Statement of

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on the

"Environmental, Safety, and Economic Implications of Nuclear Power"

Docket No. 06-IEP-[1N]
Energy Report: Nuclear Power, 2007 Workshops

Before the
California Energy Commission
Sacramento, California

NRDC
THE EARTH'S BEST DEFENSE

June 28, 2007

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Introduction. Mr. Chairman and members of the Commission, thank you for providing the Natural Resources Defense Council (NRDC) the opportunity to present its views on the issues before this Commission related to the use of nuclear power in California's energy future. NRDC is a national, non-profit organization of scientists, lawyers, and environmental specialists, dedicated to protecting public health and the environment. Founded in 1970, NRDC serves more than 1.2 members and supporters from offices in New York, Washington, Los Angeles, San Francisco, Chicago and Beijing.

The Commission, in its review of nuclear energy has provided the discussants with a list of questions to provide a framework for discussion at this workshop. While not answering each question in turn, I will attempt to address the salient issues.

Role of Nuclear Power in Reducing Greenhouse Gas Emissions. Today there are approximately 441 operational nuclear power plants in the world capable of generating 370 to 380 gigawatts of electric power (GWe). Hypothetically, 370 GWe of nuclear capacity, if operating for 50 years at 85 percent capacity factor, would displace about 34 GtC emitted by coal and gas plants.[1] While different assumptions will give different results, we estimate that sustaining this capacity for 50 years would make a contribution in reducing greenhouse gas emissions that is equivalent to roughly 1.3 Pacala/Sacolow "stabilization wedges." Without replacing the existing fleet or extending the operating life of the world's nuclear power plants beyond 60 years, we will lose about one-half of a "stabilization wedge" due to the retirement of the existing nuclear fleet.

As seen from the figure on the following page, the rate at which new nuclear plants were brought on line after 1990 has been considerably slower than it was in the 1970s and 80s. As old plants have been retired and new plants are brought on line, since 1988 the net increase in the number of nuclear plants globally has averaged about one plant per year, or about 0.23 percent per year. The growth in generating capacity and electricity output has been somewhat higher due to a combination of factors, including that fact that the new plants that have been added are larger in size than those that have been retired, many existing plant have been up-rated, and the capacity factors of plants has improved on average. This trend is expected to continue, so even if there were no net increase in the number of plants over the next 50 years, nuclear capacity and electricity output will continue to increase.

The appendix to this testimony contains an analysis by my colleague, Christopher Paine, and me of the likely U.S. and worldwide expansion of nuclear power and its effect on carbon reductions. A condensed and updated version of this analysis can be found in The Keystone Center, "Nuclear Power Joint Fact-Finding," June 2007, pp. 21-28.

Our best estimate is that the global nuclear contribution toward reducing greenhouse gas emissions is in the range of 215 to 270 GWe of additional capacity, or about 30-40 percent of one Pacala/Socolow 700 GWe "stabilization wedge."

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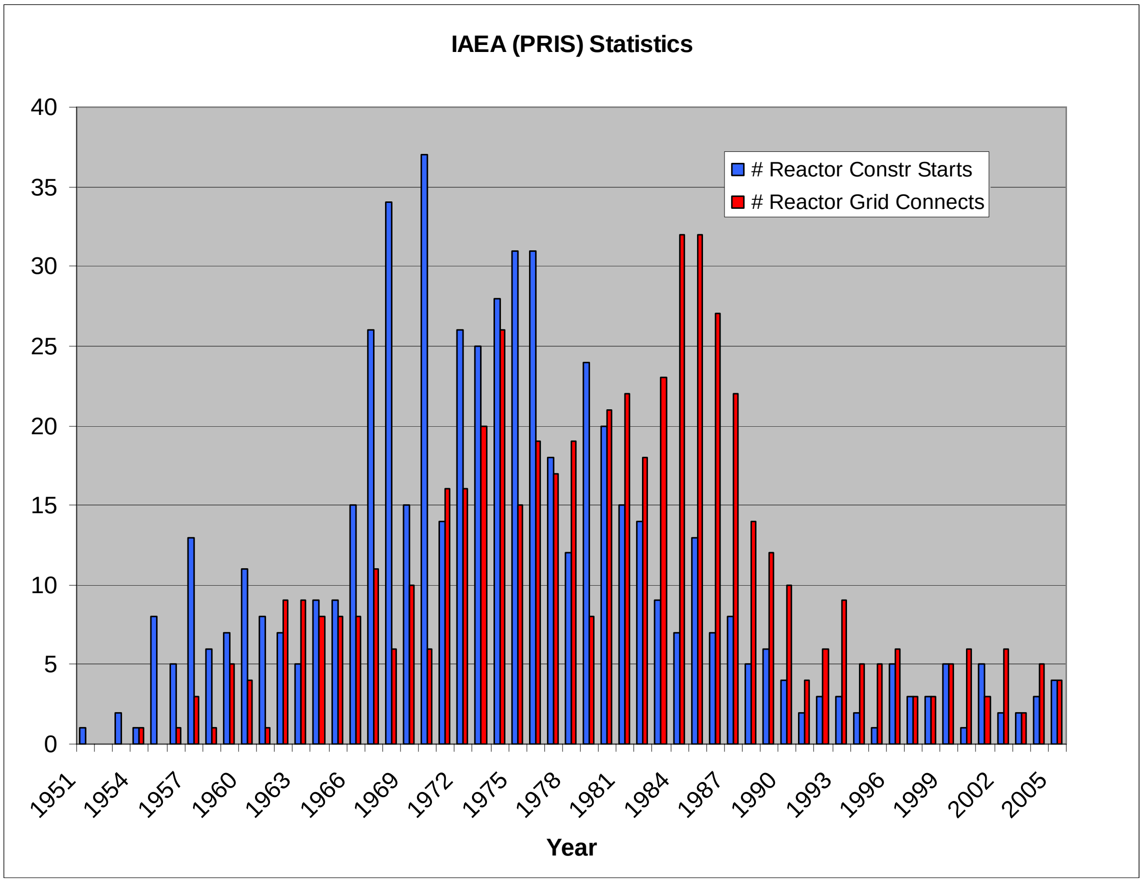
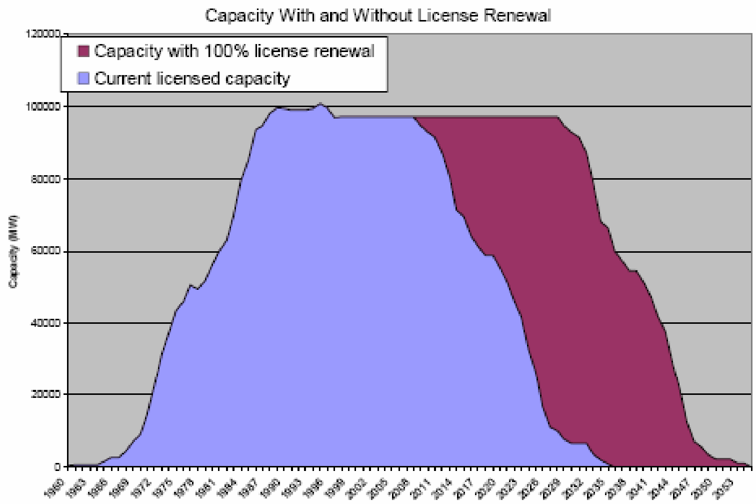
[1] Here it is assumed that 80 percent of the displaced capacity is coal generated, 20 percent gas generated, and one tCO2/MWh is emitted by coal plants and 0.4 tCO2/MWh emitted by gas plants.



