Frank Lasee
WISCONSIN STATE SENATOR
FIRST SENATE DISTRICT

Senator Lasee's Testimony

Senate Bill 288

Ending Wisconsin's Nuclear Power Moratorium

Wisconsin is in constant competition with other states for jobs. Overbearing regulations place Wisconsin at a disadvantage compared to other states that have fewer regulatory hurdles.

One example of unnecessary regulatory hurdles is Wisconsin's moratorium on building new nuclear power plants in our state.

While Wisconsin currently has an excess generating capacity, and the economics of constructing new nuclear power plants aren't favorable right now, it's important for us to remove the regulatory hurdle now so that Wisconsin might be more attractive to nuclear power plant development in the future.

Nuclear power makes no emissions to the air. With ever increasing federal regulations against conventional means of power generation, new nuclear power plants may become economically viable in the near future. We need to eliminate the regulations now so that Wisconsin is not excluded from competing for future nuclear power plants and the hundreds of great paying jobs that come with them.

Each nuclear power plant that could be built in the future creates hundreds of jobs both for construction and for staffing each new plant. Over 500 employees are needed to staff each operating nuclear power plant. It makes good sense to eliminate the nuclear power moratorium in Wisconsin.

Chair: Committee on Insurance, Housing and Trade

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KEVIN PETERSEN
STATE REPRESENTATIVE

Testimony on SB 288 – Lifting Wisconsin's Nuclear Moratorium and Adding Advanced Nuclear Energy to State Energy Policy

According to United States Department of Energy, "The USA has 100 nuclear power reactors in 31 states, operated by 30 different power companies. Since 2001 these plants have achieved an average capacity factor of over 90%, generating up to 807 billion kWh per year and accounting for 20% of total electricity generated." Despite being only 1/5 of the nation's energy, nuclear power accounts for 72% of the country's carbon dioxide emission-free generation.

Three sites are located in Wisconsin. The LaCrosse reactor in Genoa was permanently shut down in 1987. Kewaunee's reactor was shut down in May, 2014. Point Beach's two reactors have operational licenses expiring in 2030 and 2033.

SB 288 repeals the provisions of 1983 ACT 401 known as Wisconsin's Nuclear Moratorium. According to the analysis by the non-partisan Legislative Reference Bureau; "Under current law, with certain exceptions, a person may not construct any new power plant unless the Public Service Commission has issued a certificate to the person. The PSC may not issue a certificate unless specified requirements are satisfied. In addition, if the proposed power plant is a nuclear power plant, current law prohibits the PSC from issuing a certificate unless the PSC finds both of the following: 1) that there is a facility with sufficient capacity to receive the spent fuel from all nuclear power plants in the state; and 2) that construction of the power plant is economically advantageous to ratepayers based on specified factors."

A provision of the Nuclear Waste Policy Act of 1982 required the federal government construct a national repository for storing spent nuclear fuel at Yucca Mountain in Nevada. In 1983 when Wisconsin's nuclear moratorium was imposed, technology did not exist to store spent nuclear fuel in any other manner except by warehousing it offsite.

On March 3, 2010, the Department of Energy filed a motion with the Nuclear Regulatory Commission to withdraw the license application for a high-level nuclear waste repository at Yucca Mountain with prejudice. President Obama's fiscal year 2011

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budget request eliminated funding for the Office of Civilian Radioactive Waste Management.

Over 30 years have resulted in major technological advances in nuclear storage. Yucca Mountain is no longer needed. Instead, facilities can deposit their spent fuel in dry cask storage. According to the United States Nuclear Regulatory Commission; "Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year to be surrounded by inert gas inside a container called a cask. The casks are typically steel cylinders that are either welded or bolted closed. The steel cylinder provides a leak-tight confinement of the spent fuel. Each cylinder is surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and members of the public. Some of the cask designs can be used for both storage and transportation."

On August 26, 2014 the Obama Administration's Nuclear Regulatory Commission (NRC) issued a final rule on continued spent nuclear fuel storage. The Waste Confidence Decision was revised to the "Continued Storage of Spent Nuclear Fuel Rule."

The continued storage rule adopts the findings of the Generic Environmental Impact Statement (GEIS) regarding the environmental impacts of storing spent fuel at any reactor site after the reactor's licensed period of operations. As a result, those generic impacts do not need to be re-analyzed in the environmental reviews for individual licenses. The GEIS analyzes the environmental impact of storing spent fuel beyond the licensed operating life of reactors over three timeframes: for 60 years (short term), 100 years after the short-term scenario (long term) and indefinitely.

The next step for used fuel could very well be something other than putting it in dry cask storage. It is not "nuclear waste" unless we decide to waste it. The potential usable energy represented by spent fuel rods makes a compelling case for advanced nuclear energy technologies which can convert waste into fuel. Generation IV reactors using molten salt designs will be using what is currently considered nuclear waste as there fuel source.

Additionally, SB 288 incorporates advanced nuclear energy options into state energy policy using a reactor design, or amended reactor design approved after December 31, 2010, by the United States Nuclear Regulatory Commission. Advanced nuclear energy will be prioritized between combustible renewable energy resources and nonrenewable combustible energy resources.

Any nuclear-electric proposal site will still be subject to all of the limitations the Public Service Commission imposes when analyzing any new power generating facility.

The bill does not contemplate nuclear will displace any of the statutorily prioritized resources, such as energy efficiency and conservation, or renewable energy. If those sources can cost effectively and suitably supply Wisconsin's energy needs, then no nuclear plant would need to be built.

At the same time, if analyses prove nuclear energy is overly cost prohibitive, and sufficient renewables are not available, the bill still allows utilities to build or refurbish gas or other fossil fuel power plants.

Last year, the Department of Energy announced public – private research in advanced nuclear reactors in a press release titled Energy Department Announces New Investments in Advanced Nuclear Power Reactors;

"This type of public-private research in advanced nuclear reactors will help accelerate American leadership in the next generation of nuclear energy technologies, and move the United States closer to a low carbon future, "said Energy Secretary Ernest Moniz. "These types of investments are crucial to the continuing role of nuclear power as a significant contributor to the U.S. energy economy."

Our state has one of the nation's leading nuclear power programs at the University of Wisconsin - Madison. In the last 5 years the program has received multiple grants totaling approximately $16 million and is working on next generation nuclear in concert with other research powerhouses such as MIT. The proposed legislation allows advanced nuclear energy to be considered along with other energy options sending the signal Wisconsin is ready to expand its energy portfolio and reach for the future

Coal and nuclear are dependable sources of fuel for "base" load electricity. "Base" load electricity is the electricity needed 24 hours per day, 7 days per week, 365 days per year to power homes and businesses.

In other words, if the wind isn't blowing on a hot summer day, a windmill will not provide electricity to your air conditioner. Nor will solar panels produce the needed energy to heat your house on a gray winter day.

Recently, the federal Environmental Protection Agency issued global warming regulations on coal-fired power plants. Between 2012 and 2030, Wisconsin will have to reduce its carbon emissions by approximately 34%. According to the Milwaukee Journal Sentinel, the cut would be the sixth-highest in the country.

Modifying fossil fuel burning electric power plants will be extremely expensive, ranging from $3.4 billion to $13.4 billion, according to estimates from state utility regulators. Those costs will be passed on to Wisconsin families and businesses.

Middle class jobs in Wisconsin will be jeopardized. While most of the country's economy has switched from manufacturing to service and consumer driven sectors, Wisconsin's biggest employer remains manufacturing. In order to compete globally as well as domestically, Wisconsin businesses must have access to energy that is both affordable and reliable.

It is time to lift the moratorium; advanced nuclear energy is a clean, safe, and affordable way to meet future energy demands in Wisconsin, the Unites States, and around the world. It emits virtually no greenhouse gases (GHG), making it a clean power source.

SB 288 simply reopens the door to a technology that has advance well beyond what it was when our state closed that door 30+ years ago.

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

Senate Hearing
Committee on Natural Resources and Energy
Senator Robert L. Cowles, Chairman

January 5, 2016

Mr. Chairman. I am Alex Flint, representing the Nuclear Energy Institute. I'm here this morning representing 350 companies in 17 countries that build, own and operate nuclear power plants.

Perhaps it's more relevant for today's hearing that before I got my current job, I spent several decades involved in the development of energy policy. One of the things I've become convinced of over those years is that long-term energy predictions tend to make fools of those who make them.

To my way of thinking, there is a cycle to energy policy decisions. We begin by reaching consensus on changes, we enact new federal laws like we did in 1992 or 2005, and state and federal regulatory authorities begin rulemakings that eventually result in new regulations. Just when we begin to experience both the intended and unintended consequences of those new laws, they get challenged in courts with varying results, a mess ensues, and then, slowly, another consensus begins to develop and another law results.

Add to that occasional, massive market changes. In the nuclear business, when the Cold War ended and the United States began buying up huge amounts of uranium from Russian nuclear warheads and using it as fuel in our reactors to produce electricity, we saw uranium prices drop to 10 percent of what they had been during the 1980s.

Today, natural gas is transforming the electricity and manufacturing industry in ways we never predicted a decade ago. In fact, the 2005 Energy Policy Act on which I worked included key provisions to accelerate the construction of natural gas import facilities – we were worried about shortages – and now we are racing to build natural gas export facilities.

I expect we will see several more cycles of laws and regulations and changing markets over the next several decades.

Mr. Chairman, I begin with this acceptance of uncertainty because I'm not here today to tell you that a new nuclear reactor should ever be built in Wisconsin – I simply don't know. I don't know what future electricity markets will be like. I don't know the impact of the U.S. Environmental Protection Agency's Clean Power Plan or whatever comes after it. And I don't know what nuclear technology will be available in any particular year.

There are challenges associated with building and operating nuclear power plants. Just to mention one, I know Wisconsin has long been frustrated by the federal government's failure to fulfill its obligations under the Nuclear Waste Policy Act. I'm as frustrated as any of you may be, and would be glad to share my thoughts on that in response to questions if you have any.

But we must keep in mind that nuclear energy is unique in its ability to produce large-scale, carbon-free electricity around the clock. When a nuclear power plant is refueled, it runs at 100 percent capacity, 24 hours a days for 18 to 24 months until it needs refueling again, when it goes offline for somewhere around 25 days. Collectively, America's nuclear reactors produce electricity about 90 percent of the time. They operate whether or not the wind is blowing and the sun is shining, and whether or not fuel arrives by truck, barge, rail or pipeline.

Each plant produces a massive amount of electricity. Assuming Wisconsin electricity per capita use, a 1,000 MW nuclear plant would produce enough power for 945,000 homes in Wisconsin – with a relatively small footprint.

For those concerned about greenhouse gas emissions and/or clean air, America's nuclear power plants produce 63 percent of the nation's carbon-free electricity. The two Point Beach reactors on Lake Michigan account for 72 percent of Wisconsin's zero-emissions generation. No other industrial construction project compares to building a new reactor – at peak construction, each one employs about 3,500 people. Five new reactors are under construction in three states: Georgia (Vogtle 3 and 4), South Carolina (Summer 2 and 3) and Tennessee (Watts Bar 2). Together, these projects employ more than 7,000 workers and are among the largest construction projects in these states.

Nuclear plants also provide long-lasting economic benefits once operational. An average nuclear plant employs between 500-700 people, paying salaries that are over 30 percent higher than average salaries in the local area. The average nuclear plant pays around $16 million annually in state and local taxes, adding benefits to local schools, roads and other infrastructure. Each year the average nuclear plant generates approximately $470 million in economic value.

And the United States is good at operating nuclear power plants. Almost a quarter of the world's commercial reactors are in the United States, and 60 percent of the world's 438 operating reactors are based on U.S. technology. We have the world's most respected regulator and our plants are recognized for reliability, safety and operational excellence.

Looking to the future, the nuclear industry is developing a pipeline of new technologies that includes small modular reactors and advanced reactor designs. These new technologies have the potential to enhance the nuclear technology options available to utilities building new generation. Small modular reactor developers are working with the NRC on design certification applications and over 30 organizations have plans for advanced fission reactor designs. Some advanced reactor designs are being marketed to consume used fuel or provide process heat for large industrial uses. And with all that, a new nuclear power plant may never make good sense for Wisconsin – but one might.

It may be that, one day, the economy in Wisconsin will grow and the state will need more electricity. It may be that future regulations will make importing electricity from other states undesirable. It may be that future regulations will drive up prices or reduce the availability of fossil fuels. It may simply be that, like South Carolina and Georgia, Wisconsin could decide it wants to balance its generating portfolio with more non-emitting advanced nuclear energy technology as a hedge against uncertainty.

Whatever the future might be, my recommendation is that Wisconsin should empower itself with all options as it considers its future. More options are better than fewer options. One of those options should be advanced nuclear energy. Nuclear has its plusses and minuses – consider them all, but do allow yourself to consider them.

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Statement of the Sierra Club-John Muir Chapter in Opposition to SB 288 before
the Senate Natural Resources and Energy Committee
January 5, 2016

Senator Cowles and members of the committee, my name is Caryl Terrell. I would like to thank you for the opportunity to provide comments on Senate Bill 288 on behalf of the John Muir Chapter of the Sierra Club. The John Muir Chapter represents over 15,000 members and supporters living throughout the state. We work to provide opportunities for Wisconsinites to enjoy nature and advocate for the fair and rational management of our common resources so that all Wisconsin residents have access to the clean air, water, land, flora and fauna they need for their health, safety and well-being as well as to move our economy forward .

For thirty years Wisconsin has had in place commonsense conditions to protect bill payers and future generations from waste: both economic and radioactive. This bill would remove those protections putting all Wisconsinites at serious risk.

Bad Economically

The estimated cost for building a nuclear reactor is over $10 billion. Forcing us to foot the bill for a multi-billion dollar project is irresponsible and unfair. Even the CEO of General Electric said, "If you were a utility CEO and looked at your world today, you would just do gas and wind...You would never do nuclear. The economics are overwhelming."

Wisconsin already has some of the highest electricity rates in the Midwest. A new nuclear proposal could make our rates skyrocket even further. In other states with new nuclear plants, not only did rates catapult, but some saw their rates increase before the construction even began on new nuclear plants. Of course, the concern that can't be overlooked is the radioactive waste created by nuclear energy. This dangerous waste will be around for hundreds of thousands of years. With no federal nuclear waste dumps, the nuclear waste of any new plant would continue to pile up on the shore of our important waterways.

Better Options

Regardless, adding nuclear plants is not even a conversation we should or need to be having. We have better, more realistic options. Wind, solar, and energy efficiency are much cheaper than nuclear and do not come with the incredible drawbacks. There is no concern of a 'solar spill' that could result in the evacuation of communities. Instead, we'd have more energy, fewer emissions, and more family-supporting jobs. Nuclear power is a 20thCentury form of energy and will not be the future in Wisconsin. It is illogical to be having this discussion now, when we have better alternatives that our neighboring states have already embraced and we have to steadily catch up to.

Bad Environmentally

Nuclear energy is an accident waiting to happen. Nuclear energy is vulnerable to natural disasters, terrorism, and human error that can lead to meltdowns and severe radiation leaks, as shown by the tsunami and earthquake ~~this spring~~ in Fukushima, Japan, at Three Mile Island in 1979, at Chernobyl in 1986, and near disasters that occurred when Missouri River floods threatened two nuclear reactors in Nebraska and when the Las Conchas wildfire threatened the Los Alamos Nuclear Research Laboratory in New Mexico.

It hasn't even been five years since the Fukishima accident in March of 2011. After a tsunami, flooding ruined the cooling process for the reactors and led to them melting. The accident resulted in large releases of radiation into the Pacific Ocean, the contamination of crops and drinking water, and the evacuation of the local community, including 100,000 people. Last September was the first time one of the evacuation limits was lifted. The federal government estimates that a major accident at just one of Wisconsin's reactors could cost over $40 billion in property damage alone. There is no safe level of radiation. Exposure, caused by an accident or small leaks, can increase the risk of thyroid and other cancers, and it may take decades to appear.

For all these reasons we urge the committee to reject this bill. Thank you again for the opportunity to speak on this issue.

January 5, 2016
Senate Committee on Natural Resources and Energy
Testimony of Frank Jablonski

I am Frank Jablonski. I have been intermittently, and am now, a lobbyist for the Nuclear Energy Institute. Some of you may know me from before. I was also the lead author of a document sponsored by RENEW Wisconsin and the predecessor organization to Clean Wisconsin in 1995. It was called The Green Plan, and posited that we could move forward quickly toward a clean energy economy by relying strictly on efficiency, conservation and renewable energy. I still believe that we should implement energy efficiency and conservation, and use renewable energy wherever it fits in. I no longer believe it is likely to be anywhere near adequate against the scale of energy needs, environmental imperatives, and human development requirements.

I came to this perspective after re-studying nuclear in the early 2000's. I did so for about two years. Intensive investigation of the things I thought I knew about nuclear energy entirely changed my view. I became a nuclear energy advocate. Here are a few of the things I learned as I made the journey from nuclear opponent to nuclear advocate:

- Radiation is a completely natural element of our environment, and it is everywhere. Background radiation exposure for the United State's, averaged, is about 310-320 millirems per year, with about a similar amount added from medical procedures, on average. There is a region in Iran, called Ramsar, where background exposures are 13,000 to 26,000 millirem, without discerned adverse health effects. This is more than designated "hotspots" in Fukushima province.

- There are other high natural background radiation areas throughout the world. Some of them, such as hot springs in Germany, which is noted for its societal antipathy to nuclear energy, and for its new coal plants and high carbon emissions, attract people seeking what they believe to be medical benefits, and they even specify a "therapeutic dose." Coal plants emit to the ambient environment about 100 times as much radiation as nuclear plants producing the same amount of electricity. This amount is still so low as to be unconnected to adverse health impacts.

  There are a lot of environmental issues that merit worry about a lot of things, but radiation is not one of them.

- France replaced fossil fuels for electricity almost entirely over a period of about 13 years because of a planned nuclear build-out. Nuclear has scaled up to displace emitting sources of energy faster than any renewable energy options. Attached to my testimony is a paper that discusses that potential worldwide. If you want to ask me about competing scenarios based on "renewables only" please feel free.

- Spent nuclear fuel still holds about 95% or more of the energy value of fissionable materials incorporated into it. Next generation nuclear reactors, under development now in the United States, and around the world, will be able to convert today's nuclear waste into tomorrow's clean electricity. The resulting residue will degrade to background levels similar to the ore from which the fuel was taken, in 200 to 500 years.

- This forward energy potential of nuclear power bears on one of the talking points, often asserted by people who oppose nuclear energy, which is the notion that nuclear is mature technology with no path forward for significant innovation. The worldwide programs of research and development that demonstrate this to be false.

- If we decide to bury spent fuel, we can be confident that it will remain isolated form the biosphere. Natural nuclear reactors operated in Africa for hundreds of thousands of years as life was evolving on this planet. The resulting residues have moved about 10 feet in the ensuing billion + years.

- If we decide to just keep spent fuel around in dry casks, hopefully pending the commercialization of even better nuclear technology options, the NRC has concluded we can safely do so indefinitely. There is no nuclear waste crisis. There is a crisis of scientific ignorance.

- If we decide to do nothing, then we will simply be ceding opportunities for leadership on this technology elsewhere. The fundamental physics of being able to access the power of the atom are simply too compelling to believe that if we abandon or oppose it here, then nuclear power will go away. The most that anti-nuclear organizations can hope to realistically accomplish is to prevent the further use and development in advanced nations. All that is gained from that is to strips away the most effective tool to use to battle climate change in states and nations where it will be deployed with the most careful attention. In my view, this is irresponsible to the values those organizations exist to serve.

I will stop there with my written testimony, in anticipation of time limits. I could go on for a good long time about this technology, and the broad scientific consensus that supports its use, further deployment and further development.

It is time for our state to allow nuclear into the mix if, and where, it fits. This is what the legislation permits. I urge you to pass it. I urge that you pass it as an environmental measure.

PLOS | ONE

RESEARCH ARTICLE

Potential for Worldwide Displacement of Fossil-Fuel Electricity by Nuclear Energy in Three Decades Based on Extrapolation of Regional Deployment Data

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Abstract

There is an ongoing debate about the deployment rates and composition of alternative energy plans that could feasibly displace fossil fuels globally by mid-century, as required to avoid the more extreme impacts of climate change. Here we demonstrate the potential for a large-scale expansion of global nuclear power to replace fossil-fuel electricity production, based on empirical data from the Swedish and French light water reactor programs of the 1960s to 1990s. Analysis of these historical deployments show that if the world built nuclear power at no more than the per capita rate of these exemplar nations during their national expansion, then coal- and gas-fired electricity could be replaced worldwide in less than a decade. Under more conservative projections that take into account probable constraints and uncertainties such as differing relative economic output across regions, current and past unit construction time and costs, future electricity demand growth forecasts and the retiring of existing aging nuclear plants, our modelling estimates that the global share of fossil-fuel-derived electricity could be replaced within **25–34 years**. This would allow the world to meet the most stringent greenhouse-gas mitigation targets.

OPEN ACCESS

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Introduction

Human industrial and agricultural activity is now the principal cause of changes in the Earth's atmospheric composition of long-lived greenhouse gases, mainly carbon dioxide (CO_2), and will be the driving force of climate change in the 21st century [1]. More than 190 nations have agreed on the need to limit fossil-fuel emissions to mitigate anthropogenic climate change, as formalized in the 1992 Framework Convention on Climate Change [2]. However, the competing global demand for low-cost and reliable energy and electricity to fuel the rapid economic development of countries like China and India has led to a large expansion of energy production capacity based predominantly on fossil fuels. Because of this, human-caused greenhouse-gas emissions continue to increase, even though the threat of climate change from the burning of fossil fuels is widely recognized [3]. There is therefore an urgent need to assess what energy-generation technologies could allow for deep cuts in greenhouse-gas emissions and air pollution while simultaneously allowing for a rapid expansion of economic activity and prosperity in the poorer regions of the world.

Much recent attention has been given to the potential of, and constraints on, renewable energy [4]. Here we take a different tack, by making use of historical data from the Swedish nuclear program to model the feasibility of a massive expansion of nuclear power at a rate sufficient to largely replace the current electricity production from fossil fuel sources by mid-century—the time window for achieving the least-emissions pathway (representative concentration pathway 2.6 or lower) as set out in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [5]. In a supporting analysis we also model France as a case study; the French example provides an excellent example of a significantly larger nation also pursuing an electricity production policy for a prolonged period based almost entirely on nuclear energy. As part of this analysis, we detail the impact nuclear power had on historical Swedish and French CO_2 emissions, define the rate nuclear capacity was added, estimate the cost and construction time in these national nuclear programs, finally, show how they can be compared meaningfully to the current global situation.

Why consider a large-scale nuclear scenario? The operation of a nuclear reactor does not emit greenhouse gases or other forms of particulate air pollution, and it is one of few base-load alternatives to fossil energy sources currently available that has been proven by historical experience to be able to be significantly expanded and scaled up [6]. Large-hydro projects are geographically constrained and typical have widespread impacts on river basins [7]. The land use [8], and biodiversity [9] aspects of a large-scale expansion of biomass for energy make its use as a sustainable global energy source questionable.

Monetary values presented in this paper are, unless otherwise stated, reported in the value of the US dollar in 2005. When needed, inflation adjustments were done using data as provided by the U.S. Bureau of Labor Statistics. The year 2005 was chosen rather than 2014 because it is the current reference year for most major databases, including the World Bank data, and the reader can thus directly verify numbers appearing in this paper without the need for inflation adjustments. All gross domestic product (GDP) data are presented in the original form, not corrected by purchasing power parity (PPP) estimates. Using GDP-data that has not been PPP-adjusted gives more conservative results, since Swedish PPP-adjusted GDP is lower than the un-adjusted GDP for the entire time-span of interest [10]. Source data and the calculations used for all numbers presented in this paper are provided in the S1 Dataset.

Nuclear capacity impact on CO_2 emissions in Sweden

Between 1960 and 1990 Sweden more than doubled its inflation-adjusted gross domestic product (GDP) per capita while reducing its per capita CO_2 emissions through a rapid expansion of nuclear power production. The reduction in CO_2 emissions was not an objective but rather a fortunate by-product, since the effect on the climate by greenhouse-gas emissions was not a factor in political discourse until much more recently. Nuclear power was introduced to reduce dependence on imported oil and to protect four major Swedish rivers from hydropower installations [11]. As illustrated in Fig 1, in the pre-nuclear era (1960–1972), the rise in Swedish CO_2 emissions matched and even exceeded the relative increase in economic output. Once commercial nuclear power capacity was brought online, however, starting with the Oskarshamn-1 plant in 1972, emissions started to decline rapidly. By 1986, half of the electrical output of the country came from nuclear power plants, and total CO_2 emissions per capita (from all sources) had been slashed by 75% from the peak level of 1970.

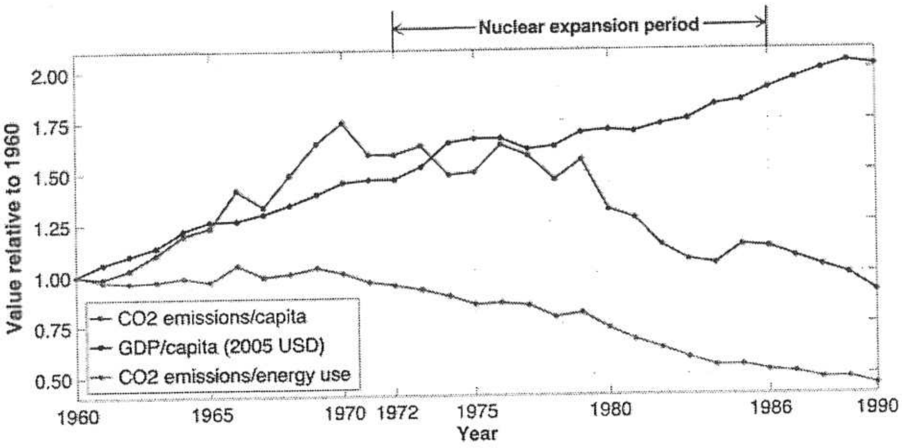

Fig 1. Swedish total CO_2 emissions and GDP per capita 1960–1990, normalized to the level of 1960.

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Based on the data available in the World Bank database, this appears to be the most rapid installation of low-CO_2 electricity capacity on a per capita basis of any nation in history (France and the U.S. installed more total nuclear capacity in the 1960 to 1980s, but less than Sweden on a per capita basis) [12]. Thus Sweden provides a historical benchmark 'best-case scenario' on which to judge the potential for future nuclear expansion.

Nuclear electricity costs in Sweden have always included a surcharge corresponding to the full estimated costs of researching, building and operating a final repository for all nuclear waste. At the end of the nuclear expansion period, Swedish electricity prices (including taxes and surcharges) were among the lowest in the world, and the running cost of the nuclear plants (per kilowatt hour [kWh] produced) were lower than all other sources except for existing hydropower installations [13].

Emissions were reduced due to the closing of fossil power plants and the electrification (by nuclear power) of heating and industrial processes that were previously fossil powered. The total energy supply from crude oil and oil-derivative products dropped by 40% (from 350 terawatt hours per year [TWh/y] to 209 TWh/y) in the period 1970–1986. In the same time period, total electricity consumption doubled and the use of electricity for heating expanded by 5.5 times (from 4.7 TWh/y to 25.8 TWh/y) [14].

The rate at which nuclear electricity production can be added

Out of the 12 commercial reactors that were built in Sweden, nine were of completely indigenous designs that were developed without the use of foreign licenses [11]. Another two reactors of indigenous design were exported to Finland and started operation during the same period (1979–1982). Research on commercial boiling water reactor (BWR) technology was initiated in Sweden in 1962. This means it took 24 years from the start of research until the technology provided a large proportion of the electricity output of the nation. The Swedish BWR development benefitted greatly from the fact that the US had already demonstrated the principles of the technology (the BORAX experiment series [15]) and had started to put small BWRs of General Electric design online in the 1960s [16].

The rate of addition of nuclear electricity in Sweden is presented in several different ways in Table 1. The values represent the cumulative change in nuclear electricity production over the period, divided by the number of years and a normalization factor (either GDP/capita or population). For example the period 1975–1986 starts with the change in production between 1974

Table 1. Production addition for the Swedish nuclear program and implications for global deployment rates of nuclear power if the same progression was followed worldwide.

Time period	Production addition		Years to replace current global fossil electricity at Swedish rate globally	
	kWh/y/y/capita	kWh/y/y/1k$-GDP	Per capita	Per GDP
Start of research to last grid connection, 1962–1986	322.5	12.4	6.5	19.2
Start of first construction to last grid connection, 1966–1986	383.9	14.7	5.5	16.1
First grid connection to last grid connection, 1972–1986	536.6	20.6	3.9	11.5
"Steady-state" addition period 1975–1986	652.3	24.9	3.2	9.5
Peak 5-year addition 1982–1986	740.0	26.5	2.8	8.9
Low 5-year addition (after 1972) 1976–1980	336.4	13.7	6.2	17.3
Peak addition year per capita 1986	1326.2	46.1	1.6	5.1
Peak addition year per $GDP 1981	1286.0	50.2	1.6	4.7

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and 1975, and ends with the change in production between 1985 and 1986. The values are then divided by the total number of production years in the span, in this case 12 years.

To put these numbers in a wider perspective, the number of years it would take to replace current global fossil fuel electricity production was calculated (weighted by population and economy) in the two right columns of the table. These estimates were based on current global data that is summarized in Table 2. Although the range of values in Table 1 is large, the analysis reveals that there is no way of selecting and weighing the available data that leads to an estimated replacement time for current fossil fuel electricity longer than two decades. These values should not be confused with the values given in Section 5, which also accounts for the replacement of the current nuclear fleet and the relative rates at which global energy consumption and GDP are growing.

In order to build nuclear power plants at any of the rates of Table 1 on a global scale, nearly all construction would have to occur in countries with an already established and experienced nuclear regulatory and licensing infrastructure in place, at least in the initial expansion period. This fact presents no major hurdle since virtually all major world energy consumers, encompassing over 90 percent of global CO_2 emissions, are nuclear power producers with active regulatory institutions [19].

Two features seen in all relatively rapidly expanding and successful nuclear programs were strong government involvement and support as well as some measure of technology standardization (indigenously designed PWRs in France, BWRs in Sweden). In this study we make no attempt at identifying and quantifying all the specific factors (societal, institutional, political, economical, technological) that enabled the rapid expansion of nuclear power in countries like Sweden and France. The question is highly complex and it is not clear whether the results of

Table 2. Global projected population, economy and fossil electricity for 2014/2015.

Parameter	Value	Source
Total gross domestic product (GDP)	7.67×10^{13} $ (2014 US$) 6.37×10^{13} $ (2005 US$)	[17]
Population	7.21 billion	[12]
GDP/Capita	10654 $ (2014 US$) 8843$ (2005 US$)	[17] [12]
Fossil fuel electricity generation	1.51×10^{13} kWh/y (Projection is for 2015)	[18]

doi:10.1371/journal.pone.0124074.t002

such a study are applicable globally. This study aims to show at what rate one can add nuclear production capacity in the "best case" scenarios as seen historically.

