GENERATING FAILURE

How Building Nuclear Power Plants Would Set America Back in the Race Against Global Warming

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Executive Summary

Far from being a solution to global warming, nuclear power will actually set America back in the race to reduce pollution. Nuclear power is too slow and too expensive to make enough of a difference in the next two decades. Moreover, nuclear power is not necessary to provide clean, carbon-free electricity for the long haul.

The up-front capital investment required to build 100 new nuclear reactors could prevent twice as much pollution over the next 20 years if invested in energy efficiency and clean, renewable energy instead. Taking into account the ongoing costs of running the nuclear plants, a clean energy path would deliver as much as five times more progress for the money.

Early action matters in the fight against global warming.

- The more total carbon dioxide pollution that humanity emits into the atmosphere, the greater the warming – and consequent damage. Earlier action allows us more flexibility to respond to an evolving understanding of humanity's role in shaping the climate.
- According to current science, humanity as a whole can emit no more than 1 trillion metric tons of carbon dioxide from 2000 through 2050 in order to have a 75 percent chance of limiting the global temperature increase to 3.6° F above the pre-industrial era – a target the international community has set to limit the severity of global warming impacts. This 1 trillion metric tons is our "carbon budget."
- To facilitate keeping total emissions within this budget, a panel of distinguished Nobel Prize-winning scientists have called on developed nations to reduce their emissions of global warming pollution by 25 to 40 percent below 1990 levels by 2020.
- Reducing emissions from power plants holds large potential for early progress. The share of the U.S. emissions budget available to electric power plants could be as little as 34 billion metric tons of carbon dioxide (CO_2) from 2010 cumulatively through 2050.

New nuclear reactors would be built too slowly to reduce global warming pollution in the near term, and would actually increase the scale of action required in the future.

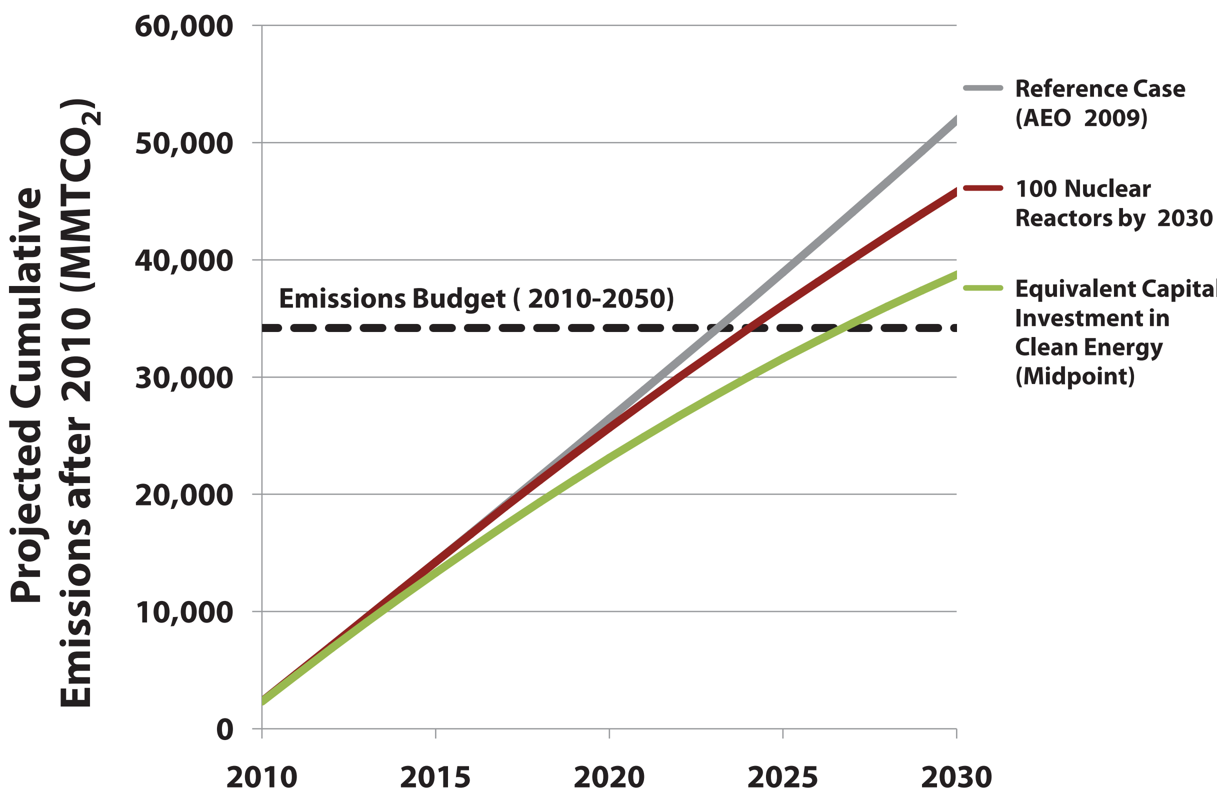
- No new reactors are now under construction in the United States. The nuclear industry will not complete the first new reactor until at least 2016, optimistically assuming construction will take four years after regulatory approval.
- However, it is likely that no new nuclear reactors could be online until 2018 or later. During the last wave of nuclear construction in the United States, the average reactor took nine years to build. New reactors are likely to experience similar delays. For example, a new reactor now under construction in Finland is at least three years behind schedule after a series of quality control failures.
- The American nuclear industry is not ready to move quickly. No American power company has ordered a new nuclear power plant since 1978, and all reactors ordered after the fall of 1973 ended up cancelled. As a result, domestic manufacturing capability for nuclear reactor parts has withered and trained personnel are scarce.
- Even if the nuclear industry managed to complete 100 new reactors in the United

States by 2030 – the level of construction advocated by supporters of nuclear power – new nuclear power plants could still only reduce cumulative power plant emissions by 12 percent over the next two decades, leading to a higher and later peak in pollution. As a result, America would burn through its 40-year electric sector carbon budget in just 15 years. (See Figure ES-1.)

In contrast, energy efficiency and renewable energy sources can make an immediate contribution toward reducing global warming pollution.

- Clean energy can begin cutting emissions immediately. Energy efficiency programs are already reducing electricity consumption by 1-2 percent below forecast levels annually in leading states, and the U.S. wind industry is already building the equivalent of three nuclear reactors per year in wind farms, and growing rapidly.

Figure ES-1: Projected Cumulative Electric Sector Emissions of Global Warming Pollution after 2010 with No Action, 100 New Reactors Built by 2030, or an Equivalent Capital Investment in Clean Energy



Nuclear reactors are too slow to cut enough pollution in the next two decades. With the up-front capital investment required to build 100 new nuclear reactors, America could achieve twice as much by investing in clean energy instead.

- With the up-front capital investment required to build 100 new nuclear reactors, America could prevent twice as much pollution in the next 20 years by investing in clean energy instead. (Midpoint estimate, see Figure ES-1 and page 21 for more details.)

- However, even this level of investment in clean energy would not be enough to keep U.S. power plant emissions within budget. (See Figure ES-1.) America should cut power plant emissions on the order of 50 percent within the next decade to limit the worst consequences of global warming.

Nuclear power is expensive and will divert resources from more cost-effective energy strategies.

- Building 100 new nuclear reactors would require an up-front capital investment on the order of $600 billion (with a possible range of $250 billion to $1 trillion), diverting money away from cleaner and cheaper solutions.

- Any up-front investment in nuclear power would lock in additional expenditures over time. Over the life of a new reactor, the electricity it produces could cost in the range of 12 to 20 cents per kilowatt-hour, or more. In contrast, a capital investment in energy efficiency actually *pays us back* several times over with ongoing savings on electricity bills, and an investment in renewable power can deliver electricity for much less cost.

- Per dollar spent over the lifetime of the technology, energy efficiency and biomass co-firing are five times more effective at preventing carbon dioxide pollution, and combined heat and power (in which a power plant generates both electricity and heat for a building or industrial application) is greater than three times more effective. In 2018, biomass and land-based wind energy will be more than twice as effective, and offshore wind power will be on the order of 30 percent more effective per dollar of investment, even without the benefit of the renewable energy production tax credit. (See Figure ES-2.)

- By 2018, and possibly sooner, solar photovoltaic power should be comparable to a new nuclear reactor in terms of its per-dollar ability to prevent global warming pollution. Some analyses imply that thin film solar photovoltaic power is already more cost-effective than a new reactor. And solar power is rapidly growing cheaper, while nuclear costs are not likely to decline.

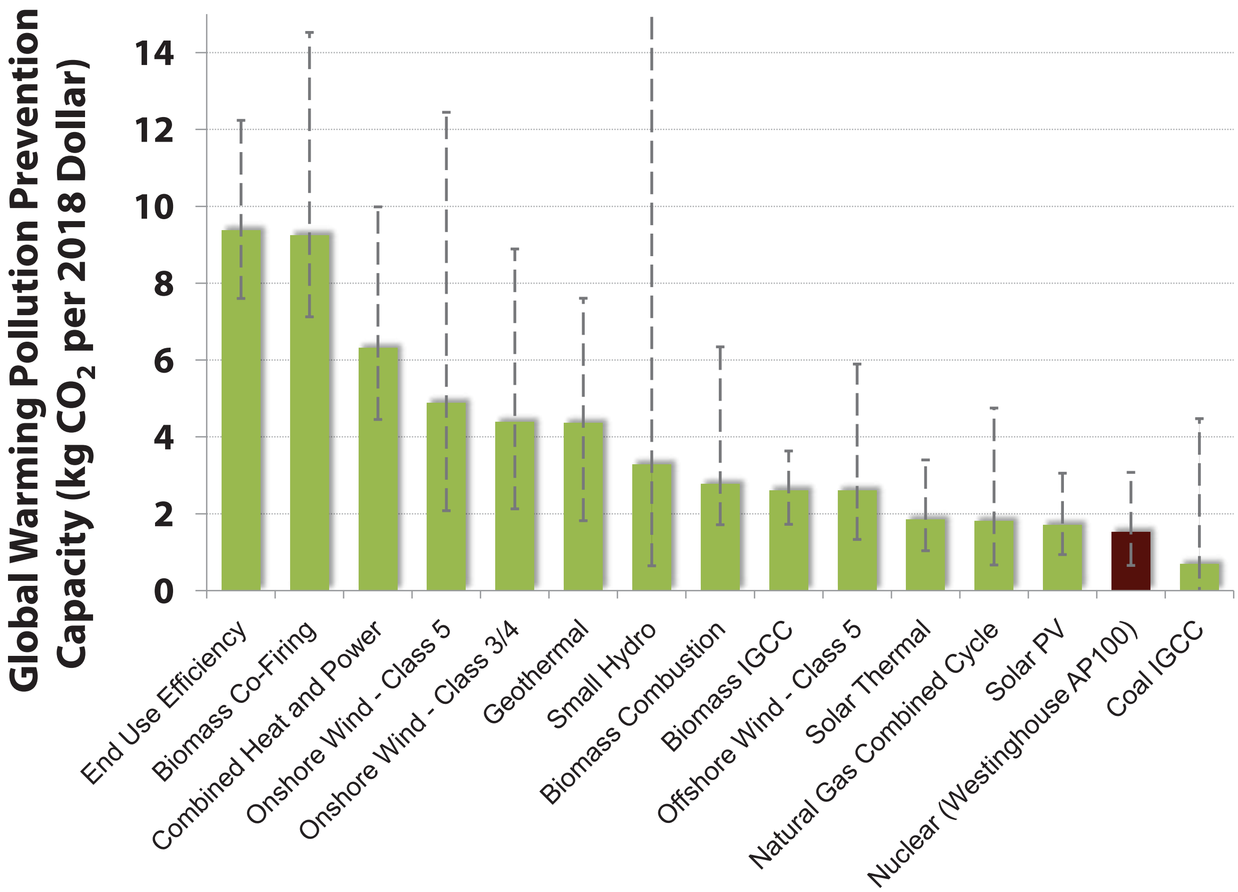
Nuclear power is not needed to provide reliable, low-carbon electricity for the future.

- Nuclear power proponents argue that nuclear plants are needed to produce low-carbon "base-load" power. However, the need for base-load power is exaggerated and small-scale clean energy solutions can actually enhance the reliability of the electric grid.

- Many clean power sources – including energy efficiency improvements, combined heat-and-power technologies and renewable energy sources such as biomass, geothermal energy and solar thermal power with heat storage – are available at any time, just like nuclear power. Others, including wind and solar photovoltaic power, are predictable with about 80-90 percent accuracy a day in advance. With proper planning and investments in a "smart grid" to facilitate wise use of resources, clean energy solutions could supply the vast bulk of America's electricity needs.

- Over-reliance on base-load power plants such as nuclear reactors can harm the reliability of the grid. Because nuclear reactors provide power in massive, inflexible, all-or-nothing blocks, they often produce large amounts of power at times when few people need it. Moreover, when a reactor fails, it can have dramatic and widespread consequences for the availability of electricity. For example,

Figure ES-2: Comparative Ability of Electricity Technologies to Prevent Global Warming Pollution, per 2018 Dollar Spent over Technology Lifetime – Online in 2018, Merchant Financing Terms



By 2018, a reasonable estimate for the first date a new reactor could be online, nuclear power will be among the least cost-effective options for reducing global warming pollution. Source: see discussion on page 29 and Methodology on page 39.

when a power line failure triggered the shutdown of two nuclear reactors at Turkey Point in southern Florida in February 2008, more than 3 million customers in the Miami area lost power for up to five hours – causing traffic jams, stranding people in elevators, and widely disrupting business.

To address global warming, U.S. policy should focus on improving energy efficiency and generating electricity from clean sources that never run out – such as wind, solar, biomass and geothermal power. State and federal leaders should:

- **Oppose additional subsidies for nuclear power.** Nuclear power has already benefited from more than $140 billion in federal subsidies over the last half-century, from liability protection to loan guarantees. The federal government should not further subsidize new nuclear power plants. Any subsidies for low-carbon energy alternatives must be judged based on their relative short-term and long-term costs and environmental advantages.

- **Reduce the nation's emissions deeply enough to prevent dangerous impacts from global warming, guided by the latest scientific understanding.** The United States should reduce its emissions of global warming pollution 35 percent below 2005 levels, with the vast majority of emissions coming domestically, and reduce emissions by more than 80 percent by 2050. Polluters should pay for any right to use the atmosphere, and any revenues should support investments in clean energy and benefit consumers. The United States should also work with other nations to achieve an international agreement to do what it takes to prevent the worst impacts of global warming.

- **Require the nation to reduce overall electricity use by 15 percent by 2020 and to obtain at least 25 percent of its electricity from clean, renewable sources of energy that never run out, such as wind and solar power, by 2025**. States should also enact similar policies or expand existing targets.

- **Strengthen energy efficiency standards and codes for appliances and buildings** with the goal of reducing energy consumption in new buildings by 50 percent by 2020 and ensuring that all new buildings use zero net energy by 2030. Advanced states should go further, aiming for all new buildings to achieve net-zero energy performance by 2020.