In the United States the high cost of new nuclear power plants (see below), their lengthy construction period, the current dependence on large federal subsidies and incentives to stimulate private investment in the sector, unresolved waste management and disposal issues, and a massive requirement to replace the current installed base of nuclear plants before 2050, will all make it difficult for nuclear to make a significantly greater contribution to carbon reductions than is already being contributed by today's fleet of U.S. nuclear power plants. Our best estimate is that U.S. nuclear power capacity will grow from about 100 GWe today to about 125 GWe by mid-century.

Assuming all reactor licenses will be extended from 40 to 60 years, as indicated in the figure on the following page (reproduced from The Keystone Center, "Nuclear Power Joint Fact-Finding," June 2007, Figure 3, p. 24.), existing U.S. nuclear power plants will reach the end of their 60 year license period between about 2030 and 2055. Because of their low operating costs, prior to 2030, there will likely be substantial pressure to extend reactor licenses once again, this time from 60 to 70 or 80 years. Thus, our estimate of capacity growth assumes that all of these reactors will be relicensed again or replaced. This will have obvious safety implications due the ageing of key safety components, including the pressure vessels.



Source: Dominion Resources, 2005

Economics. For new nuclear power plants in the United States, perhaps the best and certainly the most current economic analysis can be found in the recent Keystone Center report, "Nuclear Power Joint Fact-Finding," June 2007. The Keystone group found that a reasonable range for the expected levelized cost of nuclear power is between 8 and 11 cents per kWh delivered to the grid, before transmission and distribution costs. Since Jim Harding played a significant role in developing the Keystone cost estimate, and since he is on this panel, I will defer to Jim for further discussion of the assumptions behind this estimate.

Reactor Safety. The safety of nuclear power reactors is dependent upon their design, construction and operation. Because of improvements in operations, on balance U.S. nuclear reactors are safer today than they were before the 1979 accident at Three Mile Island. The single most important factor affecting the safety of operating plants is the safety culture at the plant. At most U.S. reactors the safety culture has improved. Of greatest concern is that some reactor operators and some plant still have an unacceptable safety culture. This is evidenced by FirstEnergy's operation of the Davis-Besse Plant and the discovery in 2002 of a football-sized cavity in the head of the reactor pressure vessel. (See The Keystone Center, "Nuclear Power Joint Fact-Finding," June 2007, p. 65).

The design of new Generation III+ nuclear plants appear, from their Probabilistic Risk Assessments (PRAs), to be safer designs than currently operating plant designs. The PRAs are useful for making relative safety assessments, but cannot accurately quantify the absolute core damage frequency—the results cannot be verified—and therefore it is not possible analytically to demonstrate that current safety goals of the Nuclear Regulatory Commission (NRC) are being met by existing reactors, or will be met by new reactor based on these new designs.

Over the next several decades the U.S. fleet and the global fleet of operating reactors will be dominated by those reactors that exist today. Therefore, the safety and security of these fleets will largely be determined by the safety and security of the existing reactors.

The nuclear safety culture, and regulatory oversight, varies widely from country to country. In some countries it is demonstrably poor. Many nuclear plants will continue to operate in these poor safety culture environments. The majority of new nuclear plants projected to be built over the next two to three decades will be constructed in countries that have demonstrably poor, or questionable, nuclear safety cultures. Consequently, if we experience another core melt accident at a nuclear power plant, it is more likely to occur overseas, despite the fact that the United States currently operates the largest share of nuclear power reactors.

Spent Fuel. For fifty years, since the National Academy of Sciences first addressed this issue, the scientific consensus has been that high-level nuclear waste, and by implication spent fuel, should be permanently sequestered in deep underground geologic repositories, and by implication the primary barrier to prevent the release of the radioactivity into the biosphere should be the geology of the site. In this regard, some amount of spent fuel can be disposed of safely in Yucca Mountain. At this time we do not know whether this is greater or smaller than the statutory limit of 70,000 tons of spent fuel and high-level nuclear waste, and for reasons highlighted below, we may never know.