Countries adopting or expanding their nuclear production capacity today have comparatively little need to develop indigenous designs and supply chains in the way Sweden did, since turn-key products are available from a number of vendors on an open competitive market. It is considerably easier to buy plants and nuclear fuel internationally today than it was in the early days of the Swedish nuclear program, with a larger number of mature, internationally marketed commercial designs on offer today compared to the situation of the mid 1960s. There is also a larger and more open fuel-supply market. Large collaborations such as the International Framework for Nuclear Energy Cooperation (formerly known as GNEP), with 64 participating and observing nations have recently been set up to facilitate the safe and efficient expansion of nuclear power globally [20].

The historical data shows that as time progresses, the impact on the average addition rate caused by the initial time lag—where energy-generation installations are being planned, licensed and built but have not yet been put online (in the Swedish case; 1966–1972)—diminishes. Once the initial ramp-up period is over and the first installations begin to come online, the rate of addition will approach a steady state. By 1974/1975, Sweden had reached a steady-state rate of capacity addition that was essentially maintained for more than a decade, as seen in Fig 2.

The Swedish experience indicates that in steady-state phase of capacity expansion, nuclear power can be added at a rate of about 25 kWh/y/y/1k$-GDP, which, if multiplied by current global GDP (Table 2), amounts to ~1500 TWh/y/y (i.e., 10% of current global fossil-fuel electricity production when scaled to the worldwide economy). The peak annual addition rate per GDP in Sweden occurred 1980–1981 and corresponds to a GDP-weighted annual addition of 3000 TWh/y, or 20% of the current global fossil-fuel electricity production.

Unit cost and construction time

Despite the uncertainties on the economics and logistics of the recent nuclear expansion [21], the current global unit cost and construction-time of nuclear reactors are actually quite comparable to the Swedish experience. The relevant Swedish historical and modern (last two years) of data are presented in Table 3.

With the exception of single first-of-a-kind projects like the highly delayed and poorly managed European Pressurized Reactor (EPR) at Olkilouto in Finland [22] and Flamanville in

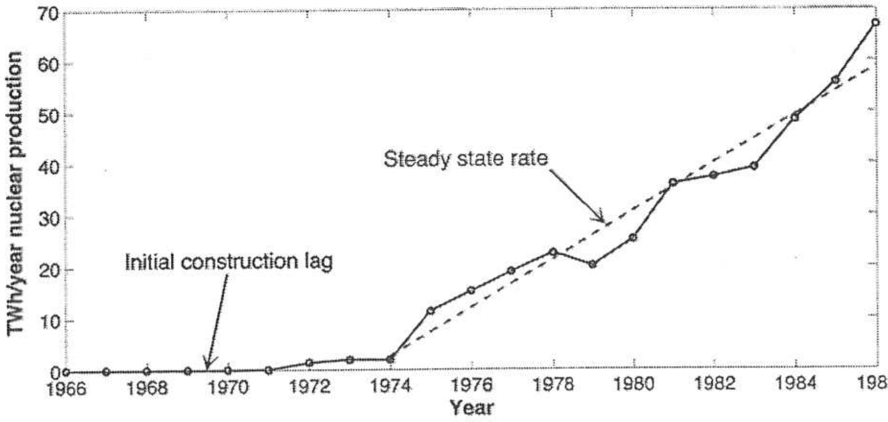

Fig 2. Swedish nuclear electricity production 1966–1986 [14].

doi:10.1371/journal.pone.0124074.g002

Table 3. Nuclear power plant construction time and cost comparison [11] [16] [12].

Parameter	All nuclear units brought online 2012–2014 (April)	Swedish nuclear program 1966–1986
# of units	8	12
Median unit capacity (MWe)	1018	935
Average unit capacity (MWe)	990	871
Median unit construction time	5.1 years	5.7 years
Average unit construction time	5.8 years	5.9 years
Median over-night unit cost per kWe (2005 USD)	1364*	~1400–1500†
Average over-night unit cost per kWe (2005 USD)	1546	~1400–1500†

*Reactor cost data for recently constructed reactors was collected from official press releases. When costs were only given as a lumped sum for multiple units at a plant, the cost for a single unit was calculated by multiplying the total plant cost by the power output of the unit relative to the total plant power output.

†Only specific cost data for the Ringhals NPP and Oskarshamn NPP was found [11]

doi:10.1371/journal.pone.0124074.t003

France [23], global data does not suggest that nuclear plants are necessarily significantly more expensive (as a fraction of the total economy) or time-consuming to build now than in the past, if efficiently managed. Recent studies by the European Commission report that new nuclear generation is economically favorable versus other generation sources, especially if all externalities of other generation sources as well would be internalized [24]. In addition, recently published data suggest that cost escalations in the French nuclear program have been much smaller than previously stated, and that the cost escalation seen was caused to a large part by excessive scale-up of the reactor units [25]. The recent global focus on small modular reactors (SMRs) has the potential to greatly reduce both complexity and uncertainty regarding construction times for new reactor projects.

While historic construction time data is available and reliable [16], cost-data is generally not clearly defined and in some cases not available at all. For the data of Table 3, all cost data for the recently constructed reactors are taken from press-releases due to the lack of officially published source data. It is worth noting is that only three countries connected new reactors to the grid in 2012–2014: China, India and South Korea. Data from these countries (particularly China and India) are arguably most important to future global CO_2 emissions reduction, because these populous and rapidly industrializing nations will constitute the bulk of energy demand and new production in the coming decades. While the cost of construction is currently stable or falling in these countries, a global expansion of nuclear power would mean increased operating costs as the price of uranium ore and fuel is driven up, at least until generation IV reactors that use recycled spent nuclear fuel and depleted uranium or thorium as their input, become widespread and economically competitive. The expansion of nuclear power production inevitably entails a proportional expansion of pressure-vessel fabrication capacity (large steel-forging presses) as well an expansion of the entire nuclear fuel cycle: mining, enrichment, fuel fabrication, recycling/reprocessing and disposal. A truly global and sustainable expansion of the type analyzed here would necessitate a transition to fast reactor systems before the turn of the century to ensure adequate fuel supply and near-complete recycling of long-lived actinide wastes [26].

Implications, Caveats and the French Experience

A surprising and encouraging result of our analysis is that the estimated time it would take the world to replace the fossil share of total electricity with nuclear power, based on Swedish experience, is less than two decades (see Table 1 for details). Moreover, this projection is grounded in reality, being based on actual historical experience rather than speculation on future technological and cost developments. This number takes in to account both the relative difference in per capita GDP between the global average today and Sweden at the time (both adjusted for inflation to the 2005 level of USD), and it also includes the total planning and build time of all the reactors and the associated regulatory infrastructure.

Replacing fossil-fuel electricity and heat production eliminates roughly half of the total source of anthropogenic CO_2 emissions [12]. Continued nuclear build-out at this demonstrably modest rate (Sweden was not, at that time, motivated by urgent concerns like climate-change mitigation), coupled with an electrification of the transportation systems (electric cars, increased high-speed rail use etc.) could reduce global CO_2 emissions by ~70% well before 2050.

However, global electricity production has grown at a more rapid rate than GDP/capita averaged over the last decade (+26% vs. +16% between 2000 and 2011) [12]. The rapidly increasing demand for electricity in economically less-developed countries and the closing of aging existing nuclear installations built in the 1960s and 1970s makes the challenge of replacing the share of fossil electricity even larger than it would first appear. Further, as electricity goals are met progressively, the world will face the added task of replacing all final energy demand—including transportation and industrial processes—with synthetic fuels and chemical batteries, based on zero-carbon sources of heat and electricity [27]. Balancing these factors, which act to increase the magnitude of the challenge, is the fact that today there is a mature world market with dozens of proven and licensed commercial nuclear power plant designs, almost half a century of engineering experience, and strong technology sharing and multilateral cooperation. There is thus no need for most countries in the 21st century to develop their own indigenous nuclear power plant designs (especially without the use of foreign licenses/patents), as was done in the 20th century Swedish program.

GDP-weighted values of Table 1 have been used to estimate a realistic value for the time it would take the world to replace current nuclear installations and all fossil fuel electricity by new nuclear. As a "low" estimate, we use the average nuclear production addition per $-GDP from start of research to the last grid connection (1962–1986); this provides an absolute upper bound for the time-to-replace estimation. An arguably more realistic estimate is the addition rate from the start of the first nuclear construction until the last grid connection (1966–1986). In this scenario, the first 6 years see no electricity production added at all. While Table 1 shows addition rates have exceed 3 times this rate, it can be used as an upper bound for a worldwide nuclear expansion. Sweden was used as the example in this paper since it is the country that

Table 4. Data used for global nuclear expansion rate estimations.

Fossil fuel electricity and all current nuclear electricity (2015 projection) [18]	1.77×10^{13} kWh/y
Addition due to the estimated difference between GDP growth and electricity demand growth	+20%
Total electricity generation to be supplied by new nuclear power plants + 20% / per current world GDP	2.13×10^{13} kWh/y
Current (2014) global GDP [17]	6.37×10^{13} $ (2005 US$)

doi:10.1371/journal.pone.0124074.t004

Table 5. Time to replace global fossil electricity and current nuclear fleet.

Country	Sweden		France	
Expansion scenario	Low	High	Low	High
Time-span	1962–1986	1966–1986	1968–2000	1974–1995
GDP-weighted addition rate (kWh/y/y/1k$-GDP)	12.4	14.7	8.8	11.1
Time to replace global fossil electricity and current nuclear	27.0 years	22.7 years	38.1 years	30.0 years

doi:10.1371/journal.pone.0124074.t005

has done the most rapid and (relative to its size) largest nuclear expansion of any nation, and thus provides an empirical estimate for how quickly such an expansion can be done. However, since Sweden is a small nation, an additional analysis was performed that also includes an extrapolation based on the much larger nuclear program of France. The relevant input data for this analysis is summarized in Table 4.

Recent data has shown that electricity demand has outpaced GDP growth by about 10% averaged over the last decade. To remain cautious in our future projections, a 20% future lag between GDP growth and electricity demand was introduced as shown in Table 4. This assumes a 20% increase in electricity production will need to be replaced per current-world GDP. The resulting time to replace the current global fossil-fuelled electricity production and the current nuclear fleet is given in Table 5.

Given this context, the low-rate estimate of the time for fossil electricity replacement based on Swedish data is 27.0 years and the high-rate estimate is 22.7 years. Averaging the high and low estimates, the conclusion is that nuclear power could replace fossil within a time span of approximately 25 ± 2 years. Using the data from the somewhat slower but larger-scale nuclear expansion in France in an identical way gives a best estimate time of replacement of 34 ± 4 years.

Even a cautious extrapolation of real historic data of regional nuclear power expansion programs to a global scale, as shown in Table 5, indicate that new nuclear power could replace all fossil-fueled electricity production (including replacing all current nuclear electricity as well as the projected rise in total electricity demand) in 25–34 years—well before mid-century, if started soon.

Conclusion

Any climate change mitigation strategy will, due to the magnitude of the challenge, inevitably be based on extrapolation of existing data and assumptions about the future. This is true whether the technologies to displace the use of fossil fuel will be based on nuclear fission, fusion, wind, solar, waves, geothermal, biomass, pumped-hydro, energy efficiency, smart grids, electric cars or other technologies and any combination of the above. No renewable energy technology or energy efficiency approach has ever been implemented on a scale or pace which has resulted in the magnitude of reductions in CO_2-emissions that is strictly required and implied in any climate change mitigation study—neither locally nor globally, normalized by population or GDP or any other normalization parameter.

This paper makes an extrapolation of actual available historic data from regional expansions of a low GHG-emitting energy technology, rather than trying to speculate further on future potential deployment strategies. The results indicate that a replacement of current fossil-fuel electricity by nuclear fission at a pace which might limit the more severe effects of climate change is technologically and industrially possible—whether this will in fact happen depends primarily on political will, strategic economic planning, and public acceptance.

Supporting Information

S1 Dataset. Contains all the data used for all calculations of this article.
(XLSX)

Author Contributions

Conceived and designed the experiments: SQ BWB. Performed the experiments: SQ BWB. Analyzed the data: SQ BWB. Contributed reagents/materials/analysis tools: SQ BWB. Wrote the paper: SQ BWB.

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Wanning Workshop + Beijing Charts + Year-End Comments

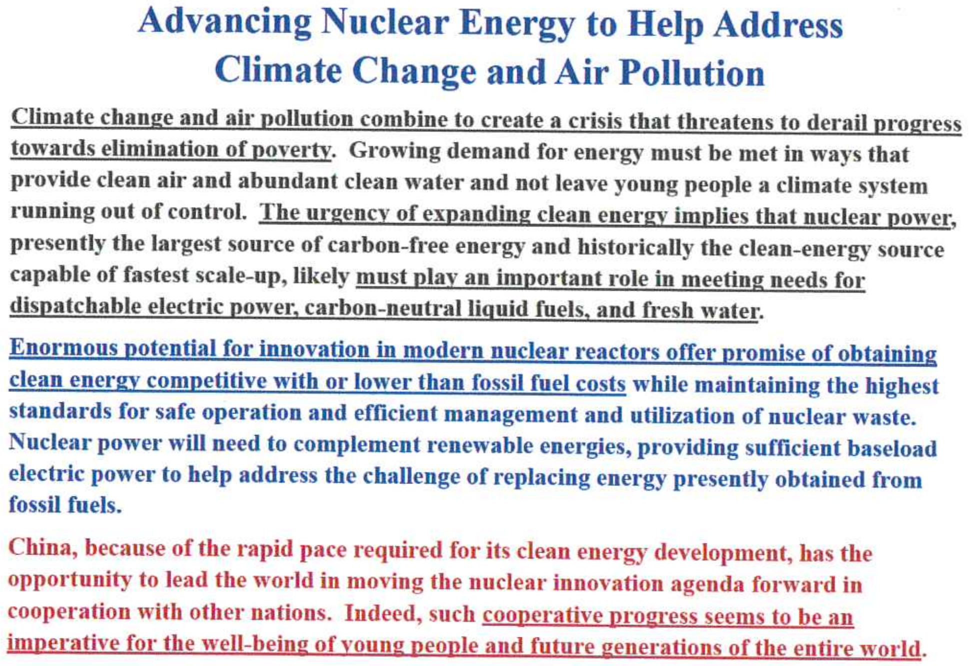
29 December 2015

James Hansen

I returned Christmas Eve from a workshop[a] in Wanning, China and talks at Peking University and Tsinghua University. The workshop was conceived after a trip to China last year (cf. Sleepless in Ningbo) to attend the Symposium on a New Type of Major Power Relationship at invitation of the Kissinger Institute on China and the United States. That symposium included trips to solar and windmill factories, but nuclear power seemed to be taken off the table despite the implausibility of phasing out coal use in China and India without the help of nuclear power. Thus I contacted nuclear energy experts Richard Lester (MIT) and Per Peterson (University of California at Berkeley) and my Chinese friends and fellow climate scientists, Junji Cao and Yunfeng Luo, with the aim of asking what role nuclear power might play in addressing air pollution and climate change. Junji was a marvelous workshop host, enlisting nuclear scientist Hongji Xu as a co-organizer. We will prepare a report with recommendations in the near future.

China's leaders have done a remarkable job in raising more people out of poverty than any case in Earth's history. Yet that progress is now threatened by the twin scourges of air pollution and climate change. Two of the days I was in Beijing were "red alert" days, with air pollution so bad that school was cancelled. Unlike my experience in Ningbo, I avoided an asthma attack with the help of a good face mask – any sleeplessness was only the result of an 11-hour time zone shift.

A crucial requirement for cleaning up the air and environment is abundant affordable electric power for all citizens, allowing replacement of many polluting activities. Chart 1 here is Chart 44 of my Tsinghua University presentation, which is available at Beijing Charts. On the way to China I took part in a 'Scientific Reticence' session at the American Geophysical Union meeting.



Advancing Nuclear Energy to Help Address Climate Change and Air Pollution

Climate change and air pollution combine to create a crisis that threatens to derail progress towards elimination of poverty. Growing demand for energy must be met in ways that provide clean air and abundant clean water and not leave young people a climate system running out of control. The urgency of expanding clean energy implies that nuclear power, presently the largest source of carbon-free energy and historically the clean-energy source capable of fastest scale-up, likely must play an important role in meeting needs for dispatchable electric power, carbon-neutral liquid fuels, and fresh water.

Enormous potential for innovation in modern nuclear reactors offer promise of obtaining clean energy competitive with or lower than fossil fuel costs while maintaining the highest standards for safe operation and efficient management and utilization of nuclear waste. Nuclear power will need to complement renewable energies, providing sufficient baseload electric power to help address the challenge of replacing energy presently obtained from fossil fuels.

China, because of the rapid pace required for its clean energy development, has the opportunity to lead the world in moving the nuclear innovation agenda forward in cooperation with other nations. Indeed, such cooperative progress seems to be an imperative for the well-being of young people and future generations of the entire world.

Chart 1. Introductory statement at Wanning workshop (cf. Beijing Charts).

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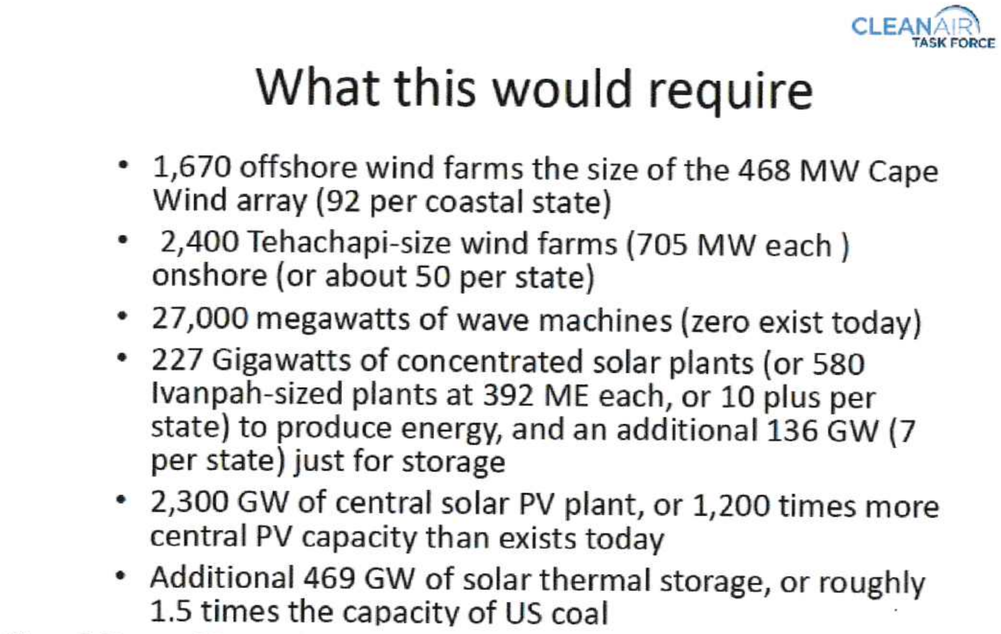
[a] Workshop on Advanced Nuclear Energy to Address Climate Change and Air Pollution, December 17-20, 2015.

Several blatant falsehoods about nuclear power were repeated in that session, including claims that (1) nuclear power has a large carbon footprint (it is actually as low as that of renewables, and it is even lower with advanced generation nuclear power), (2) nuclear power is a slow way to decarbonize (in fact all of the fastest decarbonizations in history occurred via nuclear power), (3) nuclear power gets inordinate subsidies (in fact renewable subsidies dwarf nuclear subsidies).

However, it is wrong to pit renewables against nuclear power. We need all hands on deck. Carbon-fee-and-dividend provides a way to avoid contentious discussion and allow competition. It is unfortunate for young people in the United States that the economic benefits of advanced generation nuclear will likely accrue elsewhere, given government policies seemingly designed to kill nuclear power.[b] I have felt the sting of a gross asymmetry in the renewable/nuclear energy discussion, as proponents of a role for nuclear power support renewable energies, but proponents of renewables unleash a torrent of criticism of anyone advocating a role for nuclear power.[c]

I limit this discussion with a final point: all energy sources impact the environment. The effects of old generation nuclear power can be greatly reduced with new technology. The impacts of renewable energies may not be acceptable to all environmentalists. Chart 2, for example, shows the renewables proposed by Jacobson et al. (2015).[d] Will each of the 50 states actually approve these installations? What about the new power lines criss-crossing the nation? Not included in this chart is the "water" portion of this proposed renewable power installation: it is equivalent to 50 Hoover dams, one for each state; although the proposition is to do this with a larger number of smaller dams, it is not clear that these dams would be welcomed by all environmentalists.



CLEANAIR TASK FORCE

What this would require

- 1,670 offshore wind farms the size of the 468 MW Cape Wind array (92 per coastal state)
- 2,400 Tehachapi-size wind farms (705 MW each) onshore (or about 50 per state)
- 27,000 megawatts of wave machines (zero exist today)
- 227 Gigawatts of concentrated solar plants (or 580 Ivanpah-sized plants at 392 ME each, or 10 plus per state) to produce energy, and an additional 136 GW (7 per state) just for storage
- 2,300 GW of central solar PV plant, or 1,200 times more central PV capacity than exists today
- Additional 469 GW of solar thermal storage, or roughly 1.5 times the capacity of US coal

Chart 2. Renewable energies proposed for U.S. by Jacobson (chart courtesy of Armond Cohen).

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[b] One example of many, "renewable portfolio standards" rather than "carbon-free-portfolio standards" – but it would be better to have neither, instead letting a rising carbon fee and the free market guide utility decisions.

[c] The torrent is led by 'Big Green" environmental organizations, but as with climate change "deniers" there is a large unpaid well-meaning but not very well-informed public that descends, discouraging objective analysis.

[d] Jacobson, M.Z., Delucchi, M.A. et al.: 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States, *Energy Environ. Sci.*, **8**, 2093-2117, 2015.

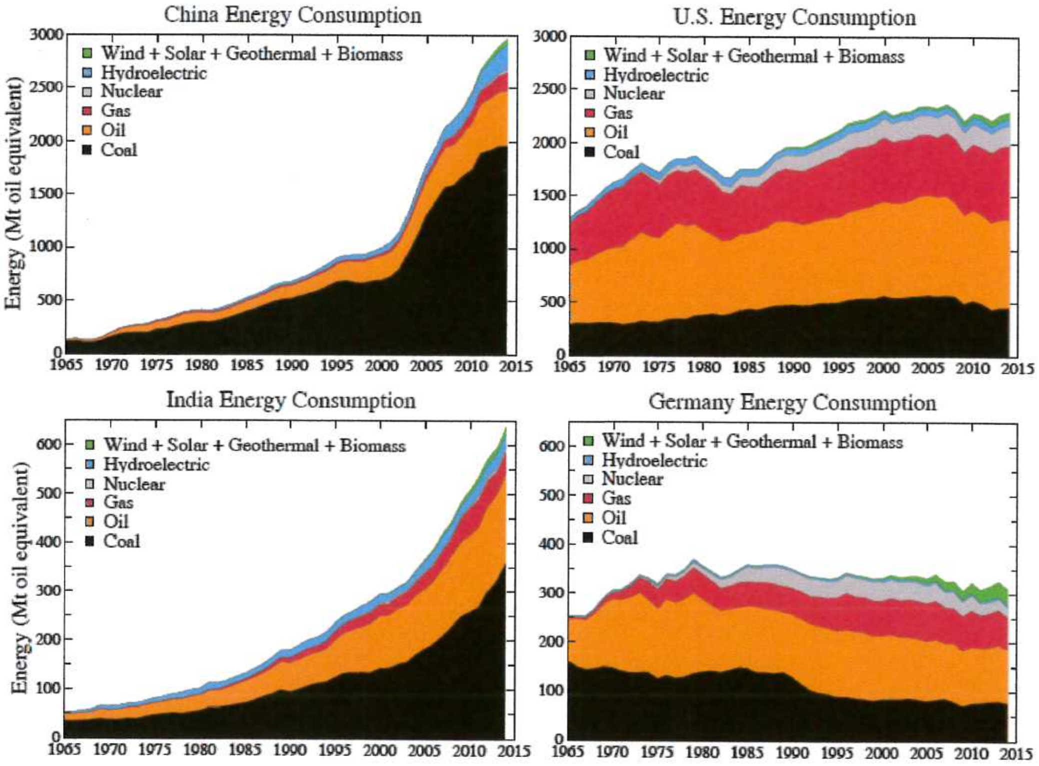


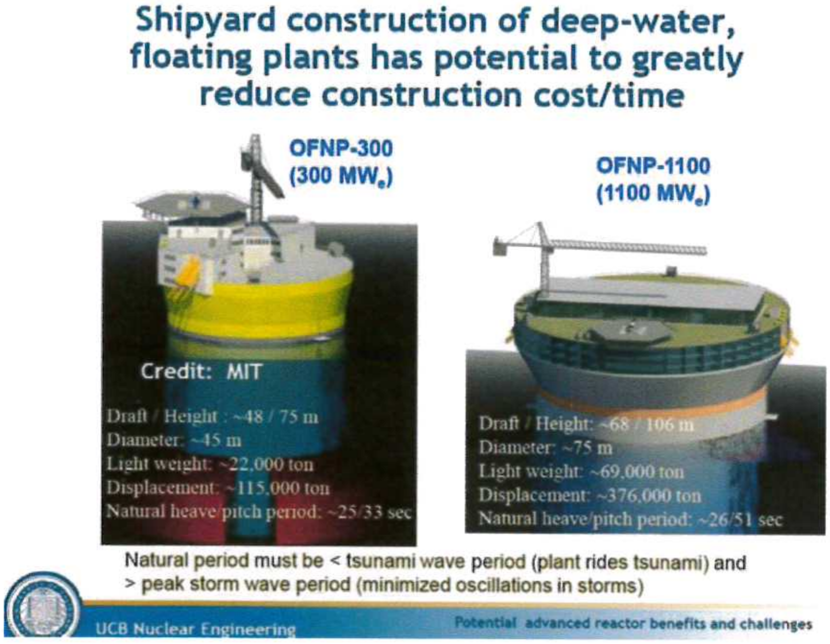
Fig. 1. Energy consumption in China, United States, India and Germany (data from BP[1]).

I briefly note here a few topics that I will address one-by-one in future communications.

Paris. Shameless preplanned back-slapping accompanied a Paris climate accord that guaranteed nothing except continued high fossil fuel emissions. Low oil and gas prices afforded a golden opportunity to introduce a rising carbon fee, the only practical way to achieve honest pricing of fossil fuels. However, such a simple honest approach without any giveaways to special interests was dismissed as being too complex to be considered. Instead continued low fossil fuel prices will spur construction of more fossil fuel infrastructure with lock-in of high future emissions.

The major economic powers, including the United States, China and the European Union, need to define a feasible path to carbon-free energy. However, the U.S. is hamstrung by extremist political factions: the far right proclaiming that climate change is a hoax and extreme liberals asserting that we are on the verge of getting all energy from renewables. The European Union is under the thumb of Germany, which has dispatched Angela Merkel on a global crusade to sell a no-nuclear-power cap-and-trade scheme designed by and for Germany. Yet, despite world-leading engineering capabilities, a large balance-of-trade surplus, and a willingness to pay high electricity prices, Germany has made little progress in reducing fossil fuel emissions (Fig. 1). [The reduction in coal use in the early 1990s was due to German unification with closing of inefficient East German coal plants (earlier data being the sum for West and East Germany). The small decline in recent decades is due at least in part to export of manufacturing.]

China may be the best hope for the rapid progress needed to save the future of young people, given the U.S. and Europe situations, despite the fact that China is responsible for only 10% of cumulative fossil fuel emissions that cause climate change (U.S. and Europe are each responsible for >25%). On a per capita basis the gap is even larger (see Fig. 2 in my prior Communication).



Shipyard construction of deep-water, floating plants has potential to greatly reduce construction cost/time

OFNP-300 (300 MW_e)

Credit: MIT

Draft / Height : ~48 / 75 m
Diameter: ~45 m
Light weight: ~22,000 ton
Displacement: ~115,000 ton
Natural heave/pitch period: ~25/33 sec

OFNP-1100 (1100 MW_e)

Draft / Height: ~68 / 106 m
Diameter: ~75 m
Light weight: ~69,000 ton
Displacement: ~376,000 ton
Natural heave/pitch period: ~26/51 sec

Natural period must be < tsunami wave period (plant rides tsunami) and > peak storm wave period (minimized oscillations in storms)

Chart 3. Schematic of shipyard-constructed nuclear power plants, P. Peterson, Wanning workshop.

Concepts for "disruptive" technologies, potentially providing abundant continuous electric power as cheap or cheaper than coal, and safer, are given in Charts 3 and 4. Such innovations are likely be developed in China because of its urgent need for clean energy, but once implications are clear there may be pressure to fix barriers that hinder nuclear power development in the West.

Near-Term Publications. Two substantial papers that occupied us most of the year are in final stages of journal review/revision. They address the issues that I believe are the most important ones determining "dangerous" climate change. The essence of the paper on ice melt/sea level was published in the "discussion" version of the paper, but the revised paper is reorganized and easier to read. I hope to be able to make both of these papers available within several weeks.

Legal Actions. As noted in earlier Communications we are involved in several legal cases whose overall purpose is to use the judicial branch of our government, which should be less subject to influence of the fossil fuel industry, as a means to move the executive and legislative branches to action on climate change. Courts were essential for securing civil rights.

An Example of Technology

Thorium-Powered Molten Salt Reactor

Operates at Atmospheric Pressure

Factory or Shipyard Construction

Uses Most Nuclear Fuel, Not <1%

Reduced Waste, Shorter Half-Life

Passively Safe Operation

Not Well-Suited for Weapons Material

Chart 4. An example of a nuclear technology that is ripe for development.

The most important case is the one against the federal government, for which I submitted my testimony several months ago. The presentation of the case is now firmly based on fundamental rights guaranteed by the Constitution for "equal protection of the law" and "due process". The case has the potential to provide a historic turning point in the fight for justice for young people.

Solicitation and the last word. I understand that some donors are not happy about discussion of nuclear power. That topic occupies only a small fraction of our work. I highlight it here because of just returning from the workshop and the great amount of disinformation on the topic. We cannot aim to tell people what they want to hear, rather we must aim for objective analyses, providing the public as much information as possible including policy options.

