning, profitable investment, and credible public discourse.

This knowledge gap is understandable because the industry has been working so hard to achieve impressive progress in so many areas at once: operational consistency and reliability, simpler and cheaper designs, better inherent safety, streamlined siting and approvals, stronger government support, and other prerequisites for nuclear revival. But while these demanding tasks have taken so much attention, our bear has gained speed, approaching from behind.

Steve Kidd, the World Nuclear Association's head of strategy and research, asked in *NEI* (September 2005): "How can new nuclear power plants be financed?" He predicted this would "prove very challenging" in the private capital market, even though several studies found circumstances in which new nuclear build could compete with "building gas- or coal-powered generating capacity of similar magnitude." Investors, he suggested, remain concerned about public opposition, siting and licensing, quick construcion at predictable cost, safety, security, liability, nonproliferation, waste, decommissioning, and smooth operation. And he felt nuclear power's economic merits would emerge if we had "power markets where different technologies can compete on a level playing field and where long-term investment in capacity is incentivised."

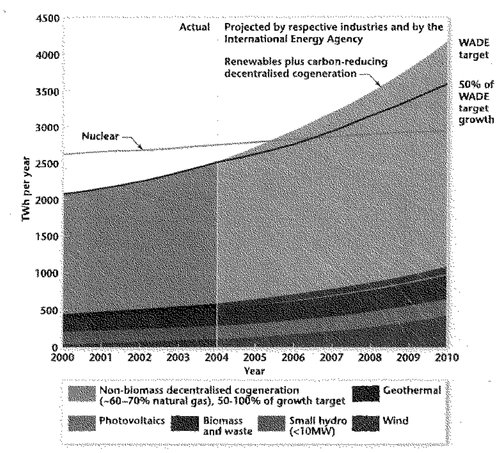


Figure 1: Worldwide electrical output of decentralised low- or no-carbon generators (except large hydro)

These issues remain important and challenging, yet the market reality is even more complex. Resolving all perceived risks wouldn't ensure nuclear power's market success. Rather, new nuclear plants and central coal- or gas-fired power plants are all uncompetitive with three other options whose status, prospects and value propositions are not well understood within the nuclear industry: certain decentralised renewables, combined-heat-and-power (CHP), and efficient end-use of electricity. In a rapidly evolving energy marketplace full of disruptive technologies, nuclear power's biggest challenges are not political but economic.

Most nuclear advocates consider the various 'micropower' and 'negawatt' (electricity saving) alternatives necessary and desirable but relatively small, slow, immature, uncertain, and futuristic – complementing central thermal stations without threatening their primacy. In this view, nuclear power will predominate within a balanced low-carbon electricity mix, and generation will remain overwhelmingly centralised, because nothing smaller could scale up enough to power a growing global economy. As the WNA website states: "Only nuclear power offers clean, environmentally friendly energy on a massive scale." Yet this view is hard to reconcile with recently compiled industry data.

DECENTRALISED COMPETITORS

The World Alliance for Decentralised Energy's (WADE's) March 2005 compilation from industry equipment sales and project data estimated that decentralised resources in 2004 generated 52% of the electricity in Denmark, 39% in The Netherlands, 37% in Finland, 31% in Russia, 18% in Germany, 16% in Japan, 16% in Poland, 15% in China, 14% in Portugal, and 11% in Canada. WADE's definition includes CHP gas turbines up to 120MWe, CHP engines up to 30MWe, CHP steam turbines only in China, windpower and photovoltaics (PVs), but no hydropower, no other renewables, no generators below 1MWe, and no end-use efficiency.

Figure 1 shows the annual output of

low- and no-carbon micropower compared with nuclear power. No hydroelectric dams over 10MWe are included. Average nuclear capacity factor (load factor) is assumed to rise linearly from 84.1% in 1982 to 88.5% in 2010. Up- and downratings, new units commissioned, and permanent retirements are shown consistently for all technologies.