The Environmental Protection Agency (EPA) has the statutory responsibility to establish criteria for judging the adequacy of the proposed Yucca Mountain repository. The objective of these criteria of course is to protect future generations from potential releases of radioactive materials. The criteria are based on three key considerations: 1) what is the highest radiation exposure dose that will be permitted to the maximally exposed individual; 2) where will this dose limit be imposed, i.e., where will the maximally exposed individual be assumed to reside; and 3) over what period of time is the dose limit imposed. The licensing criteria being established EPA (in collusion with the NRC and the Department of Energy (DOE) through secret White House reviews overseen by the Office of Management and Budget) are far from being adequately protective of future generations. In developing the licensing criteria for Yucca Mountain it appears that the highest priority has been to ensure the licensability of the Yucca Mountain site.

First, EPA "gerrymandered" the control boundary, extending it from 5 to 18 kilometers in the direction that the radioactive materials is projected to leak from the repository. EPA also cut off the time period for compliance at 10,000 years. When a Federal Court ruled that the 10,000 year cut off was unlawful because it was inconsistent with the recommendations of the National Academies of Science as required by law, EPA proposed to eviscerate the Court ruling by proposing a two-tiered dose limit—retaining the pre-10,000 year *mean* dose limit of 25 mrem and proposing a post-10,000 year *median* dose limit of 350 mrem. The mean dose is projected to be approximately three times higher than the median dose. Thus, EPA has proposed to allow the estimated mean exposure to the maximally exposed individual during the peak exposure period to be on the order of one rem per year. According to cancer risk estimates in the National

Research Council's BEIR VII report, a lifetime exposure at this dose rate today would result in one in 12 such exposed persons getting cancer from this exposure with half of the cancers being fatal.

Some would argue that 10,000 year is a sufficient compliance period. It should be noted, however, that extending the compliance period beyond the projected life of the engineered spent fuel canisters is one way to ensure that the geology of the site will be the primary barrier preventing the release of the radioactivity into the biosphere.

DOE is required to submit its Yucca Mountain license application to the NRC. In its attempt to demonstrate that the repository will meet the EPA criteria, DOE plans to run a series of calculations to predict the release and transport of radioactivity from the site. The computer code that DOE plans to use for this purpose is so large that NRC will not be able to independently run it, and neither will any potential intervenor in the licensing process. Consequently, the NRC will be unable to confirm the validity of the DOE calculations. Instead, NRC plans to run its own transport code, but only for the purpose of developing a set of questions to be answered by DOE.

The Yucca Mountain project has repeatedly failed to meet its schedule and there is a possibility that the project will be terminated by Congress. If this occurs it would represent the third failed attempt by the Federal government to solve the high-level waste/spent fuel disposal problem—the first failure being the salt vault project at Lyons, Kansas followed by the failed Retrievable Surface Storage Facility (RSSF).

Aged spent fuel can be stored safely in dry casks until a safe geologic disposal site is identified and licensed for use. However, it has been a policy of the Federal government that we should not rely on administrative controls for more than 100 years for the management and disposal of nuclear wastes.

Proliferation. There are critical shortcomings in the international safeguards regime. This could be the subject of a rather long treatise, but here we will highlight a few shortcomings.

The international safeguards regime includes, but is not limited to, the of The Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, or NPT) and safeguards requirements imposed on NPT member states under their respective safeguards agreements with the International Atomic Energy Agency (IAEA). The IAEA is the international institution responsible for safeguarding civil nuclear activities in non-weapon states. A primary purpose of IAEA's safeguards system is "to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices." And "the objective of safeguards is the timely detection of diversion of significant quantities of *nuclear material* from peaceful activities to the manufacture of nuclear weapons or of other explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

The IAEA's definition of a Significant Quantity (SQ) is "the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Significant quantities take into account unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. The SQ values currently used by the IAEA for direct use materials are not technically valid or defensible. They are too high (that is, non-conservative) by upwards to a factor of eight.

Even with the erroneously high SQ values, IAEA safeguards are currently unable to provide "timely detection," of a diversion of weapon-useful materials from commercial-size "bulk-handling" facilities located in non-weapon states. "Bulk-handling" facilities include gas-centrifuge uranium enrichment plants, plutonium-uranium mixed-oxide (MOX) fuel fabrication plants and separated plutonium storage facilities. The inability to adequately safeguard these types of facilities is in part because the "conversion times" (the time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device) are short compared to the IAEA timeliness detection goals used to define the frequency of inspections, and because the inventory differences are often larger than the SQ values.

The IAEA administers its safeguards requirements pursuant to agreements that the IAEA has with member states. The Additional Protocol is a legal document granting the IAEA complementary inspection authority to that provided in underlying safeguards agreements. A principal aim is to enable the IAEA inspectorate to provide assurance about both declared and possible undeclared activities. Under the Additional Protocol, the IAEA is granted expanded rights of access to information and sites, as well as additional authority to use the most advanced technologies during the verification process. The Additional Protocol is a voluntary undertaking and not all non-weapon states have signed and ratified Additional protocols with the IAEA. Iran, for example has not signed the additional Protocol.

The IAEA suffers from many institutional shortcomings that hinder its ability to conduct prompt thorough inspections. In addition, the international community has not demonstrated that the enforcement mechanisms are effective. The weakness of current enforcement mechanisms can be seen in the manner in which the UN Security Council has dealt with Iran and North Korea, both of which violated their IAEA agreements and the NPT.

Global Nuclear Energy Partnership. In 2006, the Bush Administration proposed a. Global Nuclear Energy Partnership (GNEP) to help expand nuclear power in the United States and abroad by attempting to reduce proliferation risks and reduce the capacity requirements for geologic disposal id spent fuel or high-level nuclear waste. As the Keystone Center report notes (p. 90), the GNEP program is not a credible strategy for resolving either the radioactive waste or the proliferation problem.