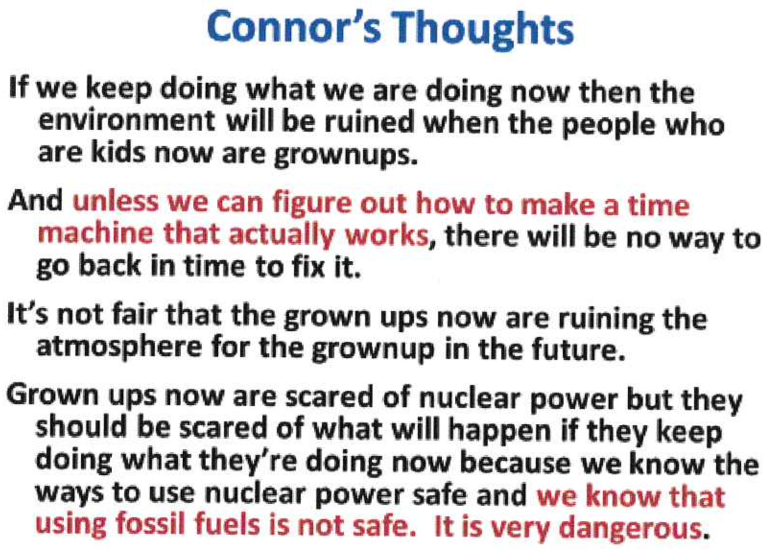
Fortunately, a gift we received from the Durst family a year ago, with 1:3 matching from the Grantham Foundation, and other contributions will cover the costs of our present 3.5 person Columbia University program for 2016. However, we need funding for our non-profit 501/C3 Climate Science, Awareness and Solutions, Inc. (CSAS Inc.). CSAS Inc. is used to pay costs of the legal actions (mainly for a brilliant young lawyer, Dan Galpern, who drafts my testimonies), computer costs for modeling and research, and travel. In 2015 I made a donation of $25K from CSAS Inc. to Our Children's Trust, which we are working closely with on the federal case, and we hope to continue to support them in 2016, but funds in CSAS Inc. are largely depleted.

Betsy Taylor is President of CSAS, Inc., I am the Chief Executive Officer, Bill McKibben and Larry Travis are Board Members, Jim Miller is a newly elected Board Member this month, and Jay Halfon is the Secretary and Treasurer. Jim Miller has been very helpful over the past 1-2 years in helping find support for the Columbia University program, in discussions with policymakers about fee-and-dividend, and recently he has encouraged us to explicitly work into our legal cases the concept of "irreparable harm", which has been effective in prior legal cases.

Donations to CSAS, Inc. should be sent to Jay Halfon, 45 West 36th Street Floor 6, New York, NY 10018, attn. Geoff Boehm. Of course we welcome support of our Columbia University program, Climate Science, Awareness and Solutions, which would allow me to spend less time fund raising in 2016 and make the program more effective. Donations to the Columbia program should be sent to Gregory Fienhold, The Earth Institute, Hogan Hall, Room 108 2910 Broadway, MC 3277 New York, NY 10025 or made online at http://csas.ei.columbia.edu/support/.

I give the old year's last word to my oldest grandson, Connor. Three years ago, as an 8-year old, unbeknowst to me, he was in the back row of an audience listening to my talk on human-caused climate change. At the end, when Anniek noticed tears running down his cheeks, she ran to him and said "Don't worry, Connor, adults are working on the problem. They will solve it."

Sometimes it is not so easy to fool young people. Connor's recent thoughts (Chart 5), as an 11-year old, do a remarkably good job of capturing the crucial "delayed response" aspect of climate change. And he seems to understand the bottom line.



Connor's Thoughts

If we keep doing what we are doing now then the environment will be ruined when the people who are kids now are grownups.

And unless we can figure out how to make a time machine that actually works, there will be no way to go back in time to fix it.

It's not fair that the grown ups now are ruining the atmosphere for the grownup in the future.

Grown ups now are scared of nuclear power but they should be scared of what will happen if they keep doing what they're doing now because we know the ways to use nuclear power safe and we know that using fossil fuels is not safe. It is very dangerous.

Chart 5. Thoughts of 11-year-old grandson on climate change and energy.

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[1] Additional graphs, for CO_2 emissions, are available at http://www.columbia.edu/~mhs119/CO2Emissions/ with longer periods covered using data of Boden et al. (Oak Ridge National Laboratory) with British Petroleum data concatenated for recent years.

1/5/2016 Testimony

PUBLIC HEARING

Committee on Natural Resources and Energy

Tuesday, January 5, 2016

10:00 AM

300 Southeast

Regarding Senate Bill 288

Relating to: requirements for approval of construction of nuclear power plants and changes to the state's energy priorities policy.

Physicians for Social Responsibility - Wisconsin is opposed to repeal of the Wisconsin 1983 ACT 401 (known as Wisconsin's Nuclear Moratorium), because repeal means construction of new nuclear reactors in Wisconsin without proof of their safe disposal of radioactive waste and their economic viability.

Greetings Natural Resources and Energy Chairman and Committee members:

My name is Amy Schultz. I am an RN at the VA Hospital, and am the president of PSR – Wisconsin.

My name is Paula Rogge. I am a board certified family physician and a member of the Steering Committee of Physicians for Social Responsibility - Wisconsin.

We are speaking on behalf of Physicians for Social Responsibility (PSR) - Wisconsin, which has over 600 members statewide. PSR - Wisconsin is opposed to repeal of the Wisconsin statute which prohibits construction of new nuclear reactors in Wisconsin without proof of their safe disposal of radioactive waste and of their economic viability.

Why?

Nuclear reactors are unsafe.

There have been accidental leaks or planned releases of radioactive materials from nuclear power plants in this country since they were built. In 2007, the NRC investigated leaks of tritium from ten different power plants around the country, including the Point Beach facility on Lake Michigan. Our Point Beach Number 1 nuclear plant is one of the oldest operating nuclear power reactors in the nation and has one of the worst NRC safety records of all US reactors.

The Union of Concerned Scientists cites 51 cases at 41 U.S. nuclear plants in which reactors have been shut down for more than a year as evidence of serious and widespread safety problems. There was a near miss of a catastrophic meltdown at the Davis-Besse reactor in Ohio in 2002, which in the years preceding the incident had received a near-perfect safety score.

Climate change and natural disasters can also threaten a plant's safety; heat waves in Europe and in the US have forced reactors to shut down or reduce output due to warming of surface waters used to cool the reactors.

> With river water so warm, the nuclear plant couldn't draw in as much water as usual to cool the facility's three reactors, or else the water it pumped back into the river could be hot enough to harm the local ecosystem, says Golden. But for every day that the Browns Ferry plant (Alabama) ran at 50 percent of its maximum output, the TVA had to spend $1 million more than usual to purchase power from somewhere else, he says. (Wiki)

The tsunami in Japan resulted in failure of cooling systems and meltdowns of the Fukushima nuclear power reactors with huge releases of radioactive isotopes into the air and water and evacuation of people within a 20 to 30 km of the meltdown.

> Estimates of radioactivity released ranged from 10-40% of that of Chernobyl's. The significantly contaminated area was 10-12% that of Chernobyl. (Wiki)

Finally, plutonium or depleted uranium ("nuclear power waste") can be used to build radioactive "dirty" bombs or primitive nuclear bombs (it only takes 5 kg of plutonium to make a nuclear fission bomb).

And the power reactors themselves are vulnerable; a simple failure in the electrical or cooling system can lead to nuclear meltdown, as in Fukushima. The containment buildings are not designed to withstand attacks using large aircrafts such as those used on 9/11.

Health effects - Chernobyl

In the 1986 Chernobyl Nuclear Power Plant core meltdown, the explosion released more than 200 times the radioactive fallout of the two nuclear weapons used in Hiroshima, and Nagasaki, spreading a radioactive cloud over Belarus, Ukraine and Russia, Europe, Greenland and parts of Asia. Those Northwest of the reactor in Sweden, Finland and Eastern Europe were exposed to up to 100 times normal background radiation. Thirty people were killed immediately. And since 1986, the rate of thyroid cancer in affected areas has increased in children and adolescents due to I-131 exposure.

A Swedish study documented a drop in school performance of children exposed in utero (8-25 weeks gestation) at time of Chernobyl accident. This effect was more pronounced in areas that received more radioactive fallout.

Nuclear waste

Nuclear waste is a huge problem; more than 54,000 metric tons of highly radioactive spent fuel has already accumulated at reactor sites around the U.S. for which there currently is no permanent repository. One of the impediments to the Yucca Mountain storage site license application is the public health requirement that the facility provide radiation safeguards from now until peak radiation occurs in about three hundred thousand years.

Wisc. Nuclear Reactors Repeatedly Fined for unsafe operations

Only four "red" findings (the highest safety failure warning in the industry) have been issued by the Nuclear Regulatory Commission (NRC) – two of them to Point Beach owners Wisc. Electric Power Co. (WEPCO)

October 30, 2004

A worker was contaminated inside the Kewaunee reactor and was rushed to the hospital after on-site decontamination attempts failed. The NRC said it did not know what isotopes had been involved. (NRC notification, 10/30/04; NRC Region 3 phone interview, 11/16/04)

March 20, 2004

The NRC fined Point Beach $60,000 for problems with the reactor's backup cooling pumps last summer. (*The Capital Times*, 3/20/04)

October 2002

A second "Red" finding by the NRC against Point Beach for problems with cold water circulation for cooling the reactor. (*NRC News*, 2/11/04)

2001

Risk of breakdown in Point Beach's cooling feedwater pumps results in a "Red" finding. (*NRC News*, 2/11/04)

June 5, 2001

Kewaunee's reactor was shut down when the computer Safety Parameter Display System and Emergency Response Data System both failed. The operators did not know the status of "emergency response availability." (NRC Event Notice #38052, 6/5/01)

Nov. 18, 1997

Point Beach Unit 2 was hastily shut down because of electrical problems. (*Mlwk Journal Sentinel*, 11/18/97)

Aug. 12, 1997

NRC recorded 21 violations at Point Beach in the 90-day period between Dec. 1996 and Feb. 1997. (*St. Paul Pioneer Press*, 8/12/97)

July 25, 1997

Reactor number 2 at Point Beach was shutdown when a cooling water pump failed. (*Mlwk Journal Sentinel*, 8/25/97)

Feb, 18, 1997

Reactor 1 at Point Beach was shut down when cooling water pump defect required pump replacement.

Dec. 1996

WEPCO fined $325,000 for 16 safety violations and a 1996 explosion inside a loaded high-level waste cask. (*Mlwk Journal Sentinel*, 8/12/97) The NRC said WEPCO was "inattentive to their duties," "starting up a power unit while one of its safety systems was inoperable," and had failed to install "the required number of cooling pumps." (*Mlwk Journal Sentinel*, 12/5/96)

Sept. 21,1996

Kewaunee reactor was shut down when "more than expected" corroded steam tubes were discovered. (*Mlwk Journal Sentinel*, 2/26/97)

May 28, 1996

A potentially catastrophic explosion of hydrogen gas, "powerful enough to up-end the 3-ton lid," pushed aside a 6,390-pound cask lid while it was atop a cask filled with high-level waste. (*Mlwk Journal Sentinel*, 6/8/95)

March 30, 1995

Point Beach reactor shut down due to instrument failure in the emergency generator system used to circulate cooling water when regular power is cut off during emergencies. (*Wisc. State Journal*, 3/30/95)

Nukewatch@lakeland.ws; Nukewatch.com

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Nukewatch@lakeland.ws; Nukewatch.com

Statement of the Citizens Utility Board

Senate Committee on Natural Resources and Energy

January 5, 2015

Mr. Chairman, members of the committee, good morning, my name is Kurt Runzler, I am the Acting Executive Director of the Citizens Utility Board, or "CUB". I'm here this morning to outline the reasons for CUB's opposition to Senate Bill 288, which would repeal important statutory language protecting electric utility ratepayers from potentially uneconomic resource decisions.

As many of you know, CUB was created by the Wisconsin legislature in 1979 to give utility ratepayers a voice before the Public Service Commission, or "PSC", the state agency that sets the rates charged by electric utilities and decides whether utility power plants or transmission lines will be constructed.

CUB has participated in cases before the PSC for the last 35 years representing the interests of the hard working citizens of this state. CUB's mission is to work to ensure that residential, farm, and small business ratepayers do not pay more than they should for basic electric utility services.

CUB supports proposals by Wisconsin's utilities that promote the construction, operation, and maintenance of an adequate, safe, and reliable electric power system at the lowest possible cost, consistent with sound business principles. CUB works to protect ratepayers from paying for utility projects, including new generating resources, that are not needed or that are not cost-effective compared to reasonable alternatives.

Importantly, the statutory language that would be repealed by SB 288 does not prohibit the construction of nuclear power plants. Rather, the current law serves as an essential checklist that the PSC must follow to help protect ratepayers from the potentially extraordinary costs of nuclear power plants.

Generally, existing law requires that before a nuclear plant can be built in Wisconsin the PSC must find that the plant is "economically advantageous" to ratepayers based upon the costs of construction, operation, and decommissioning. We know that existing nuclear facilities are struggling to continue operating in low-cost electric power markets, and that the nuclear power industry is currently struggling to complete construction of new base-load sized nuclear facilities at a price that is even in the ballpark of being cost-effective compared to readily available alternative base-load resources, such as new combined cycle natural gas plants.

For example, the cost to finance and construct the combined 2,200 megawatt Vogtle 3 and 4 AP 1000 nuclear units, currently under construction in Georgia, is now projected to be a staggering $17 billion dollars.[i] The project is already $3 billion dollars over budget, and at least three years behind schedule.[ii] [iii] Notably, the Vogtle plants are based on the same reactor design that SB 288 would place ahead of natural gas plants on Wisconsin's energy priority list.

In addition to the extraordinary costs of construction, the cost to decommission a nuclear plant can add hundreds of millions of dollars of cost to a nuclear project. For example, the projected cost to dismantle the recently shut-down Kewaunee nuclear plant near Green Bay, is an astonishing $1 billion dollars.[iv]

Repealing Wisconsin's nuclear ratepayer protection law would also remove the requirement that the PSC determine that a site will be available for disposal of spent fuel waste before approving the construction of a new nuclear plant. Removing this ratepayer protection puts Wisconsin citizens at risk for the costs of the potentially permanent on-site management of spent fuel waste at a new nuclear plant. For example, it is estimated to cost $342 million dollars for high level radioactive waste management at the closed Kewaunee nuclear plant through 2073.[v]

In comparison, the PSC is currently considering the approval of a 650 MW combined cycle natural gas power plant at the Beloit Riverside Energy Center at a cost to construct of $700 million dollars.[vi] The minimum cost per megawatt of constructing the Vogtle nuclear units versus the cost of constructing the Riverside natural gas plant shows that nuclear construction costs are currently five times greater than natural gas plant construction costs.[vii] As I noted earlier, the proposed legislation would add the Vogtle plant design to Wisconsin's energy priority list ahead of new natural gas plants.

Given the current cost to finance and build a nuclear facility compared to a combined cycle gas plant, CUB believes the inclusion of nuclear power before natural gas fired generators on the energy priority list sends the wrong public policy signal to the PSC.

In conclusion, CUB opposes the proposed repeal of Wisconsin's nuclear ratepayer protection law and modification of Wisconsin's energy priority law. Ratepayers require special protection against the extraordinary costs of nuclear power and the existing law provides that protection.

Thank you for the opportunity to present CUB's comments.

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[i] Georgia Public Service Commission, Docket No. 29849, *In the Matter of Georgia Power Company Thirteenth Semi-Annual Vogtle Construction Monitoring Report*, November 20, 2015, Direct Testimony and Exhibits of Steven D. Roetger and William R. Jacobs, Jr. Georgia Power Company owns 45.7% of the Vogtle Project and its estimated total project cost, which consists of construction costs and financing costs is $7.8 billion ($7,800,000,000/45.7 = $170,678,337 x 100 = $17.1 billion).

[ii] The total project cost is an estimate since there are four different owners for the Vogtle project, each which have different borrowing costs. The ownership shares are: Georgia Power Company at 45.7%, Oglethorpe at 30%, Municipal Electric Authority of Georgia at 22.7%, and the City of Dalton at 1.6%. (Moody's Investors Service, Global Credit Research, November 12, 2015).

[iii] Regarding completion date slippage, see generally Georgia Public Service Commission, Docket No. 29849: Georgia Power's June 2009 Monthly Status Report, July 20, 2009, and *In the Matter of Georgia Power Company Thirteenth Semi-Annual Vogtle Construction Monitoring Report*, November 20, 2015, Direct Testimony and Exhibits of Steven D. Roetger and William R. Jacobs, Jr; EnergyBiz News Services, "Vogtle Settlement Could Cost Utility Customers", November 8, 2015.

[iv] Dominion Energy Kewaunee, Inc., Kewaunee Power Station, Post-Shutdown Decommissioning Activities Report, February 26, 2013

[v] Dominion Energy Kewaunee, Inc., Kewaunee Power Station, Post-Shutdown Decommissioning Activities Report, February 26, 2013

[vi] Public Service Commission of Wisconsin, Docket 6680-CE-176, Surrebuttal Testimony of Brent R. Kitchen, Wisconsin Power and Light Company, PSC ERF #: 279341, p. 16.

[vii] The cost per MW comparison between the Vogtle units and Riverside does not include the cost of financing Vogtle in order to fairly compare the cost of construction. Georgia Power Company's (GPC) forecast of total construction, exclusive of financing costs, as of August 2015 for Vogtle is $5 billion. (See: Georgia Public Service Commission, Docket 29849, Georgia Power Company's August 2015 Monthly Status Report, September 21, 2015). GPC's 45.7% share of Vogtle equals 1,021 MW. Cost/MW approximates $4.9 million/MW. The estimated cost to construct Riverside is $700 million, which doesn't include financing costs. Riverside's Cost/MW approximates $1 million/MW.

Testimony before the Senate Committee on Natural Resources and Energy
January 5, 2016, Kelsey Amundson

Hello, my name is Kelsey Amundson and I grew up in Ashwaubenon, Wisconsin. I am a graduating senior in nuclear engineering at the University of Wisconsin – Madison with certificates in Mathematics and Nuclear Engineering Materials. I am also the current American Nuclear Society University of Wisconsin – Madison Student Section President, and I am here representing myself.

My purpose for being here today is to discuss why Senate Bill 288 should be passed. Over 70% of Wisconsin's electricity generation is from the burning of fossil fuels, including coal and natural gas [1]. A typical coal plant will emit 3.5 million tons of CO_2 per year in addition to other harmful gases and particulates [2]. These emissions can lead to serious health effects, such as asthma and even death. A study conducted by the World Health Organization concluded there were 3.7 million deaths globally due to outdoor air pollution in 2012 [3].

James Hansen, a NASA scientist, has studied how nuclear power protects health and saves lives. Included in my testimony is a graphic drawn from one of his recently published peer-reviewed papers [4]:

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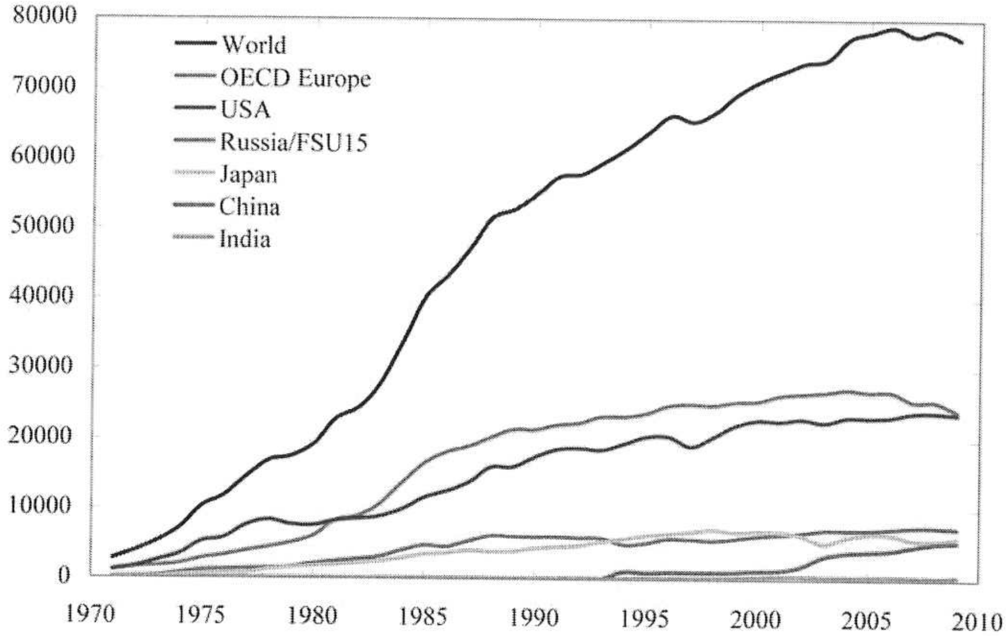
[1] *Nuclear Energy in Wisconsin*. Washington, DC: Nuclear Energy Institute, 2014. Print.

[2] "Coal Power: Air Pollution." *Union of Concerned Scientists*. N.p., n.d. Web. 17 Nov. 2015.

[3] *Burden of Disease from Ambient Air Pollution for 2012*. Rep. World Health Organization, 2014. Web. 17 Nov. 2015.

[4] Kharecha, Pushker A., and James E. Hansen. "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power." *Environmental Science & Technology* (2013): 4889-895. American Chemical Society. Web. 17 Nov. 2015.



Mean number of deaths prevented annually by nuclear power 1971-2009

If we want to improve our air quality while meeting our electrical needs, we need nuclear power. It accounts for nearly two-thirds of carbon-free electricity in the United States [5], and is the only carbon-free electricity source that we know for certain can be implemented on a large scale here in Wisconsin. For example, during the polar vortex in 2014 nuclear power was still able to produce electricity when coal and natural gas had to shutdown.

Compared to other industries, nuclear power is the only industry that takes full responsibility for the waste that is produced, which is in a solid form. Therefore nuclear waste is easier to manage and is small compared to other energy forms. To put this in perspective, if all of the electricity one-person uses over their lifetime came from nuclear power the total amount of waste would be about the size of a soda can [6]. Also there are techniques, such as reprocessing, that can further minimize the amount of waste that needs to be stored long-term.

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[5] "Clean Air." *Issues & Policy*. Nuclear Energy Institute, n.d. Web. 17 Nov. 2015.

[6] Department of Energy. "Waste from Nuclear Power Plants." Speech.

In addition to successfully managing spent fuel, nuclear is one of the safest energy sources we have available to us today. According to Forbes Magazine, nuclear power has the lowest deathprint, which is the number of deaths per kilowatt-hour, even when accidents such as Chernobyl and Fukushima are considered [7]. Nuclear power has such a low deathprint because U.S. reactors today are designed to withstand worst-case scenarios and can produce large amounts of energy per unit.

The Wisconsin senate should vote to pass this piece of legislation in order to improve our air quality, minimize our impact on the environment, and provide safe electricity production for our state. Thank you.

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[7] Conca, James. "How Deadly Is Your Kilowatt?" *Forbes.* Forbes Magazine, 10 June 2012. Web. 02 Jan. 2016.

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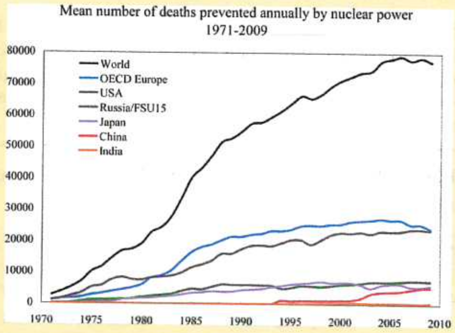
Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power

Pushker A. Kharecha* and James E. Hansen

NASA Goddard Institute for Space Studies and Columbia University Earth Institute, 2880 Broadway, New York, New York 10025, United States

Ⓢ *Supporting Information*

ABSTRACT: In the aftermath of the March 2011 accident at Japan's Fukushima Daiichi nuclear power plant, the future contribution of nuclear power to the global energy supply has become somewhat uncertain. Because nuclear power is an abundant, low-carbon source of base-load power, it could make a large contribution to mitigation of global climate change and air pollution. Using historical production data, we calculate that global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO_2-equivalent ($GtCO_2$-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning. On the basis of global projection data that take into account the effects of the Fukushima accident, we find that nuclear power could additionally prevent an average of 420 000–7.04 million deaths and 80–240 $GtCO_2$-eq emissions due to fossil fuels by midcentury, depending on which fuel it replaces. By contrast, we assess that large-scale expansion of unconstrained natural gas use would not mitigate the climate problem and would cause far more deaths than expansion of nuclear power.



INTRODUCTION

It has become increasingly clear that impacts of unchecked anthropogenic climate change due to greenhouse gas (GHG) emissions from burning of fossil fuels could be catastrophic for both human society and natural ecosystems (in ref 1, see Figures SPM.2 and 4.4) and that the key time frame for mitigating the climate crisis is the next decade or so.[2,3] Likewise, during the past decade, outdoor air pollution due largely to fossil fuel burning is estimated to have caused over 1 million deaths annually worldwide.[4] Nuclear energy (and other low-carbon/carbon-free energy sources) could help to mitigate both of these major problems.[5]

The future of global nuclear power will depend largely on choices made by major energy-using countries in the next decade or so.[6] While most of the highly nuclear-dependent countries have affirmed their plans to continue development of nuclear power after the Fukushima accident, several have announced that they will either temporarily suspend plans for new plants or completely phase out existing plants.[2] Serious questions remain about safety, proliferation, and disposal of radioactive waste, which we have discussed in some detail elsewhere.[7]

Here, we examine the historical and potential future role of nuclear power with respect to prevention of air pollution-related mortality as well as GHG emissions on multiple spatial scales. Previous studies have quantified global-scale avoided GHG emissions due to nuclear power (e.g., refs 5 and 8–10); however, the issue of avoided human deaths remains largely unexplored. We focus on the world as a whole, OECD Europe, and the five countries with the highest annual CO_2 emissions in the last several years. In order, these top five CO_2 emitters are China, the United States, India, Russia, and Japan, accounting for 56% of global emissions from 2009 to 2011.[11] To estimate historically prevented deaths and GHG emissions, we start with data for global annual electricity generation by energy source from 1971 to 2009 (Figure 1). We then apply mortality and GHG emissions factors, defined respectively as deaths and emissions per unit electric energy generated, for relevant electricity sources (Table 1). For the projection period 2010–2050, we base our estimates on recent (post-Fukushima) nuclear power trajectories given by the UN International Atomic Energy Agency (IAEA).[6]

METHODS

Calculation of Prevented Mortality and GHG Impacts.

For the historical period 1971–2009, we assume that all nuclear power supply in a given country and year would instead have been delivered by fossil fuels (specifically coal and natural gas), given their worldwide dominance and the very small contribution of nonhydro renewables to world electricity thus far (Figure 1). There are of course numerous complications involved in trying to design such a replacement scenario (e.g., evolving technological and socioeconomic conditions), and the

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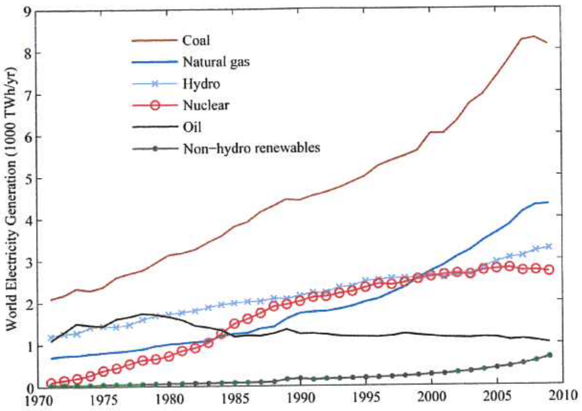

Figure 1. World electricity generation by power source for 1971–2009 (data from ref 14). In the past decade (2000–2009), nuclear power provided an average 15% of world generation; coal, gas, and oil provided 40%, 20%, and 6%, respectively; and renewables provided 16% (hydropower) and 2% (nonhydro).

Table 1. Mortality and GHG Emission Factors Used in This Study[a]

electricity source	mean value (range)	unit[b]	source
coal	28.67 (7.15–114)	deaths/TWh	ref 16
	77 (19.25–308)	deaths/TWh	ref 16 (China)[c]
	1045 (909–1182)	tCO_2-eq/GWh	ref 30
natural gas	2.821 (0.7–11.2)	deaths/TWh	ref 16
	602 (386–818)	tCO_2-eq/GWh	ref 30
nuclear	0.074 (range not given)	deaths/TWh	ref 16
	65 (10–130)[d]	tCO_2-eq/GWh	ref 34

[a] Mortality factors are based on analysis for Europe (except as indicated) and represent the sum of accidental deaths and air pollution-related effects in Table 2 of ref 16. They reflect impacts from all stages of the fuel cycle, including fuel extraction, transport, transformation, waste disposal, and electricity transport. Their ranges are 95% confidence intervals and represent deviation from the mean by a factor of ~4. Mortality factor for coal is the mean of the factors for lignite and coal in ref 16. Mean values for emission factors are the midpoints of the ranges given in the sources. Water pollution is also a significant impact but is not factored into these values. Additional uncertainties and limitations inherent in these factors are discussed in the text. [b] TWh = terawatt hour; GWh = gigawatt hour; tCO_2-eq = tonnes of CO_2-equivalent emissions. [c] Range is not given in source for China, but for consistency with other factors, it is assumed to be 4 times lower and higher than the mean. [d] Some authors contend the upper limit is significantly higher, but their conclusions are based on dubious assumptions.[35]

retroactive energy mix cannot be known with total accuracy and realism; thus, simplifying yet tenable assumptions are necessary and justified.

To determine the proportional substitution by coal and gas in our baseline historical scenario, we first examine the world nuclear reactor properties provided by IAEA.[12] On the basis of typical international values for coal and gas capacity factors (CFs),[13] we then assume that each of the 441 reactors listed in Table 14 of ref 12 with a CF of greater than 65% is replaced by coal and each reactor with a CF of less than or equal to 65% is replaced by gas.

For each country x, we first calculate $P_i(x)$, the power (*not* energy) generated by each reactor i:

$$P_i(x) = CF_i(x) \times C_i(x) \tag{1}$$

where CF_i and C_i denote the reactor capacity factor and net capacity, respectively, listed in Table 14 of ref 12. We then calculate $f_i(x)$, the CF-weighted proportion of generated power by each reactor:

$$f_i(x) = P_i(x) / \sum_i P_i(x) \tag{2}$$

Next, we calculate $F_j(x)$, the total proportion of generated nuclear power replaced by power from fossil fuel j:

$$F_j(x) = \sum_i f_i^{(j)}(x) \tag{3}$$

where $f_i^{(j)}(x)$ simply denotes grouping of all the f_i values by replacement fuel j. For reference, on the global scale, this yields about 95% replacement by coal and 5% by gas in our baseline historical scenario, which we suggest is plausible for the reasons given in the Results and Discussion section. Lastly, we calculate $I(x, t)$, the annual net prevented impacts (mortality or GHG emissions) from nuclear power in country x and year t as follows:

$$I(x, t) = \Sigma_j[IF_j \times F_j(x) \times n(x, t)] - IF_n \times n(x, t) \tag{4}$$

where IF_j is the impact factor for fossil fuel j (from Table 1), $n(x, t)$ is the nuclear power generation (in energy units; from refs 6 and 14), and IF_n is the impact factor for nuclear power (from Table 1). Note that the first term in eq 4 reflects gross avoided impacts, while the second reflects direct impacts of nuclear power.