This data shows that micropower has already eclipsed nuclear power in the global marketplace ~~already~~. About 65% of micropower's capacity and 77% of its output in 2004 was fossil-fuelled CHP, which was about two-thirds gas-fired, and emitted 30% to 80% less carbon (averaging at least 50% less) than the separate power plants and boilers or furnaces it replaced. The rest of the micropower was diverse renewables, whose operation, like nuclear power's (neglecting enrichment), releases no fossil-fuel carbon. Micropower's output lags its capacity by three years due to typically lower capacity factors for small hydro (~46%), windpower (~25-40%) and PVs (~17%) than for CHP (~83%), biofuelled generation (~70%) and geothermal (~75%).

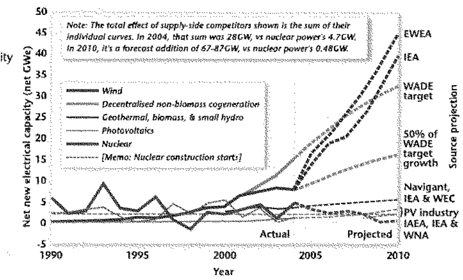
Worldwide, low- and no-carbon decentralised generators surpassed nuclear power's total installed capacity in 2002 and its annual output in 2005. In 2004 they added 5.9 times as much net capacity and 2.9 times as much annual output as nuclear power. The respective industries project that in 2010, micropower will add 136-184 times as much capacity as nuclear power will add, depending on CHP, wind and PV estimates (see Figure 2). Such projections are quite uncertain, but qualitatively clear. After 2010, whether the ageing reactor fleet declines as projected by Schneider and Froggatt (see *NEI* June 2005, p36) or more slowly as predicted by the International Energy Agency (IEA), even with major new nuclear build in countries like China, micropower will continue to pull ahead.

Figure 2 shows net capacity added by each technology in each year since 1990. Figure 2 also includes a leading indicator for nuclear power: construction starts through 2004. Their unknown size thereafter shouldn't materially affect 2010 completions. In 2004, windpower just in Germany and Spain added 2GWe each, matching the average global net addition of

Comparative cost

[illegible]

Figure 2: Global additions of electrical generating capacity by year and technology



nuclear capacity *per annum* (*pa*) during 2000-10. Worldwide nuclear construction starts will soon probably add fewer GWe *pa* than PV installations.

These comparisons omit another key decentralised competitor – saved electricity – that is seldom properly tracked but clearly substantial. At constant capacity factor, the 2.0% and 2.3% decreases in US electricity consumed per dollar of GDP during 2003 and 2004 would respectively correspond to saving 14 and more than 16 peak GWe, plus 1GWe *pa* of utility load management resources added and used. That's 6-8 times US utilities' declared 2.2GWe of peak savings achieved in 2003 by demand-side management. Since the USA uses only one-quarter of global electricity, and more efficient end-use is a global trend, worldwide electrical savings almost certainly exceed global additions of micropower (24GWe in 2003, 28GWe in 2004). Global additions of supply-side plus demand-side decentralised electrical resources are thus already an order of magnitude larger than global net additions of nuclear capacity (4.7GWe in 2004).

Few investors and policymakers realise this, because most official statistics under-report decentralised and non-utility-owned resources, show only physical energy supply, and pay little attention to drops in energy intensity, whatever their cause (in most countries, chiefly more efficient end-use technologies). Per dollar of GDP, US primary energy consumption has lately been falling by about 2.5% *pa*; electricity by 2.0% *pa*. Only 22% of the 1996-2005 increase in delivered US energy services was fuelled by increased energy supply, 78% by reduced intensity – yet the latter four-fifths of market activity remains dangerously invisible.

That invisibility lately led US merchant firms to lose ~$100 billion by building ~200GWe of combined-cycle gas plants for which there was no demand.

This calamity for investors could soon recur on a larger scale and not only in the power sector. The US Energy Policy Act of 2005 greatly increased subsidies and regulatory aid for energy supply whilst largely ignoring demand-side resources. Yet 'negawatts' expand as energy prices rise, and as policies that have held per-capita electricity use flat for 30 years in California and are decreasing it in Vermont spread to other US states.