The GNEP vision is the marriage of two failed technologies—nuclear fuel reprocessing and fast reactors. Commercial nuclear fuel reprocessing has been a universal economic failure. Moreover, it has resulted in the separation and stockpiling of a global inventory of some 250 tonnes of separated weapon-usable plutonium. This global stockpile of separated plutonium continues to grow due to the nuclear industry's failure to fabricate and burn the plutonium as MOX fuel in existing reactors as fast as it is separated.

The GNEP vision is doomed to failure because for every 100 GW of thermal reactor capacity some 40 to 75 GW of fast reactor capacity is needed to transmute the plutonium and other transuranic radioisotopes. But fast reactors have proven to be far more costly and less reliable than thermal reactors. No energy generating company in a market economy will opt to build a fast reactor that is more costly and far less reliable than a light water reactor when many modern light water reactors have compiled a track record of operating at about 90 percent capacity factor.

Efforts to develop fast reactors as plutonium breeders were failures in the United States, France, United Kingdom, Germany, Italy and Japan. Russia has one commercial size fast reactor, but it operates on HEU as Russia has to date failed to build a commercial MOX fuel fabrication plant and close the fuel cycle. More than half of all fast reactors built to date have been failures for on reason or another. The flagship fast reactors of the United States and Germany were cancelled during construction. The French Superphenix operated for 11 years at a lifetime capacity factor of 6.6 percent. The Japanese Monju reactor has not operated since 1995 and its lifetime capacity factor is about 0.4 percent and sinking. The United Kingdom's Prototype Fast Reactor had a capacity factor of 9.9 percent for the first ten of its 20 years of operation.

The application of fast reactors for submarine propulsion was also a failure in two nuclear navies—in both the U.S and the Soviet navies. According to Atomic Energy Commission (AEC) historians, Hewlett and Duncan, in their history of the U.S. nuclear navy from 1946 to 1962:

> Although makeshift repairs permitted the *Seawolf* to complete her initial sea trials on reduced power in February 1957, [Admiral Hyman G.] Rickover had already decided to abandon the sodium-cooled reactor. Early in November 1956 he informed the Commission that he would take steps toward replacing the reactor in the *Seawolf* with a water-cooled plant similar to that in the Nautilus. The leaks in the *Seawolf* steam plant were an important factor in the decision but even more persuasive were the inherent limitations in sodium-cooled systems. In Rickover's words they were "expensive to build, complex to operate, susceptible to prolong shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair."

Rickover was right, as the history of fast reactor development has demonstrated time and time again.

The pursuit of the GNEP vision, while doomed to failure, will nevertheless encourage the development of hot cells and reprocessing R&D centers in non-weapon states, as well as train cadres of experts in plutonium chemistry and metallurgy, all of which pose a grave proliferation risk.

APPENDIX.
THE NUCLEAR WEDGE

Christopher E. Paine and Thomas B. Cochran

One of the Pacala/Socolow hypothetical wedge options involved the substitution of nuclear power plants for coal plants. Under this option one "wedge" would require adding 700 GWe (net) of new nuclear capacity over the fifty year period, with all of the nuclear plants displacing coal plants, while sustaining and eventually replacing the existing deployed global capacity of 370 GWe.

The issue we address here is not whether this is a good idea, but whether using new nuclear generation to back out of CO_2 emissions is likely to be achieved on the scale and within the time frame (2010-2050) required to avert calamitous climate effects. In other words, we propose here to examine how much additional nuclear capacity might be added over the next 50 years by employing three different approaches for estimating future growth.

We begin by examining the current global nuclear capacity. In Table 1 we present the U.S. and global nuclear capacity as of the end of 2006. As of the end of 2006 commercial nuclear power plants generated about 20 percent of U.S. electricity and about 16 percent globally.

(1) Global Wedge—WNA Installed Capacity and Projections Method
The first method simply looks at the World Nuclear Association's database for reactors that are "Operating," "Building," "On Order or Planned," and "Proposed."

Table 1. Commercial nuclear power plants, current and projected, and their cumulative capacity measured in gigawatts-electric (GWe) in the U.S. and worldwide as of the end-2006.

	Reactors Operating		**Reactors Building**		**On Order or Planned**		**Proposed**		**Total**	
	No.	GWe	No.	GWe	No.	GWe	No.	GWe.	No.	GWe
World	435	369	28	23	64	69	158	124	685	585
U.S	103	98.3	1	1.2	2	2.7	21	24	127	126

Source: www.world-nuclear.org, "World Nuclear Power Reactors and Uranium Requirements," 4 January 2007.

In WNA's projections, the "On Order or Planned" category assumes completion of reactors in which "construction [is] well advanced but suspended indefinitely." The "Proposed" category includes reactors that are part of a country's or agency long-range nuclear plans, but are "still without funding and/or approvals." Given the way that nuclear build-outs have typically lagged behind official projections, these WNA categories are probably not a bad approximation for the likely maximum extent of a future nuclear build-out in response to climate change over the next 30 -50 years. Assuming the current nuclear installed base of 369 GWe is fully replicated and all the "proposed" capacity is actually built over the next 50 years, the net increase of 216 GWe contained in current global nuclear plans amounts to 30 percent of a 700 GWe carbon displacement "wedge."

Assuming all these reactors are built within the next 40 years gives a net growth rate of 5.4 GWe per year. Maintaining this rate growth rate for another decade, to get to the full fifty years, would add another 54 GWe, bringing the total increase to 270 MWe, or 39 percent of a climate-change wedge.

Assuming *all current long-term nuclear build plans are fully implemented within 30 years* – which strains the historical limits of plausibility for the nuclear power industry– yields a net capacity growth rate of 7.2 GWe/yr. Assuming continued expansion at this rate for another twenty years yields an additional 144 GWe, bringing the total wedge to 360 MWe, or just slightly over half of what is thought to be needed to avert a gigaton per year of carbon emissions by mid-century.