For the projection period 2010–2050, using eq 4, we calculate human deaths and GHG emissions that could result if all projected nuclear power production is canceled and again replaced only by fossil fuels. Of course, some or most of this hypothetically canceled nuclear power could be replaced by power from renewables, which have generally similar impact factors as nuclear (e.g., see Figure 2 of ref 7). Thus, our results for the projection period should ultimately be viewed as upper limits on potentially prevented impacts from future nuclear power.

We project annual nuclear power production in the regions containing the top five CO_2-emitting countries and Western Europe based on the regional decadal projections in Table 4 of ref 6, which we linearly interpolate to an annual scale. To set $F_j(x)$ in eq 4, we consider two simplified cases for both the global and regional scales. In the first ("all coal"), $F_j(x)$ is fixed at 100% coal, and in the second ("all gas"), it is fixed at 100% gas. This approach yields the full range of potentially prevented impacts from future nuclear power. It is taken here because of the lack of country-specific projections in ref 6 as well as the large uncertainty in determining which fossil fuel(s) could replace *future* nuclear power, given recent trends in electricity production (Figure 1, Figure S3 [Supporting Information], and ref 14).

Methodological Limitations. The projections for nuclear power by IAEA[6] assume essentially no climate-change mitigation measures in the low-end case and aggressive mitigation measures in the high-end case. It is unclear which path the world will follow; however, these IAEA projections *do* take into account the effects of the Fukushima accident. It seems that, except possibly for Japan, the top five CO_2-emitting countries are not planning a phase-down of pre-Fukushima plans for future nuclear power. For instance, China, India, and

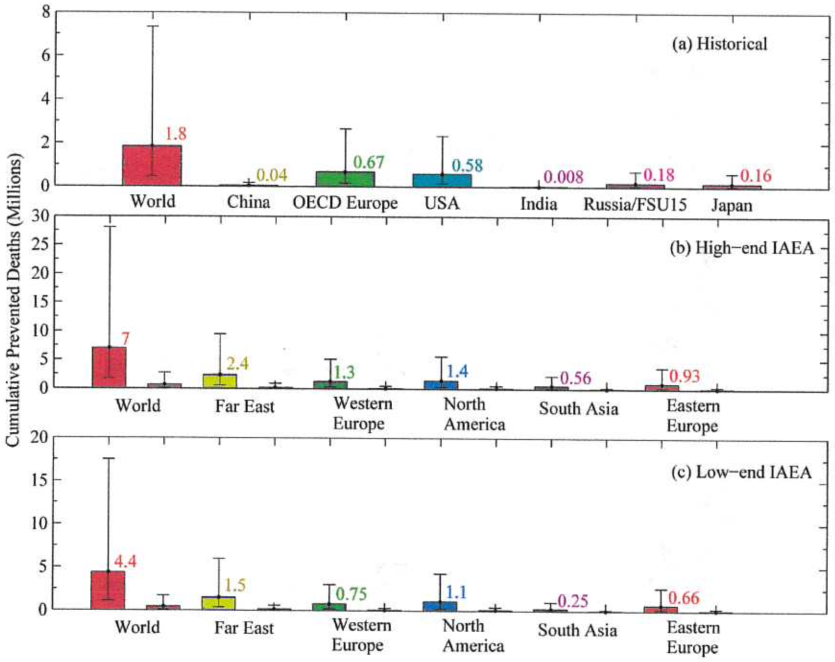

Figure 2. Cumulative net deaths prevented assuming nuclear power replaces fossil fuels. (a) Results for the historical period in this study (1971–2009), showing mean values (labeled) and ranges for the baseline historical scenario. Results for (b) the high-end and (c) low-end projections of nuclear power production by the UN IAEA[6] for the period 2010–2050. Error bars reflect the ranges for the fossil fuel mortality factors listed in Table 1. The larger columns in panels b and c reflect the all coal case and are labeled with their mean values, while the smaller columns reflect the all gas case; values for the latter are not shown because they are all simply a factor of ~10 lower (reflecting the order-of-magnitude difference between the mortality factors for coal and gas shown in Table 1). Countries/regions are arranged in descending order of CO_2 emissions in recent years. FSU15 = 15 countries of the former Soviet Union, and OECD = Organization for Economic Cooperation and Development.

Russia have affirmed plans to increase their current nuclear capacity by greater than 3-fold, greater than 12-fold, and 2-fold, respectively (see Table 12.2 of ref 2). In Japan, the future of nuclear power now seems unclear; in the fiscal year following the Fukushima accident, nuclear power generation in Japan decreased by 63%, while fossil fuel power generation increased by 26% (ref 15), thereby almost certainly increasing Japan's CO_2 emissions.

Although our analysis reflects mortality from all stages of the fuel cycle for each energy source, it excludes serious illnesses, including respiratory and cerebrovascular hospitalizations, chronic bronchitis, congestive heart failure, nonfatal cancers, and hereditary effects. For fossil fuels, such illnesses are estimated to be approximately 10 times higher than the mortality factors in Table 1, while for nuclear power, they are ~3 times higher.[16] Another important limitation is that the mortality factors exclude the impacts of anthropogenic climate change and development-related differences, as explained in the Results and Discussion section. Aspects of nuclear power that cannot meaningfully be quantified due to very large uncertainties (e.g., potential mortality from proliferation of weapons-grade material) are also not included in our analysis.

Proportions of fossil fuels in our projection cases are assumed to be fixed (for the purpose of determining upper and lower bounds) but will almost certainly vary across years and decades, as in the historical period (Figure 1). The dominance of coal in the global average electricity mix seems likely for the near future though (e.g., Figure 5.2 of ref 2). However, even if there is large-scale worldwide electric fuel switching from coal to gas, our assessment is that the ultimate GHG savings from such a transition are unlikely to be sufficient to minimize the risk of dangerous anthropogenic climate change (unless the resulting emissions are captured and stored), as discussed in the next section.

■ RESULTS AND DISCUSSION

Mortality. We calculate a mean value of 1.84 million human deaths prevented by world nuclear power production from 1971 to 2009 (see Figure 2a for full range), with an average of 76 000 prevented deaths/year from 2000 to 2009 (range 19 000–300 000). Estimates for the top five CO_2 emitters, along with full estimate ranges for all regions in our baseline historical scenario, are also shown in Figure 2a. For perspective, results for upper and lower bound scenarios are shown in Figure S1 (Supporting Information). In Germany, which has announced plans to shut down all reactors by 2022 (ref 2), we calculate that nuclear power has prevented an average of over 117 000 deaths from 1971 to 2009 (range 29 000–470 000). The large ranges stem directly from the ranges given in Table 1 for the mortality factors.

Our estimated human deaths *caused* by nuclear power from 1971 to 2009 are far lower than the avoided deaths. Globally, we calculate 4900 such deaths, or about 370 times lower than our result for avoided deaths. Regionally, we calculate approximately 1800 deaths in OECD Europe, 1500 in the United States, 540 in Japan, 460 in Russia (includes all 15 former Soviet Union countries), 40 in China, and 20 in India. About 25% of these deaths are due to occupational accidents, and about 70% are due to air pollution-related effects

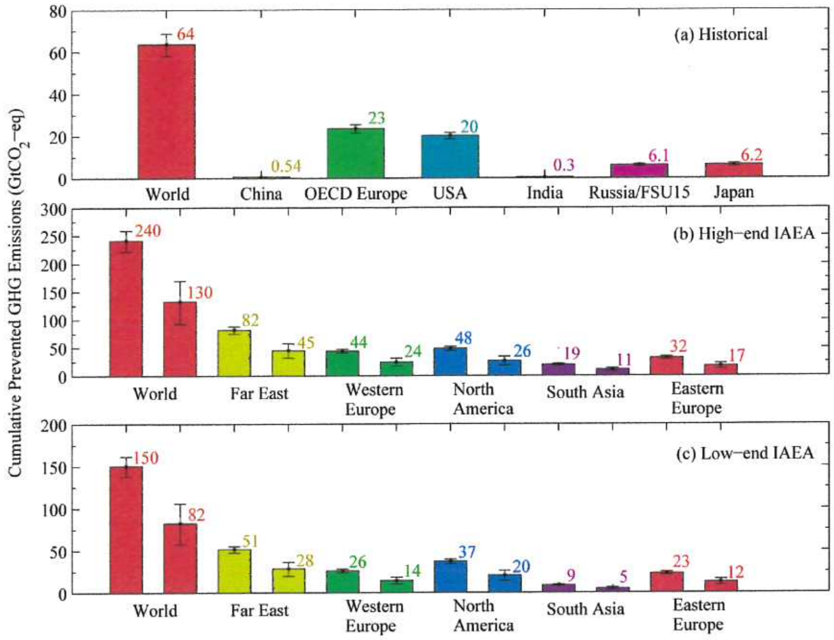

Figure 3. Cumulative net GHG emissions prevented assuming nuclear power replaces fossil fuels. Same panel arrangement as Figure 2, except mean values for all cases are labeled. Error bars reflect the ranges for the fossil fuel emission factors listed in Table 1.

(presumably fatal cancers from radiation fallout; see Table 2 of ref 16).

However, empirical evidence indicates that the April 1986 Chernobyl accident was the world's only source of fatalities from nuclear power plant radiation fallout. According to the latest assessment by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR),[17] 43 deaths are conclusively attributable to radiation from Chernobyl as of 2006 (28 were plant staff/first responders and 15 were from the 6000 diagnosed cases of thyroid cancer). UNSCEAR[17] also states that reports of an increase in leukemia among recovery workers who received higher doses are inconclusive, although cataract development was clinically significant in that group; otherwise, for these workers as well as the general population, "there has been no persuasive evidence of any other health effect" attributable to radiation exposure.[17]

Furthermore, no deaths have been conclusively attributed (in a scientifically valid manner) to radiation from the other two major accidents, namely, Three Mile Island in March 1979, for which a 20 year comprehensive scientific health assessment was done,[18] and the March 2011 Fukushima Daiichi accident. While it is too soon to meaningfully assess the health impacts of the latter accident, one early analysis[19] indicates that annual radiation doses in nearby areas were much lower than the generally accepted 100 mSv threshold[17] for fatal disease development. In any case, our calculated value for global deaths caused by historical nuclear power (4900) could be a major overestimate relative to the empirical value (by 2 orders of magnitude). The absence of evidence of large mortality from past nuclear accidents is consistent with recent findings[20,21] that the "linear no-threshold" model used to derive the nuclear mortality factor in Table 1 (see ref 22) might not be valid for the relatively low radiation doses that the public was exposed to from nuclear power plant accidents.

For the projection period 2010–2050, we find that, in the all coal case (see the Methods section), an average of 4.39 million and 7.04 million deaths are prevented globally by nuclear power production for the low-end and high-end projections of IAEA,[6] respectively. In the all gas case, an average of 420 000 and 680 000 deaths are prevented globally (see Figure 2b,c for full ranges). Regional results are also shown in Figure 2b,c. The Far East and North America have particularly high values, given that they are projected to be the biggest nuclear power producers (Figure S2, Supporting Information). As in the historical period, calculated deaths caused by nuclear power in our projection cases are far lower (2 orders of magnitude) than the avoided deaths, even taking the nuclear mortality factor in Table 1 at face value (despite the discrepancy with empirical data discussed above for the historical period).

The substantially lower deaths in the projected all gas case follow simply from the fact that gas is estimated to have a mortality factor an order of magnitude lower than coal (Table 1). However, this does not necessarily provide a valid argument for such large-scale "fuel switching" for mitigation of either climate change or air pollution, for several reasons. First, it is important to bear in mind that our results for prevented mortality are likely conservative, because the mortality factors in Table 1 do not incorporate impacts of ongoing or future anthropogenic climate change.[16] These impacts are likely to become devastating for both human health and ecosystems if recent global GHG emission trends continue.[1,3] Also, potential global natural gas resources are enormous; published estimates for technically recoverable unconventional gas resources suggest a carbon content ranging from greater than 700 $GtCO_2$ (based on refs 23 and 24) to greater than 17 000 $GtCO_2$ (based on refs 24 and 25). While we acknowledge that natural gas might play an important role as a "transition" fuel to a clean-energy era due to its lower mortality (and emission) factor relative to coal, we stress that long-term, widespread use of natural gas (without accompanying carbon capture and storage) could lead to unabated GHG emissions for many decades, given the typically multidecadal lifetime of energy infrastructure, thereby greatly complicating climate change mitigation efforts.

GHG Emissions. We calculate that world nuclear power generation prevented an average of 64 gigatonnes of CO_2-equivalent ($GtCO_2$-eq), or 17 GtC-eq, cumulative emissions from 1971 to 2009 (Figure 3a; see full range therein), with an average of 2.6 $GtCO_2$-eq/year prevented annual emissions from 2000 to 2009 (range 2.4−2.8 $GtCO_2$/year). Regional results are also shown in Figure 3a. Our global results are 7−14% lower than previous estimates[8,9] that, among other differences, assumed all historical nuclear power would have been replaced only by coal, and 34% higher than in another study[10] in which the methodology is not explained clearly enough to infer the basis for the differences. Given that cumulative and annual global fossil fuel CO_2 emissions during the above periods were 840 $GtCO_2$ and 27 $GtCO_2$/year, respectively,[11] our mean estimate for cumulative prevented emissions may not appear substantial; however, it is instructive to look at other quantitative comparisons.

For instance, 64 $GtCO_2$-eq amounts to the cumulative CO_2 emissions from coal burning over approximately the past 35 years in the United States, 17 years in China, or 7 years in the top five CO_2 emitters.[11] Also, since a 500 MW coal-fired power plant typically emits 3 $MtCO_2$/year,[26] 64 $GtCO_2$-eq is equivalent to the cumulative lifetime emissions from almost 430 such plants, assuming an average plant lifetime of 50 years. It is therefore evident that, without global nuclear power generation in recent decades, near-term mitigation of anthropogenic climate change would pose a much greater challenge.

For the projection period 2010−2050, in the all coal case, an average of 150 and 240 $GtCO_2$-eq cumulative global emissions are prevented by nuclear power for the low-end and high-end projections of IAEA,[6] respectively. In the all gas case, an average of 80 and 130 $GtCO_2$-eq emissions are prevented (see Figure 3b,c for full ranges). Regional results are also shown in Figure 3b,c. These results also differ substantially from previous studies,[9,10] largely due to differences in nuclear power projections (see the Supporting Information).

To put our calculated overall mean estimate (80−240 $GtCO_2$-eq) of potentially prevented future emissions in perspective, note that, to achieve a 350 ppm CO_2 target near the end of this century, cumulative "allowable" fossil CO_2 emissions from 2012 to 2050 are at most ~500 $GtCO_2$ (ref 3). Thus, projected nuclear power could reduce the climate-change mitigation burden by 16−48% over the next few decades (derived by dividing 80 and 240 by 500).

Uncertainties. Our results contain various uncertainties, primarily stemming from our impact factors (Table 1) and our assumed replacement scenarios for nuclear power. In reality, the impact factors are not likely to remain static, as we (implicitly) assumed; for instance, emission factors depend heavily on the particular mix of energy sources. Because our impact factors neglect ongoing or projected climate impacts as well as the significant disparity in pollution between developed and developing countries,[16] our results for both avoided GHG emissions and avoided mortality could be substantial underestimates. For example, in China, where coal burning accounts for over 75% of electricity generation in recent decades (ref 14; Figure S3, Supporting Information), some coal-fired power plants that meet domestic environmental standards have a mortality factor almost 3 times higher than the mean global value (Table 1). These differences related to development status will become increasingly important as fossil fuel use and GHG emissions of developing countries continue to outpace those of developed countries.[11]

On the other hand, if coal would not have been as dominant a replacement for nuclear as assumed in our baseline historical scenario, then our avoided historical impacts could be overestimates, since coal causes much larger impacts than gas (Table 1). However, there are several reasons this is unlikely. Key characteristics of coal plants (e.g., plant capacity, capacity factor, and total production costs) are historically much more similar to nuclear plants than are those of natural gas plants.[13] Also, the vast majority of existing nuclear plants were built before 1990, but advanced gas plants that would be suitable replacements for base-load nuclear plants (i.e., combined-cycle gas turbines) have only become available since the early 1990s.[13] Furthermore, coal resources are highly abundant and widespread,[24,25] and coal fuel and total production costs have long been relatively low, unlike historically available gas resources and production costs.[13] Thus, it is not surprising that coal has been by far the dominant source of global electricity thus far (Figure 1). We therefore assess that our baseline historical replacement scenario is plausible and that it is not as significant an uncertainty source as the impact factors; that is, our avoided historical impacts are more likely underestimates, as discussed in the above paragraph.

Implications. More broadly, our results underscore the importance of avoiding a false and counterproductive dichotomy between reducing air pollution and stabilizing the climate, as elaborated by others.[27−29] If near-term air pollution abatement trumps the goal of long-term climate protection, governments might decide to carry out future electric fuel switching in even more climate-impacting ways than we have examined here. For instance, they might start large-scale production and use of gas derived from coal ("syngas"), as coal is by far the most abundant of the three conventional fossil fuels.[24,25] While this could reduce the very high pollution-related deaths from coal power (Figure 2), the GHG emissions factor for syngas is substantially higher (between ~5% and 90%) than for coal,[30] thereby entailing even higher electricity sector GHG emissions in the long term.

In conclusion, it is clear that nuclear power has provided a large contribution to the reduction of global mortality and GHG emissions due to fossil fuel use. If the role of nuclear power significantly declines in the next few decades, the International Energy Agency asserts that achieving a target atmospheric GHG level of 450 ppm CO_2-eq would require "heroic achievements in the deployment of emerging low-carbon technologies, which have yet to be proven. Countries that rely heavily on nuclear power would find it particularly challenging and significantly more costly to meet their targeted levels of emissions."[2] Our analysis herein and a prior one[7] strongly support this conclusion. Indeed, on the basis of combined evidence from paleoclimate data, observed ongoing climate impacts, and the measured planetary energy imbalance, it appears increasingly clear that the commonly discussed targets of 450 ppm and 2 °C global temperature rise (above preindustrial levels) are insufficient to avoid devastating climate impacts; we have suggested elsewhere that more appropriate targets are less than 350 ppm and 1 °C (refs 3 and 31−33). Aiming for these targets emphasizes the importance of retaining and expanding the role of nuclear power, as well as energy efficiency improvements and renewables, in the near-term global energy supply.

■ ASSOCIATED CONTENT

Supporting Information

Comparison with avoided GHG emissions in projection periods of prior studies; figures showing upper and lower bounds for prevented deaths and GHG emissions assuming nuclear power replaces fossil fuels from 1971−2009, projections of nuclear power production by region, and total electricity production from 1971−2009 by fuel source for the top five CO_2-emitting countries and OECD Europe. This material is available free of charge via the Internet at http://pubs.acs.org.

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Author Contributions

P.K. designed the study with input from J.H.; P.K. performed the calculations and analysis and wrote the paper with feedback from J.H.

Notes

The authors declare no competing financial interest.

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State by State, 2014

State	Sulfur Dioxide (Short Tons)	Nitrogen Oxides (Short Tons)	Carbon Dioxide (Million Metric Tons)
Alabama	65,057	27,095	33.55
Arizona	10,184	26,613	24.07
Arkansas	15,746	11,562	10.00
California	38	471	6.87
Connecticut	3,091	2,839	7.77
Florida	13,526	8,576	16.03
Georgia	40,048	15,712	23.05
Illinois	180,124	75,180	79.96
Iowa	7,203	4,444	4.12
Kansas	10,920	5,901	7.32
Louisiana	18,823	13,822	11.96
Maryland	26,877	11,361	11.52
Massachusetts	1,126	1,034	2.83
Michigan	62,157	24,671	26.85
Minnesota	22,042	13,599	12.61
Mississippi	11,038	8,105	7.01
Missouri	14,067	4,961	8.84
Nebraska	17,523	10,811	10.03
New Hampshire	1,984	1,823	4.99
New Jersey	59,038	24,957	25.31
New York	10,717	10,525	21.45
North Carolina	22,046	18,050	29.95
Ohio	34,830	12,804	15.17
Pennsylvania	147,496	62,350	63.23
South Carolina	28,209	23,096	38.33
Tennessee	48,867	20,798	24.10
Texas	42,713	13,470	27.64
Vermont	988	907	2.48
Virginia	16,263	13,315	22.10
Washington	4,574	5,847	7.08
Wisconsin	20,206	7,428	8.80
Total	957,521	482,130	595.03

Source: Emissions avoided by nuclear power are calculated using regional fossil fuel emissions rates from the Environmental Protection Agency and plant generation data from the Energy Information Administration.
Updated: 5/15

PUBLIC TESTIMONY OF AL GEDICKS BEFORE THE SENATE COMMITTEE ON NATURAL RESOURCES AND ENERGY ON TUESDAY, JANUARY 5, 2016;

RE: SENATE BILL 288
RELATING TO REQUIREMENTS FOR APPROVAL AND CONSTRUCTION OF NUCLEAR POWER PLANTS AND CHANGES TO THE STATE'S ENERGY PRIORITIES POLICY. BY SENATORS LASEE AND WANGGAARD.

My name is Al Gedicks and I am an environmental sociologist and professor emeritus at the University of Wisconsin-La Crosse. I have written extensively about the impact of past uranium mining on Native American communities. I am also the executive secretary of the Wisconsin Resources Protection Council, a statewide environmental organization.

My main concern about Senate Bill 288 is that it is seeks to promote a technology that is not affordable and is a barrier to a clean-energy future, not a part of it. Furthermore, **if Wisconsin's common sense moratorium on new nuclear power plants is repealed, the U.S. Department of Energy (DOE) will have all the more reason to reconsider the Wolf River Batholith as a permanent nuclear waste repository.**

The idea that nuclear power is **clean defies common sense**. Would a truly "clean energy" source produce "**one of the most hazardous substances on earth**" according to the U.S. Government Accountability Office?[1] Of course not.

The argument that nuclear power is affordable is not supported by the evidence. The Toshiba-Westinghouse AP 1000 reactors under construction at Southern Company's Plant Vogtle and SCANA's VC Summer at South Carolina are at least 39 months delayed, with more delays expected. They are also billions of dollars over budget. Plant Vogtle was originally estimated at $14 billion for two reactors and is now nearly $21 billion. Many of Vogtle's critics are retirees who live on Social Security benefits who have told the Public

Service Commission how much they are hurt by rising power bills. "I'll be dead before I get any of the benefits from the reactors, which I didn't want in the first place," said Gloria Tatum at a recent hearing.[2]

The lead-time for new nuclear plants is 10 to 15 years, too late in the battle to forestall global warming. Nuclear power, not matter the reactor design, **cannot address climate change in time.** Renewables are faster to deploy and can provide low-carbon power more cheaply than nuclear and **without the dangers of nuclear waste.**

A recent report from Dr. Arjun Makhijani at the Institute for Energy and Environmental Research emphasizes that:

> ***An objective assessment of the facts leads to the clear conclusion that nuclear power is already economically obsolete, quite apart from a number of other considerations. The same amount of money can produce far greater CO2 reductions with wind and solar energy than with nuclear. The time-related financial and climate risks (delayed, costly, and cancelled plants) of nuclear power also point in the same direction.***[3]

These are just some of the most obvious and compelling reasons to preserve Wisconsin's common sense nuclear power moratorium. Less obvious but just as if not more compelling is the message that this legislation will be sending to the U.S. Department of Energy (DOE) at the precise moment when the DOE is launching a so-called "consent-based process" to site an underground repository for high-level nuclear waste in the aftermath of the failed attempt to site such a repository at Yucca Mountain, Nevada, in part because of the State~~'s~~ of Nevada's opposition to that proposed disposal facility. Nine states have banned the construction of new reactors until the waste problem is solved or until substantial progress is made on the issue.[4]

The DOE is desperate to find a host for a permanent geologic repository for nuclear waste and Wisconsin is high on the list of potential sites because of the granite bedrock of the Wolf River Batholith in northeastern Wisconsin.[5] In the 1980s the DOE ranked Wisconsin's Wolf River Batholith as Number Two for a second high-level nuclear waste repository.[6] The proposed area for the facility would encompass 1,024 square miles and extend over seven counties, including Langlade, Shawano, Waupaca, Menominee, Portage, Marathon and Oconto counties, and the land of three tribes (Stockbridge-Munsee, Menominee and Ho-Chunk).

Groundwater movement in the granite could carry harmful radioactive ~~waste~~ contaminants into drinking water. Radioactive contaminated water would then flow from the Wolf River into the Fox River, which connects to Lake Winnebago and Green Bay, putting the people and the environment in this area at risk. Wisconsin citizens and Indian tribes were overwhelmingly opposed to becoming nuclear guinea pigs for the DOE. In a 1983 statewide referendum, **89% voted against a nuclear waste disposal site in Wisconsin.**[7] In January 1986 the DOE conducted several public hearings in the potentially affected communities. After massive public opposition at the public hearings the DOE said it would indefinitely postpone the search for the second nuclear waste site.

This legislation ignores the entire history of Wisconsin citizen and tribal opposition to a nuclear waste repository in the state. Have the representatives and senators that have signed on to this bill consulted their constituents in potentially affected communities about becoming a host for a nuclear waste repository?[8] Because that is a much more likely outcome for Wisconsin than ever seeing a new nuclear reactor being built and becoming operational.

A typical nuclear reactor will generate 20 to 30 tons of high-level nuclear waste annually. Regardless of what the nuclear industry and its proponents say, There is no known way to safely dispose of this waste, which remains dangerously radioactive for thousands of years. The only existing geologic repository for nuclear waste in this country is the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. Until quite recently, this site was considered **the model of safe nuclear waste storage.** But On Valentine's Day 2014, plutonium and other radioactive elements were accidentally released into the atmosphere from the WIPP Site. One millionth of a gram of plutonium, if inhaled into your lungs, can cause lung cancer. "What makes this event so disturbing," said Robert Alvarez, a nuclear waste expert and a former assistant to the energy secretary, "is that radiation went half a mile up the shaft into the open environment. Twenty two workers were exposed to small amounts of radiation."[9] The plant has been shut down since the accident.

There is no good reason to expose Wisconsin communities and Indian tribes to the risks of radioactive contamination when there are nuclear and carbon-free renewable energy technologies that are truly cleaner, safer, faster and cheaper. Let's not repeal the Nuclear Moratorium Law simply because the nuclear industry can't or won't play by the common sense rules that have protected Wisconsin citizens for 33 years.

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[1] U.S. Government Accountability Office (GAO), *Commercial Nuclear Waste: Effects of a Termination of the Yucca Mountain Repository Program and Lessons Learned.* Washington, DC, April 2011.

[2] Tom Crawford, "Georgians, get ready for a power bill sticker shock," *GainesvilleTimes.com* December 16, 2015.

[3] Arjun Makhijani, "Short paper on Nuclear Power and Low-Carbon Alternatives," Prepared for the Nuclear Fuel Cycle Royal Commission Public Session, October 1, 2015, Institute for Energy and Environmental Research, Takoma Park, MD.

[4] Matthew Wald, "Revamped Search Urged For a Nuclear Waste Site," *New York Times*, January 27, 2012; "US DOE Plans to Launch Consent-Based Process to Site Nuclear Waste Facilities," Platts, McGraw Hill Financial, December 21, 2015.

[5] Tammy Rauen, *Perspectives for a High-Level Nuclear Waste Facility in Wisconsin.* Clean Wisconsin, 2003.

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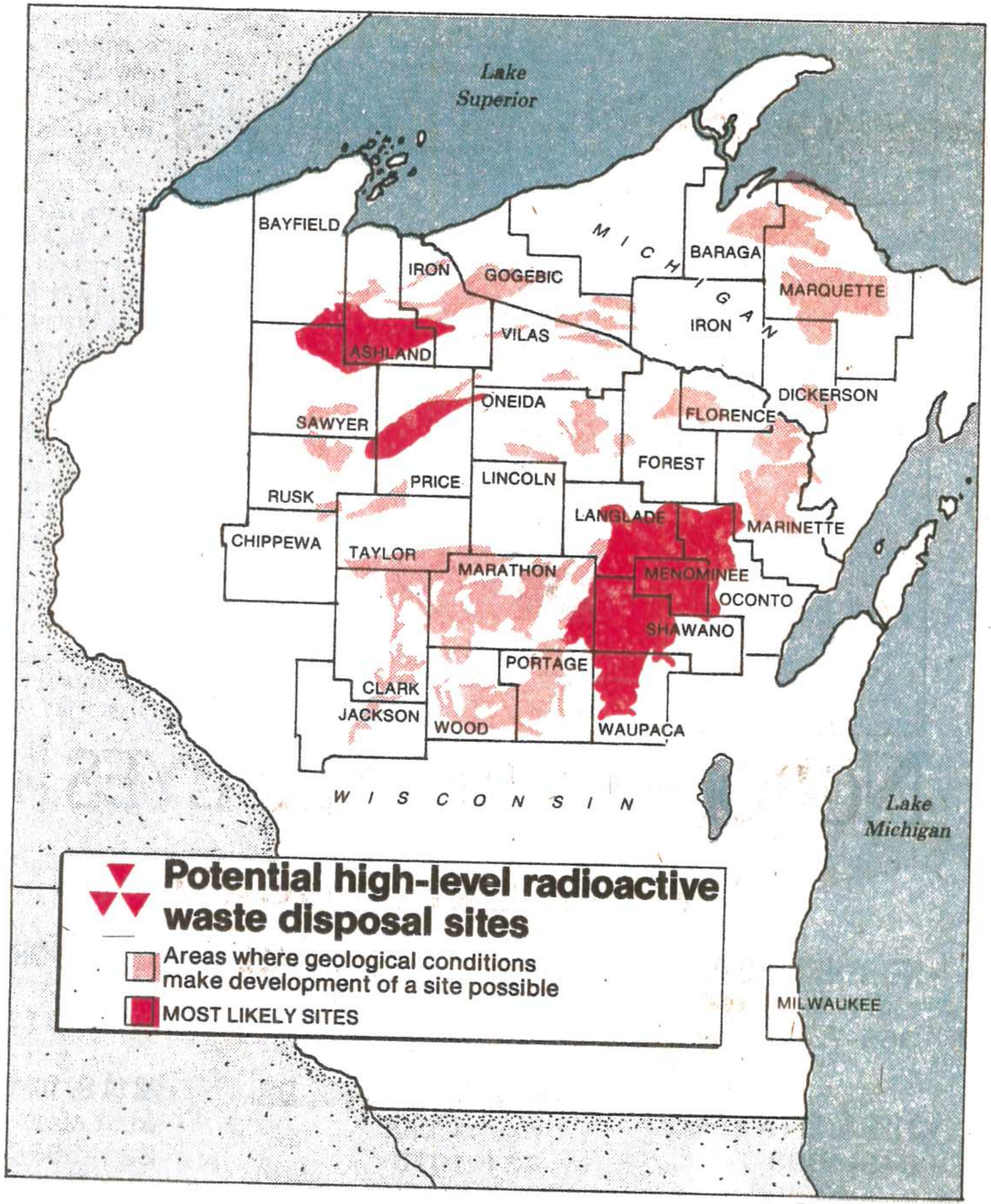
[6] Quincy Dadisman, "3 areas in state cited as likely A-waste sites," *Milwaukee Sentinel*, March 9, 1984; Dames and Moore, *Crystalline Intrusions in the U.S. and Regional Geologic Characteristics Important for Storage of Radioactive Waste*. Cincinnati, OH, December, 1979.