- **Invest in electric grid modernization** to maximize our potential to take advantage of a diverse range of energy efficiency opportunities and clean power sources.

Introduction

People around the world are growing increasingly alarmed about global warming – and for good reason. Every day, it seems, scientists announce a new finding that points toward grave peril for our civilization.[1]

The damaging impacts of warming – from the acidification of the world's oceans to melting glaciers and rising sea levels – are happening even faster than the most eye-opening predictions made by the United Nations' Intergovernmental Panel on Climate Change just two years ago.[2] Scientists are becoming increasingly concerned that critical thresholds are a matter of years or a few decades away – beyond which lay dramatic and irreversible changes to our world and our way of life.[3]

Given the pollution that humans have already produced, some impacts, such as the melting of mountain glaciers and the resulting disruption of water supplies, will be unavoidable and irreversible.[4] However, with immediate, swift and decisive action at all levels of government – local, state, national and international – we still have a chance to avoid many of the most catastrophic impacts of global warming.

Given the scale of the threat, we should put every possible solution on the table, except for the status quo. We should carefully consider all sources of carbon-free energy – even nuclear power – to make sure that we choose the approach most likely to deliver success.

The nuclear industry has worked tirelessly over the last decade to position itself as a solution to global warming.[5] On the surface, the case looks reasonable. Nuclear power is capable of producing large amounts of electricity while emitting little to none of the heat-trapping gases that cause global warming.[6] Nuclear power advocates have coalesced around a vision of building 100 new reactors in the United States by 2030, doubling the current fleet of reactors and moving America's economy away from its dependence on polluting fossil fuels.[7]

This report takes a closer look at how new nuclear power could contribute to the fight against global warming. The report focuses on the need for solutions that deliver rapid and substantial progress in reducing America's emissions of global warming pollution within the next 10 to 20 years; cut pollution in a cost-effective way compared to other strategies; and maintain reliable electricity service.

By these measures, nuclear power simply isn't up to the job. Putting aside the unresolved problem of how to safely dispose of nuclear waste, the environmental impacts of mining and processing uranium, the risk of nuclear weapons proliferation, and the potential consequences of an accident or terrorist attack at a nuclear power plant, the nuclear industry simply cannot build new reactors fast enough to deliver the progress we need on a time scale that will make enough of a difference. Moreover, new nuclear reactors are far more expensive than other forms of emission-free electricity. Investing in a new generation of nuclear reactors would actually delay needed progress and divert critical investment dollars away from better solutions.

Despite billions in government subsidies made available through the Energy Policy Act of 2005, and a streamlined permitting process at the Nuclear Regulatory Commission, no new nuclear reactors are yet under construction. Looking at the state of the industry in 2009, nuclear industry experts at the Massachusetts

Institute of Technology warn that without more government action to support the technology, "nuclear power will diminish as a practical and timely option for" reducing the odds of catastrophic global warming.[8]

This report concludes that government action to address global warming would be better focused on the wide range of other technologies that can deliver emission reductions more quickly and cheaply than nuclear power while also providing reliable electricity service. Despite decades of generous federal subsidies to the nuclear industry, nuclear power is not now ready to address the challenge of global warming – especially on the short timeline required for meaningful action. Piling additional subsidies or policy preferences upon the previous largesse extended toward the nuclear industry would only serve as a dangerous distraction in the fight to prevent the worst impacts of global warming.

Fueled by global warming, a mountain pine beetle infestation has killed 6.5 million acres of forest in the western United States. Preventing the most catastrophic impacts of global warming will require rapid and substantial cuts in global warming pollution over the next 10 to 20 years. The nuclear industry simply cannot build new reactors fast enough to deliver the progress we need. Investing in a new era of nuclear power would divert money from more effective solutions. And nuclear power is not necessary for reliable electricity service.

Photo: iStockPhoto.

America Must Act Quickly to Limit the Consequences of Global Warming

"We are faced with the fact that tomorrow is today. We are confronted with the fierce urgency of now. In this unfolding conundrum of life and history, there is such a thing as being too late. Procrastination is still the thief of time. Life often leaves us standing bare, naked and dejected with a lost opportunity. The "tide in the affairs of men" does not remain at the flood; it also ebbs. We may cry out desperately for time to pause in her passage, but time is deaf to every plea and rushes on. Over the bleached bones and jumbled residue of numerous civilizations are written the pathetic words: 'Too late.'"

– Martin Luther King, April, 4, 1967, at Riverside Church in New York City

Global warming is rapidly changing America's climate, driven largely by combustion of fossil fuels for energy.[9] The country is becoming hotter.[10] Sea level is rising.[11] Rainstorms and hurricanes are becoming more intense.[12] Landscapes are changing – from Western forests ravaged by drought, bark beetles and fires, to the degradation of coral reefs along the Florida Keys, to shifts in the timing of seasons and in the habitable ranges of plant and animal species across the country.[13]

Should our emissions of global warming pollutants continue unchecked, America and the world face catastrophic consequences. Global average temperatures could increase by as much as 11.5° F by the year 2100 (depending on the pace of the emissions increase).[14] Sea level could rise by as much as 6.5 feet by the end of the century, causing extensive coastal flooding.[15] Hurricanes could become more severe.[16] And America could experience extended periods of hot weather and drought, punctuated by heavy downpours, interfering with water supplies and agriculture and exacerbating smog pollution.[17]

To limit the impacts of global warming, America must rapidly and substantially reduce its emissions of global warming pollution. The more global warming pollution that humanity emits into the atmosphere, the greater the warming – and the damage – that will become unavoidable. Early action will help prevent the worst impacts while also allowing greater flexibility to respond to an already changing climate, and help lead the world toward preserving a livable future. It is in this context that we must evaluate potential approaches to mitigate global warming and focus on those approaches with the greatest odds of success.

Global Warming Threatens the Health and Well-Being of All Americans

Global warming poses a serious threat to the health and well-being of people across America and around the world. Global warming is already changing America's climate. And if we do not act quickly to limit emissions of global warming pollution, the consequences could be catastrophic.

Global Warming Is Rapidly Changing America's Climate

According to the United Nations' Intergovernmental Panel on Climate Change, the evidence that humans are altering the earth's climate is "unequivocal."[18] For example:

- Worldwide, temperatures have increased by more than 1.4° F since pre-industrial times.[19]
- The oceans have absorbed 80 percent of the extra heat in the climate system, causing the water to expand.[20] Coupled with melting glaciers, this has caused sea levels to rise by about eight inches – with the rate of increase accelerating.[21]
- Hurricanes have become more intense, and the frequency of extreme rain and snowstorms has increased.[22]
- At the same time, droughts in many parts of the world have become longer and more severe, especially in the tropics and subtropics.[23]

These changes are also affecting the United States.

- Rising temperatures are changing the timing of the seasons and shifting the habitable area for plant and animal species northward and higher in altitude across the country.[24]
- Levels of carbon dioxide are increasing in the air as well as the ocean, causing ocean waters to become more acidic and contributing to the decline of ocean ecosystems, including a 50 to 80 percent decline in coral on reefs along the Florida Keys.[25]
- Western forests are being ravaged by drought and pine beetles. From the Rockies to the Cascades, the pine beetle has killed 6.5 million acres of forest.[26] Milder winters linked to global warming have increased winter beetle survival from 10 percent to 80 percent, allowing the beetle population to rise dramatically.[27] Simultaneously, hotter summers have weakened the trees' ability to fight off beetles.[28]

If Emissions Continue to Increase, the Consequences Will Be Catastrophic

The more global warming pollution that humanity emits, the more serious the consequences. And the changes will be largely irreversible for a thousand years after emissions stop.[29]

On our current emissions path, humanity risks increasing the average global temperature by 10° F or more (above the pre-industrial era) by the end of this century.[30] Warming on this scale would have catastrophic consequences, including: [31]

- Extinction of as much as 70 percent of all species on earth.[32]
- Acidic "dead zones" in the ocean that could endure for thousands of years.[33]
- The loss of unique ecosystems such as the Amazon rainforest.[34]
- Sea level rise of as much as 6.5 feet in the next century, causing extensive coastal inundation in areas such as south Florida and Louisiana and increasing the risk of storm surge flooding in major coastal cities.[35]
- Continuing sea level rise marching on for thousands of years. The Greenland and West Antarctic ice sheets could melt, raising sea level by 30-40 feet.[36] Ultimately, sea level could increase 250 feet, reaching levels associated

with the climate at the end of the Eocene era, 34 million years ago.[37]

- Widespread drought across as much as a third of the globe, straining water supplies and agriculture.[38] By mid-century, the U.S. southwest could fall into permanent drought exceeding even the severity of the Dust Bowl era.[39]
- Extreme heat waves. Peak temperatures greater than 120° F could threaten most of the central, southern, and western United States by the end of the century.[40]
- More intense hurricanes, driven by warming seas. The number of severe category 4 and 5 hurricanes could increase from 13 to 17 worldwide per year by 2050.[41]
- More intense wildfires. By the end of the century, wildfires in the West could be five times as severe as they are today.[42] Each degree in temperature rise could increase the area burned in a typical fire by 300 percent, and more than double the costs of protecting homes.[43]

Additionally, the more pollution humanity emits, the greater the risk that we will cross a critical "tipping point," accelerating climate change beyond human control. For example, melting permafrost threatens to release massive quantities of methane, a potent global warming gas, from decaying material now frozen underground. Or, changes such as the current pine beetle infestation in Western forests could transform an ecosystem from one that absorbs carbon from the atmosphere to one that emits carbon.[44] In other words, the risk that global warming will cause severe, unforeseen and uncontrollable impacts increases with every pound of coal or gallon of gas that humans burn.

To Limit the Consequences of Global Warming, America Must Swiftly and Substantially Cut Emissions of Global Warming Pollution

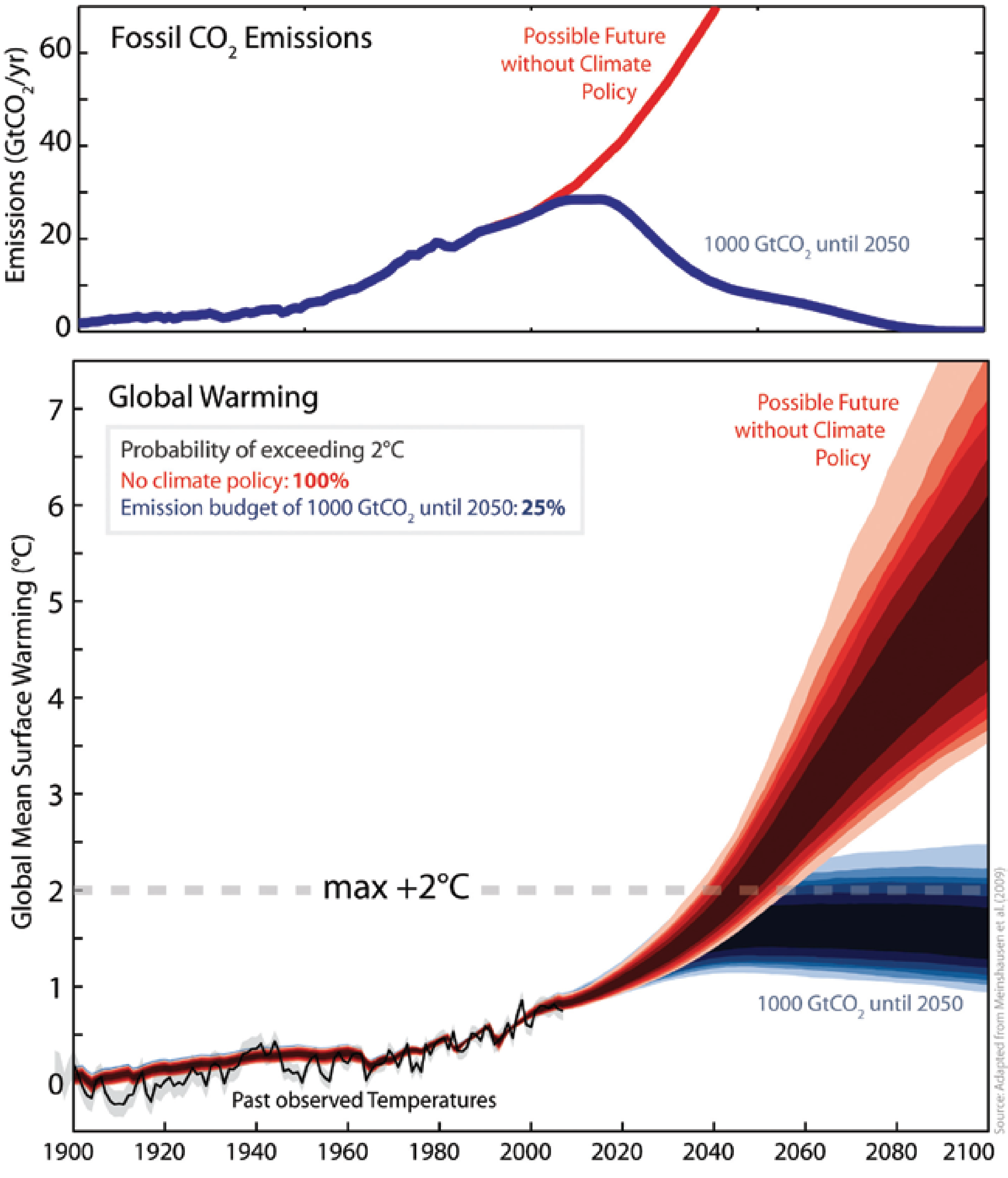
In order to minimize the impacts of global warming, America must quickly and dramatically cut its emissions of global warming pollution.

The international community has agreed to work to limit global warming to 3.6° F (or 2° C) above temperatures in the pre-industrial era.[45] According to current scientific understanding, to have even odds of meeting this target, the concentration of carbon dioxide in the atmosphere must not rise above roughly 450 parts per million (ppm) – and perhaps substantially less.[46] (Current concentrations are already greater than 380 ppm.[47]) Additional limits must be placed on other types of heat-trapping gases.

This means that humanity can only emit so much global warming pollution into the atmosphere before the odds of limiting the temperature increase to 3.6° F become increasingly unlikely. This amount is our "carbon budget," or ultimate limit on allowable pollution.

Science makes two critical points clear. The faster we cut our emissions, the easier it will be to stay within our carbon budget and the less risk we face. Early action allows more flexibility to respond to an evolving understanding of humanity's role in shaping the climate, making a wider variety of options available. Correspondingly, the higher and later the peak in emissions, the harder we will have to work to keep emissions within budget, the higher the potential costs, and the greater the risk that our options will run out.