Because of the need to replace the existing installed base of nuclear reactors, the actual annual build rate for large new reactors would have to be even higher than the 5-7 per year suggested by looking at net capacity additions alone. (This problem is discussed in more detail in (3) below.) This case might be regarded as the maximum estimate of what nuclear might conceivably achieve in the way of carbon displacement. It is substantial, but measured by the scale of the problem, one-half of one wedge over 50 years is far from being the major panacea for global warming that some suggest nuclear could become, particularly in light of the opportunity costs involved in the scale of nuclear investment, and its marginal relevance for most societies in the developing world.

(2) Global Wedge—*Status Quo* Estimation Method

Another way of estimating nuclear's potential contribution is simply to extrapolate from the recent historical performance of the industry while making some reasonable assumptions about trends in reactor size and power uprates. The average capacity of U.S. commercial nuclear power plants in 2006 was 0.954 GWe. In the rest of the world the average capacity was approximately [(369-98)/(435-103)=] 0.816 GWe. If we assume that the continued displacement of older smaller plants by new larger plants brings the global average plant capacity up to 1 GWe by 2050, then an additional [435-369=] 66 GWe of capacity would added globally without any net increase in the number of nuclear power plants worldwide.

If we also assume that the rest of the world follows the U.S. lead by uprating the capacity of existing plants (i.e., increasing the maximum permitted operating capacity) and that these uprates average five percent, then an additional [(369-98)*0.05=] 14 GWe would be added. The sum of these two terms (displacement of older plants with new, larger plants and a five percent uprate) is [66+14=] 80 GWe.

Alternatively, from 1989 to 2006, the average plant capacity increased from [327.6GWe/423=] 0.774 GWe/plant to [370 GWe/435=] 0.85 GWe/plant. If this trend continues for an additional 50 years, by 2050 the average plant size will increase by [(0.85-0.774)*(50/16)=] 0.24 GWe/plant, and the capacity will increase by [0.24 GWe*435=] about 104 GWe.

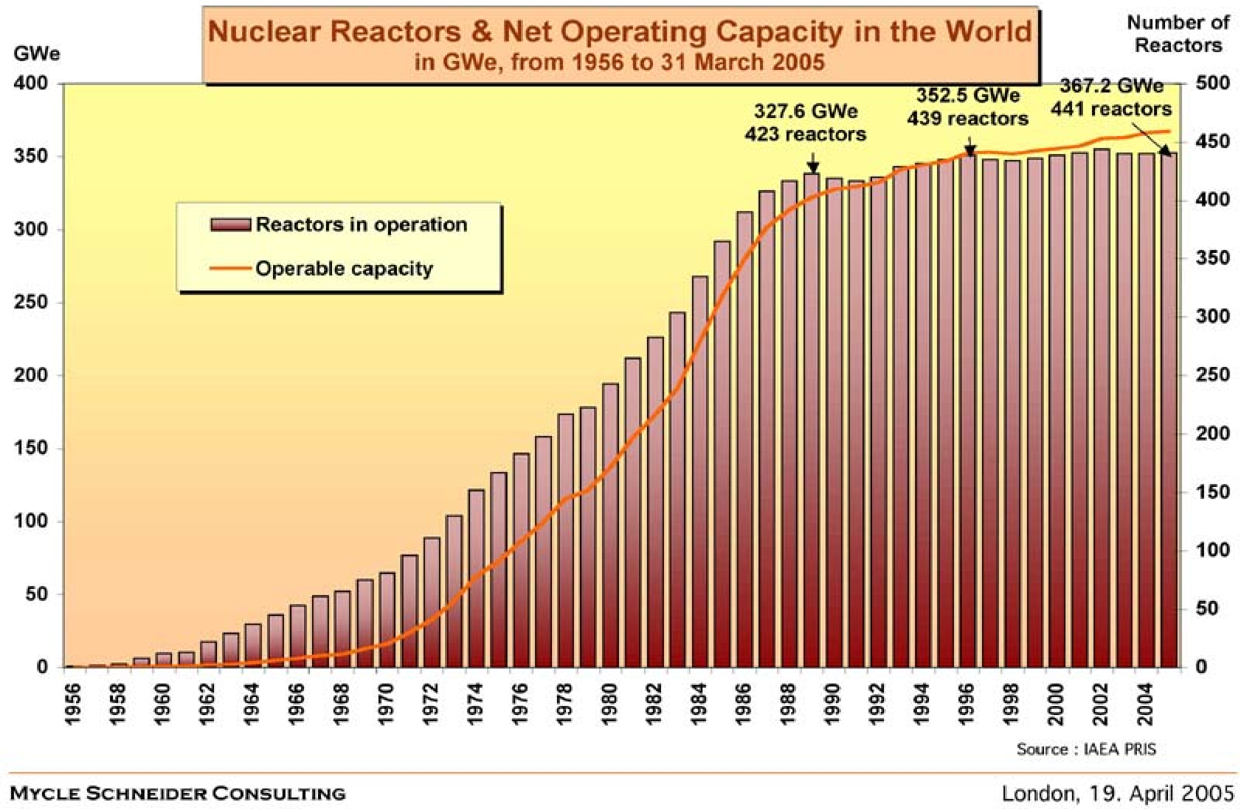
Thus, without increasing the net number of nuclear plants we can project that by 2050 the worldwide nuclear capacity could reasonably increase by as much as 80 to 91 GWe. Figure 1 on the next page shows the historical growth of nuclear power plants worldwide. During the 17 year period, from 1989 to 2006, the number of nuclear plants globally has increased from 423 to 435 power plants, or at an average rate of about 0.7 plants (net) per year. During that same period the cumulative reactor capacity increased from 327.6 GWe to 370 GWe, or at an average rate of 2.5 GWe (net) per year. If these growth rates were sustained for an additional fifty years there would be another 35 nuclear plants (net) representing a net addition of 125 GWe.