Like micropower, efficiency tends to be installed more quickly than supplies. If it continues to reach customers and grab revenues first, it will glut markets, crash prices, and bankrupt producers, just as it did under similar conditions in the mid-1980s. This would intensify investors' risk aversion.

Many factors tug energy outcomes in diverse directions. Windpower, for example, is heavily subsidised in the UK where it has yet been slowed onshore by local opposition, and offshore by two years' government debate on how to finance its links to the grid. Similarly, US windpower gets a production tax credit (PTC) but its erratic and brief renewals by Congress have repeatedly bankrupted leading wind turbine producers. Overall, the correlation between renewable installation rates and government subsidies is not clear-cut. Neither are per-kWh subsidies' relative sizes for renewables versus central plants, particularly nuclear power. Nor is it obvious whether relative subsidies are more or less important than the barriers that in most countries still block fair competition. This analytic fog makes it dangerous to assume that micropower's success is subsidy-driven, or that its obscure implementation obstacles are less important or tractable than nuclear's familiar ones.

A simpler explanation for micropower's market success might be superior basic economics. Figure 3 supports this hypothesis by comparing the cost of a kWh delivered to the retail meter from various marginal sources.

In concluding that nonhydro renewables are unsuitable "for large-scale power generation where continuous, reliable supply is needed," the WNA commits two common fallacies: supposing that making large amounts of electricity requires large generating units, and forgetting that *ceteris paribus*

Conservatisms

[illegible]

many small units near customers are more reliable than fewer, bigger units far away. Central thermal stations are no longer the cheapest or most reliable source of delivered electricity, because generators now cost less than the grid and have become so reliable that 98-99% of US power failures originate in the grid. Thus the cheapest, most reliable power is typically produced at or near customers. Three-quarters of US residential and commercial customers use electricity at an average rate not exceeding 1.5 and 12kWe, respectively – severely mismatched to central plants' GWe scale. The WNA acknowledges a debate about scale, but ignores its profound implications and assumes central plants will remain dominant. Prudent investors favour micropower.

COMPARATIVE POTENTIAL

Of course, if decentralised resources had little potential to meet the world's rising needs for energy services, they'd be of minor competitive concern: one should worry about a bear, but hardly about a mouse. Yet a mighty swarm of mice is another matter. The modern literature suggests that decentralised resources' collective practical potential has been understated, as if the stunning technological and economic advances in conventional energy supply didn't apply to its rivals. To the contrary, such progress tends to be faster in decentralised resources. For example:

- At less than the delivered cost of just operating a zero-capital-cost nuclear plant (~$0.04/kWh), potential US electricity savings range from two to four times nuclear power's 20% share of the US electricity market, according to bottom-up assessments summarised by the Electric Power Research Institute (EPRI) and Rocky Mountain Institute's joint *Scientific American* article (September 1990). EPRI's Clark Gellings confirmed in 2005 that the US electric end-use efficiency resource is probably now even bigger and cheaper, because better mass-produced technologies more than offset savings already captured. Utility-specific data confirms a broad downward trend in the unit cost of 'negawatts'.
- CHP potential in industry and buildings is very large if regulators allow it. Waste-energy CHP alone is preliminarily estimated by Lawrence Berkeley National Laboratory to have a technical potential nearly as large as today's US nuclear capacity, though cost and feasibility are very site specific.

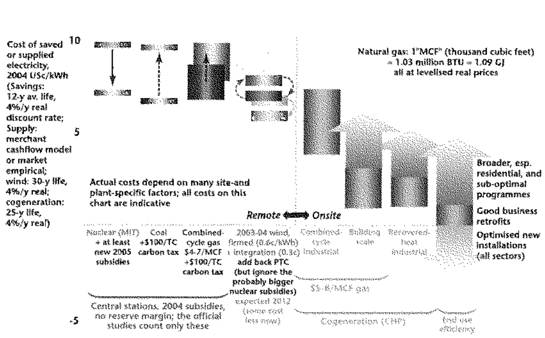


Figure 3: Nuclear power's competitors on a consistent accounting basis. Levelised cost of delivered electricity or end-use efficiency (at 2.75¢/kWh delivery cost for remote sources).