Figure 1: Limiting Total Global Emissions of Carbon Dioxide to 1 Trillion Metric Tons From 2000 to 2050 Would Yield a 75 Percent Chance of Limiting Warming to 3.6° F (2° C) or Below[51]



Total Emissions Must Not Exceed Our "Carbon Budget"

According to current scientific understanding, humanity as a whole can emit no more than a total of 3.7 trillion metric tons of carbon dioxide from the beginning of our history onward through the next 500 years in order to have a 50-50 chance at limiting global warming to an average temperature increase of no more than 3.6° F (2° C) above the pre-industrial era.[48]

Humanity has already emitted more than 1.8 trillion metric tons of carbon dioxide pollution so far. From now (2009) through 2050, we must emit less than that same amount again in order to have even odds at meeting the international target for mitigating climate change. At current emission rates, the world is on pace to exceed this "carbon budget" in less than four decades – at which time we will have committed the world to a future of dangerous global warming.[49]

To increase the odds to 75 percent that we will be able to limit warming to 3.6° F or below, we will have to accept a global carbon budget of 1 trillion metric tons of carbon dioxide emissions during the first half of this century.[50] (See Figure 1.)

Scientists note that the target may need to be substantially lower, given the likelihood that our understanding of human influence on the climate will continue to evolve. And even warming of 3.6° F carries significant consequences and major risks for human civilization.[52] Leading climate scientists, including Dr. James Hansen of NASA, have called for reducing atmospheric carbon dioxide below current levels, which would require reducing our fossil fuel emissions to zero as quickly as possible. Then, we would have to develop and deploy methods of removing pollution from the atmosphere.[53] In this view, we have already exceeded our carbon budget and must act with even greater speed.

Early Action Matters

The most important thing we can do to address global warming, then, is to cut our emissions of global warming pollution as quickly and sharply as we can, while laying the groundwork for future reductions in the years to come. The more rapidly we reduce emissions, the less risk we assume, and the more room we leave to maneuver in later years.

Recognizing the necessity of swift action, the chief of the Intergovernmental Panel on Climate Change, Rajendra Pachauri, has called on developed nations to ensure that global emissions peak no later than 2015.[54] Emissions must then fall rapidly thereafter. A large panel of top United Nations scientists and Nobel Prize winners has called on developed nations to reduce emissions of global warming pollution by 25 to 40 percent below 1990 levels by 2020.[55]

The world must then continue to slash emissions rapidly, achieving cuts of at least 50 percent by mid-century, and perhaps substantially more.[56] Developed countries with the largest capacity to act will need to reduce emissions by 80 to more than 95 percent.[57] Afterwards, the world must then embark on a program to zero out all emissions of global warming pollution, and very possibly deploy technologies to remove carbon dioxide from the atmosphere.[58]

Because carbon dioxide can persist in the atmosphere for well over 100 years, the timing of emissions is less important than keeping overall emissions within the carbon budget.[59] As a consequence, if the world is unable to achieve deep cuts in global warming emissions by 2020, then the world will have to work harder and make deeper and faster cuts in emissions before 2050.

Early action increases the odds that keeping emissions within the overall budget will be politically and technologically feasible.

Setting a Carbon Budget for the United States

Setting a carbon budget for the world, and allocating responsibility for emission reductions among the world's countries, is a difficult political decision that the international community will have to grapple with.

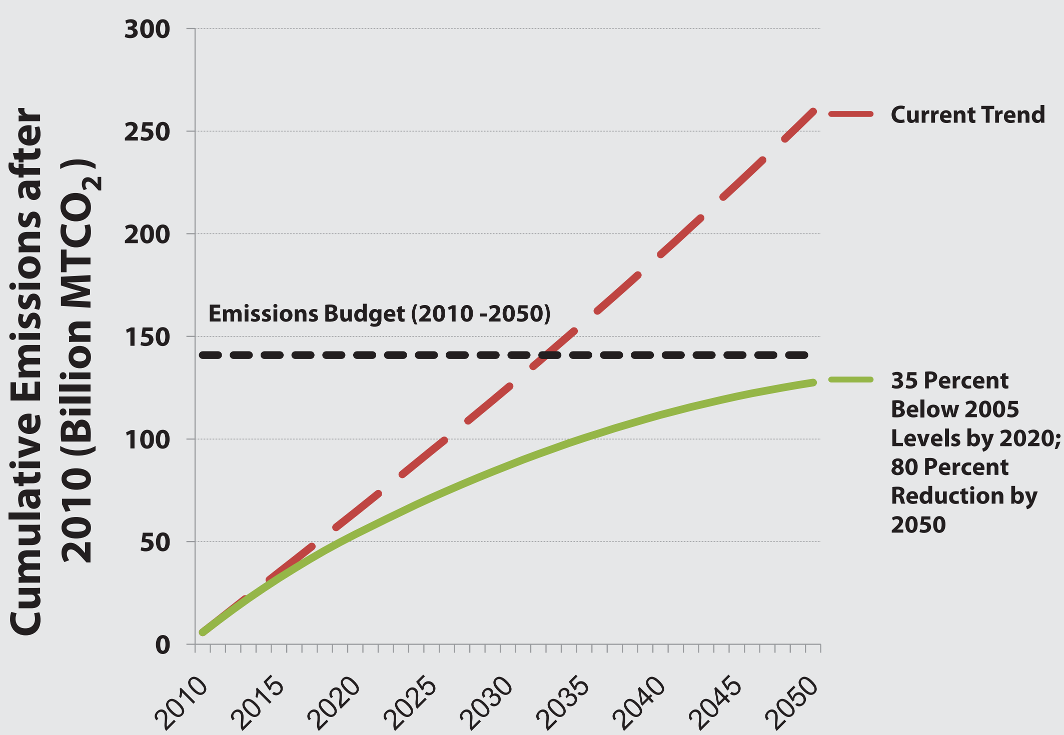
For the purposes of elucidating the argument in this report, we assume a world carbon budget of 1 trillion metric tons of carbon dioxide from 2000 through 2050. Limiting emissions to this amount will give the world about a 3 in 4 chance of keeping the global average temperature from rising higher than 3.6° F above the pre-industrial era.[66]

We assign 20 percent of this budget, or 200 billion metric tons, to the United States, which is approximately our share of cumulative emissions by mid-century under a simplified scenario in which all countries work toward equalizing per-capita emissions of global warming pollution at about 800 kilograms per person per year.[67] By the end of 2009, we will have already used up 30 percent of this budget, leaving just 140 billion metric tons of allowable emissions for the next 40 years.[68]

Keeping emissions below this overall limit would require reducing U.S. carbon dioxide emissions by 35 percent below 2005 levels by 2020 and 80 percent by 2050, while having the United States make a significant contribution to emission reductions in other nations. (See Figure 2.)

Most early progress is likely to come through reducing emissions from electricity generation. As a result, the United States may need to limit emissions from electricity generation to 34 billion metric tons of CO_2 from 2010 cumulatively through 2050, or less.[69] This figure is a rough guide to what the U.S. electric sector must accomplish to do its part to limit the consequences of global warming.

Figure 2: Keeping Cumulative Emissions Below Our 2050 Carbon Budget Will Require Cutting Annual Emissions 35 Percent by 2020 and 80 Percent in Four Decades



The United States Plays a Critical Role

Because the U.S. is responsible for far more of the global warming pollution now in the atmosphere than any other country, the degree of emission reductions required here will be greater than in less-developed countries.[60]

Early Progress Is Most Likely to Come from the U.S. Electricity System

To meet our goals for limiting the consequences of global warming, we must achieve rapid, deep and sustained cuts in emissions from the U.S. electricity system. For this reason former Vice President Al Gore has challenged the United States to switch its entire electricity system to run on clean energy instead of fossil fuels by 2018, and to ultimately reduce emissions of global warming pollution 90 percent by mid-century.[61]

Displacing coal-fired power from the U.S. electricity system is one of the most likely sources of early cuts in global warming pollution.
Photo: Kenn Kiser.

The U.S. electricity system is one of the most likely sources of early cuts in global warming pollution. About 40 percent of total U.S. carbon dioxide emissions come from the generation of electricity.[62] About 80 percent of these emissions come from coal – despite the fact that coal provides just under half of U.S. electricity.[63] Preventing the construction of any new coal-fired power plants and phasing out the use of coal in existing power plants would cut emissions substantially. Furthermore, relative to the transportation sector with its millions of gasoline-powered engines, cuts in the electricity sector will be easier and cheaper to obtain in the near term, and may set the stage for transitions such as shifting vehicle fuel from gasoline to electricity.[64]

There are many low-carbon options for electricity generation and broad public consensus on shifting America away from its dependence on fossil fuels.[65] Resources with the potential to deliver emission cuts span the spectrum from nuclear power to energy efficiency and from carbon capture and sequestration to clean energy sources that never run out, such as wind, solar and geothermal power.

Given the importance of quick and effective action to reduce America's emissions of global warming pollution, it is crucial that we invest in the options likely to deliver the best results.

Nuclear Power Is Not a Solution to Global Warming

Nuclear power is not necessary to provide reliable, low-carbon electricity for the future. Far from being a solution to global warming, a major national investment in nuclear power would actually set America back in its efforts to reduce pollution. Even building 100 nuclear reactors by 2030 would be too slow to make enough of a difference, and too expensive compared to other sources of clean, emission-free electricity. And that investment – which would likely run into the trillions of dollars – would foreclose opportunities to invest in other clean technologies with the potential to deliver greater emission reductions, faster.

Nuclear Power Is Too Slow to Reduce Global Warming Pollution in the Near-Term

Building 100 new nuclear reactors would happen too slowly to reduce global warming pollution in the near-term, and would actually increase the scale of emission cuts required in the future.

At best, the nuclear industry could have a new reactor up and running by 2016, assuming that construction could be completed in four years. This pace would be faster than 80 to 95 percent of all reactors completed during the last wave of reactor construction in the United States.[70] If construction follows historical patterns, it could take nine years after a license is issued before the first reactor is up and running – into the 2020s.

Under this very plausible scenario, new nuclear power could make **no** contribution toward reducing U.S. emissions of global warming pollution by 2020 – despite the investment of hundreds of billions of dollars for the construction of nuclear power plants. And even if the industry completed 100 new reactors by 2030, which is highly unlikely, these reactors would reduce cumulative power plant emissions of carbon dioxide over the next two decades by only 12 percent below business as usual, when a reduction of more than 70 percent is called for. In other words, 100 new nuclear reactors would be too little, too late to successfully meet our goals for limiting the severity of global warming.

At Best, No New Reactors Could Be Completed Until 2016

No new reactors are now under construction in the United States. The nuclear industry will not complete the first new reactor until 2016, optimistically assuming construction will take four years after regulatory approval.

From application development to operation, the nuclear industry expects that a new nuclear reactor would take 10 years to build.[71]

- Construction cannot begin on any new reactors until the U.S. Nuclear Regulatory Commission (NRC) approves a reactor design and issues a license. This is not likely to happen before 2011 or 2012.

- To date, reactor manufacturers have submitted plans for three new types of nuclear reactor designs for certification. The NRC expects official hearings around the suitability of these designs to begin in 2010 or 2011, with decisions arriving later.[72] One type of reactor is already certified through 2012, but then must be re-certified.[73]

- Power companies have submitted applications to build and operate 26 new reactors, with as many as eight more expected.[74] As of

Delays are Already Mounting in the Nuclear Renaissance

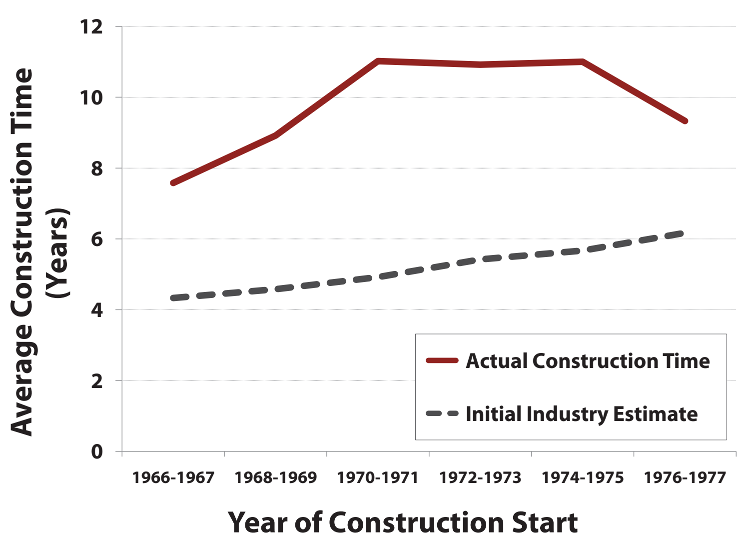
Companies seeking to build new nuclear power plants are already suffering delays. In October 2009, the NRC rejected the certification of a new reactor design over concerns that a key component could not survive an earthquake – a setback for as many as 14 planned reactors.[80] Since the end of 2008, nine reactor license applications have been canceled or indefinitely suspended, and the Tennessee Valley Authority has canceled plans to finish a partially-built reactor.[81] Plans for another 10 to 12 reactors have been delayed or are failing to find adequate business partners to share the risk.[82] Such developments increase the odds that the nuclear industry will not achieve much expansion, if any, over the next decade – and underscore the danger of depending on nuclear power to deliver urgently needed progress in reducing global warming emissions.

October 2009, the NRC is actively reviewing applications for 22 of these reactors.[75] The nuclear industry expects this process to take up to four years for the first reactors, followed by public hearings and a rulemaking.[76] Later reactors may take two to three years.[77]

The nuclear industry estimates that construction work on a new reactor could be completed in four years.[78] If the NRC begins to issue licenses in 2012, that would imply that as many as three new reactors could be online by 2016, with two more by 2018.[79]

However, this schedule could very well be too optimistic.

Figure 3: Construction Times Were Consistently Underestimated During the Last Wave of U.S. Nuclear Reactor Deployment [87]



The Nuclear Industry Has Consistently Overestimated How Fast Reactors Can Be Built

During the last wave of nuclear power plant construction in the United States (from the late 1960s into the early 1990s), the nuclear industry predicted that reactors could be built in 4-6 years. However, the average reactor ended up taking nine years to complete.[83] In other words, actual construction times were almost double projections – consistently – across several decades of reactor construction work. (See Figure 3.)

Also notable is the fact that later reactors tended to take longer to complete than the first reactors. (See Figure 4.) This pattern is the opposite of a typical learning curve, where later units often can be completed faster and for less cost as an industry gains efficiency and economies of scale – especially with simple products manufactured in high volumes.[84] Nuclear reactors are big, complex, and difficult to manufacture in high volumes. In addition, many reactor projects suffered from unanticipated quality control problems during construction.[85]

Today, the nuclear industry promises that new, standardized designs and technological advances will enable reactor construction to proceed quickly, without the mistakes of the past.[86] However, recent experience with reactor construction in Finland and France – two of the only active nuclear construction projects in the Western world – raise the very real possibility that nothing has fundamentally changed.

A New Generation of U.S. Nuclear Reactors Would Likely Experience Construction Delays

A new generation of nuclear reactors in the United States would likely face delays that could push construction times well beyond four years.