Adding this recent historical "base-case" growth projection to the "capacity creep" and power uprates previously outlined above [125 GWe + 104 GWe] gives a total nuclear growth of 229 GWe by 2056. This represents about 32 percent of one Pacala/Socolow 700 GWe carbon displacement "wedge."

(3) Global Wedge—IEE Japan Projection

To estimate an optimistic grow rate in commercial nuclear power, we begin with an estimate by an institution that is likely to look favorably upon the expansion of nuclear power. The Institute of Energy Economics of Japan (IEEJ) has projected a 114 GWe increase in the installed capacity for nuclear power generation by 2030, which amounts to an average growth rate of 4.75 GWe per year (net).[1] The average lifetime of the existing fleet of 435 reactors is uncertain, but if we assume that it is on the order of 45 years, then we can expect the retirement of about 10 plants per year. At 0.85 GWe per plant this would be equivalent to an average annual retirement of 8.5 GWe of nuclear capacity. Thus, 4.75 GWe per year (net) is equivalent to 13.25 GWe per year of total new capacity, or about 10 to 13 new plants per year. This is consistent with the rate of new plant additions achieved during the period 1970-1986, when there was no installed base of nuclear reactors needing replacement.

Figure 1:



It should be noted that nearly all of the growth in nuclear capacity is projected by IEEJ to take place in Asia: "Of the 114 GW increase in the installed capacity for nuclear power generation expected in the world during the period up to 2030, 110 GW of capacity will be added by new power plants in Asia."[ii] In the rest of the world new builds will barely offset retirements. next fifty years. Notably, this 240 GWe addition represents about one-third of a climate-change wedge.

If this 4.75 GWe per year (net) growth rate is sustained for fifty years—about three times longer than the first "nuclear renaissance"—then by this method worldwide nuclear capacity will increase by about 240 GWe, or from 370 GWe today to about 610 GWe fifty years from now. This optimistic estimate represents a 65 percent increase in nuclear capacity over the next fifty years.

In sum, we estimate that the worldwide nuclear capacity could plausibly grow by 216 GWe to 360 GWe over the next fifty years. The highest estimate also seems the least credible, as it is premised on the completion of all reactors proposed in global long-range plans for nuclear energy deployment within 30 years, and continued deployment at that rate for another 20 years. Absent this "best case", the results produced by all three methods cluster within the fairly narrow range of 216 – 270 GWe, or about 30-39 percent of one Pacala/Socolow 700 GWe "wedge."

This analysis is focused solely on historical and planning data and likely estimates to be drawn from such data. This analysis does not address other relevant matters that may affect the growth of worldwide nuclear capacity such as proliferation, fuel cycle concerns, direct economic competition or the availability of subsidies. The bottom line is that the heavy lifting required to solve the global warming problem will have to be supplied by other technologies.

A U.S. Wedge

NRDC defines a "U.S. wedge" as an emission reduction of one Gt CO_2-equivalent in 2050 (0.27 GtC), approximately one-quarter of a global emissions wedge defined by Socolow and Pacala, reflecting the fact that U.S. emissions are almost 25 percent of global emissions today. Thus one "U.S. wedge" is equivalent to about 175 GWe, assuming that nuclear power is displacing roughly the current mix of generating sources in the U.S. (actual emissions from the electric sector are calculated with the CarBen spreadsheet model, which accounts for the changing mix of generating sources over time).

The U.S. DOE's EIA, in its Annual Energy Outlook-2007, nuclear power plant capacity will grow to 112.6 GWe by 2030, including 3 GWe of additional capacity uprates. The new capacity [112.6-3=] 9.6 GWe over 24 years, represents an average new capacity addition rate of 0.4 GWe per year.

Today in the United States, new nuclear power plants are not economically competitive with coal plants or natural gas-fueled plants in the absence of large government subsidies or stringent controls on from fossil-fueled plants.[iii] The growth in U.S. nuclear capacity projected by EIA is entirely in response to huge federal subsidies provided to the nuclear industry under the 2005 Energy Act. The levelized lifetime cost of electricity generation from the new nuclear plants that qualify for the subsidies are projected to be reduced by up to $2/MWh, or by as much as 30 percent. Thus, the growth in domestic nuclear capacity after 2030 will depend on whether the Federal government limits CO_2 emissions through a carbon cap and emissions trading scheme or grants the nuclear industry a new round of subsidies.

If we assume that during the period 2030 to 2056, the net additions continue at the same rate of 0.4 GWe per year, the U.S. nuclear capacity fifty years from now will be about 125 GWe, which represents a 25 GWe increase or about 15 percent of one "U.S. wedge."

The most economically efficient way to address the economic, enviromental, and security risks of new nuclear power plants (and other energy technologies) is to internalize the costs of avoiding or mitigating these risks in the market price of electricity and fuels. The United States can do this effectively by first regulating both carbon dioxide emissions and the unique risks posed by the nuclear fuel cycle, and then letting the competitive marketplace deliver the lowest-cost technologies for providing energy services *that meet minimum universal criteria for environmental sustainability, public health, and energy* *security*. An unbridled global competition among energy sources without such standards is, as we have seen in recent decades, a formula for environmental degradation, mounting threats to public health, and geopolitical chaos.

The U.S. and global nuclear industry largely rejects this “level playing field” approach. Despite the public expenditure of some $85 billion on civilian nuclear energy development over the last half century, its lobbyists continue to aggressively seek and obtain additional federal subsidies, so that investors in new nuclear power plants can earn a return on what would otherwise be a dubious commercial investment. Meanwhile, these subsidies displace government funding that could otherwise be directed toward cleaner, more competitive efficiency and renewable technologies with a much wider market potential for reducing global warming pollution. The fastest, cleanest, and most economical solutions to global warming will come if energy efficiency and renewable energy compete on a playing field that has been “leveled” by regulatory and taxation schemes that compel the pricing of polluting energy alternatives at closer to their true costs to society and the environment, not merely at their immediate costs of extraction and combustion.