[7] Wisconsin Blue Book, 1983-1984, p. 875. Ballot Question: "Do you support the construction of a national or regional high-level radioactive waste disposal site in Wisconsin?"

[8] For example, Rep.Kevin Petersen from Waupaca County? Rep. John Macco from the Green Bay area? Rep. Bob Kulp from Marathon County?

[9] Matthew Wald, "In U.S. Cleanup Efforts, Accident at Nuclear Site Points to Cost of Lapses," *New York Times*, October 30, 2014.



—By a Sentinel artist

3 areas in state cited as likely A-waste sites

By Quincy Dadisman

Hard rock formations in 24 counties in Wisconsin and 5 counties in Upper Michigan have been identified by the US Department of Energy as possible sites for disposing of high-level radioactive waste, government documents show.

Three of the sites in Wisconsin appear to be strong possibilities for waste burial plots, geologists and official reports indicate.

The geologists who were interviewed based their speculation on the belief that any site must be on rock that spreads over at least 36 square miles.

Also, the site must not be too close to an earthquake fault line, a spot where rock is cracked.

In interviews with a Milwaukee Sentinel reporter, the geologists said the formations they see as potential sites are:

- The megmatite complex of northern Wisconsin, a block of rock extending from north-central Sawyer County and southern Bayfield County into Ashland and Iron Counties.
- The northern Wisconsin granitic complex, extending from northeastern Rusk County across northern Price County.
- The Wolf River batholith, which underlies parts of Langlade, Marathon, Marinette, Menominee, Oconto, Portage, Shawano and Waupaca Counties.

The site eventually selected from areas in the eastern third of the United States with crystalline rock formations will be used for the nation's second disposal facility for high-level wastes from nuclear reactors.

Battelle Memorial Institute, a research firm in Columbus, Ohio, is the principal consultant to the Energy Department in the search. Battelle is now analyzing geological maps and records.

Waste Turn to Page 15

Milw Sentinel March 9, 1984

TESTIMONY OF LAUREN AZAR IN SUPPORT OF WI AB 384/SB 288
JANUARY 5, 2016

I am Lauren Azar and am here to testify in support of AB 384/SB 288. New nuclear power – if it is safe and well run – must be available to Wisconsin for its changing generation portfolio. I am speaking on my own behalf and am not being compensated for this testimony.

Governor Doyle appointed me to the Public Service Commission of Wisconsin in 2007. I had the pleasure of serving as a Commissioner from 2007 to 2011. In 2011, I moved to Washington D.C. and became the Senior Advisor to the Secretary of the United States Department of Energy (DOE). I advised Secretary Steven Chu from 2011 to 2013. In 2013, I moved back to Madison where I opened both a law firm and consulting firm serving clients nationwide in the electric industry.

I have long supported safe, nuclear power for electricity generation:

- In 2004, I represented Dominion Resources in its purchase of the Kewaunee Nuclear Power Plant;
- As a Commissioner, in 2007, I was the sole vote against the sale of the Point Beach Nuclear Power Plant from WE Energies to a merchant owner. I voted against the sale, not because I disliked nuclear power. To the contrary, I voted against the sale because I believed we needed more protections to ensure this valuable asset would remain operational in Wisconsin. (Of course, in 2013, the Kewaunee Nuclear Plant shutdown because it was no longer profitable to operate);
- I have toured Areva's nuclear waste recycling facility in Normandy, France; and
- I have also toured ITER, which is a nuclear fusion reactor being built in France by a consortium of seven countries including the United States.

Power plants emit about 37% of the all carbon dioxide emissions in the United States. Along with renewable energy, nuclear power is a powerful tool in combating climate change. Accordingly, AB 384/SB 288's proposed change to Wisconsin's Energy Priorities Law—inserting advanced nuclear energy after renewable resources but before non-renewable resources—is appropriate.

The language of Wisconsin's existing law on nuclear power suggests that Legislators, in 1983, were concerned about storing nuclear waste in Wisconsin. While there is no centralized nuclear waste storage facility in the United States, the waste from Wisconsin's three nuclear reactors is being stored safely on site. In 2013, DOE announced that it would work on building a series of consolidated interim storage facilities (CISF) until a permanent underground disposal facility is ready. One CISF is proposed in New Mexico and is expected to be operational by April 2020. Areva plans to submit an application in 2016 for another CISF, which would be located in Texas. In addition to CISF's, new types of nuclear reactors-- such as molton salt reactors-- are being designed that would utilize existing nuclear waste as the fuel for the reactor. In short, the storage of nuclear waste should not be an impediment to developing new nuclear generators in Wisconsin.

I am, perhaps, most excited about the potential development of small modular nuclear reactors (SMRs) in Wisconsin. SMRs (300 MWs or less) are small factory-fabricated reactors that can be transported by truck or rail. SMRs are scalable and require less initial capital investment than traditional nuclear. Developers are hopeful that SMRs will be available for commercial operation within a decade.

In sum, I urge the Legislature to pass AB 384/SB 288. Wisconsin needs as much flexibility as possible in the face of a rapidly changing generation portfolio. Nuclear is a strong, safe, and carbon-free source of electricity.

WMC
WISCONSIN MANUFACTURERS & COMMERCE

To: Senate Committee on Natural Resources and Energy
From: Lucas Vebber, Director of Environmental and Energy Policy – WMC
Date: January 5, 2016
RE: Testimony in Favor of Senate Bill 288

Chairman Cowles and Committee Members:

Thank you for the opportunity to testify today. My name is Lucas Vebber and I am the Director of Environmental and Energy Policy at Wisconsin Manufacturers and Commerce (WMC). WMC is the state's chamber of commerce and manufacturers' association. We have almost 4,000 members of all sizes and across all sectors of the state's economy. One in four private sector employees in Wisconsin works for a WMC member company. WMC is dedicated to making Wisconsin the most competitive state in the nation. I am here today to testify in favor of Senate Bill (SB) 288.

SB 288 would repeal our Wisconsin's more than 30-year-old "nuclear moratorium" law, which has, in effect, prevented the building of any new nuclear facilities in our state for the past three decades. Given the mandates coming at us from the federal level, namely the EPA's "Clean Power Plan" (CPP),this issue has taken on added importance. Now, more than ever, Wisconsin must have a serious conversation about the future of energy generation in our state, and unless the moratorium is repealed, nuclear power cannot be a part of that conversation.

Why is this issue so urgent now? Wisconsin generates more than 60% of our state's energy from coal power. Under the CPP, we will need to reduce carbon emissions by more than 40%. To meet that stringent goal we will have to replace coal with lower-carbon alternatives. Despite earlier drafts of the CPP, the final rule discourages natural gas and puts a heavy emphasis on renewable energy sources like wind and solar, and nuclear. Wind and solar alone are simply unable to meet the demands of Wisconsin's energy users and cannot be considered a substitute for the efficient and effective baseload power that coal currently provides. If the sun stops shining or wind stops blowing, the lights will literally go out. Without the ability to ramp up coal plants to meet demand, Wisconsin needs reliable baseload power solutions for the future, which nuclear power could provide.

Through all of this, I need to be clear: nuclear power is not a silver bullet. It is more expensive than other energy sources, and comes with its own unique set of challenges. Passing this bill does not mean that shovels will go in the ground to begin building new nuclear facilities next week, or that the lengthy regulatory process for approving a nuclear facility is changed in any way. However, Wisconsin needs to have a serious conversation about the future of energy generation, and nuclear power must at the very least be a part of that conversation. Nuclear is not our only compliance option for the CPP, but it certainly should be considered and compared against the alternatives to determine what is in the best interests of Wisconsin over the long term.

Thank you very much for the opportunity to testify today, I would be happy to answer any questions that committee members may have.

Wisconsin Senate
Committee on Natural Resources and Energy
c/o Senator Robert L. Cowles, Chair
Wisconsin Senate
Room 118 South
State Capitol
Madison, WI 53707-7882

5 January 2016

Dear Sen. Cowles and other members of the Committee on Natural Resources and Energy:

For the past several years, I've served as a citizen chair for two air quality/emissions and energy work groups in the Capital area. This is a complex public policy area. At one point, the first work group (2011-13) was asked to check into nuclear power and related emerging technologies (e.g., Small Modular Reactors or SMRs), technical areas that lie outside my professional training. In addition to internet research by staff to the work group, input was sought from relevant experts, here and abroad.

Your committee could possibly also benefit from the research of one of those experts: Michael Dittmar. Dr. Dittmar's advice was important in shaping the local work group's recommendations of the work group. Those recommendations were eventually endorsed over 40 partners from both non-profit and for-profit sectors.

The recommendations that were endorsed in turn became the framework for a second work group that I am also chairing (2014-present). We are currently reviewing an expert (university) contractor's final report on county-level baseline inventories for air emissions, conservation/efficiency opportunities, and renewable energy opportunities.

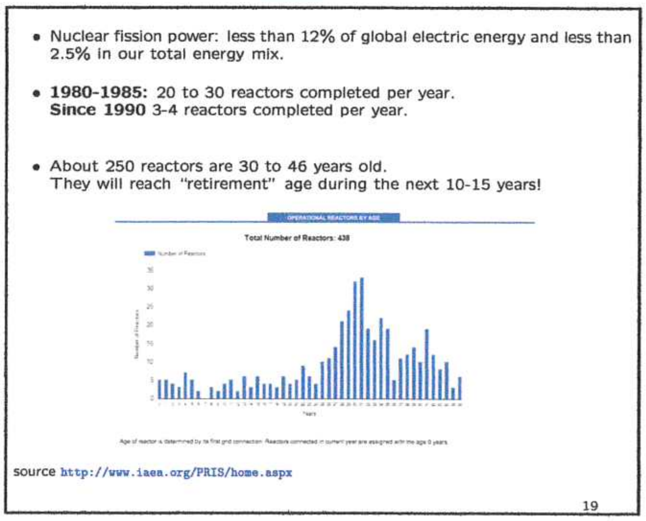
Dr. Dittmar is a researcher with the Institute of Particle Physics of ETH Zurich, who also works at CERN (*Conseil Européen pour la Recherché Nucléaire* / European Organization for Nuclear Research) in Geneva. He is the author of scholarly articles and other publications on nuclear fission and fusion, including the availability of relevant fuels (e.g., uranium). His publications include a AUG-NOV 2009 four-part series titled The Future of Nuclear Energy: Facts and Fiction [http://www.theoildrum.com/tag/michael_dittmar]:

Part I: Nuclear Energy Fission Today
Part II: What Is Known About Secondary Uranium Resources?
Part III: How (un)Reliable Are the Red Book Uranium Resource Data?
Part IV: Energy from Breeder Reactors and from Fusion?

Here are a few links to a few more recent articles by Dr. Dittmar:

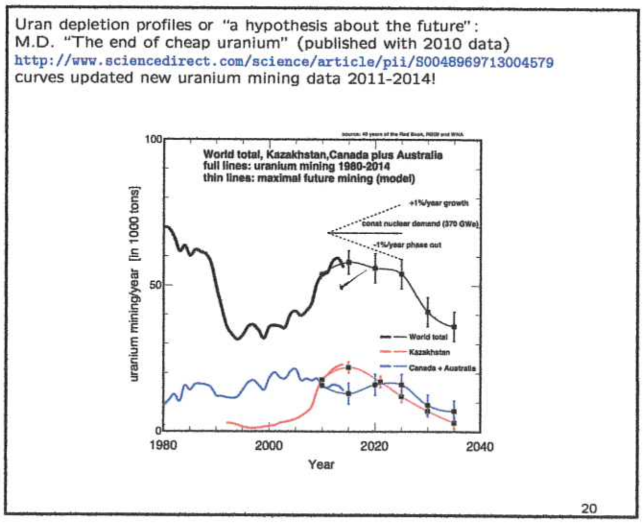
http://www.theguardian.com/environment/cif-green/2010/aug/16/nuclear-energy-renaissance
http://go-nuclear.org/2013-10-30-08-35-57/item/740-future-of-nuclear-energy-facts-fiction-michael-dittmar
http://www.technologyreview.com/view/416325/the-coming-nuclear-crisis/
http://ihp-lx2.ethz.ch/energy21/Riotalk_October2015.pdf
http://ihp-lx2.ethz.ch/energy21/STOTEN14690.pdf

Here are three graphics from Dr. Dittmar's recent presentations, showing the future of uranium availability:

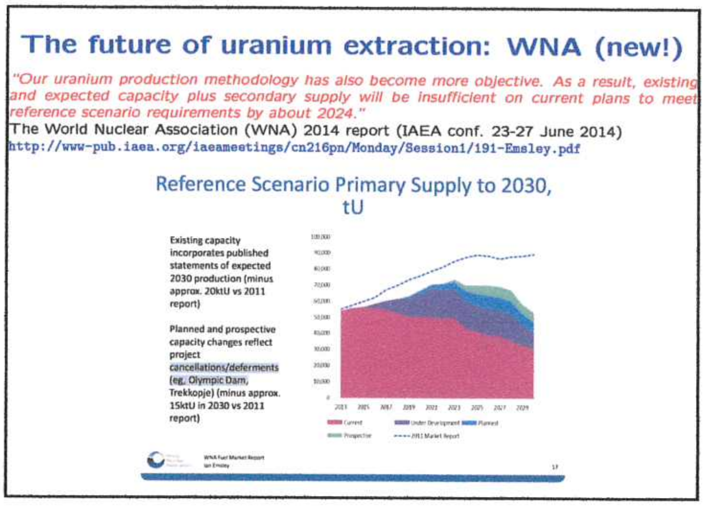


- Nuclear fission power: less than 12% of global electric energy and less than 2.5% in our total energy mix.
- **1980-1985:** 20 to 30 reactors completed per year.
  Since 1990 3-4 reactors completed per year.
- About 250 reactors are 30 to 46 years old.
  They will reach "retirement" age during the next 10-15 years!

source http://www.iaea.org/PRIS/home.aspx



Uran depletion profiles or "a hypothesis about the future":
M.D. "The end of cheap uranium" (published with 2010 data)
http://www.sciencedirect.com/science/article/pii/S0048969713004579
curves updated new uranium mining data 2011-2014!



The future of uranium extraction: WNA (new!)

"Our uranium production methodology has also become more objective. As a result, existing and expected capacity plus secondary supply will be insufficient on current plans to meet reference scenario requirements by about 2024."

The World Nuclear Association (WNA) 2014 report (IAEA conf. 23-27 June 2014)

http://www-pub.iaea.org/iaeameetings/cn216pn/Monday/Session1/191-Emsley.pdf

Reference Scenario Primary Supply to 2030, tU

Existing capacity incorporates published statements of expected 2030 production (minus approx. 20ktU vs 2011 report)

Planned and prospective capacity changes reflect project cancellations/deferments (eg, Olympic Dam, Trekkopje) (minus approx. 15ktU in 2030 vs 2011 report)

In other words, the limits on uranium extraction argue entirely against investing time and other resources in consideration of nuclear power for the future energy needs of Wisconsin.

Dr. Dittmar is also pessimistic about breeder reactors, fusion reactors, and "new" approaches such as Small Modular Reactors. In his expert view, none of these technologies will be commercially viable within the coming generation.

In light of Dr. Dittmar's research, along with other expert counsel, in autumn 2012 our work group called for a focus on conservation and efficiency, while transitioning to solar and wind, and eschewing nuclear power as well as fossil fuels, by 2050 or sooner. While our recommendations were rather audacious, since then, the Stanford Solutions Project has provided a scenario whereby Wisconsin can meet all its projected 2050 energy needs with a 37% reduction in energy use through conservation/efficiency, using mostly solar and wind, while transition away from fossil and nuclear (http://thesolutionsproject.org/infographic/#wi).

Given all the above information, and hoping for the best future for Wisconsin, I urge your committee to focus on conservation/efficiency, and renewable energy in the form of solar and wind.

It is interesting to note that Lt. Gov. Rebecca Kleefisch has for quite some time been aware of the need for Wisconsin to focus on renewable energy:

> *In a March [2015] radio interview with Sykes, she acknowledged that states developing clean, renewable energy sources have a "competitive advantage" over states like Wisconsin that don't. "When I'm talking to my colleagues in the National Lieutenant Governors Association and they have already gotten online to different (carbon emissions) standards than what is traditional in our state, all of a sudden they have a competitive advantage," Kleefisch said.* (http://www.wisconsingazette.com/wisconsin/governor-kleefischbreakas-scott-walker-goes-presidential-rebecca-kleefisch-is-emerging-from-the-shadows-of-an-administration-that-didnt-want-her.html)

Dr. Dittmar is aware of the general legislative purpose of today's public hearing. He is willing to provide relevant expert testimony to your committee, from Switzerland. I strongly believe that your committee will find Dr. Dittmar's testimony very valuable, and hope that you will seek it out.

Thank you for your consideration of this referral.

Sincerely,

Jon Becker

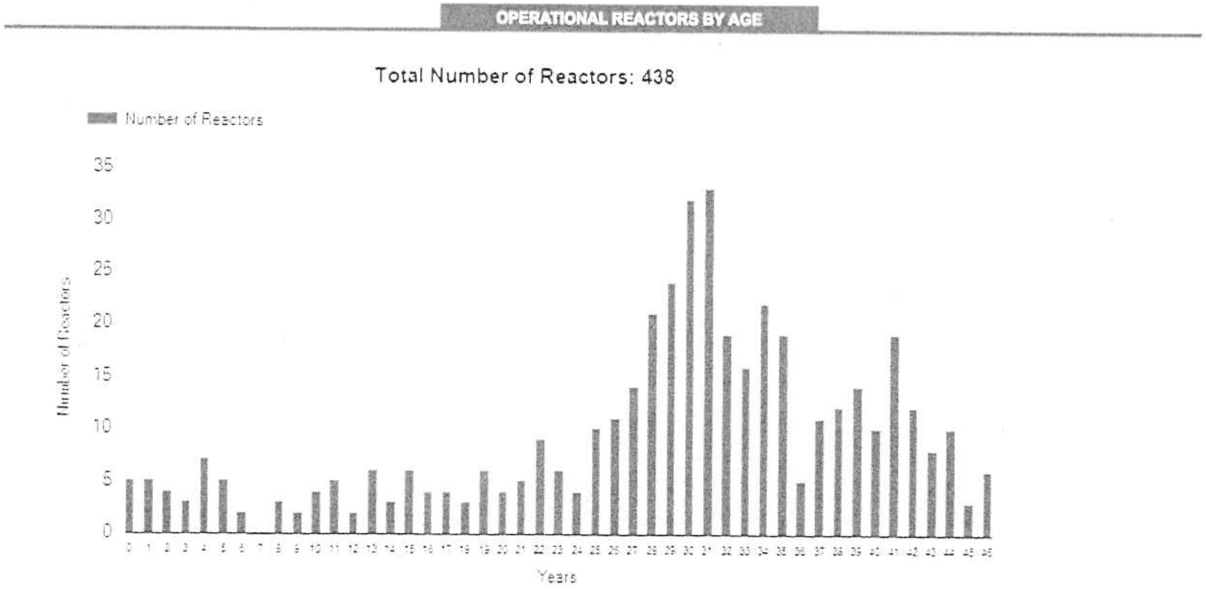
Jon Becker
POB 3292
Madison, WI 53704
+ USA 608 469.0316 mobile (home office)

Electric energy from nuclear fission today

- Nuclear fission power: less than 12% of global electric energy and less than 2.5% in our total energy mix.

- **1980-1985:** 20 to 30 reactors completed per year.
  Since 1990 3-4 reactors completed per year.

- About 250 reactors are 30 to 46 years old.
  They will reach "retirement" age during the next 10-15 years!

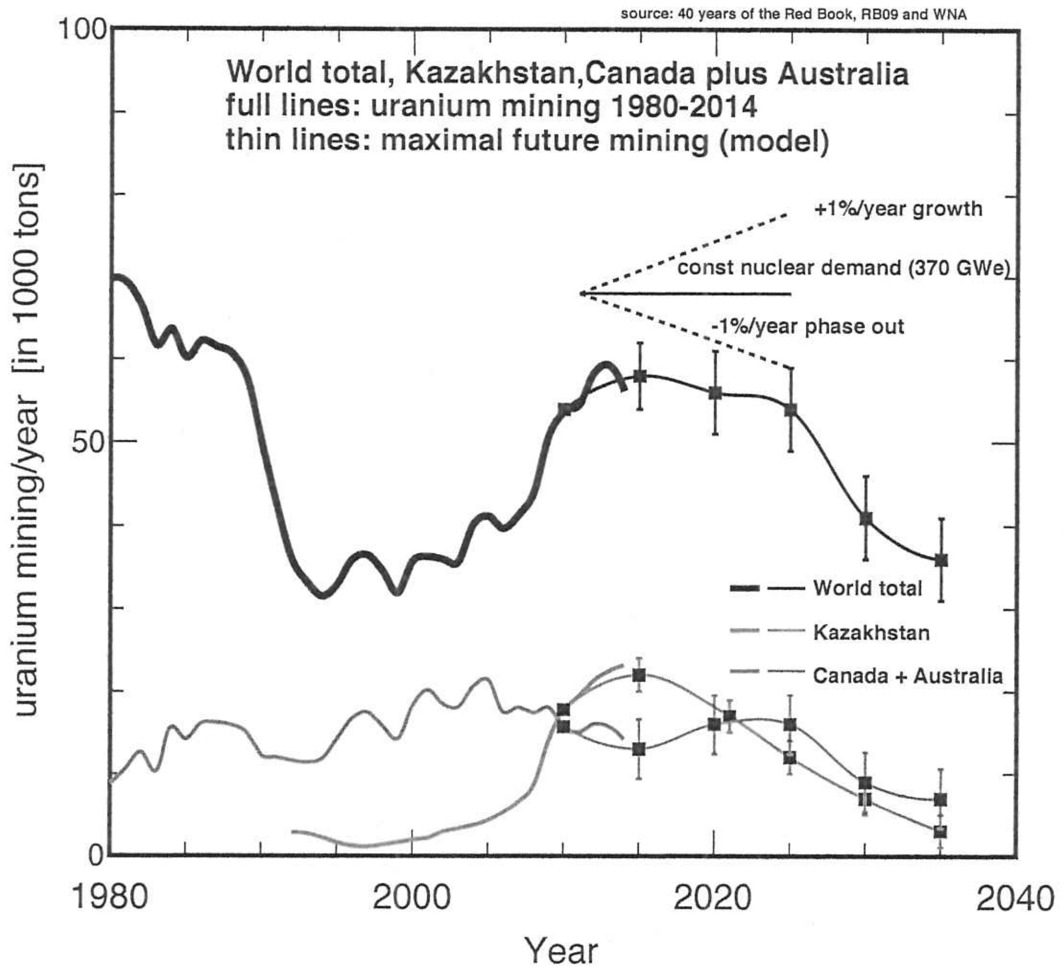


Age of reactor is determined by its first grid connection. Reactors connected in current year are assigned with the age 0 years.

source `http://www.iaea.org/PRIS/home.aspx`

The future of uranium extraction: A model!

Uran depletion profiles or "a hypothesis about the future":
M.D. "The end of cheap uranium" (published with 2010 data)
`http://www.sciencedirect.com/science/article/pii/S0048969713004579`
curves updated new uranium mining data 2011-2014!



The future of uranium extraction: WNA (new!)

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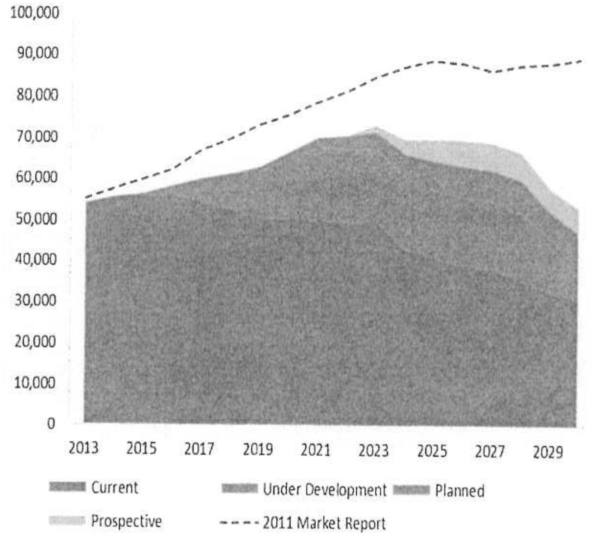


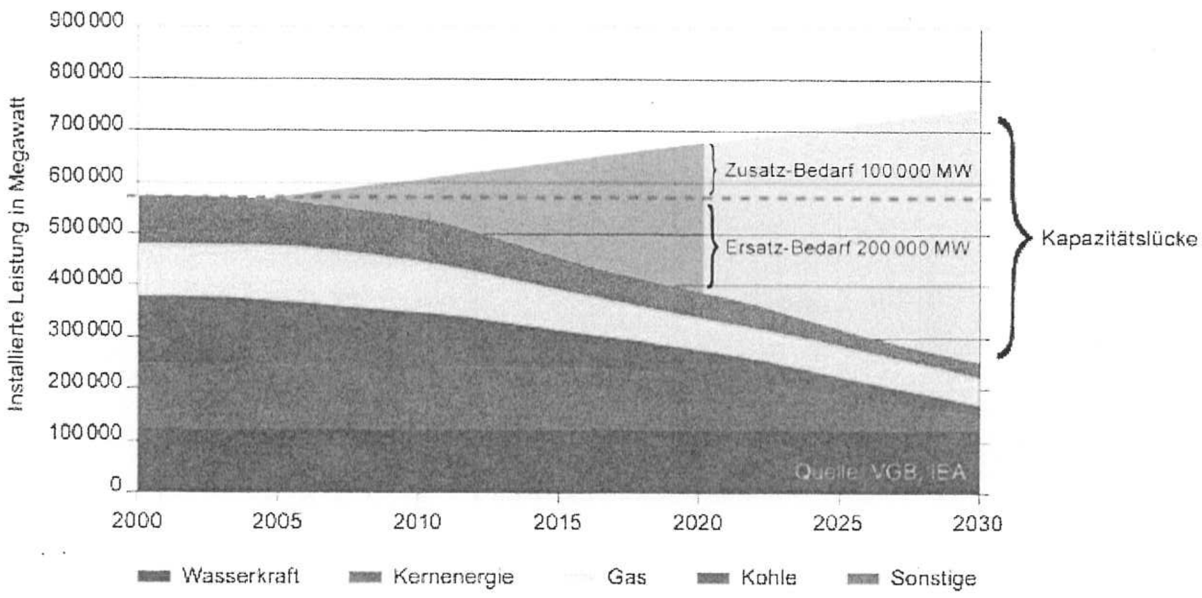
WNA Fuel Market Report
Ian Emsley

Electric energy in Europe and on the Planet, an uncertain future not only for Western Europe.

Important decisions need to be made during the next years!
Phasing out fossile fuels (CO2 problem) and ageing nuclear power plants

Grosser Ersatzbedarf in Europa

Entwicklung der installierten konventionellen Kraftwerkskapazitäten EU25

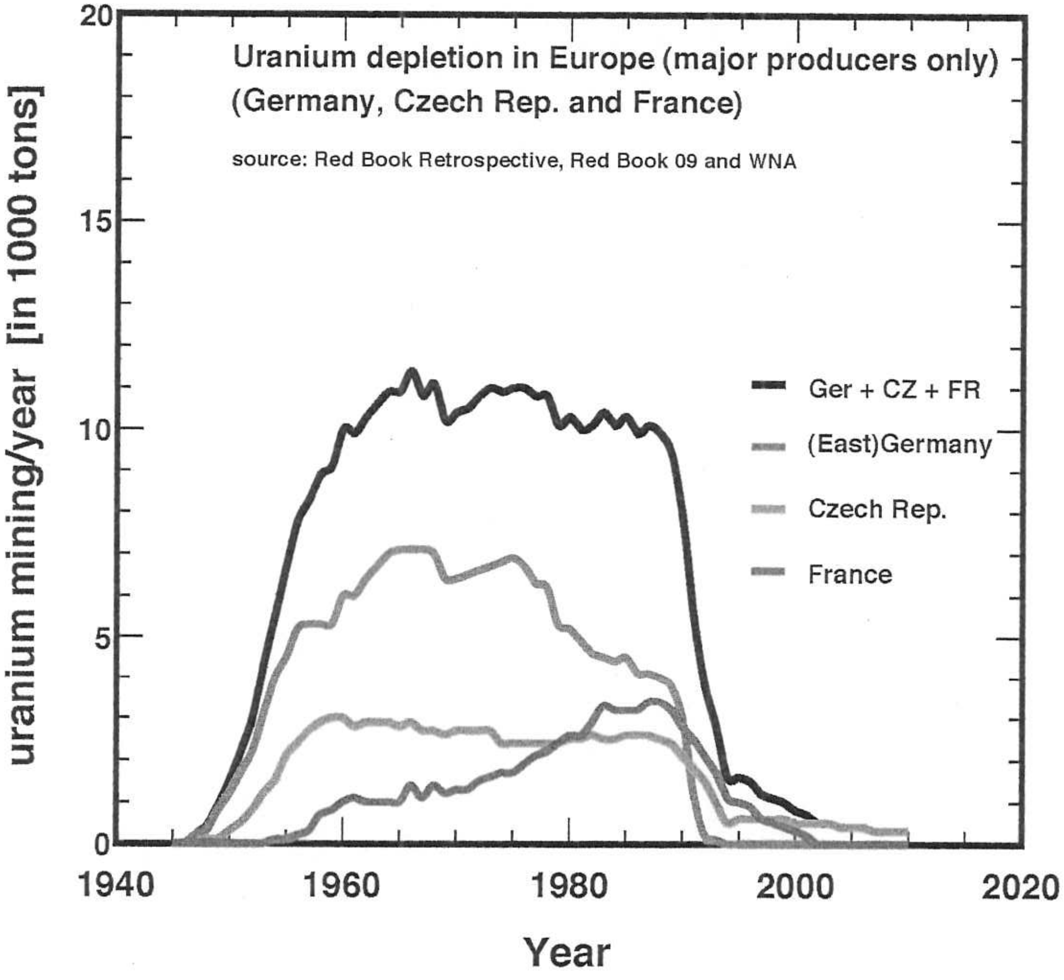


Axpo Holding AG
02.06.2006 / Seite 4

source: AXPO electric energy perspectives 2020 and VGB Powertech 2003 and `http://ihp-lx2.ethz.ch/energy21/Axporama_talk.pdf`

Western Europe: Uranium terminated

Uranium extraction: stopped since 2000,
despite claims that: (1) uranium price is negligible and
(2) the goal of import independence (100% imports since 2000)
imports in 2013 = 198 Mtoe



(source: IAEA Red Book uranium resources, various years)

Do Not Vote to repeal the common sense requirements in the Nuclear Moratorium:

The proposal to overturn the common sense requirements of the Nuclear Moratorium is based on the false notion that nuclear energy is "clean, green and sustainable". I'm here to tell you that this is a lie.