A reactor now under construction in Finland exemplifies this risk. The reactor is now at least three years behind schedule after a series of quality control failures, and its builder, a French government-owned nuclear developer called Areva, is no longer committing to a specific target date for completion.[89]

The reactor is the first of its kind in the world, incorporating advanced design features the industry had hoped would facilitate rapid completion and keep costs in check.[90] However, the project has suffered from delays and cost overruns, much like past nuclear reactor projects.

Areva and its contractors have made a variety of costly mistakes during construction. Welds for the reactor's steel liner were flawed, and had to be redone. Water coolant pipes were revealed as unusable. And concrete poured in the foundation was suspect, with too much moisture content to meet safety requirements.[91]

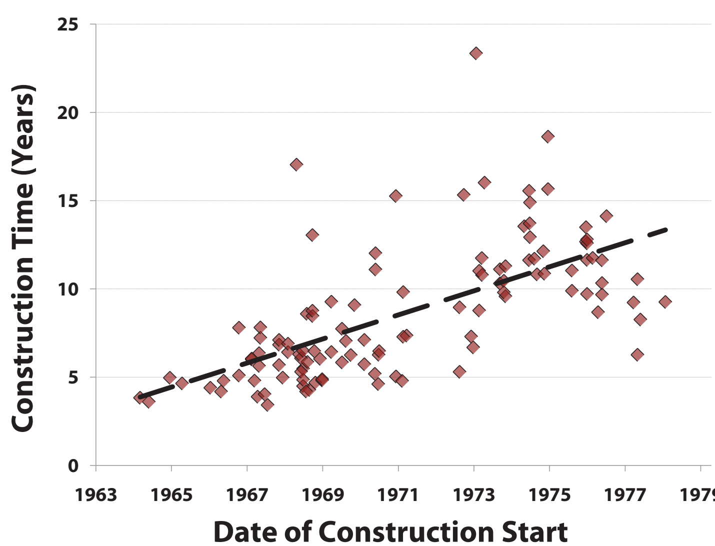
While the project was initially scheduled for completion in summer 2009 (a four-year construction time), Areva has scrapped the timeline.[92]

As of September 2009, the project is $3.3 billion over budget.[93] Areva and the Finnish utility TVO are locked in a dispute over who will be responsible for the cost overruns.[94] Meanwhile, a coalition of Finnish industries estimates that the delays will indirectly cost electricity users $4 billion in higher power bills.[95]

The Finnish reactor is not the only nuclear project behind schedule. A second Areva reactor being built in France is at least nine months behind schedule.[96] Project coordinators admitted in late 2008 that the project was 20 percent over budget.[97] The last four reactors built in France took an average of 10.5 years to complete.[98]

If a new generation of U.S. nuclear reactors faces delays approaching this scale, it is possible that no new reactors could be up and running before 2020. While new reactors are under construction, the United States would continue to operate existing dirty power plants, making it impossible for the nation to meet near-term targets for reducing global warming pollution.

Figure 4: During the Last Wave of U.S. Reactor Deployment, Construction Duration Tended to Escalate Over Time[88]

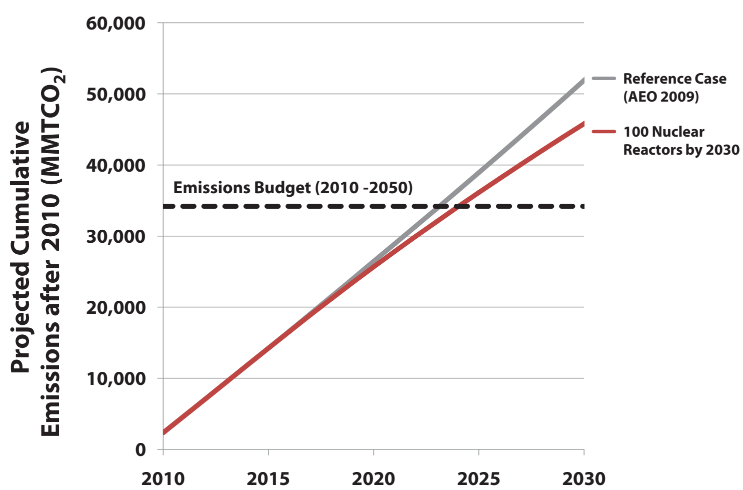


The American Nuclear Industry Is Not Ready to Move Quickly

No American power company has ordered a new nuclear power plant since 1978, and all reactors ordered after the fall of 1973 ended up cancelled.[99] As a result, domestic manufacturing capability for nuclear reactor parts has withered and trained personnel are scarce.[100] While the United States had 900 certified nuclear component suppliers two decades ago, today there are fewer than 200.[101] In addition, only two metal foundries in the world today are capable of forging heavy nuclear reactor vessels – and they are located in Japan and France.[102] Only the facility in Japan has the capability to forge vessels larger than 500 tons.[103] The nuclear industry must compete with the petrochemical industry for access to these facilities.[104]

The industry is not capable of taking on a large number of new reactor construction projects without time to re-establish a trained workforce and a resilient supply chain – a probable source of delay. While new reactor component factories opening as early as 2011 could ease this situation somewhat, the industry could have as many as 30 to 70 active reactor construction projects at any one time on a sustained trajectory to build 100 new reactors by 2030.[105]

Figure 5: Projected Cumulative Electric Sector Emissions of Global Warming Pollution after 2010 with No Action or 100 New Reactors Built by 2030



Nuclear power is too slow to deliver enough pollution cuts in the next two decades. Even if the nuclear industry managed to complete 100 new reactors in the United States by 2030, nuclear power could still only reduce total electric sector emissions 12 percent below forecast levels by 2030, leading to a higher and later peak in emissions. As a result, America would exceed its 2010-2050 power plant emissions budget by 2025 – 25 years too early to meet our goals for reducing the severity of global warming.

Even Without Delays, the Nuclear Path Is Too Slow to Keep Global Warming Emissions Within Budget

Even with generous assumptions about speed and effectiveness, building 100 new reactors in the United States by 2030 will not reduce global warming pollution fast enough to keep our carbon emissions within budget – and therefore not fast enough to meet our goals for limiting the consequences of global warming.

First, assume that the nuclear industry can deliver on its ambitious timelines and successfully complete 100 new reactors (about 100 gigawatts of generation capacity) in two decades. Then, assume that every kilowatt-hour of nuclear power would displace coal, the largest source of carbon-intensive power generation. Finally, assume that next-generation nuclear reactors operate at an average of 90 percent of full capacity – an upper-bound estimate from a group of nuclear technology experts.[106] Under these best-case conditions, building 100 active nuclear reactors could prevent more than 750 million metric tons of carbon dioxide ($MMTCO_2$) pollution in 2030. Overall power plant emissions would be 20 percent below 2005 levels.

However, these nuclear reactors would not be able to reduce emissions while they are under construction. In other words, the nuclear path delivers a late start in cutting pollution. As a result, building 100 new reactors could only reduce cumulative power plant emissions of global warming pollution by 12 percent over the next two decades compared to doing nothing. (See Figure 5.) On this path, America would still exceed its 2010-2050 electric power emissions budget by 2025 – 25years too soon. (See "Setting a Carbon Budget for the United States" on page 13 for a brief explanation of the source of the budget line represented in Figure 5.)

In conclusion, building 100 new nuclear reactors by 2030 would be too little, too late when it comes to preventing global warming pollution. By leading to a higher and later peak in emissions, using nuclear power as a primary strategy to address global warming would ensure that the United States exceeds its 2010-2050 power plant emissions budget. As a result the nuclear path would cut into what little margin of error we have, increasing the risk of catastrophic global warming.

Clean Energy Solutions Can Reduce Pollution Much Faster Than 100 New Reactors

Clean energy solutions have a significant advantage over nuclear power when it comes to reducing global warming pollution. Individual clean energy measures are small – as simple as installing a new light bulb in a home or erecting a single wind turbine. Small means fast. Millions of individual workers could participate in a clean energy transition at the same time. And many individual clean energy measures can add up to a rapid, large-scale cut in emissions.

Energy Efficiency and Clean Energy Measures Can Be Deployed Quickly

Individual energy efficiency and clean energy measures can be implemented in a matter of minutes to just a few years. Each individual measure delivers results right away. For example:

- Designing and building a super energy-efficient building requires little to no extra time compared to the effort required to build and design a standard building. Simple changes in design and construction can yield homes, institutions, and commercial buildings that use 70 percent less energy than standard structures.[107] Adding small-scale clean energy systems – solar photovoltaic panels or small wind turbines, for instance – can yield buildings that produce as much energy as they consume over the course of an entire year.

- Retrofitting an existing structure to achieve higher energy performance can take a matter of days to months to a few years. Contractors can weatherize an existing home in an average of three days.[108] Installing a home solar photovoltaic system typically takes less than a week.[109] Larger businesses or institutions can upgrade lighting, heating and cooling equipment, or mechanical systems in a matter of months to just a few years.[110]

- With available transmission infrastructure, today's power companies can build a utility-scale wind farm in as little as one year, and a concentrating solar thermal power plant in as little as two to three years after groundbreaking.[111] The components of these systems are largely modular. Making a bigger wind farm simply requires installing more wind turbines, and making a larger solar power plant basically requires installing more mirrors or more steam turbines. The modular and scalable nature of construction makes projects simple relative to traditional coal-fired or nuclear power plants, and better able to take advantage of economies of scale. Wind, concentrating solar thermal, and geothermal energy, however, must be integrated into the transmission grid. Projects that require major new power lines to be built could take longer to complete. (See "The Importance of Grid Modernization" on page 20.)

- Production of large amounts of energy efficient products and renewable energy technologies

The Importance of Grid Modernization

A rapid and massive expansion of renewable electricity generation through wind, concentrating solar thermal, geothermal, and related energy sources will require investments to modernize the U.S. electricity grid. Needed steps may include expanding transmission infrastructure into areas with large amounts of renewable electricity resources, such as the windy plains of North Dakota or the sun-soaked desert Southwest. Grid modernization may also require investments to improve the integration of distributed sources of electricity, such as rooftop solar panels.

While these costs are real, available evidence indicates that they will be relatively small. For example, the U.S. Department of Energy estimates that generating 20 percent of America's electricity supply from wind power by 2030, including necessary transmission upgrades, would cost the average household just 50 cents per month compared to sticking with coal- and gas-fired power.[113] And this estimate excludes the benefits of cleaner air, conserved water and less global warming. Moreover, the U.S. electricity grid would require upgrading to accommodate a massive deployment of nuclear power as well.

That said, in order for the majority of America's electricity to come from renewable sources of power, electricity system planners must plan ahead. Building major new transmission lines can require five years or more. To the extent that necessary investments in grid modernization are delayed, it could limit the speed of a transition to a renewable electricity system.

Fortunately, many clean energy sources – such as energy efficiency, combined heat and power, and solar photovoltaic panels – can make a difference right away, with no added transmission capacity. These energy sources are located at or near where the energy will be used and do not require the addition of massive new power lines. These energy sources alone can provide the energy equivalent of well over 150 new nuclear reactors in the U.S. over the next two decades. (See discussion on pags 25 and 33.) The deployment of massive amounts of energy efficiency measures and distributed generation can also ease pressure on existing transmission infrastructure and enable more wind farms and concentrating solar thermal plants to contribute than would otherwise be possible.

can be ramped up quickly. For example, worldwide capacity for solar panel production nearly doubled in 2008 alone and has increased by roughly five-fold since 2004.[112]

Individual Clean Energy Measures Quickly Add Up to Substantial Results

Clean energy measures are individually small and modular, but massed together, they can deliver substantial emissions reductions within just a few years.

- Energy efficiency programs active now in states such as California, Oregon, Connecticut, Vermont and New York are supplying most new electricity needs – cutting electricity consumption by 1-2 percent below forecast levels per year.[114] Reducing electricity consumption by 1.2 percent per year (below a no additional action forecast) across America as a whole, starting in 2010, could deliver the same amount of energy as building more than 30 nuclear reactors by 2016 – the earliest possible date the U.S. could have even three new reactors up and running.[115]

- In 2008, the wind industry brought 8,500 MW of wind energy generation capacity online, with another 4,000 MW in the first half of 2009.[116] The installations increased U.S. wind energy capacity by more than 50 percent – two years ahead of schedule on a trajectory to supply 20 percent of America's electricity by 2030, as mapped out by the U.S. Department of Energy.[117] Wind accounted for almost half of all new generation capacity completed in 2008.[118] In energy equivalent terms, these new wind turbines are equal to more than

America's Clean Energy Economy Is Ready to Take on This Challenge

Compared to the nuclear reactor manufacturing and construction industry, which has been in decline for 30 years, America's clean energy economy is a major part of today's business landscape, and is growing rapidly. Many workers are already working in the clean energy industry. Many more – such as displaced auto manufacturing workers in Michigan, or steel workers in Pennsylvania – already have most of the skills needed to join the clean energy workforce.

- According to the American Council for an Energy-Efficient Economy, the U.S. economy invested $300 billion in energy efficiency in 2004, supporting 1.6 million jobs across all sectors.[124]
- According to research by the Pew Charitable Trusts, entrepreneurs launched nearly 70,000 new clean energy businesses in America from 1998 to 2007.[125] During that period, clean energy created more than 750,000 jobs – and produced them 2.5 times faster than the economy as a whole.[126]

Workers inspecting a wind turbine.

Photo: NREL.

- In 2007 and 2008, wind turbine manufacturers announced, added or expanded more than 70 facilities – representing 13,000 new jobs.[127]
- More than 65,000 businesses across the United States manufacture, install, service or supply a wide variety of clean energy technologies.[128]

three new nuclear reactors.[119] Wind energy experts predict that wind will become the dominant source of new electric generating capacity in 2009-2012, with 36,000 to 40,000 MW installed (the energy equivalent of 10-12 new nuclear reactors).[120]

- The concentrating solar power industry is actively installing facilities in the southwestern United States, with 8,500 MW of generating capacity expected to be online by 2014.[121] This capacity is the rough energy equivalent of two to three nuclear reactors.[122] Rooftop solar photovoltaic panels are booming as well, with California alone on pace to install 3,000 MW by 2017.[123]

With the Capital Investment Required to Build 100 Nuclear Reactors in the Next Two Decades, Clean Energy Could Deliver Double the Impact

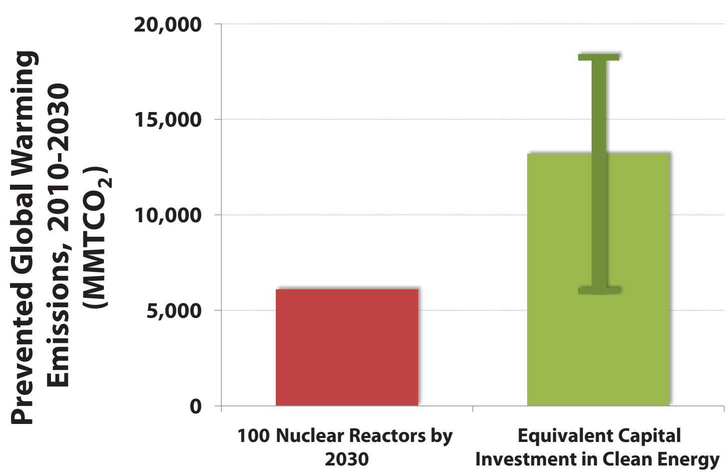
Through 2030, investing in clean energy could deliver double the impact of a comparable investment in nuclear power. The speed at which small, modular clean energy measures can be deployed means that capital invested in clean energy can begin preventing pollution right away, making a bigger overall difference in the next two decades.