Despite the fact that a national global warming emissions cap-and-trade system would materially assist the economic case for nuclear power, the nuclear industry has not been willing to openly advocate for such a system. This suggests either that the industry privately lacks confidence in its own optimistic claims that nuclear energy is ready to play a big future role in displacing carbon, or that big generating companies prefer that U.S. taxpayers shoulder the lion’s share of the risk, while they harvest the carbon savings from new nuclear plants to prolong the profitability of their polluting coal-fired plants. Possibly both explanations are true.

Existing nuclear plants can compete favorably with fossil-fuel plants because they have relatively low operation, maintenance and fuel costs, and their excessive capital costs have long since been forcibly absorbed by ratepayers and bondholders. But the continuing high construction costs of new nuclear power plants make them uneconomical. In fact, there have been no successful nuclear plant orders in the United States since 1973.

To jumpstart private investment in the first 6,000 megawatts (MW) of new nuclear power capacity, Congress granted roughly $10 billion in new subsidies—in the form of production tax credits, loan guarantees, federal “cost-sharing,” and “regulatory risk insurance”—as part of the 2005 Energy Policy Act. The high capital cost of constructing an individual nuclear power plant has in the past dictated a trend toward ever larger reactor units in order to recoup the multi-billion investments required. At a price tag of $2.5 billion to $4.0 billion each, reactors typically require a long investment recovery period, on the order of 25-40 years. Moreover, they usually require at least a decade or more to plan, license, and build, creating a persistent problem of economic “visibility” for nuclear reactor projects in what has now become a more competitive and shifting energy marketplace, at least in the United States.

The timescales involved in the current subsidy program illustrate the nuclear economic visibility problem. The Internal Revenue Service will distribute future annual production tax credits—nominally amounting over the first eight years of operation to a maximum of $1 billion for each thousand megawatts of new capacity—among all "qualifying" new nuclear reactor projects that have:

- ■ applied for a construction/operating license from the Nuclear Regulatory by the end of 2008;
- ■ begun construction of the reactor building by January 1, 2014, and;
- ■ received a certification from the Department of Energy that it is "feasible" to place the facility in service prior to January 1, 2021.

It is difficult to forecast today what U.S. and global energy market conditions will be like five years hence, much less in 2021. It is also difficult to predict the size of the subsidy ultimately available to each new reactor's owner, as this depends on the total number of projects that actually begin construction by 2014. How many ways can this gift from the taxpayers be divided before the commercial viability of each individual project is undermined? Similar concerns surround the availability and distribution of the loan guarantees, which are critical to gaining financing for plants that would be built in partially deregulated "merchant" environments, in which the owner-investors in the plant are supposed to bear the risk of competing in the wholesale energy marketplace, where long-term relative prices for nuclear versus other forms of generation are difficult to forecast.

Needless to say, absent favorable shifts in the underlying economic determinants of nuclear power, the addition of 6000–9000 heavily subsidized nuclear megawatts to the national grid beginning 10-15 years from now does not really diminish any of the immediate challenges posed by global warming, unless these plants displace existing or currently planned conventional coal-fired power plants.

If these subsidized "first mover" nuclear plants fail to produce major design, component production, and construction innovations that significantly reduce the high capital cost of subsequent nuclear power plants—and there is little evidence to date indicating they will—then private investors will return to looking unfavorably on the industry once the current tax credits and guarantees expire. The cost growth already occurring in the new Areva "European" power reactor under construction in Finland is not encouraging. The 2002 cost estimate of $2.3 billion for this 1500 MW reactor had grown to $3.8 by July 2006, and this number does not include "off-balance-sheet" costs of 1.5-2 billion euros ($1.92 - $2.56 billion) that reactor builder Areva has separately agreed to devote to the project.

A probable total project cost at or above $5 billion for this new reactor is certain to scare U.S. utilities and capital investors from making an aggressive commitment to nuclear energy in the near term. Moreover, as the technologies for renewables, energy efficiency, and industrial waste-heat co-generation continue to improve, they will become increasingly attractive investment alternatives to nuclear power.

A national cap on carbon emissions would certainly help reduce nuclear's significant current cost differential with large coal- and gas-fired power plants, but it will not ensure that nuclear stays competitive with these smaller, cheaper, cleaner, faster, and more flexible distributed sources of electric power generation.

The Non-Carbon Impacts of the Nuclear Fuel Cycle Remain Significant and Complex

Although the nuclear fuel cycle emits only small amounts of global warming pollution, nuclear power still poses significant risks to the world. Since the origins of the global nuclear power industry in the 1950's, ostensibly "peaceful" nuclear materials, equipment and expertise in a number of countries have been diverted to secret nuclear weapons programs, and could be again.[iv]

Stockpile of nuclear materials potentially usable in nuclear weapons are also susceptible to theft by, or eventual sale to, terrorists or international criminal organizations. Storage pools of spent nuclear fuel are likewise vulnerable to terrorist attacks that could disperse lethal levels of radioactivity well beyond the plant perimeter. An accidental release of radioactivity, whether from a reactor accident, terrorist attack, or slow leakage of radioactive waste into the local environment, poses the risk of catastrophic harm to communities and to vital natural resources, such as underground aquifers used for irrigation and drinking water.

There are continuing occupational and environmental health risks associated with uranium mining and milling, especially in areas where such activities are poorly regulated. And underground repositories, meant to isolate high-level radioactive waste and spent fuel from people and the environment for thousands of years, are subject to long-term risks of leakage, poisoning the groundwater for future generations.