Nuclear power is both dangerous and expensive. The nuclear waste generated by nuclear reactors is so toxic that it must be stored for hundreds of thousands of years. One of the proposed storage sites here in Wisconsin is at the Wolf River Batholythes- and I ask you if you'd like to have nuclear waste stored here. Another alternative is what we presently are doing with our nuclear waste, i.e. storing it on-site at the reactors. These on-site storage facilities are vulnerable to attack and if targeted, they would be the equivalent of detonating a nuclear bomb with the radioactive release that would occur. We know from the 3 most well known nuclear reactor accidents, 3 Mile Island, Chernobyl, and Fukishima, that the damage to the people in communities around nuclear reactors is irreparable. The deaths related to the radiation from Chernobyl are thought to be over 900,00 since that accident. The reactors in Fukishima are continuing to melt down and to pollute the surrounding area. The mining and processing of Uranium is far from being carbon free, that is, it is very energy intensive. It is also done on lands inhabited by indigenous people. There are 10,000 abandoned uranium mines with piles of radioactive tailings blowing toxic dust and sickening the people that live and work nearby. We are promised by the nuclear industry proponents that reactors are safe but our own Pt. Beach plant's safety record contradicts this with it's 3 "red" safety violations which are the worst violations and are more than any other in our country. The technology is flawed and human error in both construction and operation of nuclear reactors has contributed to nuclear reactor accidents. The costs for 1 nuclear power plant is close to $10 billion dollars and it takes up to 10 years to build 1 reactor. This cost is born out by the rate payers and it doesn't include the costs to decommission the plant at the end of its life or the costs that come with an accident. Please note that in Georgia where a nuclear reactor is being built, the completion date is over 3 years delayed, costing $1million/day for each day it is delayed. The rate payers there have had 4 rate hikes since this project began. The nuclear industry is dying. Why is

Wisconsin trying to prop it up when the money could be better used to develop renewables such as wind and solar? Please keep the common sense requirements of the nuclear moratorium in place.

Amy Schulz, RN, BSN
President of Physicians for Social Responsibility Wisconsin

cleanwisconsin
your environmental voice since 1970

1/5/16

To: Members, Senate Committee on Natural Resources and Energy

From: Amber Meyer Smith, Clean Wisconsin

SUBJECT: Opposition to AB 384/SB 288

Clean Wisconsin is committed to clean, safe, cost-effective electricity to meet our energy needs, and to thoroughly review all solutions to our global warming crisis. We recognize that climate change threatens environmental damage of unprecedented magnitude, and that reducing atmospheric carbon concentrations has taken on new urgency in the last decade.

In order for Wisconsin to take a lead in addressing the climate crisis, and to most cost effectively meet the carbon reductions spelled out in the Clean Power Plan, Clean Wisconsin continues to prioritize:

1) Controlling demand and use of electricity by promoting energy conservation and efficiency. Conservation and efficiency are the cheapest and cleanest electricity resources, and will relieve the pressure for any new generation.
2) Supporting the decommissioning of dirty, costly coal facilities.
3) Advocating that our energy needs be met with cleaner, safer, and homegrown renewable energy sources like wind, solar and bioenergy.

Because of this overarching goal for clean, safe, homegrown and cost effective electric generation, nuclear power remains an undesirable and impractical alternative for the following reasons:

It is the most capital-intensive and costly way to generate electricity. The estimated cost for building just one new nuclear reactor is more than $10 billion. In fact, the two most recent nuclear reactors being built in the United States – in Georgia and South Carolina – are years behind schedule and billions of dollars over budget. Both projects are using the modular design AP1000 reactor, which is the "advanced nuclear energy" called out in AB 384/SB 288, which are the latest in nuclear technology and were expected to streamline construction time and costs. Four similar projects using the AP 1000 reactors in China are also experiencing cost overruns and construction delays.

The costs for waste disposal continue for decades after decommissioning. In Wisconsin, municipal governments currently bear the costs for the stockpiles of nuclear waste in their community. By comparison, wind energy combined with storage technology is already cheaper than building a nuclear reactor; and the price of solar has decreased drastically in recent years. Clean energy can deliver 5 times more pollution-cutting progress per dollar. New nuclear power costs between 9-13.4¢ per KWh while wind is around 2.3¢ per KWh.

Nuclear plants are not a silver bullet for addressing climate change. They cannot be built fast enough to have a significant impact on global warming for many decades. New plants take at least 10 years for construction and licensing, and even adding another 50 nuclear reactors nationwide (they are currently about 100) would only reduce emissions by 10%. In contrast, energy efficiency and renewable energy investments can have immediate and significant impacts. In addition, uranium mining, milling, leeching, plant construction and decommissioning all produce greenhouse gases, so it is not an energy source devoid of emissions.

Unlike renewables, the fuel is not homegrown. Wisconsin pays for mining and creating fuel in other states and countries rather than taking advantage of the solutions we have in our manufacturing, forestry, and agricultural sectors to produce renewable energy that keeps money in our own economy.

The technology has not advanced to the point that there is a safe way to manage the dangerous, high-level radioactive wastes that are the necessary by-product. Dry-cask storage is only a temporary fix to the problem of growing stockpiles of spent fuel rods that will take tens of thousands of years to be rendered safe. There is still no permanent repository or safe way to transport spent fuel to such a location.

Nuclear reactors present a significant safety risk from weather, security, and even simple human error. The consequences of radiation exposure can be catastrophic for generations to come, and the impact to the environment is devastating. Fukushima is the most recent example, but Chernobyl and Three-Mile Island remain as part of the nuclear legacy. The federal government estimates that a major accident at just one of Wisconsin's reactors could cost over $40 billion in property damage alone.

We are also concerned about the part of the bill that adds nuclear energy to the energy priorities law. In particular, we question prioritizing it over gas generation, which could be a large part of Wisconsin's immediate efforts to reduce carbon emissions through the Clean Power Plan. That re-prioritization just doesn't make sense.

Over 30 years ago, after the meltdown at Three Mile Island, Wisconsin put into place common sense safeguards around new nuclear power development until there is a safe repository for spent fuel, and the technology becomes safe and cost-effective. Clean Wisconsin has supported efforts to change that law when they were considered as part of a larger effort to advance all forms of clean energy, and we will continue to support our current nuclear laws until there is a broader discussion about Wisconsin's energy future.

Instead of focusing on technologies that are extremely expensive, risky and will take decades to build, we ask that the Legislature focus on real, immediate and cost-effective solutions to reduce carbon emissions through increases to our energy efficiency and renewable energy systems.

Reverse our Moratorium on Nuclear Plant Construction

Preamble: This testimony is from Richard Steeves, M.D., Ph.D., of Madison, Wisconsin. My Ph.D. is in the field of Medical Biophysics, and is from the University of Toronto.

My testimony today is given on my own behalf, and I do not represent any organization, but for the past 35 years I have been using radiation to treat cancer patients at the University of Wisconsin. Thus, while I'm not a nuclear engineer, I do understand ionizing radiation pretty well, and reading outside my immediate field of study has given me deep concern over three issues.

Comment 1: The rationale for the current moratorium on future nuclear plant construction is based upon the public's fear of the unchecked accumulation of nuclear waste. But the word WASTE is a misnomer, since it consists mostly of unused uranium fuel which, while it has no value in our current, aging nuclear fleet, has the capacity to generate vast amounts of energy in the next generation of compact, fast-neutron reactors. This 4th generation of reactors will soon be needed, not only to replace our old reactors, but also to replace the highly polluting coal plants that now dominate our electric grid. With help from our own University, Wisconsin has the potential to become a leader in modernizing its production of energy for the future. This is a great opportunity that we must not lose.

Comment 2: Lifting a moratorium in and of itself does not require our State to spend millions of its precious dollars, but rather, it offers us the **liberty** to attract future investors in the deployment of a new source of carbon-free energy. I say "new", because the idea is very new in the public mind, even though the idea of "integral fast reactors" was pioneered at the Argonne National Laboratory back in 1984.

Comment 3: It is not my intent at this hearing to elaborate on the sound rationale used by a highly respected climatologist, Dr. James Hansen, to advance Nuclear Energy to help address Climate Change and air pollution, but I would like to offer the following link as strong evidence in support of that very worthy goal.

http://www.columbia.edu/~jeh1/mailings/2015/20151229_Sleepless.pdf

My name is **Greg Piefer,** from **Middleton,** Wisconsin, and I am testifying today in support of Senate Bill 288. Passing this bill would allow Wisconsin to consider advanced nuclear energy as one option for our state's energy future.

I'm the **CEO** of **SHINE Medical Technologies** and we are dedicated to being the world-leader in the safe, clean, affordable production of medical tracers and cancer treatment elements. Our highest priority is delivering a high-quality supply of the medical ingredients required by nearly 100,000 patients each day—ingredients that are the backbone of over thirty medical procedures, primarily used to detect and treat heart disease and cancer. The process we have developed to do this uses new nuclear technology to reduce the amount of radiation and nuclear waste footprint of isotope production by hundreds of times, while maintaining cost effectiveness and compatibility with the existing supply chain. I know the role that innovation can play in increasing efficiency and safety, decreasing environmental impacts, and creating jobs. While SHINE Medical Technologies does not produce electricity, regard for the environment has always been one of SHINE's core values, and is extremely important to me personally.

As a PhD in nuclear engineering, I have an extensive background in nuclear technology, in both nuclear fission and fusion. As a businessman, I know well that Wisconsin businesses have long been well-served by a diverse portfolio of electric generating assets. Energy planners and regulators should have access to all options to provide the mix of fuel sources and technologies that can ensure a clean, affordable, reliable electric system for Wisconsin.

In addition to being a zero-carbon-emission source of energy, nuclear power's tremendous energy density results in an environmental impact that can be contained safely while carbon emissions from other sources are free to cause whatever environmental damage they will. Once released they are not retrievable. Nuclear fuel provides millions of times more energy per kg than fossil equivalents, resulting in millions of times lower waste by mass, and all of it is kept contained compared to fossil fuel plants. For example, in Wisconsin, the average household uses approximately 10,000 kWH of energy per year. If provided by nuclear energy, this house would generate approximately 40 grams or less than a tenth of a pound of high level waste per year, which is the size of a small pellet. By comparison, the same household would generate over 20,000 lbs of CO2 emissions per year if provided by coal, and over 10,000 lbs of CO2 if provided by natural gas. That's 1.2 million gallons with coal and over half a million gallons with gas. Per household. In aggregate, WI's electricity demand is approximately 70 billion kWH. If provided by nuclear, the entire state would generate only 280 tons of high level waste—a quantity that can be contained and managed. On the other hand, if provided by coal, WI would release over 8 trillion gallons of CO2 to the atmosphere which cannot be recovered.

Some people disagree on the impacts of man-made CO2 to the environment, but regardless of who is right, the <u>potential</u> consequences of climate change greatly exceed the costs and risks associated with adapting our energy mix to reduce emissions. Advanced nuclear energy technologies offer improved safety and efficiency over the already proven zero-carbon nuclear plants in the U.S. today, and are a great channel to produce the energy we need while helping ensure the health of the human population.

While a long term disposal site for high level radioactive waste is very desirable, and should continue to be sought, we must do what we can to minimize the potential effects of our energy use on our environment now. Given the choice between a containable, manageable waste stream and one that is massive and uncontrollable, the choice is clear. Nuclear energy must be part of our energy future if we want to be in control of the impacts of our waste streams, and their impacts on the environment.

Given the importance of a reliable energy supply to our economy, and the greatly reduced environmental footprint and manageability of nuclear waste when compared to fossil emissions, I ask the Assembly to pass Senate Bill 288 and thank you for your time this morning.

TESTIMONY TO WISCONSIN SENATE COMMITTEE ON NATURAL RESOURCES AND ENERGY IN OPPOSITION TO SB 288

January 5, 2016

Chuck Baynton

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My name is Chuck Baynton and I am a constituent of Sen. Darling and Rep. Jim Ott. I will give written copies of this testimony to Committee members. I have appended two exhibits to my prepared text. One is from a physics periodical, *APS Physics*. The other is from Aesop's Fables. I speak here representing only myself, in opposition to Senate Bill 288, which would repeal the two preconditions to licensing any new nuclear power reactor in Wisconsin.

Main Risks of Nuclear Power

Three important concerns related to nuclear power are its impact on proliferation of nuclear weapons, its cost, and disposal of the radioactive waste it creates.

Regarding proliferation, we should remember that most of the world's countries regard the United States as a shining example of a technologically advanced society. The more we turn to nuclear power, the more other countries will think it's smart to do the same. But spent nuclear fuel contains plutonium, which is ideal starting material for atomic weapons. The more other countries adopt nuclear power, the more plutonium they will have, and the more daunting it will be to keep all that plutonium from being used to make weapons.

Wisconsin law doesn't directly address this concern. That makes sense, because it's a matter of *international* policy. Still, we'd be wise to take note of this unintended consequence if we add more nuclear power to our mix.

Wisconsin law does concern itself with the cost factor, and rightly so. When adding nuclear to our power mix raises the cost of electric power, that adversely impacts citizens. It also adversely impacts large industrial users of power and makes Wisconsin a less attractive place to do business. If nuclear power ever became the low-cost alternative, as its proponents decades ago forecast it would be, the cost restriction in current law would be no barrier to new nuclear power facilities here.

But as a medical doctor, I'm mostly a science guy, not a high finance guy, so my focus today will be the waste provision of Act 401.

The Waste Disposal Problem

As you know, Act 401 requires that before a new nuclear power reactor can be licensed in Wisconsin, there needs to be a federally licensed permanent disposal repository with sufficient capacity to accept all the high-level civilian nuclear waste generated in Wisconsin. This has been on the books since 1984.

But now, over two generations into the era of nuclear power, there is still no deep disposal facility for spent nuclear fuel rods. None in the United States and none anywhere in the world.[1] The announced target date to begin deep disposal of spent nuclear fuel in this country has serially changed from 1998[2] to 2009[3] to 2025[4] to “when necessary,[5]” to (to paraphrase the latest link in the chain) “maybe never, but it doesn’t matter.”[6]

This chain of events brings to mind the fable that gives our language the expression “sour grapes.”[7] In the fable, a fox who truly wants the grapes is repeatedly frustrated in his effort to get them. Rather than face his frustration squarely, he ends by conjuring a reason that he can do just as well without them.

Here we face a similar sour grapes question: is the last step in the chain of waste-disposal delays an instance of sour grapes, not truly science-based?

Let’s keep that question in mind, without passing judgment yet.

From 1987 until the first several years of this century, Yucca Mountain in Nevada was designated as the first United States site for a deep repository for spent nuclear fuel. However, by 2010, plans for a deep repository at Yucca Mountain had been abandoned, and no other site had taken its place.[8]

The August 2014 Rule

Wisconsin Assembly Rep. Kevin Petersen, lead sponsor of the Assembly companion bill to SB 288, has written an opinion piece[9] which says, in part,

> "Yucca Mountain is no longer needed. Instead, facilities such as Kewaunee and Point Beach are employing dry cask storage. Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year to be surrounded by inert gas inside a container called a cask.
>
> “On August 26, 2014 the Obama Administration’s NRC issued (a rule entitled) ‘The Continued Storage of Spent Nuclear Fuel Rule.’ The rule adopts the NRC’s finding (that) spent nuclear fuel can be safely managed in dry casks indefinitely when licensing nuclear reactors."

Here Rep. Petersen states a strong case for repeal of the waste storage restriction in Act 401, but only if the NRC is right that indefinite dry cask storage is safe. Thus the sour grapes question from a moment ago becomes important to Wisconsin.

Let me tell you the main reason that I am here today. You have all heard what Rep. Petersen says about dry cask storage for an indefinite duration. I believe that none of you should be asked to vote on SB 288 until you hear what emerges when you look for an answer to the sour grapes question.

Where should we turn for an even-handed answer? There are two good places. One is the physics community, or that part of it whose livelihood is not the designing of nuclear power reactors. The other is the federal courts.

Comment from the Physics Community

A Google search of "Continued Storage of Spent Nuclear Fuel Rule August 2014" readily yields an answer from the physics community. It's the attached article from *APS Physics*. The heart of the matter, quoting the article, is this: "There is a long-standing international consensus that deep geologic final disposal of nuclear waste is required. This consensus is partly in response to concerns that it is impossible to assure indefinite institutional controls on surface storage facilities."

In email correspondence, authors Robert and Susanne Vandenbosch stressed to me that the United States remains part of that consensus. Primary responsibility for a deep repository rests with the Department of Energy, not the NRC, and DOE policy is still to pursue a deep repository.

This policy has statutory underpinning too, in the Nuclear Waste Policy Act of 1982.[10] Later legislation in 1987 and 1992 changed some provisions of the Act, but not the commitment to ultimate disposal of spent nuclear fuel in deep, sealed underground repositories.[11]

In case any of you wish to explore this issue further with Dr. Robert and Dr. Susanne Vandenbosch, they assure me that they would be glad to share their expertise with you.

Before moving on to the federal courts, one more key point: if it's so clear-cut that only deep geologic disposal is safe in the long run, how on earth did the NRC decide otherwise?

You're not going to believe this, but it's easy. Since the danger of indefinitely long surface storage is closely tied to uncertainty about institutional control, all you have to do is to wish that uncertainty away, and you can find permanent surface storage to be safe. That's exactly what NRC did.

Please don't take my word for it. Turn to page 2 of your copy of the *APS Physics* article and read the passage I've yellow highlighted for you. Third paragraph below where you find the definitions of SMALL, MODERATE, and LARGE risks.

Comment from the Courts

What can we learn about proper management of spent nuclear fuel from our federal courts? Quite a lot.

From 1984 to 2010, the NRC issued a series of documents called Waste Confidence Decisions. Most of the predictions I read you, about when deep burial of nuclear waste would begin, made their debut in a Waste Confidence Decision.

The process of Waste Confidence Decisions came about as a result of lawsuits against the NRC. There is a good summary of this history in the decision in *New York v. NRC*, the most recent of these lawsuits.[12]

In essence, the Court ruled that NRC's 2010 Waste Confidence Decision had failed to take the "hard look" at risks of spent nuclear fuel storage that the National Environmental Protection Act of 1969 requires.[13]

The Court noted "we are focused on the effects of a *failure* (emphasis in the original) to secure permanent storage. The (NRC) apparently has no long-term plan other than hoping for a geologic repository. If the government continues to fail in its quest to establish one, then (spent nuclear fuel) will seemingly be stored on site at nuclear plants on a permanent basis."[14]

The important word here is "permanent." When NRC speaks of leaving spent nuclear fuel in casks "indefinitely," it speaks of an interval of time that lacks an endpoint. Make no mistake, when Rep. Petersen writes of leaving spent nuclear fuel in dry casks indefinitely, he is saying permanently. He is saying he can accept leaving spent nuclear fuel permanently on the site of every nuclear reactor that ever comes to Wisconsin.

In its decision in *New York v. NRC*, the Court vacated the 2010 Waste Confidence Decision and ordered the NRC to try again. The August 2014 Continued Storage Rule and its related Generic Environmental Impact Statement (GEIS) are the results of that order. This time the NRC finally dropped the term "confidence" from its document title, perhaps to avoid ridicule.

The Attorneys General of New York, Connecticut, and Vermont, joined by the Natural Resources Defense Council and others, promptly responded to the August 2014 NRC storage rule with a new lawsuit, alleging that the rule is little more than a repackaging of the 2010 rule.[15] Briefs have been filed in the case and oral argument is scheduled next month.[16] NRC claims in its brief that its present rule and GEIS fulfill all the requirements imposed by *New York v. NRC.*

A decision in the case may well come this year. How will that decision go? It's hard to predict, but it is worth noting that the three state AGs chose this fight, and the NRC is in it under duress. That suggests at least some optimism on the anti-NRC side.

A decision in favor of that side would likely force NRC to jettison its claim that spent nuclear fuel can safely be stored in dry casks at reactor sites forever.

Recommendations

So what should this Committee do? My suggestion is that you take a conservative approach. A conservative approach would recognize that sometimes expert government agencies get it wrong.

A conservative approach is often the right approach when the circumstances involve large risk and significant uncertainty. In medical practice, this conservatism is enshrined in the principle "first of all, do no harm" which all medical students learn early in their training. It's the right approach to driving on an icy Wisconsin highway on a winter night: BAC of zero, not just less than .08, and slow down.

And the conservative, cautious approach is the right approach to nuclear power. If the Department of Energy solves the waste disposal problem, the disposal provision of Act 401 ceases to block new nuclear power reactors. But as long as that problem is unresolved, Act 401 provides valuable protection against the almost incalculable risks that would come with *de facto* permanent dry cask storage in locations that were never intended to be used that way. Best, then, to keep Act 401 in place.

Of course, you have other options. You might retain either provision of Act 401 and drop the other, or you might defer action on this issue until the DC Circuit Court decides the current suit. It would be an embarrassment to Wisconsin and this legislature if, relying on the notion that open-ended cask storage is safe, you repeal Act 401, and on the heels of that choice the Court throws out the NRC document that claims it's safe.

Certainly you should beware the voice that tells you you must act without first taking time to reflect on today's testimony. There is no red light and siren here.

Whatever you decide, I hope my testimony today helps you to analyze your options.

Endnotes

1. Vandenbosch, Robert and Vandenbosch, Susanne, *Nuclear Waste Stalemate: Political and Scientific Controversies,* University of Utah Press, 2007, chapter 12.

2. *ibid.,* p. 61.

3. Vandenbosch, Robert and Vandenbosch, Susanne, "Nuclear Waste Confidence: Is Indefinite Storage Safe?" in *APS Physics* January 2015.

4. *New York v. NRC*, 681 F.3d 471 (DC Circuit 2012), p. 5

5. Vandenbosch and Vandenbosch, "Nuclear Waste Confidence"

6. Vandenbosch and Vandenbosch, "Nuclear Waste Confidence"

7. The attached version of "The Fox and the Grapes" is in Winter, Milo (illus.), *The Aesop for Children*, Rand McNally (Chicago), 1919, p.20.

8. Vandenbosch and Vandenbosch, "Nuclear Waste Confidence"

9. www.waupacanow.com/2015/12/12/opening-the-door-to-nuclear-power/ accessed 1/3/2016

10. "The (NRC) noted that the Nuclear Waste Policy Act mandates a repository program, demonstrating the continued commitment and obligation of the federal government to pursue one." *New York v. NRC,* 681 F.3d 471 (DC Cir 2012), p. 10.

11. Vandenbosch and Vandenbosch, *Nuclear Waste Stalemate,* chapters 4, 5, and 8.

12. *New York v. NRC*, 681 F.3d 471 (DC Cir 2012), decided June 8, 2012

13. *New York v. NRC*, especially pp. 2-3, 9, and 21. The National Environmental Protection Act is the law that put "environmental impact statement" in our lexicon.

14. *New York v. NRC*, p. 13.

15. http://www.nrdc.org/media/2014/140826a.asp

16. The case number is 14-1210.

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Nuclear Waste Confidence: Is Indefinite Storage Safe?

Robert Vandenbosch and Susanne E. Vandenbosch

On Aug 26, 2014 the waste confidence rule was updated and the name changed. Waste Confidence refers to a finding by the Nuclear Regulatory Commission that spent fuel[1] from nuclear reactors can be safely isolated from the environment, either until a final disposal repository becomes available or in the new ruling for an indefinite period of time. Its main effect is to allow resumption of licensing of new reactors and extension of the licenses of currently operating reactors. Like the first waste confidence rule of 1984, the 2014 rule was passed in response to a court order.[2] This latter court order came in the context of the failure of the United States to complete licensing activities for a repository at Yucca Mountain in Nevada.[3] The Nuclear Regulatory Commission was ordered to develop a waste confidence rule that included the possibility there would never be a repository.[4] The court ruled that the need for updating the waste confidence rule was the failure of the previous rule to satisfy all the provisions of the National Environmental Protection Act.[5] This led the Nuclear Regulatory Commission to evaluate various environmental impacts[6] for three time frames[7].

The Nuclear Energy Institute (NEI), the nuclear power industry's trade association, was pleased with the issuance of the new rule. Ellen Ginsburg, NEI's Vice President, said "the completion of this rulemaking is an important step that will facilitate final agency decisions on pending industry licensing actions such as license renewals of operating reactors and early site permitting for new reactors."[8] In contrast, Geoffrey Fettus, lead counsel for the Natural Resources Defense Council, one of the petitioners in the Court case, issued the following statement: "The Nuclear Regulatory Commission failed to analyze the long-term environmental consequences of indefinite storage of highly toxic and radioactive nuclear waste; the risks of which are apparent to any observer of history over the past 50 years. The Commission failed to follow the express directions of the Court."[9]

The origin of this action so soon after the establishment of the 2010 rule (which in turn dates back to the first waste confidence decision in 1984) was a lawsuit challenging the 2010 rule filed by several eastern states, several public interest groups and the Prairie Island Indian Community. The suit, *New York v. NRC*, claimed that the Nuclear Regulatory Commission failed to comply with NEPA, the National Environmental Protection Act. The Court ruled that the rulemaking in fact did not fully comply with the Act, and vacated the 2010 rule and Decision.[10] The Court identified two kinds of deficiencies in the Nuclear Regulatory Commission's analysis. The first has to do with the assumption regarding the eventual final disposal of spent fuel in a repository. The 2010 rule had stated that "the Commission believes there is a reasonable assurance that sufficient mined geologic repository capacity will be available to dispose of the commercial high-level radioactive waste and spent fuel……when necessary".[11] The Court held that the Commission needed to examine the environmental effect of failing to ever establish a repository. The second kind of deficiency is related to inadequate examination of the risk of spent fuel pool leaks and fires. We will be focusing on the repository availability issue in the present discussion. First we will review the origin of a nuclear waste confidence decision.

The general context of a waste confidence decision has to do with whether it is proper to license reactors that will produce waste that could provide a long-lasting threat to the health and safety of the public. The supporting document for the 2014 rule and decision update, "Generic Environmental Impact Statement of Continued Storage of Spent Nuclear Fuel" (NUREG-2157)[12], gives a brief history of waste confidence rulemaking. Like the present update, this issue came to a head as a result of a Court of Appeals remand to the Commission, in this case in response to a suit *Minnesota v. NRC* decided in 1979.

In response to the 1979 remand, the Commission issued its first Waste Confidence Decision in 1984. It found "reasonable assurance that safe disposal of high level radioactive waste and spent fuel in a mined geologic repository is technically feasible" and that "one or more mined geologic repositories…. will be available by the years 2007-09, and that sufficient repository capacity will be available within 30 years beyond expiration of any reactor operating license…". It furthermore found "reasonable assurance that…spent fuel generated in any reactor… can be stored safely and without significant environmental impacts for at least 30 years beyond the expiration of that reactor's operating licenses…".[13]

In 1990 the Commission revisited the waste confidence issue, and in the light of the slow progress on developing a repository issued a revised finding that they had reasonable assurance that at least one mined geologic repository will be available within the first quarter of the twentieth century. They also broadened their reassurance about safe storage for thirty years beyond the original licensed life to include that of renewed or revised licenses.[14]

By the time of the 2010 revision the Obama administration had declared Yucca Mountain "not workable" and any prospect for a geological repository seemed remote. As mentioned above, the response of the Commission was to say that it "believes there is reasonable assurance that sufficient mined geologic repository capacity will be available ….. when necessary". It also made a generic determination that spent fuel can be stored safely for at least 60 years beyond the licensed life of a reactor. In 2013 Alley and Alley characterized the approach to waste confidence as one that "looks like shooting an arrow at a wall, drawing a bulls-eye around it, and proclaiming yourself an excellent marksman".[15] The 2014 version, no longer with the title "Waste Confidence", fits in with this progression. Pressed by the Court, it considers three time frames including the possibility that a repository never becomes available. The 2014 rule no longer contains a statement corresponding to the 2010 statement "…spent fuel…..can be stored safely and without environmental impacts for at least 60 years beyond the licensed life for operation…", but rather simply states that the "Commission has generically determined that the environmental impacts of continued storage of spent nuclear fuel…are those impacts identified in NUREG-2157, 'Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel'".[16] This generic environmental impact statement, (GEIS) is 1300 pages long and difficult to summarize.

The GEIS breaks the environmental impacts considered into 20 categories, from Land Use to Public and Occupational Health, Accidents, and Sabotage or Terrorism. Each of these categories are evaluated for three assumed timeframes for storage before availability of a repository. The short term time frame assumes a repository will be available within 60 years after termination of a reactor's operating lifetime, the long-term 160 years, and an indefinite timeframe which assumes that a repository never becomes available. The Commission considers the short-term timeframe to be the most likely scenario[17]. The indefinite timeframe was included in response to the Court order.

For each category and for each timeframe the GEIS rates the impacts as small, moderate or large. The general definitions of significance levels are:[18]

SMALL: The environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. For the purposes of assessing radiological impacts, the Commission has concluded that radiological impacts that do not exceeded permissible levels in the Commission's regulations are considered small.

MODERATE: The environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.

LARGE: The environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

For most categories the impacts were declared to be small for all three timeframes. Exceptions included Air Quality for short timeframes, Historic and Cultural Resources and Aesthetics for all timeframes, and Traffic for away-from-reactor storage for long and indefinite timeframes.

The most important issue is the question of when or if a geological repository will become available for final disposal. The NRC believes that a repository is "most likely" to become available during the shortest of the three time frames considered.[19] Commission Chairman Allison Macfarlane in her notational vote[20] questioned that conclusion and asked that statements in the GEIS and Federal Register notice be revised to characterize repository availability in the near-term as "one reasonable scenario" rather than the "most likely scenario".[21] This request was apparently not accepted by the majority of the Commissioners and the original language remained in the final GEIS and Federal Register notice. A related issue is whether institutional control will be exercised over the long term. In evaluating the environmental impacts for this timeframe it was assumed that institutional control would remain throughout the indefinite timeframe.[22] But the GEIS goes on to acknowledge that "although too remote to calculate meaningfully, a permanent loss of institutional controls would likely have 'catastrophic consequences'". (Commissioner Magwood objected to this wording, but it was not changed in the final GEIS). It is important to remember that there is a long-standing international consensus that deep geological final disposal of nuclear waste is required. This consensus is partly in response to concerns that it is impossible to assure indefinite institutional controls on surface storage facilities. US policy to provide for permanent disposal in a geological repository was formalized by passage of the Nuclear Waste Policy Act of 1982.