- Modern windpower's US potential on readily available rural land is at least twice national electrical usage.
- Other renewable sources of electricity are also collectively important – small hydro, biomass power (especially CHP), geothermal, ocean waves, currents, solar-thermal, and PVs. These sources and windpower also tend to be statistically complementary, working well under different weather conditions. All renewables together (excluding big hydro), plus solar technologies that indirectly displace electric loads (daylighting, solar water heating, passive heating and cooling), have a practical economic potential many times total US electricity consumption – at least an order of magnitude greater than nuclear power provides today.
- Even at such a scale, a diversified renewable portfolio needn't raise land-use concerns. For example, a rather inefficient PV array covering half of a sunny area 160×160km could meet all annual US electricity needs. In practice, since sunlight is distributed free, PVs would be integrated into building surfaces, and installed on roofs, over car parks, and along roads, both to save land and to make the power near loads. Specious claims persist comparing (say) the footprint of a nuclear reactor with the (generally miscalculated) land area of which a fraction – a few percent for wind turbines – is physically occupied by energy systems and infrastructure. In fact, total fuel cycle land use is roughly comparable for solar, coal and nuclear.

Thus renewables clearly have a very large global potential. The IEA's *World Energy Outlook 2004* foresees a 2030 renewable potential of ~30,000TWh *pa* (less than a quarter of it from hydropower). Such massive production would become far easier with CHP and efficient end-use. It still wouldn't be easy, but neither would central stations of similar output – especially for serving the two billion people not now on any grid.

COMPARATIVE SPEED

But might decentralised supply- and demand-side resources be too slow to deploy, requiring central stations to provide enough reliable power, quickly enough, to meet burgeoning demand? This widely held view seems inconsistent with observed market behaviour. As shown above, micropower and efficient end-use, despite many obstacles, are already adding an order of magnitude more GWe *pa* than nuclear power worldwide. Their brisk deployment reflects short lead times, modularity and economies of mass production (they're more like cars than cathedrals); usually-mild siting issues (except in some unusual windpower cases); and the inherently greater speed of technologies deployable by many diverse market actors without complex regulatory processes, ponderous enterprises, or unique institutions.

Of course every energy option faces specific obstacles, barriers, and hence risk of slow or no implementation at scale. Efficiency, for example, faces some 60-80 market failures, many arcane, that have left most of it unbought. Yet US electric intensity has declined at an unprecedented average rate of 1.5% *pa* since 1996 even though electricity is the form of energy most heavily subsidised, most prone to split incentives, least priced on the margin, and sold by distributors widely rewarded for selling more kWh. Such firms as DuPont and IBM routinely cut their energy intensity by 6% *pa* with attractive profits and no apparent constraints.

Letting all decentralised resources really compete risks not a dry hole but a gusher. Just during 1982-85, when California's three investor-owned utilities offered a relatively level playing field, fair competition elicited 23GWe of efficiency plus 21GWe of generation (13GWe of it actually bought) rising by 9GWe *pa*. The resulting glut, 144% of the 1984 peak load of 37GWe, forced bidding suspension in 1985, lest every fossil and nuclear plant be displaced (which in hindsight could have been valuable).

Investors appreciate that diversification is wise but must be intelligent. The strategic virtue of a diversified portfolio doesn't justify buying every technology or financial asset on offer. The sweeping claim that 'we need every energy technology' – as if we had infinite money and no need to choose – is often made but cannot withstand analysis. The WNA's website doesn't mention demand-side resources, and denies the existence of a large and compelling literature of nuclear-free, least-cost, long-term scenarios published over decades (in 1989, for example, Vattenfall published a roadmap for rapid economic growth, full nuclear phaseout, one-third power-sector CO_2 reduction, and $1 billion *pa* cheaper energy services). But investors with similarly limited vision are in for a shock. As all options compete and as increasingly competitive power markets clear, any supply investment costlier than end-use efficiency or alternative supplies risks being stranded by retreating demand.