Cost estimates for new nuclear reactors vary widely, since none have been built in the U.S. in more than 30 years.[129] The U.S. Department of

Energy has put forward one of the most optimistic forecasts of possible nuclear reactor costs over the next two decades, projecting that the capital cost of reactor construction could be as low as $2,400 per kilowatt (kW) by 2030 (in 2007 dollars).[130] (Many independent experts find this estimate implausible.[131]) However, even if building a nuclear reactor turns out to be this inexpensive and quick, 100 new nuclear reactors by 2030 could – at best – prevent the same amount of pollution as investing that same capital into clean energy solutions such as energy efficiency. (See Figures 6 and 7.)

On the other hand, if building a new nuclear reactor turns out to be an expensive and time-consuming endeavor, like many reactors built in the 1970s, reactors could cost as much as $10,000 per kW (2008 dollars).[132] Putting that level of capital investment into energy efficiency and renewable energy technologies instead would prevent three times as much pollution by 2030. (See Figures 6 and 7.)

Figure 6: Potential Reduction in Total Electric Sector Emissions of Global Warming Pollution, 2010-2030, from 100 New Reactors Built by 2030 vs. an Equivalent Capital Investment in Clean Energy



Investing in clean energy can deliver greater progress, faster, than a comparable investment in nuclear power. Building 100 new nuclear reactors by 2030 could prevent about 6 billion metric tons of carbon dioxide pollution. However, putting that same capital investment into clean energy solutions instead would prevent 6 to 18 billion metric tons of pollution (with the range representing uncertainty over how much a new nuclear reactor would cost, since none have been built in the United States in more than 30 years).

Comparing Nuclear Cost Estimates

Cost estimates from different sources are notoriously difficult to compare directly. Estimates often rely on different assumptions (such as the duration of construction) and they can exclude important costs (such as finance). The figures cited on page 22 are meant to give a plausible range of the up-front capital investment needed to build 100 new nuclear reactors.

For a direct comparison of the cost of nuclear generated electricity with other sources of power, averaged over the entire lifetime of each technology to enable meaningful comparison, see page 28.

At a mid-range reactor cost estimate of $6,250 per kW (2008 dollars), putting an equivalent investment into energy efficiency and renewable energy would prevent twice as much pollution by 2030 as building 100 new reactors.[133] (See Figures 6 and 7.) (See the Methodology section for more details.)

To Keep Power Plant Emissions Within Budget, America Will Have to Do Much More

Power plant emissions are on pace to exceed the U.S. power sector emission budget by 2024 with no further action. To keep emissions from exceeding this budget, the nation must respond swiftly and decisively.

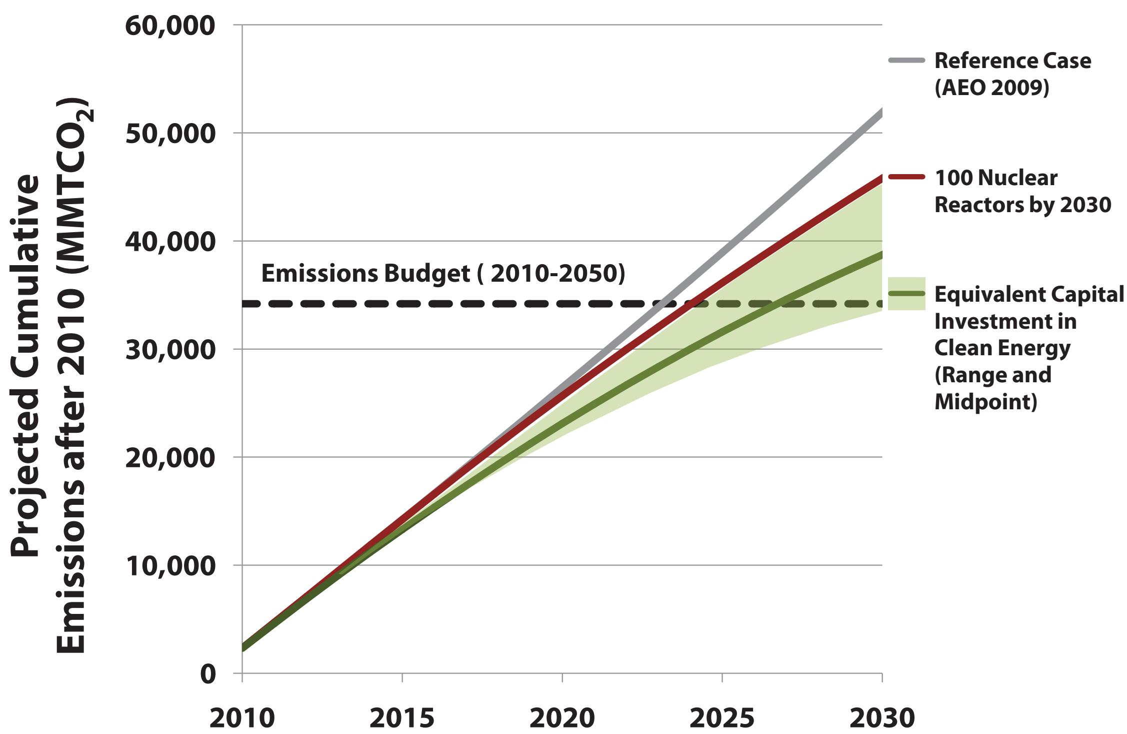
In the next two decades, clean energy deployment equal to the capital investment in 100 new nuclear reactors could reduce global warming pollution by 6 billion to 18 billion metric tons of carbon dioxide – 11 to 35 percent below forecast levels. However, even this level of clean energy deployment that would not be enough to keep U.S. power plant emissions within budget. (See Figure 7.) America will have to do much more to reduce power plant emissions within the next 20 years to limit the worst consequences of global warming.

Keeping power plant emissions within this budget would require reducing emissions by more than half in the next 10 years, and then reducing emissions by 95 percent by mid-century. Achieving progress on this scale will require a level of effort approaching that called for by Al Gore when he challenged the nation to end its dependence on fossil fuels for electricity generation within a decade.[134]

Quick Action Through Clean Energy Can Demonstrate International Leadership

If the United States chooses nuclear power as its primary strategy to reduce emissions of global

Figure 7: Projected Cumulative Electric Sector Emissions of Global Warming Pollution after 2010 with No Action, 100 New Reactors Built by 2030 or an Equivalent Capital Investment in Clean Energy



Clean energy solutions can deliver results faster than nuclear power. With the up-front capital investment required to build 100 new nuclear reactors, America could achieve twice as much by investing in clean energy instead. (Given the wide range of uncertainty over the cost of a new nuclear reactor, clean energy could at least equal the performance of new nuclear power by 2030, and at most perform three times better. See the shaded wedge in the figure above.) However, even this level of clean energy deployment would not be enough to keep U.S. power plant emissions within budget. America will have to do much more to reduce power plant emissions within the next 20 years to limit the worst consequences of global warming.

warming pollution, it is likely that the nation would have *little or nothing* to show for it in terms of real emission reductions from the electric power sector in the next 10 years. The failure of the United States to demonstrate real emission reductions would erode U.S. leadership in addressing global warming and likely reduce the international community's appetite for action.

We need other countries across the world to act rapidly and forcefully alongside the United States in order to have a chance at limiting global warming to 3.6° F above the pre-industrial era – thus controlling the severity of global warming impacts.

Showing a commitment to urgent action by adopting a clean energy path, however, could demonstrate more U.S. leadership, bringing the international community closer to achieving an ambitious, binding and firm agreement to fight global warming. Urgent action to deploy clean energy can also help America take a leadership role in building a clean technology and clean energy economy.[135]

Choosing to Build New Reactors Would Divert Resources from More Cost-Effective Strategies

Choosing to build new reactors would divert resources from more cost-effective strategies. Building 100 new nuclear reactors could have an up-front cost on the order of $600 billion (with a possible range of $250 billion to $1 trillion).[136] Investing this money in reactor deployment would foreclose opportunities to pursue cheaper and faster options.

New nuclear reactors would be far more costly than other forms of emission-free electricity. Even the most optimistic estimates for the average cost of power from a new nuclear reactor are 300 percent higher than the cost of energy efficiency or the cost of co-firing biomass in an existing power plant, and well above renewable technologies like wind power. Moreover, any new nuclear reactors won't be operational until well into the next decade, whereas clean energy sources can be deployed now.

The cost advantages that clean energy has over nuclear power are likely to become even more pronounced over time, while we wait for the nuclear industry to finish its first new reactor. According to Moody's Investor Service, "…nuclear generation has a fixed design where construction costs are rising rapidly, while other renewable technologies are still experiencing significant advancements in terms of energy conversion efficiency and cost reductions."[137]

Building 100 New Nuclear Reactors Would Divert Resources from Cheaper and More Effective Solutions

If both nuclear power and clean energy technologies such as renewable energy and energy efficiency improvements can reduce global warming pollution, why can't we just pursue both paths – reducing emissions now through clean energy and in the future with nuclear?

In a world of unlimited resources, such a path would be conceivable. But in the real world of public policy, governments must make choices about how to allocate limited resources. Moreover, to retain public support for efforts to reduce global warming pollution, government will need to demonstrate that it is acting in ways that minimize the costs of emission reductions and deliver the greatest benefit for the smallest expenditure.

Recent estimates for the up-front cost of building a new nuclear reactor suggest that building 100 of them could require an up-front investment on the order of $600 billion.[138]

However, the capital cost of a new nuclear plant is only part of the full story. Any up-front investment in nuclear power would lock in additional expenditures across decades. Once a plant is built, the price of the electricity it generates will reflect the ongoing need to pay off debt; the cost of operating and maintaining the plant; the cost of fueling the plant with uranium; the cost of decommissioning the plant and disposing of the waste; and the cost of transmitting and distributing the electricity to consumers. For 100 reactors, these costs would add up to additional trillions over a period of decades.

An investment in energy efficiency would deliver vastly superior results. Investing in energy efficiency actually *pays us back* with ongoing savings on electricity bills. Efficiency measures are almost always cheaper even than operating existing power plants. For example, analysts at the consulting firm McKinsey & Company estimate that investing $520 billion in energy efficiency measures would eliminate $1.2 trillion in waste from the U.S. economy, saving citizens and businesses nearly $700 billion (in net present value terms).[139] In other words, energy efficiency could provide the same level of impact as building 160 nuclear reactors in the next ten years – at net savings.[140]

An investment in renewable sources of power can deliver carbon-free electricity for much less cost than nuclear power. Many types of renewable energy have the advantage of zero fuel costs, since wind and sunlight and the earth's heat are free. Other types of clean energy, such as solar photovoltaic panels, have the advantage of being located near where the energy will be used, minimizing the cost of transmitting and distributing electricity. And these technologies require no special waste handling or decommissioning.

Compared to clean energy solutions, nuclear power is extremely expensive. The total extra cost to the U.S. economy of building 100 new nuclear reactors, above and beyond a least-cost clean energy approach, could fall in the range of $1.9 to $4.4 trillion over the entire lifetime of the reactors.[141]

"The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power, with an additional $140 billion to come before the decade is out, and only the blind, or the biased, can now think that the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible."

"Nuclear Follies," a cover story in Forbes Magazine, February 11, 1985.

Cost Estimates for Nuclear Power Continue to Rise

In 2003, experts at the Massachusetts Institute of Technology and Harvard concluded that "today, nuclear power is not an economically competitive choice."[142] The researchers predicted that without subsidies and financial support for the nuclear industry, "nuclear power faces stagnation and decline."[143] The U.S. Congress responded by streamlining the permitting process at the Nuclear Regulatory Commission and authorizing billions in new subsidies through the 2005 Energy Policy Act. However, in 2009, the MIT researchers took another look at the nuclear industry and found that despite the new support, "increased deployment of nuclear power has been slow both in the United States and globally …."[144]

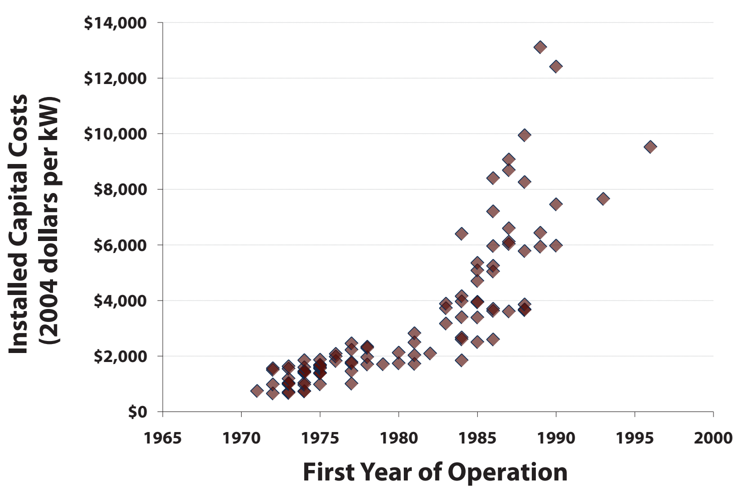
High costs are a major obstacle in the way of building new reactors. In the past decade, cost estimates for new nuclear power plants have only escalated.

In the early 2000s, nuclear industry executives estimated that construction costs for building a new nuclear reactor could approach $1,500 per kW of power generating capacity, plus finance costs.[145] They said the lower costs would make nuclear power competitive with coal and natural gas.