All of these problems have potential remedies, but most are not in effect today. For example, current international arrangements are insufficient to *prevent* a non-weapon state, such as Iran or Japan, from suddenly changing course and using nominally peaceful uranium enrichment or spent-fuel reprocessing plants to separate nuclear material for weapons. While long term isolation of nuclear waste in stable geologic formations appears achievable technically, there is not a single long-term geologic repository for spent nuclear fuel in operation anywhere in the world.

Before nuclear power can qualify as a strategically and environmentally sound approach to reducing global warming pollution, the international nuclear industry, the respective governments, and the International Atomic Energy Agency must also insure that:

- ■ nuclear fuel cycles do not afford access, or the technical capabilities for access to nuclear explosive materials, principally separated plutonium and highly enriched uranium;
- ■ the Nuclear Nonproliferation Treaty regulating nuclear power's peaceful use is reinterpreted to prohibit the spread of latent as well as overt nuclear weapons capabilities, by barring exclusively national ownership and

control of uranium enrichment (or reprocessing) plants in non-weapon states;
■ the occupational and environmental health risks associated with uranium mining and milling are remedied; and
■ existing and planned discharges of spent nuclear fuel and other high-level radioactive waste are safely sequestered in geologic repositories that meet scientifically credible technical criteria for long term containment of the harmful radioactivity they contain.

A Balance Sheet for New Nuclear Power

The Plus Side:

■ Very low emissions of carbon and other combustion-related air pollutants (but still some, from uranium mining, milling, enrichment, reactor construction-decommissioning and waste management activities)
■ Large, concentrated source of round-the-clock base-load power.
■ Low fuel costs compared to fossil alternatives.
■ If greenhouse-gas emissions are effectively "taxed" at $100-$200 per ton under a cap-and-trade system, nuclear might compete effectively in the United States with large coal and gas-fired central station power plants.

The Downside

■ Nuclear remains expensive low carbon power ($0.9 - $0.10/kWh delivered) compared to $0.025 - $0.030 for end-use efficiency improvements; $0.06 - $0.07 for wind; and $0.026-$0.04 for recovered heat co-generation).
■ Long gestation/construction period and huge capital costs increase risk of market obsolescence and "stranded costs" (i.e. costs that cannot reasonably be recovered by continuing to operate the plant for its planned life).
■ Subject to infrequent, but prolonged and costly planned and unplanned shutdowns (a recent study by the Union of Concerned Scientists documents 12 year-plus reactor outages since 1995, 11 of them "safety-related.").
■ Large "lumpy" increments of nuclear capacity require expensive overall power system excess capacity to ensure grid reliability in the event of reactor outages.
■ Any nuclear power investment may at any moment become hostage to the conduct of the worst performer—or even the average performer on a bad day—in the event of a reactor accident or near-accident anywhere on the globe
■ No licensed path (yet) to opening first long-term geologic repository for safely isolating spent fuel, and nuclear "renaissance" will require either additional expensive and hard-to-establish geologic repositories, or even more expensive and hazardous spent-fuel reprocessing
■ Nuclear security concerns and risks are heightened in an age of transnational terrorism

■ Acute proliferation concerns arise if advanced fuel cycles are used, or if uranium enrichment capability spreads to additional countries that are not already nuclear weapon states
■ All stages of the nuclear fuel cycle involve potentially harmful, or in some cases disastrous environmental impacts (e.g. Chernobyl), requiring continuous and vigorous regulation, with significant financial penalties exacted for poor environmental and safety performance to ensure compliance
■ Huge heat dissipation requirements require either large evaporative cooling withdrawals and/or thermal discharges into already overburdened lakes and rivers, or massive and expensive fan-driven air-cooling towers
■ Climate-change in the direction of hotter-drier summers spells trouble for reactors that rely primarily on cheaper once-through or evaporative water-cooling
■ The nuclear fuel cycle offers little prospect of increasing "energy independence," as the bulk of world uranium resources are located outside the United States, while the current DOE proposal for a "Global Nuclear Energy Partnership" would actually increase the US responsibility for recovering and managing foreign nuclear waste returned to the United States for secure storage and eventual reprocessing.

Conclusion

Because nuclear power is both a global and heavily state-subsidized and -managed industry with important security implications, it has never risen or fallen as an energy resource based solely on its comparative economics. For better or worse, it remains part of the state-sponsored global energy picture, and is likely to remain so for many decades. Despite its complexities and high capital costs, it can supply large increments of base-load power in a concentrated footprint while locally emitting low levels of global warming and other polluting emissions that characterize the burning of fossil fuels. And unlike the cost and supply uncertainties involved in guaranteeing an uninterrupted flow of almost daily fossil fuel imports, nuclear fuel can be obtained under long-term contracts and imported as little as once a year or less, or it can be produced domestically.

But nuclear power's appeal is limited to advanced industrial states and /or rapidly growing industrial economies with the capital resources, transmission infrastructure, and technical expertise needed to support and safely manage a nuclear energy sector. As the present analysis bears out, the costs and complexities of nuclear power impose an inherent limitation on its practically achievable rates of growth, such that even under favorable assumptions regarding the fulfillment of current national long-range plans for nuclear expansion, nuclear power globally for the next 50 years is likely to account for no more than one-third to one-half of a climate stabilization "wedge," with the more likely outcome being at the low end of this range.

[i] Institute of Energy Economics, Japan, November 2006, http://www.world-nuclear.org/info/reactors.htm, p.2.
[ii] Ibid.

[iii] *The Future of Nuclear Power: An Interdisciplinary MIT Study*, MIT (2003), Chapter 5, pp. 37-45, and Appendix to Chapter 5, pp. 131-156.

[iv] At various times over the past 50 years these countries have included India, Pakistan, North Korea, Iran, Argentina, Brazil, South Korea, Taiwan, Libya, and South Africa.