OIL, CLIMATE, AND STRATEGY

A major argument often made for new nuclear build is oil displacement; yet this has already been largely completed. Only 3% of US electricity is made from oil and less than 2% of US oil makes electricity. Worldwide, these figures are around 7% and falling. Most of that oil, too, is residual, not distillate, and is burnt on relatively small grids by smaller plants with low capacity factors, unsuited to nuclear displacement. Both oil and fungible natural gas can be far more cheaply displaced by other means, mainly by doubled end-use efficiency.

A more compelling need is displacing coal-fired electricity to protect the earth's climate. Yet nuclear power's dubious competitive economics could make it counterproductive, for four reasons:

- Most of the carbon displacement should come from end-use efficiency, because it's profitable – cheaper than the energy it saves – and quick to deploy.
- End-use efficiency should save not just coal but also oil, particularly in transport. Comprehensive energy efficiency addresses 2.5 times as much CO_2 emission as any electricity-only initiative.
- Supply-side carbon displacements should come from a diverse portfolio of short-lead-time, mass-producible, widely applicable and accessible, benign, readily sited, rapidly deployable resources.
- The total portfolio of carbon displacements should be both fast and effective.

This last point highlights a troublesome implication of Figure 3's cost comparison. Buying a costlier option, like nuclear power, instead of a cheaper one, like 'negawatts' and micropower, displaces less carbon per dollar spent. This opportunity cost of not following the least-cost investment sequence – the order of economic and environmental priority – complicates climate protection. The indicative costs in Figure 3 (neglecting any differences in the energy embodied in manufacturing and supporting the technologies) imply that we could displace coal-fired electricity's carbon emissions by spending $0.10 to deliver any of the following:

- 1.0kWh of new nuclear electricity at its 2004 US subsidy levels and costs.
- 1.2-1.7kWh of dispatchable windpower at zero to actual 2004 US subsidies and at 2004-2012 costs.
- 0.9-1.7kWh of gas-fired industrial cogeneration or ~2.2-6.5kWh of building-scale trigeneration (both adjusted for their carbon emissions), or 2.4-8.9kWh of waste-heat cogeneration burning no incremental fossil fuel (more if credited for burning less fuel).
- From several to at least 10kWh of end-use efficiency.

The ratio of net carbon savings per dollar to that of nuclear power is the reciprocal of their relative cost, corrected for gas-fired CHP's carbon emissions (assumed here to be threefold lower than those of the coal-fired power plant and fossil-fuelled boiler displaced). As Bill Keepin and Greg Kats put it in *Energy Policy* (December 1988), based on their still-reasonable estimate that efficient use could save about seven times as much carbon per dollar as nuclear power, "every $100 invested in nuclear power would effectively release an additional tonne of carbon into the atmosphere" – so, counting that opportunity cost, "the effective carbon intensity of nuclear power is nearly six times greater than the direct carbon intensity of coal fired power." Whatever the exact ratio, their finding remains qualitatively robust even if nuclear power becomes far cheaper and its competitors don't.

Speed matters too: if nuclear investments are also inherently slower to deploy, as market behaviour indicates, then they don't only reduce but also retard carbon displacement. If climate matters, we must invest judiciously, not indiscriminately, to procure the most climate solution per dollar and per year. Empirically, on both criteria, nuclear power seems less effective than other abundant options on offer. The case for new nuclear build as a means of climate protection thus requires reexamination.

Micropower and its natural partner, efficient end-use, have surpassed and outpaced central stations despite many obstacles. Being diverse, ubiquitous, plentiful, widely available, largely benign, and popular, they are also hard to stop. To be sure, much work remains to purge the artificial barriers to true competition between all ways to save or produce energy, regardless of which kind they are, what technology or fuel they use, how big they are, or who owns them. But such a free market, for which Kidd rightly calls, seems increasingly unlikely to favour nuclear power. Rather, the economic fundamentals of distributed resources promise an ever-faster shift to very efficient end-use combined with diverse generators the right size for their task. That shift could render insufficient or even irrelevant the resolution of the perceived non-economic risks that preoccupy the nuclear industry.

The better the industry and its investors understand this, the more likely they are to fulfil reasonable expectations, apply their talents effectively, and help achieve the global energy, development, and security goals to which we all aspire.

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