However, these early estimates have turned out to be overly optimistic. Recent estimates for the average cost of electricity from a new nuclear plant over its entire lifetime are four times higher than this initial projection that promoters of a "nuclear renaissance" put forward in the early part of the decade.[146]

No nuclear companies have signed a contract guaranteeing a price for a new nuclear reactor. When Canada asked for guaranteed cost bids to build two new reactors, the results blew far past expectations. The only company willing to guarantee its work quoted a price of $26 billion to build two new reactors – or $10,800 per kW – more than seven times higher than cost estimates from early in the decade.[147] Areva offered its technology for $23 billion – or $7,400 per kW – but its bid was deemed non-compliant, likely because it would not guarantee the price.[148] Both of these quotes were more than double the threshold for competitiveness.[149]

Figure 8: Actual Capital Costs of Completed U.S. Nuclear Reactors (in 2004 Dollars)[153]



Nuclear Reactors Tend to Run Aground on Skyrocketing Construction Costs

High and escalating bids for new nuclear reactor projects should not be a surprise. Nuclear reactor construction projects in the U.S. have regularly run aground on skyrocketing construction costs. Of 75 nuclear reactors completed between 1966 and 1986, the average reactor cost more than triple its original construction budget.[150] Later-built reactors came in as much as 1,200 percent over budget.[151]

Economists commonly expect that new products and technologies become cheaper over time, as companies gain experience and develop economies of scale. However, in the case of the last generation of nuclear power in the United States, the opposite proved to be true. The first nuclear reactors ever built were among the least expensive, while costs spiraled wildly out of control in the final decades of reactor construction. (See Figure 8.) For plants beginning operation in the late 1970s and onward, inflation-adjusted capital costs escalated from just under $2,000 per kW to more than $10,000 per kW (in 2004 dollars).[152]

Seen through the lens of history, nuclear industry predictions that new designs and modular construction techniques will bring costs down appear overconfident.[154] Developing new nuclear power plants will likely remain prone to high cost "surprises" and increased financial risk for power companies and their customers.[155] Due to the large amount of money required to build an individual reactor, the investment ratings firm Moody's calls nuclear construction a "bet the farm risk" for a typical utility.[156]

Nuclear Power Is More Costly than Other Forms of Emission-Free Electricity

Power from a new nuclear reactor would be more costly than other forms of emission-free electricity. Recent estimates for the average cost of electricity from a new nuclear power plant over its entire lifetime range from a low of 8 cents to a high of 30 cents per kilowatt-hour (kWh), with the bulk of estimates falling between 12 and 20 cents per kWh.[157] For many of these estimates, add another 2 cents per kWh to transmit and distribute the electricity from the nuclear plant to the customer.

Vast amounts of clean energy are available – now – at far less cost.[158]

- Energy from a new nuclear reactor would be two to six times more expensive than saving electricity through efficiency – including utility and consumer investment. Across the country, the average utility cost of saved energy is 2.5 cents per kWh, three to four times cheaper than building any kind of new power plant.[159] Including consumer contributions to efficiency measures, the average total resource cost of efficiency is around 4.6 cents per kWh.[160] Analyses of future energy efficiency potential typically find vast available resources with average utility lifetime costs of around 4 cents per kWh in the residential sector and 2 cents per kWh or less in the commercial and industrial sectors.[161] Moreover, as the scale and scope of energy efficiency programs increase, they tend to become even more cost effective.[162]

- Combined heat and power and recycled energy technologies are also extremely cost-effective sources of electricity. Recycled energy technologies can generate electricity for about 3 cents per kWh.[163] Combined cycle industrial heat and power installations can generally produce power for 4.5 to 5.5 cents per kWh, including credit for the value of useful heat that the generators also produce.[164] And smaller building-scale CHP technology can deliver electricity for less than 6 cents per kWh, again counting the value of the useful heat also produced by the generator.[165]

- Energy efficiency, distributed solar power, and combined heat and power have the added advantage of saving or generating energy near where it will be used, avoiding transmission and distribution costs. In addition, saving or generating energy locally minimizes electricity losses that can occur while transporting electricity from a distant power plant.

Large potential supplies of clean energy from wind, solar, biomass and geothermal sources are also available – now – at costs well below estimates for new nuclear power. For example:

- America's entire electricity needs could be met by the wind blowing across the Great Plains or the sunlight falling on a 100 mile square patch of the desert Southwest, or a tiny fraction of the natural heat just beneath the surface of the earth anywhere across the country.[166] Diverse, locally-based resources are available in every state. Even the southeastern United States has enough biomass, wind, and low-impact hydroelectric resources to meet 25 percent of its electricity needs within the next two decades.[167]

- The U.S. Department of Energy (DOE) estimates that wind energy resources across the U.S. as a whole could produce more than 1.5 million GWh per year for between 6 and 10 cents per kWh (2006 dollars).[168] (This price includes estimated transmission costs, assuming that the existing grid has 10 percent spare capacity that could be used for wind, and that appropriate planning will allow new lines to be constructed as needed.) This amount of wind would be the energy equivalent of 190 nuclear reactors.[169] DOE estimates that generating 20 percent of America's electricity supply with wind by 2030 would cost the average household just 50 cents per month more compared to sticking with coal- and gas-fired power – and excluding the benefits of cleaner air and conserved water.[170]

- The California Public Utilities Commission estimates that in the western United States:[171]
    - Nearly 200,000 GWh per year of renewable electricity could be delivered locally for 9 cents per kWh or less;
    - An additional 200,000 GWh per year of renewable electricity could be locally delivered at costs of 10 cents per kWh or less; and
    - Well over 500,000 GWh per year of additional renewable electricity could be delivered locally at a cost of 12 cents per kWh or less.

Electricity from these renewable resources – the energy equivalent of more than 110 nuclear reactors – would be available at 8 to 12 cents per kWh delivered, half to two-thirds of a mid-range estimate for the cost of power from a new nuclear power plant.[172] Developing U.S. renewable energy and energy efficiency resources could save Americans more than $200 billion on energy bills by 2020.[173]

Per Dollar Spent, Clean Energy Is More Effective at Preventing Pollution than New Nuclear Power

In at least the next six years, new nuclear power cannot be obtained in the United States at any price. However, many other energy technologies are available now that can deliver cost-effective reductions in pollution. Recent estimates for the cost of a new nuclear power plant place it well above many alternatives, including energy efficiency, combined heat and power, wind power (on land and off shore), biomass, landfill gas, geothermal, some types of solar thermal power and natural gas combined cycle power.[174]

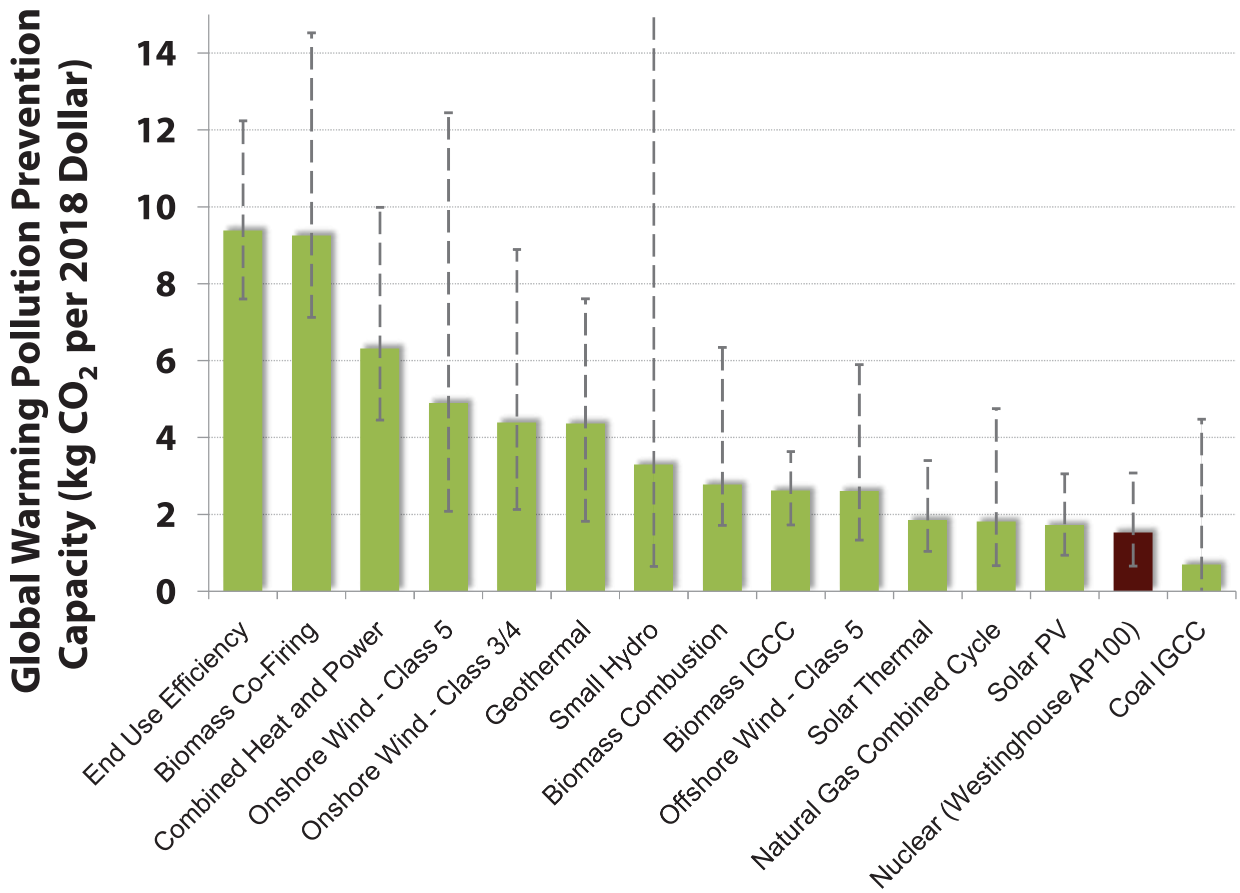
Research done for the California Energy Commission (CEC) in 2009 provides a relatively recent, apples-to-apples comparison of the estimated costs of different generation technologies with an in-service date of 2018, a decent guess as to when the first nuclear reactors might become available.[175] The estimates are partially specific to western states, and include the effects of some tax and incentive policies now authorized through that year (but not the renewable energy production tax credit, which is currently set to expire by 2013). These factors aside, the research gives a general idea of how generation technologies stack up. Many additional studies, using different starting assumptions, support the conclusion that energy efficiency and many forms of renewable power are expected to be substantially more cost-effective than nuclear power.[176]

The CEC figures also exclude solutions like energy efficiency, biomass co-firing and combined heat and power, so this report draws on other sources to include them. Finally, this report does not consider possible intermediate solutions such as replacing coal-fired power with greater utilization of existing natural gas-fired power plants, which are also likely to be more cost-effective ways to prevent carbon emissions than building new nuclear plants.

In 2018, the CEC projects that new nuclear power will be more costly than most other forms of low-emission electricity, whether financed by a public utility, an investor-owned utility, or a merchant generator.[177] Under investor-owned utility financing, per dollar spent (over the lifetime of the technology), energy efficiency would be five times more effective at preventing global warming pollution, and combined heat and power (in which a power plant generates both electricity and heat for a building or industrial application) would be greater than three times more effective. (See Figure 9.) Even without the benefit of the production tax credit in 2018, biomass, geothermal and land-based wind energy will be more than twice as effective, and offshore wind will be on the order of 40 percent more effective. Under merchant financing terms, nuclear fares even more poorly, with CEC expecting both solar thermal and solar photovoltaic power to be more cost-effective ways to reduce pollution.

By 2018, solar photovoltaic power should be comparable to a new nuclear reactor in terms of its per-dollar ability to prevent global warming pollution. However, solar power is falling in price far faster than any other generation technology. Solar prices have fallen by more than 80 percent

Figure 9: Comparative Ability of Electricity Technologies to Prevent Global Warming Pollution, per 2018 Dollar Spent over Technology Lifetime– Online in 2018, Merchant Financing Terms[178]



By 2018, a reasonable estimate for the first date a new reactor could be online, nuclear power will be among the least cost-effective options for reducing global warming pollution. Per dollar spent, nuclear power would be less effective than other low- or zero-emission energy solutions. Efficiency, combined heat and power, wind power, geothermal energy, biomass combustion, small scale hydropower and offshore wind all outperform nuclear. (For simplicity, this figure assumes that power from these new sources at scale would displace an average unit of electricity from the existing U.S. electricity grid. Error bars represent a possible range of values for each technology, given the range of resource quality and location, and uncertainty around cost estimates. See the Methodology section for more details.)

since 1980.[179] And prices continue to decline as public policies encourage growth in capacity for solar panel manufacturing, distribution and installation.[180] Recent cost improvement is apparent in utility decisions to build nearly 1,000 MW of large-scale solar photovoltaic power plants in Florida and California – 10 times bigger than any now in service across the world.[181]

In fact, recent analysis by the investment firm Lazard implies that thin-film solar photovoltaic and solar thermal power technologies, with existing incentives, are already competitive with and even ahead of nuclear power.[182] Lazard also highlights biomass co-firing – in which an existing coal-fired power plant replaces up to 15 percent of its typical fuel with plant matter – and landfill gas as additional cost-effective options.[183]

The fact that clean energy is more cost-effective than new nuclear reactors is reflected in the conclusion of a recent report by the European Renewable Energy Council, the German Aerospace Center and Greenpeace, which shows that currently available clean energy technology could be deployed in the United States to deliver massive reductions in global warming pollution – at half the cost and with twice the job creation as an equivalent amount of nuclear and coal-fired power. Similarly, the non-profit Nuclear Policy Research Institute and the Institute for Energy and Environmental Research have published a report demonstrating how the United States can create an economy with zero emissions of global warming carbon dioxide pollution within 30 to 50 years at a reasonable cost, without nuclear power.[184]

What Could an Equivalent Capital Investment in Clean Energy Achieve?

Investing $600 billion could potentially get us 100 new nuclear reactors by 2030. Alternatively, if we invested that money in clean energy solutions, we could get the double the impact, without the drag on the economy that the high cost of nuclear power would impose.

At an optimistic reactor cost forecast used by the Energy Information Administration of around $2,500 per kW of capacity (see page 22), building 100 new reactors would cost $250 billion up-front. Investing that same amount of capital in energy efficiency could reduce America's electricity consumption by about 12 percent below the reference case by 2030.[185] This level of investment in energy efficiency would deliver emission reductions equal to building 100 new nuclear reactors by 2030, but unlike nuclear, pollution prevented through efficiency would come at net savings, since energy efficiency is so much more cost-effective than building new reactors.

At mid-range costs of around $6,500 per kW, near those forecast by Moody's and comparable to recently proposed reactors, building 100 nuclear reactors would cost $650 billion.[186] Directing $590 billion of this capital investment to efficiency measures could capture a large fraction of America's identified potential for electric energy efficiency, reducing electricity consumption by 25 percent below business as usual by 2030. The remaining money could purchase enough wind turbines and other renewable energy equipment to generate an additional 130 billion kWh by 2030.[187] Altogether, this package of clean energy would yield as much energy as more than 170 nuclear reactors in 2030.[188] This package of clean energy would reduce twice as much pollution as nuclear through 2030, with net savings on electricity costs – which nuclear power cannot offer.

Should the highest cost forecasts for nuclear power come true, building 100 new reactors could cost $1 trillion. This level of investment in clean energy solutions could yield as much electricity as more than 270 new nuclear reactors in the year 2030.[189] This package of clean energy would reduce three times as much pollution as nuclear through 2030, for far less total cost.

Nuclear Power Is Not Needed to Provide Reliable, Low-Carbon Electricity for the Future

Proponents of nuclear power often make the claim that nuclear reactors are necessary because they are a source of emission-free "base-load" electricity which "must run uninterrupted night and day" in order to ensure the reliability of electric service.[191]

Patrick Moore, a public relations consultant working on behalf of the nuclear industry, summed up the argument, writing in the *Washington Post* in 2006:[192]

> "Nuclear energy is the only large-scale, cost-effective energy source that can reduce [global warming] emissions while continuing to satisfy a growing demand for power… Wind and solar power have their place, but because they are intermittent and unpredictable they simply can't replace big base-load plants such as coal, nuclear and hydroelectric. Natural gas, a fossil fuel, is too expensive already, and its price is too volatile to risk building big base-load plants. Given that hydroelectric resources are built pretty much to capacity, nuclear is, by elimination, the only viable substitute for coal. It's that simple… Every responsible environmentalist should support [nuclear power]."