With the assumption that institutional controls will remain indefinitely, and that canisters and casks would be replaced about every 100 years, the GEIS concludes that environmental effects on public and occupational health (including radiological effects) would be SMALL (capitalization in GEIS). This is a rather remarkable assumption and conclusion for the Nuclear Regulatory Commission to incorporate into a Rule. It is based on a much more limited analysis and much less restrictive radiation standardsthan are in place for a deep geological disposal facility such as are applicable to the pending Yucca Mountain repository. Chairman Macfarlane hinted at this in a statement in her notational vote: "if the environmental impacts of storing waste indefinitely on the surface are essentially small, then is it necessary to have a deep geologic disposal option?"[23]. However her request that the staff should fully evaluate the potential range of environmental impacts for indefinite, no-repository storage under two scenarios- keeping and losing institutional control, was not accepted by the Commission.

The public may not share the confidence of the Nuclear Regulatory Commission about nuclear waste confidence. There is also concern that the Commission's action in approving this rule and supporting Generic Environmental Impact Statement may undermine the already precarious governmental support for addressing properly the nation's nuclear waste problem. A Blue Ribbon Commission, established by the Obama Administration after their request to withdraw the Yucca Mountain repository license application, urged prompt action on their recommendations which require some congressional action. Among their recommendations was prompt action to develop another geological repository. A bill to implement their recommendations is languishing in a Senate committee.

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[1] Spent fuel is also referred to as radioactive waste, nuclear waste, and more recently used fuel. It includes fission products and actinide elements produced by fission and neutron capture. Fission of Uranium-235 splits the nucleus into two unequal parts and fast neutrons. Some of the isotopes of these elements are radioactive. Some isotopes of particular concern are Iodine-131 with a 8 day half-life and Cesium-137 with a 30 year half-life. Some of the neutrons produced in the fission process are captured by Uranium-238 to form Neptunium-239 which undergoes beta decay to form Pu-239. Pu-239 after chemical separation from other elements in the irradiated nuclear fuel can be used to produce a bomb and therefore poses a proliferation risk. Neutrons also produce Neptunium-237, with a 2 million year halflife.

[2] *New York v. NRC*, 681 F.3d 471 (D.C. Cir. 2012 (ADAMS Accession No. ML 12191A407)

[3] This repository site was selected in 1987 with passage of the Nuclear Waste Policy Amendments Act by congressional conference committee. See Chpt. 5 in Vandenbosch, Robert, and Susanne E. Vandenbosch, "Nuclear Waste Stalemate: Political and Scientific Controversies", University of Utah Press, 2007.

[4] Referring to a possible failure to ever establish a geologic repository, the Court said "The Commission can and must assess the potential environmental effects of such a failure." P. 13, *New York v. NRC*. To the average person and certainly the attentive public this may seem like a ludicrous assignment as well as unnecessary. A committee of the National Research Council has suggested evaluating the ability of a geological repository, the Yucca Mountain repository in Nevada, from the perspective of environmental impacts until the time of peak risk. For Yucca Mountain they suggested this would likely be longer than 10,000 years. This is a more manageable frame than the indefinite period suggested by the court. (See National Research Council, *Technical Basis for Yucca Mountain Standards*, 1995).

[5] Pp. 7, 21 of *New York v. NRC*

[6] These were land use, socioeconomics, environmental justice, air quality, climate change, geology and soils, surface water quality,

surface water quality and consumptive use, groundwater quality and consumptive use, terrestrial resources, aquatic ecology, special status species and habitats, historic and cultural resources, noise, aesthetics, waste management of LLW, mixed waste and nonradioactive waste, transportation traffic and health impacts, public and occupational health , accidents, and sabotage or terrorism. The Nuclear Regulatory Commission estimated whether the impacts would be SMALL, MODERATE OR LARGE for each of these categories.

[7] A short term time frame assumes a repository will be available within 60 years after termination of a reactor's operating lifetime, the long-term 160 years, and an indefinite timeframe which assumes that a repository never becomes available.

[8] http://www.nei.org/News-Media/Media-Room/News-Releases/Nuclear-Industry-Commends-NRC-for-Finalizing-Used

[9] http://www.nrdc.org/media/2014/140826a.asp

[10] *New York v. NRC*, 681 F.3d 471 (D.C. Cir. 2012 (ADAMS Accession No. ML 12191A407)

[11] Section 51.23(a), Federal Register 75 FR 81037, Dec. 23, 2010

[12] http://pbadupws.nrc.gov/docs/ML1423/ML14238A284.pdf

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[15] "Too Hot to Touch: The Problem of High-Level Nuclear Waste" William M. Alley and Rosemarie Alley, Cambridge University Press, New York, 2013. p. 117.

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[17] Nuclear Regulatory Commission, Continued Storage of Spent Nuclear Fuel, 79FR 56245, September 19, 2014.

[18] Nuclear Regulatory Commission, Continued Storage of Spent Nuclear Fuel, 79FR 56246, September 19, 2014.

[19] P. xxx of Executive Summary, GEIS September, 2014 and in final Federal Register rule, Federal Register 79 FR 56245, Sept. 19, 2014

[20] The Nuclear Regulatory Commission has a rather unique way of voting. Commissioner's record their vote, which may include partial as well as full approval of a proposal, and supporting documentation and specific suggestions for any requested changes. These are circulated among the Commissioners prior to a final vote.

[21] P. 3, "Chairman Macfarlane's Comments on SECY-14-0072 "Proposed Rule: Continued Storage of Spent Nuclear Fuel", Aug. 7, 2014, released as Commission Voting Record on Aug. 26, 2014. http://www.nrc.gov/reading-rm/doc-collections/commission/cvr/2014/2014-0072vtr.pdf

[22] P. xxxi of Executive Summary, GEIS September, 2014

[23] P. 1, "Chairman Macfarlane's Comments on SECY-14-0072 "Proposed Rule: Continued Storage of Spent Nuclear Fuel", Aug. 7, 2014, released as Commission Voting Record on Aug. 26, 2014. http://www.nrc.gov/reading-rm/doc-collections/commission/cvr/2014/2014-0072vtr.pdf

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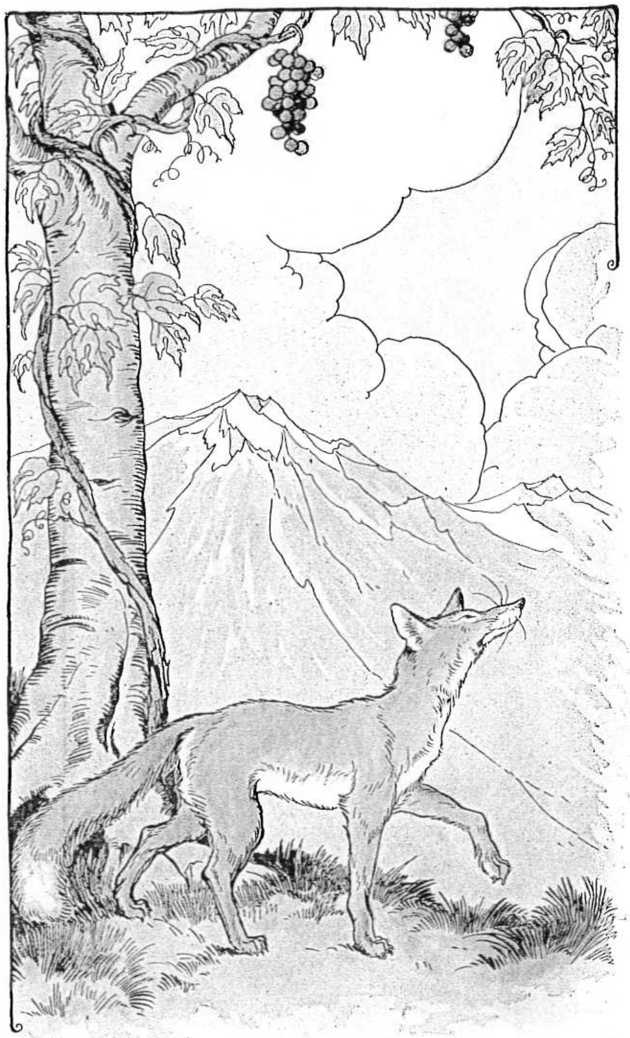

THE FOX AND THE GRAPES

A Fox one day spied a beautiful bunch of ripe grapes hanging from a vine trained along the branches of a tree. The grapes seemed ready to burst with juice, and the Fox's mouth watered as he gazed longingly at them.

The bunch hung from a high branch, and the Fox had to jump for it. The first time he jumped he missed it by a long way. So he walked off a short distance and took a running leap at it, only to fall short once more. Again and again he tried, but in vain.

Now he sat down and looked at the grapes in disgust.

"What a fool I am," he said. "Here I am wearing myself out to get a bunch of sour grapes that are not worth gaping for."

And off he walked very, very scornfully.

There are many who pretend to despise and belittle that which is beyond their reach.

THE BUNDLE OF STICKS

A certain Father had a family of Sons, who were forever quarreling among themselves. No words he could say did the least good, so he cast about in his mind for some very striking example that should make them see that discord would lead them to misfortune.

One day when the quarreling had been much more violent than usual and each of the Sons was moping in a surly manner, he asked one of them to bring him a bundle of sticks. Then handing the bundle to each of his Sons in turn he told them to try to break it. But although each one tried his best, none was able to do so.

Testimony before the Senate Committee on Natural Resources and Energy
January 5, 2016 (Richard Rolland)

Hello, I'm Richard Rolland. I grew up in Waukesha County and I just graduated in December at the University of Wisconsin-Madison, finishing my Master's and Bachelor's dual degree program in nuclear engineering. Additionally, I have a double major in economics and a certificate in physics for my undergraduate studies.

I came here today to discuss a major reason why Senate Bill 288 should pass and why nuclear power in Wisconsin should be promoted. This reason is that nuclear power is a reliable source of energy. An example of this occurred during the 2014 polar vortex, which I'm sure we all remember. According to Forbes contributor James Conca, nuclear and wind helped prevent major blackouts throughout the nation. In fact, he stated "without nuclear, we would have had blackouts, and real public danger at these temperatures" [1]. This was due to nuclear power plants having 95% of their total capacity operational during the polar vortex compared to fossil fuels which had a significant amount of shutdowns due to the temperature experienced and the shortage of natural gas during the polar vortex [1] [2]. With wind producing minimal amounts of the necessary power required for the electric grid [3]; having a supply of nuclear energy in cases of low temperatures and other abnormal environmental events will keep the state's power on.

Additionally, nuclear energy has the benefit of operating reliably throughout the year. Nuclear reactors in the nation spend, on average, approximately 90% of their time producing electricity, with the rest of the time mostly consisting of scheduled outages [3] [4]. In comparison, wind and solar power spent approximately 30% of their time in 2014 producing electricity [3]. Therefore, nuclear power provides a major benefit to our electrical grid by allowing for a reliable power source throughout the year.

Before I end, I want to mention another reason to allow the option for nuclear power plants to once again be built in Wisconsin. This is due to the Nuclear Engineering Department at the University of Wisconsin-Madison. According to U.S. News' rankings in 2015, University of Wisconsin is tied for 3rd place for the best graduate nuclear engineering school in the country [5]. Sadly, extraordinary talent from the state is being lost as many nuclear engineering graduates are leaving the state due to minimal career opportunities in Wisconsin. To not even allow for potential construction of a nuclear power plant in Wisconsin due to the moratorium is unwise based on the vast educational knowledge of nuclear engineering present in the state.

The Wisconsin legislature should vote to pass this piece of legislation to allow nuclear power the opportunity to make the Wisconsin energy grid more reliable and to allow Wisconsin nuclear engineering graduates to be a part of Wisconsin's energy industry. Thank you.

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My name is Margi Kindig. I am a retired attorney, served as a citizen member of Governor Doyle's Task Force on Global Warning, and was on the board of Clean Wisconsin for several years.

I have been an environmentalist for my entire adult life, which as you can see is quite a long time! For most of that time I was opposed to nuclear power because I considered it to be dangerous. Born and raised in Manitowoc, I worried about the Point Beach and Kewaunee nuclear power plants and supported those who opposed their construction. But I am here today to urge you to support this bill.

The reason for my change of heart can be summarized in one word: science. As a practicing attorney I had little interest in science until I began to read about climate change, first in the popular press and, later, in more sophisticated publications. Parenthetically, I also happened to marry someone with a PhD in microbiology who challenged some of my long (and strongly!) held beliefs.

I learned about the Intergovernmental Panel on Climate Change, the National Academies of Science, and consensus science generally. And what I learned is that my position on nuclear power was not supported by science but was an ideologically-driven position which parroted many of the organizations on which I had until then depended for my information.

I would like to point out just a few of the misconceptions I held about nuclear power.

For example, I always thought Three Mile Island was quite a dangerous accident with grave consequences. In fact, there was only a tiny amount of radiation released at Three Mile Island, and no adverse health effects in the surrounding population. Repeated studies found a small statistically non-significant increase in the rate of cancer in the area around Three Mile Island but no causal connection between those cancers and the accident.

Nevertheless, there are still many people – well-educated, widely read and intelligent people – who talk about deformed babies and deaths from cancer as a result of Three Mile Island.

And Chernobyl has been painted as almost apocalyptic. While it was without a doubt the worst nuclear accident the world has ever seen – and the only one that resulted in fatalities - its effects have been grossly exaggerated. Fewer than 50 people died as a direct result of the radiation, including less than 20 deaths from thyroid cancer. In addition, there were approximately 6000 cases of thyroid cancer in children that were successfully treated.

The same un-founded fears about the dangers of radiation that followed Three Mile Island and Chernobyl have plagued discussions about Fukushima.

The fact is that there have been no deaths attributed to radiation exposure as a result of the Fukushima disaster. One worker has died of leukemia but it is not known whether the leukemia was caused by radiation or would have occurred regardless – because, of course, some people living in the area would have died from leukemia had there been no accident. It is now widely recognized that the greatest public health impacts of Fukushima were a result of *fear* of radiation, not radiation itself.

There is not time to address at any length another issue often raised by opponents of nuclear power, namely the waste. But again, the science does not support the level of fear stoked by nuclear power opponents. Spent fuel has been stored safely for more than half a century. The waste from burning fossil fuels, by contrast, simply goes into the air where it is neither contained nor safe-guarded.

But don't believe me. Go to the best sources of science that exist and read for yourself. Go to UNSCEAR (the United Nations Scientific Committee on the Effects of Atomic Radiation); our own National Acadamies of Science (probably the best source of science in the U.S.); and the World Health Organization.

My reason for supporting this bill is that I am convinced the world needs more nuclear power to avoid the worst impacts of climate change. There are those who argue that we can achieve the necessary emission reductions by investing more heavily in conservation and efficiency – clearly the low-hanging fruit – and renewables such as wind, solar and hydropower.

But the best sources of science do not support that optimism. Here I would refer you to a joint report from the National Academy of Sciences, the National Academy of Engineering and the National Research Council called "America's Energy Future". You can read it for free online. The report concludes that efficiency measures could potentially save 30 percent of the energy used in the U.S. economy by 2030, but the barriers to doing so are formidable. Non-hydropower renewables, with accelerated deployment, could supply up to 10 percent of the country's electricity by 2020, potentially rising to as much as 20 percent by 2035.

It is disheartening that what has been both a safe and clean source of electricity is so vilified by environmentalists and progressives, particularly when nuclear power is compared to coal. Coal is estimated - conservatively - to kill 10,000 people in the United States alone every single year, year after year after year. Globally, the number is, of course, much higher. And that does not even count coal's contribution to global warming.

Even more perplexing is the argument that natural gas is better than nuclear. The recent and ongoing leak in Southern California is spewing 1200 tons of methane each day, a greenhouse gas many times more potent than carbon dioxide. Thousands of residents have had to be evacuated. That – not spent nuclear fuel – is truly uncontained waste.

I am a latecomer to the environmentalist-turned-nuclear-power-supporter movement, but I am in good company. Four of the world's top climate scientists, including Dr. James Hansen, released an open letter to the environmental community two years ago urging it to drop its opposition to nuclear power. I have attached a copy of their letter to my written testimony. Other prominent environmentalists who have changed their position on nuclear power include Stewart Brand, author of The Whole Earth Catalog; Patrick Moore, a founder of Greenpeace; Jeffrey Sachs, director of the Earth Institute at Columbia University; and Mark Lynas, award-winning author of several books about climate change. You can find a more complete list on the website of the UW American Nuclear Society, Student Section at http://blog.atomicbadger.org/

If you want an excellent summary of the science behind what I have said today, written for the lay person, I highly recommend Nuclear 2.0, Why a Green Future Needs Nuclear Power, by Mark Lynas. Dr. Hansen also has a very useful website: http://www.columbia.edu/~jeh1/

But the bottom line is that we need it all – conservation, efficiency, renewables, and nuclear - if we hope to slow down the impacts of climate change that we are already seeing around the world.

Thank you.
Margi Kindig net
mkindig@charter.et

Kerry Emanuel
Shared publicly - Nov 3, 2013

Kerry Emanuel originally shared:

To those influencing environmental policy but opposed to nuclear power:

As climate and energy scientists concerned with global climate change, we are writing to urge you to advocate the development and deployment of safer nuclear energy systems. We appreciate your organization's concern about global warming, and your advocacy of renewable energy. But continued opposition to nuclear power threatens humanity's ability to avoid dangerous climate change.

We call on your organization to support the development and deployment of safer nuclear power systems as a practical means of addressing the climate change problem. Global demand for energy is growing rapidly and must continue to grow to provide the needs of developing economies. At the same time, the need to sharply reduce greenhouse gas emissions is becoming ever clearer. We can only increase energy supply while simultaneously reducing greenhouse gas emissions if new power plants turn away from using the atmosphere as a waste dump.

Renewables like wind and solar and biomass will certainly play roles in a future energy economy, but those energy sources cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires. While it may be theoretically possible to stabilize the climate without nuclear power, in the real world there is no credible path to climate stabilization that does not include a substantial role for nuclear power

We understand that today's nuclear plants are far from perfect. Fortunately, passive safety systems and other advances can make new plants much safer. And modern nuclear technology can reduce proliferation risks and solve the waste disposal problem by burning current waste and using fuel more efficiently. Innovation and economies of scale can make new power plants even cheaper than existing plants. Regardless of these advantages, nuclear needs to be encouraged based on its societal benefits.

Quantitative analyses show that the risks associated with the expanded use of nuclear energy are orders of magnitude smaller than the risks associated with fossil fuels. No energy system is without downsides. We ask only that energy system decisions be based on facts, and not on emotions and biases that do not apply to 21st century nuclear technology.

While there will be no single technological silver bullet, the time has come for those who take the threat of global warming seriously to embrace the development and deployment of safer nuclear power systems as one among several technologies that will be essential to any credible effort to develop an energy system that does not rely on using the atmosphere as a waste dump.

With the planet warming and carbon dioxide emissions rising faster than ever, we cannot afford to turn away from any technology that has the potential to displace a large fraction of our carbon emissions. Much has changed since the 1970s. The time has come for a fresh approach to nuclear power in the 21st century.

We ask you and your organization to demonstrate its real concern about risks from climate damage by calling for the development and deployment of advanced nuclear energy.

Sincerely,

Dr. Ken Caldeira, Senior Scientist, Department of Global Ecology, Carnegie Institution

Dr. Kerry Emanuel, Atmospheric Scientist, Massachusetts Institute of Technology

Dr. James Hansen, Climate Scientist, Columbia University Earth Institute

Dr. Tom Wigley, Climate Scientist, University of Adelaide and the National Center for Atmospheric Research

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Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy

by Arjun Makhijani, Ph.D.

Note: The color insert is at the end of this pdf file.

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the phase-out of fossil fuels would have the greatest negative economic impact. Public policy and direction of financial resources can help ensure that new energy sector jobs that pay well are created in those communities.

D. New Coal-fired Power Plants

New coal-fired power plants that do not have provisions for capture and sequestration of CO_2 should be prohibited. New pulverized coal-fired power plants would have a life of about 40 years or more. Since these plants are now quite expensive, the owners of new ones would constitute a formidable lobby to advocate slowing down, diluting, or stopping mandatory reductions in CO_2 emissions. Since wind-generated electricity is already economical relative to coal with sequestration, there is no reason to allow the building of new power plants that would emit large amounts of CO_2 for decades.

E. Ending Subsidies for Nuclear Power and Fossil Fuels

Nuclear power still gets a significant subsidy in the form of government-provided accident insurance. Further, despite all the talk of a nuclear power renaissance, not a single new nuclear power plant has been ordered as of this writing (July 2007), despite added subsidies for license application and other costs that were enacted into law as part of the Energy Policy Act of 2005. Congress is considering 80 to 100 percent loan guarantees for new power plants, that may extend to as many as 28 plants, at $4 billion to $5 billion each.[17] Even so, Standard & Poor's, the well-known Wall Street credit rating agency, has stated that:

> …an electric utility with a nuclear exposure has weaker credit than one without and can expect to pay more on the margin for credit. Federal support of construction costs will do little to change that reality.[18]

This means that Wall Street, or at least an influential portion of it, considers nuclear power such a high risk that the credit rating of a utility ordering it would be likely to suffer, even if the federal government provides subsidies. The result of an order would, therefore, likely increase the costs of electricity across the board, making any utility that ordered a nuclear plant less competitive.

The escalating costs of finding, characterizing and developing a deep geologic repository program for nuclear waste provide an added element of risk. Expanding nuclear power plant capacity significantly will likely require a second repository, when it is already unclear whether the proposed Yucca Mountain repository for disposing of spent fuel can ever be licensed. The site's deficiencies have been extensively written about, including by the present author.[19] Adding more nuclear power plants risks more repositories, higher costs for repositories, or higher costs for reprocessing, or all three. Further, heat waves and droughts may cause nuclear power plants to be shutdown for extended periods at times of peak demand. Since such events are expected more frequently in a warming world, an element of intermittency may be introduced into nuclear energy.

Massive subsidies should not be sustained indefinitely for any source of energy, and especially not one that carries significant nuclear proliferation, waste, and severe accident risks. Nuclear power advocates claim that it could be part of the solution of the climate change problem. CO_2 emission caps will cause the costs of fossil-fuel-related generation to increase. Nuclear power should be able to compete with that in the marketplace. There is no sign that it will be able to do so. Nuclear power should be eliminated from the U.S. economy as the current plants reach the end of their licensed lives.[20] Specifically, the following policies should be adopted:

1. All subsidies for new nuclear power plants, including government-supplied and guaranteed insurance, tax credits, and licensing subsidies should be ended.
2. Government should explicitly declare that it will not take responsibility for nuclear waste disposal from new nuclear power plants and that its responsibility extends only to existing power plants for their licensed lifetimes.
3. A regulatory infrastructure for reactor safety for existing reactors and for waste management and disposal should be maintained.
4. Onsite storage of spent fuel should be hardened against terrorist attack.
5. The insurance provisions for present plants should more realistically reflect the estimated damages from worst-case accidents that are estimated to be part of the plants' design vulnerabilities.
6. The ban on reprocessing spent fuel enacted under President Carter should be re-imposed.

Fossil fuels have been around far longer than nuclear power. Subsidies and tax breaks or loan guarantees for new applications, such as processing coal to produce liquid fuels, are especially counterproductive at a time when public policy needs to focus on achieving CO_2 emission reductions in ways that will not aggravate other problems. The exception that we would make to this policy is the full commercialization of IGCC technology, because essentially the same technology that is now proposed for coal would also be useful for electricity generation using biomass as a fuel. Carbon sequestration should also be developed for the reasons that have been discussed in Chapters 3 and 6.

F. Corporate and NGO Actions

The potential for a regulatory zero-CO_2 goal to achieve change is being illustrated in the marketplace, even from consideration of goals that are far short of this plan. For instance, the U.S. Climate Action Partnership (USCAP), which consists of corporations and large environmental non-government organizations,

CHAPTER 8: ROADMAP FOR A ZERO-CO_2 ECONOMY

It is technologically and economically feasible to phase out CO_2 emissions and nuclear power at the same time. The analysis in this report indicates that it can be done at reasonable cost by 2050. The goal could be achieved about one decade earlier, if biomass and hydrogen can be produced with high efficiency of solar energy capture and if greater efforts at energy efficiency are made. As discussed in Chapter 6, it is also possible that addressing some issues, such as creating a distributed grid with several new technologies, may take longer. The most important step at the present time to ensure the phase-out happens is to set a mandatory goal of a zero-CO_2 emissions U.S. economy as much before 2060 as possible. We first set forth a preferred renewable energy scenario to frame the detailed timeline. The action plan in the timeline also contains the contingency elements that provide redundancy in case the preferred approach cannot be realized to its fullest.

A. A Preferred Renewable Energy Scenario

Various possible components of an approach that would be preferable to the reference scenario were discussed in Chapter 6. This roadmap stresses a renewable energy economy based on a desired outcome rather than in the reference scenario. The main problem in the reference scenario is the relatively large area of land that would be required to cultivate the biomass needed mainly for liquid and gaseous biofuels that would replace fossil fuels in all sectors of the economy. Another problem is that the large amount of liquid and gaseous biofuels results in large energy losses. Five to six percent of the land area of the United States (and possibly more) would be needed. Impacts in particular regions would be considerably greater. While this is within the realm of feasibility, setting a course for a more efficient economy, with a component of hydrogen derived from wind and solar energy would be preferable.

Besides considerations of land area, there may also be issues of water use both in biomass crop production and in their processing into fuels. In view of these considerations, policy should seek to have considerably greater efficiency in all areas where liquid or gaseous biofuels are involved. The following appears to be a reasonable approach for that portion of energy demand relative to the reference scenario (electricity use and use of solid biomass for electricity generation remain unchanged):

- A significant reduction in use of gaseous biofuels in the residential and commercial sectors, for instance through greater efficiency and greater use of solar thermal heating. This applies mainly to space and water heating.
- A significant reduction in use of liquid biofuels in transportation through greater efficiency than in the reference scenario. As discussed in Chapter 6, the reference scenario assumptions are not very ambitious in relation to presently available and foreseeable technology.
- A reduction in biofuel requirements for feedstocks and fuel uses in industry though greater efficiency and greater use of solar thermal energy.

Some of the remaining hydrocarbon biofuel demand could be met using hydrogen in industrial combustion engines, greater use of electricity in the residential, commercial, and transportation sectors, and in industry. We assume that aircraft, much industry and most long-distance road transport will still use liquid biofuel hydrocarbons.

If these technological goals were realized, the overall biomass requirements would be significantly reduced. Electricity production would increase somewhat. And there would be a role for hydrogen in transportation (probably in internal combustion engines) and a greater role for hydrogen in industry. Hydrogen would be produced by a combination of electrolysis using wind energy and by one or more direct solar hydrogen production methods. In this preferred scenario, the land requirements for biofuels could be reduced to 2 to 3 percent of the U.S. land area (compared to 5 to 6 percent in the reference scenario).

Realizing this preferred renewable energy scenario would require:

- More stringent standards for buildings and vehicles compared to the reference scenario.
- Extended adoption of the concept of zero net energy beyond buildings to areas, communities, and institutions.
- Greater emphasis on research, development, and demonstration of electrolytic hydrogen from wind energy.
- Full commercialization of at least one technology for direct hydrogen production from solar energy in the next twenty years.
- Ensuring through government procurement and other incentives that, once the hydrogen production and use technologies are close to commercializa-

tion, that the infrastructure for its use will be created. Distributed hydrogen infrastructure – that is, infrastructure close to the point of use can probably be realized more expeditiously than a centralized system.

B. Timeline for Transformation

The following is a brief timeline based on the analysis in this report. The list is not comprehensive but indicative and based on the technologies that appear to be important at this time.

2007

1. Enact a physical limit of CO_2 emissions for all large users of fossil fuels (a "hard cap") that steadily declines to zero prior to 2060, with the time schedule being assessed periodically for tightening according to climate, technological, and economic developments. The cap should be set at the level of some year prior to 2007, so that early implementers of CO_2 reductions benefit from the setting of the cap. Emission allowances would be sold by the U.S. government for use in the United States only. There would be no free allowances, no offsets, and no international sale or purchase of CO_2 allowances. The estimated revenues – approximately \$30 to \$50 billion per year – would be used for demonstration plants, research and development, and worker and community transition.
2. Eliminate all subsidies and tax breaks for fossil fuels and nuclear power (including guarantees for nuclear waste disposal from new power plants, loan guarantees, and subsidized insurance).
3. Ban new coal-fired power plants that do not have carbon storage.
4. Enact high efficiency standards for appliances at the federal level.
5. Enact stringent building efficiency standards at the state and local levels, with federal incentives to adopt them.
6. Enact stringent efficiency standards for vehicles and announce the intention of making plug-in hybrids the standard U.S. government vehicle by 2015.
7. Put in place regulations requiring the recycling of batteries used in plug-in hybrids and electric cars.[1]
8. Put in place federal contracting procedures to reward early adopters of CO_2 reductions.
9. Establish a standing committee on Energy and Climate under the U.S. Environmental Protection Agency's Science Advisory Board.

2008–2009

1. Publish draft regulations and their finalization for treating CO_2 as a pollutant, cap and trade, etc.
2. Publish and finalize governmental purchase rules for biofuels to include liquid fuels made from microalgae .
3. Begin government purchase of plug-in hybrids.

4. Increase funding for the National Renewable Energy Laboratory (NREL), including an acceleration of the solar hydrogen and electrolytic hydrogen program.
5. Commission an evaluation of programs and policies (such as rebates, rate structures, etc.) in California and other states for applicability across the country.
6. Create an NREL program to evaluate and develop the uses of aquatic plants as energy sources.
7. Create a joint federal-state-local government task force on growing biomass for energy on constructed wetlands and begin planning pilot and demonstration projects.
8. Fund the following in collaboration with industry:
    - Design of Integrated Gas-Turbine Combined Cycle plant for biomass, especially for high productivity biomass.
    - Research on and development of nanocapacitor (supercapacitor) storage.
    - Large-scale demonstration plant for the production of liquid fuels and methane from microalgae.
9. Commission a thorough optimization for integrating wind and solar electricity with hydropower and combined cycle natural gas standby into a distributed electric grid. The study should also explore the concept of a "smart grid," which integrates electrical and thermal storage components.[2]
10. Commission an economic impact study for areas with high fossil fuel production to devise policies for a just transition to a renewable energy system.

Also in this period a number of actions would be needed to prepare for a first test of a vehicle-to-grid system. A V2G Task Force – a joint federal effort with Independent System Operators in cooperation with one state (such as California) where the institutional infrastructure is already in place – would be created to carry out and evaluate such a test.