Were nuclear power to be "the only viable substitute for coal," it would indeed be difficult for any "responsible environmentalist" to oppose it – even with the astronomical cost, the long timelines for construction, the risks posed by weapons proliferation and accidents, the environmental impacts of uranium mining and nuclear plant operation, and the still unresolved dilemma of how to safely and responsibly transport and manage the highly radioactive waste over millennia.

"I think base-load capacity is going to become an anachronism." … "We may not need any [new nuclear or coal plants], ever."

- Jon Wellinghoff, Chair of the Federal Energy Regulatory Commission, speaking to reporters at a U.S. Energy Association forum, April 22, 2009.[190]

But nuclear power is not an indispensible source of carbon-free electricity. It is not needed to meet "growing power demand" in a world where cost-effective energy efficiency opportunities abound. "Large scale" power plants are as much of a curse as they are a blessing in running a well-functioning electric grid. And alternative clean energy sources are fully capable of replacing coal-fired power plants – particularly if we make necessary investments to improve the electric grid.

The Myth: Nuclear Plants Are Needed to Produce Base-Load Power

Nuclear power proponents often argue that nuclear power is among the only practical sources of low-carbon "base-load" power, giving it a supposedly irreplaceable role in a low-carbon future. In other words, nuclear power may cost more and may be considered less desirable by the public than clean energy technologies, but we must accept it in order to keep the lights on in the future without triggering dangerous global warming.

To understand why these claims do not hold water, it is necessary to take a step back and look at how we produce and use power in the United States. Demand for electricity varies a great deal from hour to hour and from season to season. In the Mid-Atlantic region in 2008, for example, the amount of electricity required at 5 p.m. on a hot June afternoon was nearly three times greater

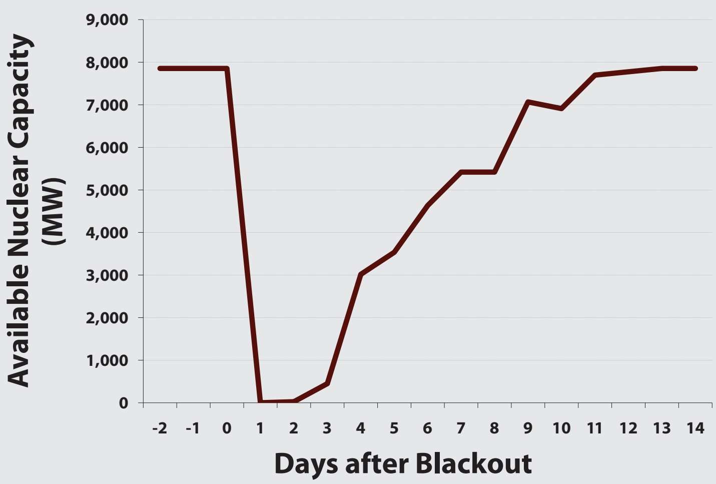
Bigger Isn't Always Better: The Failure of a Nuclear Reactor Can Have Dramatic Consequences for the Reliability of Electricity Service

Nuclear reactors produce electricity in huge, all-or-nothing blocks of power, and are incapable of reacting nimbly to changes in electricity demand. From a reliability viewpoint, this aspect of nuclear power is actually a disadvantage. In fact, when power is supplied in huge blocks by large central station power plants, the failure of any individual power plant or power line carries a great risk of widespread electricity supply disruption.

Existing nuclear power plants, particularly in recent years, have had a decent record of reliability. But when a nuclear reactor does shut down – even if such an event happens relatively infrequently – it can wreak havoc on the electric grid. For example, when two reactors at Turkey Point in southern Florida shut down in February 2008 because of a power line failure, the resulting power outage cut off electricity to more than 3 million customers in the Miami area for up to five hours – causing traffic jams, stranding people in elevators, and widely disrupting business.[194]

Nuclear plants have a history of unanticipated failures, which sometimes lead to sustained outages.

Figure 10: Available Capacity of Nine Affected Nuclear Power Plants after the Northeast Electric Blackout in August 2003[199]



Of all 132 nuclear reactors ever built in the United States, 28 shut down prematurely because of cost or reliability problems, or in the case of Three Mile Island Unit 2, a near-meltdown.[195] Problems at another 35 reactors resulted in one or more outages of at least one year.[196]

In addition, it can take days or weeks for a nuclear reactor to return to full output after an emergency shutdown. For example, nine nuclear reactors shut down automatically during the wide-ranging Northeast electric blackout that occurred on August 14, 2003. Nearly two weeks elapsed before these reactors regained full generation capacity.[197] (See Figure 10.) Prolonged deactivation of nuclear reactors in Canada threatened to cause another blackout in the days after the event. Government officials asked Ontario citizens to cut their electricity consumption in half to keep the system online.[198] A large amount of backup generation capacity had to be mobilized at high prices to restore electric service in the absence of the nuclear reactors.

An electricity system made up of millions of small clean energy measures would yield a more flexible, more reliable electricity system compared to a new generation of nuclear power plants. In contrast to a single large power generating station, it is unlikely that all of the pieces of a diverse portfolio of clean energy resources will fail at the same time. The transient removal of any single small, clean generation unit or even group of units has little to no effect on the overall system. This will be especially true in a "smart grid," where the electricity system operator will have the ability to manage electricity demand at the same time as supply.

Moreover, distributed clean energy technologies – such as energy efficiency, rooftop solar panels and combined heat and power systems – are located near where the energy will be used, reducing the need for power to travel over transmission lines. These resources insulate individual customers from wider electricity disruptions. And since nearly all power failures originate in the transmission system, energy resources that bypass power lines can reduce the opportunity for grid failures in the first place.[200]

than the amount of electricity used at 5 a.m. on a temperate May morning.[193]

Base load, therefore, is that slice of power demand that must be satisfied day or night, across all the seasons.

Power is supplied to the grid by a variety of different generating technologies, each with its own characteristics. Nuclear and coal-fired power plants have typically been assigned to meet the base load – in part because they have been the cheapest to run (and will therefore always be the first plants dispatched to the grid) and in part because they are physically unable to be turned on and off at the flick of a switch. Restarting a nuclear plant, for example, is a days-long process. Because of these characteristics, nuclear and coal-fired power plants are often called *base-load power plants*.

There is no iron clad rule, however, that base load must be met by a traditional base-load power plant. Electricity is electricity, after all, and as long as enough power is generated – from any source – to balance demand, the lights will stay on. And as long as grid operators can predict and control the flow of power to the system, the lights will stay on reliably.

It is not necessary, therefore, for society or electricity consumers to build unnecessarily expensive nuclear power plants *solely* because they have low costs of operation or generate power constantly. Indeed, other approaches can satisfy the need for base-load power and electricity at all times of day, using clean and cost-effective energy resources.

Building a Reliable Grid with Clean Energy

Expending vast amounts of ratepayer money on huge, central station power plants – such as nuclear power plants – may have been the way utilities safeguarded the reliability of the grid in the past, but it doesn't have to be the way we do it in the future. By intelligently investing our resources and engaging in sound planning, America can dramatically increase its use of clean energy technologies while safeguarding the reliability of the electric grid.

Step 1: Reduce Demand Through Energy Efficiency

Nuclear power advocates often argue that nuclear is necessary to "satisfy a growing demand for power."[201] However, our electricity system wastes a great deal of energy. By eliminating that waste through energy efficiency programs, we can get much more work done with the same – or even less – electricity.

Altogether, experts at the American Council for an Energy-Efficient Economy estimate that the United States could cost-effectively reduce its overall energy consumption by 25 to 30 percent or more over the next 20 to 25 years – ensuring that America uses less energy several decades from now than we do today, even as our economy grows.[202] Reducing electricity consumption by 25 percent below forecast levels by 2030 would save more than 1.2 trillion kilowatt-hours of electricity

America could reduce its energy consumption by 25 to 30 percent over the next 20 years through energy efficiency.

Photo: Eric Delmar.

in that year – equivalent to the output of more than 150 new nuclear reactors.[203]

Energy efficiency improvements reduce demand at all parts of the day. Energy efficiency efforts targeted at particular sources of base load power demand – such as refrigerators, "stand-by" power consumption from appliances, and industrial facilities – can address the specific slice of electricity demand currently met by "base load" generators with low operating costs. Moreover, energy efficiency programs can save America trillions on energy costs. From a societal perspective, efficiency is almost always cheaper than operating existing power plants.

Step 2: Use Renewable and Efficient "Base-Load" Power Sources

Nuclear power proponents tend to equate "clean energy" with "intermittent energy." While it is true that two large sources of clean energy – wind and solar power – are intermittent, many are not. These sources could be used to directly supplant existing traditional base-load power plants, such as coal plants. Geothermal energy, biomass and landfill gas power plants, as well as concentrating solar power plants outfitted with thermal storage, are just as capable of producing consistent electricity as existing coal, nuclear and hydroelectric plants. In the future, other renewable technologies that are capable of delivering consistent, always-on power, such as ocean current turbines, could also be deployed.

Concentrating solar thermal power with heat storage can provide reliable electricity even when the sun isn't shining.

Photo: eSolar.

Additionally, combined heat and power units – which capture waste heat from buildings or industrial operations to generate electricity – can operate on demand, greatly reducing emissions compared to traditional coal- or natural gas-fired power plants. Hospitals and other large institutions often use combined heat and power to guarantee that power will be available, even when the larger electricity grid fails. Combined heat and power can offer similar reliability benefits for many types of buildings and industries.

Step 3: Integrate Predictable, Intermittent Forms of Clean Energy

Solar and wind energy are both intermittent forms of generation, generating power only when the sun is shining or the wind is blowing. But that does not mean that they cannot provide a sizeable share of America's electricity – especially when integrated over large areas and coupled with other clean power technologies. For example, Denmark already generates more than 20 percent of its electricity from wind power alone, and has studied the possibility of deploying wind power at penetrations as high as 100 percent.[204]

Studies of the electricity system have shown that, with effective planning, the system can accommodate the integration of large amounts of wind and solar power, without the need for additional backup power sources and with minimal cost.[205] At penetrations of up to 20 percent wind power, the U.S. Department of Energy estimates that the cost of integrating wind power will be no more than 10 percent of the wholesale value of the power – which would result in the cost of wind power continuing to be much less that of a nuclear power plant.[206]

Intermittent resources can be more effectively integrated into the system with improved forecasts of power output, and by increasing the number and geographic dispersion of generators. With today's technology, wind power output over a large region can now be forecast with 80 to 90 percent accuracy a day in advance, and with 90 to greater than 95 percent accuracy an hour in advance.[207] Similarly, solar power output can be forecast using models predicting solar intensity throughout the day, taking into account the angle of the sun and anticipated cloud cover.

Increasing the number of wind turbines, solar panels, and other clean energy resources in a system – especially if they are linked with effective transmission and distributed over a wide area – can smooth power output levels and increase predictability.[208] For example, researchers at the Rocky Mountain Institute and the University of Colorado found that an optimized portfolio of wind and solar power, in as few as six locations, can reduce the variability of overall power output by more than half.[209] The larger the system, the more likely that some part of it will be generating electricity at any given time, even if the wind stops blowing or a cloud drifts over in some areas.

To achieve even higher penetration, wind, solar and other types of clean energy power plants could be hybridized with biogas or natural gas turbines, much like a gasoline-electric hybrid car. Other types of hybrid plants could be possible, including offshore wind coupled with ocean wave or ocean current turbines.

One of the more promising ideas for a hybrid power plant involves combining solar with biogas or natural gas. Plant economics are improved by using a single steam-driven turbine, with heat coming from either the sun, or from natural gas or biogas, depending on conditions.[210] This design avoids duplicating infrastructure such as transmission lines compared to having a fully separate backup power plant. Solar systems could even be

Wind power in America could provide more energy than 190 new nuclear reactors, with power output predictable with 80 to 90 percent accuracy a day in advance.

Photo: NREL.

added as a new source of heat to existing power plants, in areas with appropriate conditions.[211]

Step 4: Build a Smarter Grid

The reliability of electric service and the flexibility of the system can be increased through smart grid technology. America's current electricity grid is designed to be a one-way street, with centrally generated power distributed to meet demand. While "smart grid" is used to refer to a variety of measures, ultimately this technology is meant to use the power of modern computer networks to make the electricity system into a two-way street, which can accommodate power generated in many locations and exert control over load, supply and even energy storage.

Widely deployed, well-designed smart grid technology could help the electricity system to respond dynamically to stress, exert fine control over energy uses to maintain reliability, accommodate the addition of large amounts of diverse sources of renewable electricity – from wind farms to neighborhood solar panels, and integrate energy storage technologies such as a network of batteries in plug-in electric or hybrid electric cars.[212]

As a result of the Obama administration's economic recovery package, $1.2 billion in smart grid test projects are now or will soon be underway.[213] For example,

- Southern California Edison is working on systems to combine customer control over home energy usage in response to system-wide electrical demand, solar panel output, home energy storage, and plug-in electric vehicle need.[214]
- IBM and a North Carolina technology company called Consert have deployed a smart grid pilot project that allows the utility to "cycle appliances on and off" based on customer profiles detailing home preferences such as ideal home temperature and daily schedule.[215] A test run cut average energy consumption by 20 percent, with one household achieving a 50 percent cut.[216]

In October 2009, the Obama administration injected another $3.4 billion into electric grid modernization, as a further part of the economic recovery package.[217] Private companies are contributing an additional $4.7 billion to the effort.[218] This level of investment will purchase 18 million smart electricity meters – covering more than 10 percent of all electricity customers in the country.[219]

Step 5: Integrate Storage into the Electric System

Energy storage technologies could ultimately enable America's electricity system to rely completely on clean sources of electricity that never run out, breaking free entirely from fossil fuels and nuclear power. Promising energy storage technologies include compressed air storage, pumped water storage, heat storage, and batteries – such as those found in a plug-in electric or hybrid electric car.

Compressed air storage uses underground caverns or aquifers to hold pressurized air, which can be released later to drive a turbine and generate electricity.[220] These facilities can store hundreds of hours of energy, and the technology is proven at large scale. A 280 MW facility has been operating in Germany since 1978, and a 110 MW facility has served in Alabama since 1991.[221] The natural gas industry currently uses underground caverns like these to store much of the nation's natural gas supplies.[222]

Pumped water storage involves pumping water from a downhill reservoir to an uphill one, then releasing the water to generate electricity when necessary.[223] The U.S. already uses more than 20,000 MW of this technology.[224] Pumped storage may even be possible without traditional dams. A company called Riverbank Power is actively testing a plan to drill deep holes in the ground near a river, with the potential to generate as much as 1,000 MW of power for six hours before pumping the water back up to the surface. The company is testing the technology at the former site of the Maine Yankee nuclear power plant, decommissioned more than a decade ago.[225]

Solar developers are now building concentrating solar thermal power plants in the desert Southwest that incorporate molten salt tanks, which can store the sun's heat with greater than 99 percent efficiency. The heat can be used to generate power when needed, even at night or when the sun isn't shining.[226]

Finally, companies are developing batteries that can directly store electrical energy.[227] Some of these batteries are large and stationary. Another promising idea combines smart grid technology with an electric or hybrid-electric vehicle system, in which every parked vehicle becomes a storage device to hold and dispatch clean power.[228]

Policy Recommendations

Nuclear power is not the best available solution we have in the fight against global warming. In fact, it is a dead end. Putting aside the unresolved problem of how to safely dispose of nuclear waste and the risk of nuclear weapons proliferation, the nuclear industry simply cannot build new reactors fast enough to deliver the progress we need on a time scale that will make enough of a difference. Moreover, new nuclear reactors are far more expensive than other forms of emission-free electricity. Investing in a new generation of nuclear reactors would actually delay needed progress and divert critical investment dollars away from better solutions.

As a matter of public policy, America should focus on improving energy efficiency and generating electricity from clean sources that never run out – such as wind, solar, biomass and geothermal power. These clean energy solutions can deliver more emission reductions for our money – faster – than nuclear power. Integrated in a "smart grid," clean energy resources can ensure a reliable, safe, secure and affordable supply of electricity, while rapidly and substantially cutting global warming pollution.

Accordingly, state and federal leaders should:

Refrain from directing new subsidies to the nuclear industry.

- Nuclear power is already the most heavily supported form of electric power in America. From 1950 to 1999, the federal government subsidized nuclear power to the tune of $145 billion.[229] The value of all the subsidies currently on offer to the nuclear industry is substantial – reaching as high as $13 billion for a single new reactor.[230] However, the nuclear industry is asking for more than $120 billion in loan guarantees for proposed new reactors, far in excess of the $18.5 billion that Congress has thus far appropriated.[231] Applied to 34 possible new reactors, Physicians for Social Responsibility calculate that the nuclear industry could need as much as $170 to $320 billion in loan guarantees.[232] The Congressional Budget Office considers the risk of default on nuclear loan guarantees as well above 50 percent, primarily because nuclear is not cost-competitive with other generation sources.[233] In addition to expanded loan guarantees, the nuclear industry wish list includes a variety of tax incentives and favorable regulatory treatment.[234]
- The federal government should not further subsidize new nuclear power plants. Any subsidies for low-carbon energy alternatives must be judged based on their relative short-term and long-term costs and environmental advantages.[235]

Reduce the nation's emissions enough to prevent the worst impacts of global warming, guided by the latest scientific understanding.

- The United States should work in concert with other nations to keep cumulative world emissions from exceeding 1 trillion metric tons of carbon dioxide, or equivalent, from 2000 to 2050. Progress on this scale is necessary to give the world a 75 percent chance of limiting global warming to 3.6° F above the pre-industrial era – a target the international community has set to limit the severity of global warming impacts.
- In order to make this goal possible, the U.S. should commit to reducing emissions by at least 35 percent below 2005 levels by 2020. The

nation should then aim to reduce emissions by 80 percent or more by 2050.

- Any policy designed to reduce America's emissions of global warming pollution should ensure that polluters pay for any right to use the atmosphere, and direct resulting revenues into accelerating the transition to clean energy sources and easing the impact on consumers. Additionally, the policy should include strict rules for the integrity of any carbon "offsets" to ensure that efforts to reduce emissions are successful.

Require America to obtain at least 25 percent of its electricity from clean, sustainable energy sources such as wind and solar power by 2025.

- States with renewable electricity standards (RES) are leading the nation in taking advantage of America's ample clean energy potential.[236] The United States should set a national renewable electricity standard that requires that at least 25 percent of America's electricity come from new renewable energy sources by 2025. Achieving that target would put the nation well on its way to dramatic cuts in emissions of global warming pollution. Individual states should go further.

Require America to reduce overall electricity use 15 percent by 2020.

- America has vast potential to use energy more efficiently. To take advantage of that potential, the nation should adopt an energy efficiency resource standard (EERS) similar to those adopted by leading states across the country. Such a standard would set a concrete goal for improved energy efficiency and unleash the resources needed to achieve that goal. A federal EERS should seek to reduce electricity demand by 15 percent by 2020 and natural gas demand by 10 percent, with more ambitious goals in later years.

- Combining energy efficiency and renewable energy with a national effort to limit emissions of global warming pollution enhances the benefit of these policies to America's economy. For example, the Union of Concerned Scientists has found that combining an EERS and RES with a cap on global warming pollution would deliver $1.6 trillion in consumer savings through 2030 compared to continuing on our current path.[237]

Strengthen energy efficiency standards and codes for appliances and buildings.

- America should ensure that all buildings and appliances use energy efficiently. New codes should aim to reduce energy consumption in new buildings by 50 percent by 2020 and ensure that all new buildings use zero net energy by 2030. Individual states should go further.

Invest in electric grid modernization.

- America should upgrade its electricity transmission and distribution system to maximize our potential to take advantage of a diverse range of energy efficiency opportunities and clean power sources.

Methodology

The starting point for modeling the policies and technologies evaluated in this report was the Energy Information Administration's (EIA) *Annual Energy Outlook 2009*, updated reference case.[238] The "no additional action" scenario in this report matches the levels of power generation, fuel consumption and carbon dioxide emissions forecast by the EIA. We model the emissions impact of building 100 new nuclear reactors, or deploying clean energy measures with an equivalent capital investment, relative to this initial forecast.

Calculating a Carbon Budget for the United States

This report accepts a world carbon budget of 1 trillion metric tons – the limit on allowable emissions from 2000 to 2050 to have a 75 percent chance of meeting international goals for limiting the severity of global warming. We assign 20 percent of this budget, or 200 billion metric tons, to the United States, which is approximately the U.S. share of cumulative emissions by mid-century under a simplified scenario in which all countries work toward equalizing per-capita emissions of global warming pollution at about 800 kilograms per person per year.[239] By the end of 2009, 140 billion metric tons of allowable emissions will remain for the next 40 years, due to pollution already emitted this decade.[240]

We calculate that the U.S. must reduce emissions of carbon dioxide 35 percent below 2005 levels by 2020 and 80 percent by 2050 to stay within this budget.

Given this emissions trajectory, we assume that two-thirds of the reductions through 2020 and half of the total required reductions overall come from the electricity sector. This is equivalent to reducing electric sector emissions by 55 percent below 2005 levels in the next 10 years, and then reducing emissions by 95 percent by mid-century.

The early emission reductions required are comparable in magnitude to those described by the EIA in modeling the impact of the American Clean Energy and Security Act, in a scenario with no international offsets and limited availability of nuclear or carbon capture and sequestration technology.[241] Under these conditions, U.S. power plant emissions could fall 37 percent by 2015.

Given these parameters, we estimate that U.S. power plants must keep cumulative emissions below 34 billion metric tons from 2010 through 2050 to enable the nation to do its part in limiting the consequences of global warming.

Modeling the Emissions Impact of Building 100 New Nuclear Reactors by 2030

Starting with the power generation and emissions pathway described in the *Annual Energy Outlook 2009*, we model the impact of building 100 new nuclear power plants, using the following key assumptions:

- The nuclear reactors will have an average size of 1,000 MW.
- The reactors will operate with an average capacity factor of 90 percent, an upper bound estimate of the Keystone study.[242]
- Electricity generated by the reactors will 100 percent displace average coal-fired power from the U.S. electricity grid – a best case assumption.

- The first reactors will come online in 2016 and construction will proceed evenly with 100 reactors operational by 2030.
- Nuclear power has zero emissions of global warming pollution.
- Total electricity demand, generation by fuel for all sources other than nuclear and coal, and emission rates by fuel proceed as forecast in *Annual Energy Outlook 2009*.

Developing a Clean Energy Scenario Based on the Capital Investment Needed to Build 100 New Nuclear Reactors

Starting with the range of overnight capital investment required to build 100 new reactors – $250 billion to $1 trillion, with a mid-point of around $650 billion – we created a mid-, lower- and upper-bound scenario of clean energy deployment that could be achieved with the same level of up-front investment.

With the lower bound investment of $250 billion, energy efficiency could reduce America's electricity consumption by about 12 percent below the reference case by 2030, assuming an average program plus customer cost of 4.6 cents per kWh. We assume that all of the costs of efficiency measures are up-front capital costs, and we specifically exclude all resulting consumer and utility savings when comparing nuclear capital investment with efficiency. This assumption therefore significantly understates the actual advantages of energy efficiency compared to nuclear and is highly conservative.

At mid-range costs, building 100 nuclear reactors would cost around $650 billion. $590 billion of this could be used to capture a large fraction of America's identified potential for electric energy efficiency, reducing electricity consumption by 25 percent below business as usual by 2030. Since energy efficiency is the most cost-effective clean energy resource, we maximize its use. Based on reference case assumptions for the capital cost and performance of various renewable electricity technologies outlined in *Assumptions to the Annual Energy Outlook 2009*, the remaining $70 billion could purchase enough wind turbines and other renewable energy equipment to generate an additional 130 billion kWh by 2030, assuming an even rate of investment from 2013 to 2030.[243]

For the upper margin, we assume a nuclear capital investment of $1 trillion and low-end renewable capital costs from *Assumptions to the Annual Energy Outlook 2009*. In addition to the energy efficiency measures described in the mid-range case, this level of investment could drive the installation of enough infrastructure to generate about 900 billion additional kWh of renewable energy by 2030, assuming an even rate of investment from 2013 to 2030.[244]

Modeling the Emissions Impact of Clean Energy

In modeling the emissions impact of clean energy, we assume that a unit of energy efficiency displaces an average unit of coal-fired electricity. Additionally, we assume that a unit of renewable electricity displaces half a unit of natural gas and half a unit of petroleum or coal. Additionally, we assume that efficiency and renewable power have zero emissions of global warming pollution, and that emissions rates by fuel progress over time as described in the *Annual Energy Outlook 2009.*

Calculating the Per-Dollar Capability of Energy Technologies to Prevent Global Warming Pollution

We compare all technologies, assuming for simplicity that each displaces an average unit of power from the U.S. electricity system, with an average emission rate per *Annual Energy Outlook 2009*.

We use lifecycle carbon dioxide emission rates per kWh for a variety of renewable technologies and new nuclear reactors from a 2008 report by Stanford scientist Mark Jacobson.[245] We supplement these figures with lifecycle emission data for combined heat and power and traditional technologies from a range of additional sources.[246]

We use levelized cost estimates for an in-service date of 2018, using merchant financing, from the California Energy Commission for the following technologies:[247]

- Onshore Wind - Class 5
- Onshore Wind - Class 3/4
- Geothermal
- Biomass Combustion
- Hydro - Small Scale and Developed Sites
- Biomass IGCC (Integrated Gasification Combined Cycle)
- Offshore Wind - Class 5
- Nuclear (Westinghouse AP100)
- Solar Thermal
- Solar Photovoltaics[248]
- Natural Gas Combined Cycle
- Natural Gas Simple Cycle
- Coal IGCC

We supplement these figures with additional technologies, including:

- End Use Efficiency, based on estimates by the American Council for an Energy Efficient Economy of 4.6 cents per kWh total resource cost, inflated to 2018 dollars assuming a 3 percent per year inflation rate, and with a 25 percent plus or minus uncertainty factor applied;[249]
- Combined heat and power (CHP), derived from estimates for recovered heat industrial CHP, combined cycle industrial CHP, and building-scale CHP by the Rocky Mountain Institute, with a 3 percent per year inflator applied to approximate 2018 cost;[250] and
- Biomass co-firing cost estimates from the investment firm Lazard, with a 3 percent per year inflator applied to approximate 2018 cost.[251]

With this information, we calculated the ability of each technology to displace carbon emissions based on the average emission rate of the U.S. electricity grid, taking into account each technology's lifecycle carbon emissions. Error bars in the resulting figure represent high and low bounds of pollution reduction cost-effectiveness, given a range of available resources, locations, and uncertainty in cost estimates.

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169 Compared to nuclear output on an energy-equivalent basis, per note 119.

170 See note 113, page 163.

171 Energy and Environmental Economics, Inc. for the California Public Utility Commission, *Generation Costs* (Microsoft Word document), 16 November 2007; available at www.ethree.com/cpuc_ghg_model.html.

172 Mid-range estimate of 16 cents per kWh, plus 2 cents for transmission and distribution, per note 129. More than 110 reactors: compared to nuclear output per note 119.

173 The Union of Concerned Scientists (UCS) estimates that a national renewable electricity standard of 25 percent by 2025 would reduce electricity prices by more than 4 percent annually, and natural gas prices by more than 2 percent annually, saving consumers more than $95 billion: Union of Concerned Scientists, *Clean Power, Green Jobs: A National Renewable Electricity Standard Will Boost the Economy and Protect the Environment*, March 2009; and similarly, experts at the American Council for an Energy-Efficient Economy estimate that a national energy efficiency resource standard would save Americans close to $170 billion on their energy bills by 2020: Laura Furrey, Steven Nadel and John "Skip" Laitner, *American Council for an Energy-Efficient Economy, Laying the Foundation for Implementing A Federal Energy Efficiency Resource Standard*, March 2009.

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175 Joel Klein, California Energy Commission, *Comparative Costs of California Central Station Electricity Generation Technologies*, CEC-200-2009-017-SD, Draft Staff Report, August 2009.

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178 Sources: see Methodology.

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186 See note 129.

187 Assuming an even rate of investment from 2013 to 2030, and based on reference case assumptions for the capital cost and performance of various renewable electricity technologies outlined in: U.S. Department of Energy, Energy Information Administration, *Assumptions to the Annual Energy Outlook 2009*, Report DOE/EIA-0554, March 2009. All wind or a mix of landfill gas, biomass co-firing, geothermal and wind would have a similar capital cost.

188 Compared to nuclear output per note 119.

189 In addition to the energy efficiency measures described in the mid-range case, this level of investment could drive the installation of enough infrastructure to generate about 900 billion additional kWh of renewable energy by 2030. All wind or a mix of landfill gas, biomass co-firing, geothermal and wind would have a similar capital cost. See note 187. Compared to nuclear energy output per note 119.

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192 Patrick Moore, Greenspirit Strategies (a PR firm working for corporate clients including the nuclear industry), "Going Nuclear: A Green Makes the Case," *Washington Post*, 16 April 2006.

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247 See note 175.

248 This calculation assumes 100 percent of the cost of installing a solar PV system is born by the utility as in the case of a utility-built project. However, when solar PV systems are simply subsidized by ratepayers through feed-in-tariffs or rebates, the per unit of energy cost of solar PV to the utility/ratepayer, dramatically falls making distributed solar power much more cost effective from a utility perspective than this analysis shows.

249 See note 159.

250 See note 165.

251 See note 182.