2010–2020

1. Begin implementation of the hard cap for large fossil fuel users at about the 2005 level of CO_2 emissions. It would be set to decline by 3 percent per year relative to the base year in the first ten years, and adjusted thereafter.
2. Begin a policy of installing roof-top and parking lot solar PV installations at federal facilities with a goal of making the federal government buildings a zero-net energy institution by 2030 or 2035 and begin revenue sharing with the state and local governments for the same purpose.
3. Build and test 5,000- to 10,000-vehicle V2G systems in three different regions.
4. Build several demonstration plants, from small to large, for growing high productivity plants (microalgae, water hyacinths, duckweed, etc.), in conjunction with wastewater treatment plants or in areas where runoff that is

high in nutrients is creating ecological problems. Build at least one plant where wastewater is piped out of metropolitan areas to areas with degraded land for biomass and biofuels production.

5. Continue development of fuel cells, especially for stationary applications.
6. Construct an electrolytic hydrogen plant for testing and demonstrating infrastructure for hydrogen for internal combustion engine vehicles.
7. Begin building pilot plants for promising solar hydrogen technologies.
8. Begin and complete construction of a 1,000 MW solar thermal plant with twelve-hour energy storage.
9. Enact building standards at the state and local level for residential and commercial buildings.
10. Begin designing and building an IGCC plant using biomass with no coal or other fossil fuels.
11. Complete evaluation of liquid and gaseous fuel production from microalgae, prairie grasses.
12. Design and build a pilot plant for liquid and gaseous fuels from aquatic plants.
13. Design and build a demonstration plant for nighttime storage of carbon dioxide emitted from fossil fuel plants with the aim of using the CO_2 to grow microalgae in the daytime.
14. Begin using liquid fuels from microalgae on a commercial scale in the 2015 to 2020 period.
15. Design and build a demonstration hot rock geothermal plant.
16. Ensure that all housing subsidized by the federal government, including housing provided with government-subsidized loans or insurance, is built to at least Gold LEED standards. (LEED stands for Leadership in Energy and Environmental Design; it is a building certification program.)
17. Conduct a study evaluating the amounts by which public transit riders subsidize automobile users in high traffic cities.
18. Complete an evaluation of the wind farm with compressed energy storage planned for Iowa and commission second generation demonstrations.[3]
19. Build an offshore wind-energy-based electrolytic hydrogen demonstration plant for distributed onshore hydrogen production
20. Begin design and construction of demonstrations of CO_2 sequestration, with a research design that will allow evaluation of the risks of leaks and the potential for sudden releases of CO_2 after disposal.
21. Build a large-scale Fresnel lens solar concentrator solar photovoltaic power plant.
22. Evaluate and put in place a program for hydrogen-fueled commercial aircraft, including a demonstration project.
23. Issue biennial reports from the EPA's Energy and Climate Committee, which would allow updating of the program for eliminating CO_2 emissions.

2020–2030

Toward the end of this period, the backbone of the energy system is transformed. At this stage, about half of the electricity and half of the total energy inputs would come from renewable sources. Major changes in the efficiency of the U.S. economy will have become institutionalized. Different ways of doing business will have become the norm. The CO_2 cap will have declined to about half of the base level in the 2025-2030 period, possibly lower. A mix of storage technologies, solar thermal power stations, solar PV, wind farms, and other technologies would be in place. Electricity storage technologies, V2G, and the construction of regional distributed electricity grids would be well underway. Aircraft would begin using biofuels on a significant scale. The transformation of vehicles to using electricity would be well advanced. Plug-in hybrids and all-electric vehicles would be the standard new vehicles being purchased in the latter part of this period.

A decision on whether hydrogen would be a major energy carrier would also be made in this period, after evaluation of the technologies and costs of its production and use based on pilot and large-scale demonstrations. Zero net energy would be achieved for state, local, and federal buildings and by many commercial, residential and industrial buildings and in many communities and areas. Efficiency standards would have been upgraded. It would be routine to make energy-related upgrades to buildings prior to sale.

Other expected features of this period:

- The personal vehicle sector begins a major transformation to electric and plug-in hybrid vehicles as the standard production vehicles.
- Use of IGCC plants running on biomass begins. If not, other modes of deployment of biomass, such as methane production, are put into place.
- Hot rock geothermal energy, wave energy, and other technologies, possibly including carbon sequestration, transition to the commercial stage.

If solar hydrogen or electrolytic hydrogen from wind energy transition to the commercial scale by about 2025, an earlier elimination of CO_2 emissions would be possible. If, on the other hand, some technologies, such as electricity storage from intermediate-scale solar PV, compressed air storage, and V2G do not become commercial, the transition could be delayed. It is not necessary for all these technologies to be commercial, but a combination that would provide for electricity grid reliability on renewable energy alone should exist and be commercial by about 2030. The term "commercial" in this context includes the price that large users of fossil fuels must pay for scarcer CO_2 emission allowances.

Table 8-1 shows the technologies for supply, storage, and conversion, their current status, and the dates when they might come into use in a renewable energy economy, up to about 2025. Table 8-2 shows the same for demand-side technologies.

Table 8-1: Roadmap – Supply and Storage Technologies

Technology	Status	Deployable for large-scale use	Next steps	CO_2 abatement cost; obstacles; comments
Solar PV intermediate-scale	Near commercial with time-of-use pricing	2010 to 2015	Orders from industry and government; time-of-use electricity pricing	$10 to $30 per metric ton; no storage; lack of large-scale PV manufacturing (~1 GW/yr/plant); some manufacturing technology development needed.
Solar PV – large-scale	Near commercial	2015 to 2020	Large-scale demonstration with transmission infrastructure, ~5,000 MW by 2015-2020	$20 to $50 per metric ton; no storage; transmission infrastructure may be needed in some cases
Concentrating solar thermal power plants	Near commercial; storage demonstration needed	2015 to 2020	~3,000 to 5,000 MW needed to stimulate demand and demonstrate 12 hour storage, by 2020	$20 to $30 per metric ton in the Southwest. Lack of demand main problem.
Microalgae CO_2 capture and liquid fuel production	Technology developed, pilot-scale plants being built	2015	Large-scale demonstrations – 1,000 to 2,000 MW by 2012; nighttime CO_2 storage and daytime CO_2 capture pilot plants by 2012. Large-scale implementation thereafter. Demonstration plants for liquid fuel production: 2008-2015	Zero to negative at oil prices above $30 per metric ton or so for daytime capture; nighttime capture remains to be characterized. Liquid fuel potential: 5,000 to 10,000 gallons per acre (compared to 650 for palm oil).
Wind power – Large-scale, land-based	Commercial	Already being used	Transmission infrastructure and rules need to be addressed; optimize operation with existing natural gas combined cycle and hydropower plants	Negative to $46 per metric ton for operation with combined cycle standby. Areas of high wind are not near populations. Transmission development needed
Solar PV intermediate storage	Advanced batteries and ultracapacitors are still high cost	~2020	Demonstration of vehicle-to-grid using stationary storage (ultracapacitors and advanced batteries) – several ~1 MW-scale parking lot installations	Five fold cost reduction in stationary storage and lithium-ion batteries needed. Main problems: lack of large-scale manufacturing and some manufacturing technology development needed

Table 8-1 (continued): Roadmap – Supply and Storage Technologies

Technology	Status	Deployable for large-scale use	Next Steps	CO_2 abatement cost obstacles; comments
Solar PV intermediate-scale with Vehicle-to-Grid	Planning stage only. Technology components available. Integration needed.	~2020 to 2025	By 2015, several 5,000 to 10,000 vehicle demonstrations of V2G technology	V2G could reduce the cost of solar PV electricity storage from several cents to possibly ~1 cent per kWh
Biomass IGCC	Early demonstration stage	~2020	Pilot- and intermediate-scale plants (few MW to 100 MW) with various kinds of biomass (microalgae, aquatic plants), 2015 to 2020	Baseload power
High solar energy capture aquatic biomass	Experience largely in the context of wastewater treatment; some laboratory and pilot plant data	~2020	2010 to 2015 pilot plant evaluations for liquid fuel and methane production with and without connection to wastewater treatment	May be comparable to microalgae biofuels production. 50 to 100 metric tons per acre
Hot rock geothermal energy	Concept demonstrated; technology development remains	2025?	Build pilot and demonstration plants: 2015-2020 period	Baseload power
Wave energy	Concepts demonstrated	2020 or 2025?	Pilot and demonstration plants needed	Possible baseload power
Photolytic hydrogen	Laboratory development	Unknown – possibly 2020 or 2025	Significantly increased R&D funding, with goal of 2015 pilot plants	Potential for high solar energy capture. Could be a key to overcoming high land-area requirements of most biofuels
Photoelectrochemical hydrogen	Concept demonstrated; technology development remains	Possibly 2020 or 2025	Significantly increased R&D funding, with goal of 2015 pilot plants	High solar energy capture. Could be a key to overcoming problems posed by agricultural biofuels (including crop residues)

Table 8-1 (continued): Roadmap – Supply and Storage Technologies

Technology	Status	Deployable for large-scale use	Next Steps	CO_2 abatement cost obstacles; comments
Advanced batteries	Nanotechnology lithium-ion batteries; early commercial stage with subsidies	2015	Independent safety certification (2007?); large-scale manufacturing plants	Large-scale manufacturing to reduce costs. Could be the key to low cost V2G technology
Carbon sequestration	Technology demonstrated in context other than power plants	Unknown. Possibly 15 to 20 years.	Long-term leakage tests. Demonstration project ~2015-2020	For use with biomass, plus back up, if coal is needed
Ultracapacitors	Commercial in certain applications but not for large-scale energy storage	2015 to 2020?	Demonstration test with intermediate-scale solar PV. Demonstrate with plug-in hybrid as a complement to battery operation for stop-and-start power	Complements and tests V2G technology. Significant cost reduction needed for cost to be ~\$50/metric ton CO_2. Lower CO_2 price with time-of-use rates
Nanocapacitors	Laboratory testing of the concepts	Unknown.	Complete laboratory work and demonstrate the approach	Has the potential to reduce costs of stationary electricity storage and take ultracapacitor technology to the next step
Electrolytic hydrogen production	Technology demonstrated	Depends on efficiency improvements and infrastructure development	Demonstration plant with compressed hydrogen vehicles needed ~2015-2020	Could be used in conjunction with off-peak wind power

Table 8-2: Roadmap – Demand-Side Technologies, 2008-2020

Technology	Status	Deployable for large-scale use	Next steps	CO_2 price; obstacles; comments
Efficient gasoline and diesel passenger vehicles	Commercial to ~40 miles per gallon or more	Being used	Efficiency standards needed	Efficiency depends on the vehicle. Can be much higher.
Plug-in hybrid vehicles	Technology has been demonstrated	2010	Efficiency standards, government and corporate orders for vehicles	Large-scale battery manufacturing needed to reduce lithium-ion battery cost by about a factor of five.
Electric cars	Technology with ~200 mile range has been demonstrated; low volume commercial production in 2007 (sports car and pickup truck)	2015 to 2020	Safety testing, recycling infrastructure for battery materials, large-scale orders, solar PV-V2G demonstration	One of the keys to reducing the need for biofuels and increasing solar and wind power components.
Internal combustion hydrogen vehicles	Technology demonstrated	Depends on infrastructure development	10,000 psi cylinder development and testing of vehicles. Demonstration project	
Biofuels for aircraft	Various fuels being tested	2020?	Fuel development, safety testing, emissions testing	
Hydrogen-fuel aircraft	Technology has been demonstrated	2030?	Aircraft design, safety testing, infrastructure demonstration	In combination with solar hydrogen production, could reduce need for liquid biofuels.
Building design	Commercial, well known	Already being used	Building standards, dissemination of knowledge, elimination of economic disconnect between building developers and users	Residential and commercial building energy use per square foot can be reduced 60 to 80 percent with existing technology and known approaches. CO_2 price, negative to $50 per metric ton.
Geothermal heat pumps	Commercial	Already being used	Building standards that specify performance will increase its use	Suitable in many areas; mainly for new construction.

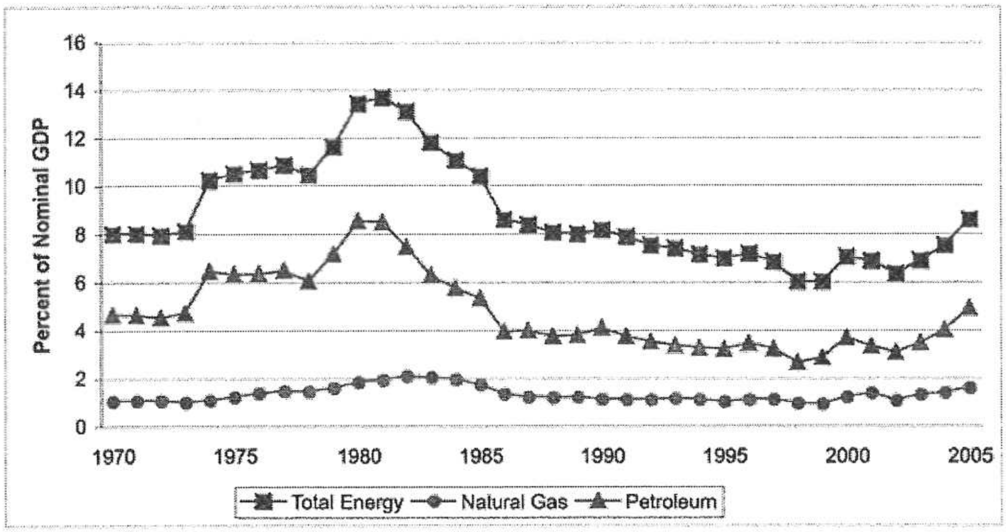
Table 8-2 (continued): Roadmap – Demand-Side Technologies, 2008-2020

Technology	Status	Deployable for large-scale use	Next steps	CO_2 price; obstacles; comments
Combined heat and power (CHP), commercial buildings and industry	Commercial	Already being used	Building performance standards and CO_2 cap will increase use	CO_2 price negative to <$30 per metric ton in many circumstances.
Micro-CHP	Semi-commercial	Already being used	Building performance standards will increase use	
Compact fluorescent lighting (CFL)	Commercial	Being used currently	Appliance and building regulations needed	Negative CO_2 price. Mercury impact of disposal needs to be addressed.
Hybrid solar lightpipe and CFL	Technology demonstrated; beta-testing being done in commercial establishments	2012 to 2015?	Government and commercial sector orders	Solar concentrators focus light indoors; work in conjunction with CFL. Five-fold cost reduction needed.
Industrial sector: examples of technologies and management approaches: alternatives to distillation, steam system management, CHP, new materials, improved proportion of first pass production	Constant development of processes	Various	Hard cap for CO_2 with annual assured decreases and no free allowances will lead to increase in efficiency	Variable. Negative to possibly $50 per metric ton, possibly more in some cases. Great potential for economical increases in efficiency exists at present costs, since energy costs have gone up suddenly. Successful reductions of energy use indicate that overall cost will be modest, with possible reduction in net cost of energy services.

C. Macroeconomics of the Transition

In the three decades following 1970, U.S. energy expenditures fluctuated from a low of about six percent (very briefly when prices collapsed in the late 1990s) to about 14 percent of the GDP. About 8 percent has been more typical, leaving aside the fluctuations caused by the turbulence immediately following the crises of 1973 and 1979. The proportion fell briefly to about 6 percent in the late 1990s, when oil prices declined steeply, dipping to a low of $12 per barrel.

Figure 8-1: Proportion of GDP Spent on Energy



Source: Courtesy of the Energy Information Administration of the United States Department of Energy

By 2050 the GDP will be nearly $40 trillion (constant 2004 dollars) under business-as-usual economic growth.[4] The energy use projected under the business-as-usual scenario is 160 quadrillion Btu, while that estimated for the reference scenario for the present analysis is about 76 quadrillion Btu. Both figures include losses in electricity production; the latter also includes losses in biofuels production. (The energy consumption in 2005 was about 100 quadrillion Btu.)

We have estimated the proportion of GDP that would be devoted to the energy services, such as transportation and heating and cooling in buildings. One overall criterion for an economical transition to a renewable energy economy is that the proportion of GDP devoted to energy services be no different than has been typical in recent decades, apart from the brief extreme swings occasioned by very rapid increases and decreases of oil prices. It is more difficult to compare this macroeconomic estimate for the reference scenario with the proportion of GDP that would be devoted to energy under the business-as-usual scenario. For the purposes of comparison, we use present prices, though this represents a rather unrealistic picture. The reason is that such a projection is built into a business-as-usual scenario, which is less a projection than an estimate of energy use in the future in the absence of major changes in the global economic, political, security, and resource picture. We chose a benchmark eight percent of GDP for energy expenses as a figure of merit for the reference scenario. A comparison with business-as-usual is made under assumption of present energy prices.[5] We address issues connected with business-as-usual projections separately (see Section C below).

1. The Residential and Commercial Sectors

A computation of the future cost of energy services under the reference scenario requires estimates of energy supply costs (fuel and electricity) and of additional investments that will be necessary to achieve the higher efficiency relative to the business-as-usual scenario.

Present costs of ethanol, hydrogen from electrolysis, and other biofuels indicate that the costs of biofuel supply for the residential and commercial sectors may be somewhat higher in the future than that of fossil fuels in 2005. We have assumed a delivered cost of $20 per million Btu, which is rather on the pessimistic side, in order not to underestimate the future fuel cost in a reusable energy economy.

For electricity, we assume a delivered cost to residential and commercial customers of about 12 cents per kWh for two-thirds of the supply, based on IGCC technology with sequestration and coal as a fuel, with which much of the future renewable electric supply system would have to compete in the absence of subsidies. For the rest, we have assumed that the cost would be typical of an intermediate-level solar PV system. We also assume that storage corresponding to one day's average output would be part of such a system. Storage capacity costs are taken to be $200 per kWh, which is about one-fifth the present price of ultra-capacitors.[6] The installed cost of solar PV systems is assumed to average $1.50 per peak watt, without storage. The generation per peak installed kW is taken as 1,800 kWh per year for a non-tracking system. A two-cent charge for distribution is added, since distribution systems will likely have to be strengthened for widespread use of intermediate-scale solar PV systems. The overall cost for such a system comes to about 18.2 cents per kWh. Combining the two estimates yields an average electricity cost for the residential and commercial sectors of 14.1 cents per kWh. Other forms of storage could be used instead or as complements in a "smart grid" system that combines supply-side and demand-side storage.[7]

For the business-as-usual scenario, we have used January 2006 costs: $12 and $10 per million Btu for the residential and commercial sectors respectively for fuel, and 9.57 cents and 8.81 cents per kWh for electricity. As discussed above, these are only notional costs used here to represent an unchanged and smooth business-as-usual energy future.[8] They are unlikely to be representative of actual future costs if energy demand grows as estimated in the business-as-usual scenario. Increasing fuel consumption implies growing imports of oil and natural gas (See Section C below), which will likely affect market and geopolitical conditions adversely.

We also assume that additional investments will be needed relative to business-as-usual to achieve the efficiencies that are built into the demand structure in the reference scenario. It is more difficult to make reliable estimates of such investments far into the future in part because there are fewer generally applicable examples.

1. For new commercial buildings, the added investment assumed is $10 per square foot, which is greater than examples of platinum level LEED-certified buildings. LEED (Leadership in Energy and Environmental Design) is a building certification program that evaluates not only energy efficiency but also other environmental aspects such as water use and the nature of the materials used on construction. We have not attributed any of the costs to aspects of environmental design other than energy use.

2. Residential building costs are much more variable, varying from $70 to over $200 per square foot for environmentally advanced buildings. There is no discernible pattern, except that buildings that include solar PV, solar thermal space or water heating, or geothermal heat pumps would cost somewhat more. (see Table 8-3). We assumed that the higher efficiency in the reference scenario would add about 10 percent per square foot to the cost of advanced buildings being built at present, as illustrated in Table 8-3. Only costs for efficiency improvements are included. The costs for solar PV, solar thermal installations, and combined heat and power systems were added separately.

3. For existing buildings, we assumed an investment at the time of sale of the homes and a turn over rate of a little over 5 percent per year. The total sales of existing homes between 2010 and 2050 would be about 300 million (since existing homes would be sold more than once in the period). We assumed that there would be an investment of $20,000 in one-third of these transactions.

Table 8-3: Examples of Cost of Green Building Award-Winning Homes for Efficiency Improvements Only

Climate/State	cost/sq. ft.	area, sq. ft.	Cost $
Moderate/MD or VA	100	1900	190000
Cold/WI	76	2728	207328
Hot/TX	115	1994	224310
Moderate/CA	70	2543	163610
Cold/CO	98	2864	280672
Cold/MI	198	3453	676194
Cold/ID	75	2653	198975
Moderate/MD	58	3716	192128
Moderate/OR	235	2544	565540
Total		24395	2698757
Average	111		

Source: Energy Value Housing Awards at http://www.nahbrc.org/evha/winners.html (EVHA 2007) and, for the first building in the list at PRSEA 2003.

Note: The additional costs of solar thermal installations over and above those of conventional systems are taken to be: solar PV at $6,000 per peak watt, solar thermal water heating systems at $5,000, and geothermal heat pumps at $7,500 for those homes that have them. These costs have been subtracted from the building cost and separately accounted for in the reference scenario and Table 8-4 below.

Table 8-4 shows the results for the residential and commercial sectors. The total estimated annual energy and investment costs for the residential and commercial sectors in terms of GDP impact are about the same as energy costs in the business-as-usual scenario. The lower per house and per square foot, higher needed investment, and higher anticipated per unit costs of electricity and fuels under the IEER reference scenario are taken into account. The net estimated GDP impact of reducing residential and commercial sector energy use by efficiency improvements and converting entirely to renewable energy sources is small and well within the range of the uncertainties in the calculations.

Table 8-4: Annual Residential (R) and Commercial (C) Energy and Investment Costs in 2050, in Billions of Constant 2005 Dollars

Item	IEER Reference Scenario	Business-as-Usual Scenario
R + C Electricity	$326	$442
R + C Fuel	$150	$247
Sub-total energy cost	$476	$689
Added annual investment for efficiency (Notes 2 and 3)	$205	$0
Total GDP-basis amount (rounded)	***$681***	***$689***
GDP in 2050 (Note 4)	$40,000	$40,000
GDP fraction: residential and commercial energy services	***1.70%***	***1.72%***

Notes:
1. Business-as-usual (BAU) fuel and electricity prices: about $12 per million Btu and 9.6 cents per kWh. Reference Scenario prices: $20 per million Btu and 14.1 cents per kWh respectively. BAU electricity price is from January 2006.
2. Added efficiency investments: existing residences: $20,000 per residence each time, assumed to occur in one of every three sales of existing buildings between 2010 and 2050; new = $10 per square foot (about $20,000 per house, approximate LEED-certified house added cost); plus cost of replacing appliances every 15 years with then-prevailing advanced appliances. Investments for solar thermal heating, combined heat and power, and geothermal heat pumps added to these figures for the proportion of residential area using them. LEED stands for Leadership in Energy and Environmental Design; it is a building certification program.
3. Commercial efficiency investments: $10 per square foot; this is more than examples of platinum level LEED investment. Investments for solar thermal heating, combined heat and power, and geothermal heat pumps have been added to these figures.
4. GDP = consumption expenditures + investment + government spending (on goods and services) + exports – imports.

Under the stated assumptions, the costs in the residential sector are somewhat higher than business-as-usual and those in the commercial sector are somewhat lower. A calculation for an average individual homeowner who purchases a new, detached home in the year 2050, with features weighted by the proportion in which they are used in the reference scenario indicates that the added cost would be $20 to $100 per month. An interest rate of 7 percent and a 30-year mortgage has been assumed. The latter figure is less than 0.7 percent of median household income in 2050. The range reflects uncertainties as to the marginal increased cost of efficiency based on estimated added costs of efficient homes over typical homes at present of 3 to 8 percent.[9]

2. Transportation

Estimating the costs of the transformation of the vehicular sector for the technologies in the reference scenario is rather difficult and relies on a projection of the costs of plug-in hybrids and electric vehicles. The most important uncertainty is the cost of batteries. At present the cost is around $1,000 per kWh. This is too expensive to compete with gasoline cars at $3 per gallon. However, as noted, present battery costs are dominated by low volume of manufacture and the nascent nature of the industry. We assume battery costs of $200 per kWh, which are anticipated in less than a decade (see Chapters 3 and 5). We also assume that the entire cost of the battery needed for a 200-mile range would be additional cost over a gasoline car. Efficiency assumptions for the year 2050 for personal vehicles are as follows:

- Business-as-usual: about 40 miles per gallon.
- IEER reference scenario: 10 miles per kWh
- An average electricity cost of 14.1 cents per kWh, assuming that partial off-peak and partial on-peak charging will result in average electricity rates for vehicle charging. This assumption may appear rather adverse for electric cars. However, it is realistic to assume that facilities similar to gas stations would be commonly used for quick charging of vehicles in addition to off-peak charging in a context where electric vehicles and/ or plug-in hybrids with high capacity for running on electricity only would be the standard vehicles on the market.

The reduced costs of maintenance (no oil changes, no tune-ups, lower brake replacement rate, etc.) of electric vehicles are not taken into account. With these assumptions, the proportion of GDP devoted to fuel cost for personal vehicles would be about 0.9 percent for the business-as-usual scenario and 0.5 to 0.6 percent for the reference scenario. Another way to look at these numbers is that personal and small business transportation in the reference scenario would be comparable to the business-as-usual scenario with present achievable electric vehicle efficiency and battery cost of $200 per kWh. At future efficiency of 10 miles per kWh, the battery cost could be about $400 per kWh. Hence, improvements in vehicle efficiency and reductions in battery costs can go hand-in-hand in improving electric vehicle economics.

Personal transportation fuel use represents only about half the fuel consumption in transportation. The proportion of energy costs in the transportation sector would therefore be 2 to 3 percent, possibly less, under these assumptions in the year 2050.

D. Projecting Business-as-usual

A business-as-usual future would be characterized by a lack of restrictions on fossil fuel consumption and hence most likely growing oil and natural gas imports. Such an energy future may be characterized by economic turbulence and higher prices that are not captured by the notional prices used in the comparisons above. Business-as-usual is an historical construct that facilitates technical calculations, but should not be regarded as an estimate of the evolution of the energy future of the United States or the world.

An energy future that follows the past pattern of increasing oil imports would likely be wracked by volatility in oil prices. Disruptions in supply, such as those caused by Hurricane Katrina, may also be more frequent due to the increasing effects of severe climate change. If the United States does not commit to serious reductions in oil consumption, there would be no prospect that China, India, and other developing countries would do so. The overall global economic and political environment in which these and other countries, including the European Union and Japan, compete for oil and gas would be very likely to deteriorate. This problem of resource competition would likely be much worse in areas where production costs are very low, at present mainly the Persian Gulf region, where costs are less than $3 per barrel, but also in other areas, where production costs are moderate.

Another way of saying the same thing is that business-as-usual projections of energy use are unlikely, in the same way that projections made before 1973 became unlikely in the face of the political, military, and economic crisis represented by the events of 1973 and 1979. They changed the energy picture in the United States profoundly (see Chapter 1). The main choice is whether energy use will become more efficient and more oriented towards domestic renewable resources by deliberate policy or whether it will be driven there willy-nilly by recurrent global crises.

CHAPTER 9: SUMMARY

A three-fold global energy crisis has emerged since the 1970s; it is now acute on all three fronts:

1. **Climate disruption**: Carbon dioxide (CO_2) emissions due to fossil fuel combustion are the main anthropogenic cause of severe climate disruption, whose continuation portends grievous, irreparable harm to the global economy, society, and current ecosystems.
2. **Insecurity of oil supply**: Rapid increases in global oil consumption and conflict in and about oil exporting regions make prices volatile and supplies insecure.
3. **Nuclear proliferation:** Non-proliferation of nuclear weapons is being undermined in part by the spread of commercial nuclear power technology, which is being put forth as a major solution for reducing CO_2 emissions.

This book examines the technical and economic feasibility of achieving a U.S. economy with zero-CO_2 emissions without nuclear power. This is interpreted as an elimination of all but a few percent of CO_2 emissions or complete elimination with the possibility of removing from the atmosphere some CO_2 that has already been emitted. We set out to answer three questions:

- Is it possible to physically eliminate CO_2 emissions from the U.S. energy sector without resort to nuclear power, which has serious security and other vulnerabilities?
- Is a zero-CO_2 economy possible without purchasing offsets from other countries – that is, without purchasing from other countries the right to continue emitting CO_2 in the United States?
- Is it possible to accomplish the above at reasonable cost?

The overarching finding of this study is that a zero-CO_2 U.S. economy can be achieved within the next thirty to fifty years without the use of nuclear power and without acquiring carbon credits from other countries. In other words, actual physical emissions of CO_2 from the energy sector can be eliminated with technologies that are now available or foreseeable. This can be done at reasonable cost while creating a much more secure energy supply than at present. Net U.S. oil imports can be eliminated in about 25 years. All three insecurities – severe climate disruption, oil supply and price insecurity, and nuclear proliferation via commercial nuclear energy – will thereby be addressed. In addition, there will be large ancillary health benefits from the elimination of most regional and local air pollution, such as high ozone and particulate levels in cities, which is due to fossil fuel combustion.

The achievement of a zero-CO_2 economy without nuclear power will require unprecedented foresight and coordination in policies from the local to the national, across all sectors of the energy system. Much of the ferment at the state and local level, as well as some of the proposals in Congress, is already pointed in the right direction. But a clear long-term goal is necessary to provide overall policy coherence and establish a yardstick against which progress can be measured.

A zero-CO_2 U.S. economy without nuclear power is not only achievable – it is necessary for environmental protection and security. *Even the process of the United States setting a goal of a zero-CO_2, nuclear-free economy and taking initial firm steps towards it will transform global energy politics in the immediate future and establish the United States as a country that leads by example, rather than one that preaches temperance from a barstool, especially in the matter of nuclear power and the technologies that are associated with it, some of which are directly relevant to nuclear weapons production.*

A. Findings

Finding 1: A goal of a zero-CO_2 economy is necessary to minimize harm related to climate change.

According to the Intergovernmental Panel on Climate Change, global CO_2 emissions would need to be reduced by 50 to 85 percent relative to the year 2000 in order to limit average global temperature increase to 2 to 2.4 degrees Celsius relative to pre-industrial times. A reduction of 80 percent in total U.S. CO_2 emissions by 2050 would be entirely inadequate to meet this goal. It implies annual U.S. emissions of about 2.8 metric tons per person.

A global norm of emissions at this rate would leave worldwide CO_2 emissions almost as high as in the year 2000.[1] In contrast, if a global norm of approximately equal per person emissions by 2050 is created along with a 50 percent global reduction in emissions, it would require an approximately 88 percent reduction in U.S. emissions. An 85 percent global reduction in CO_2 emissions corresponds to a 96 percent reduction for the United States. An allocation of emissions by the standard of cumulative historical contributions would be even more stringent.

A U.S. goal of zero-CO_2, defined as being a few percent on either side of zero relative to 2000, is both necessary and prudent for the protection of global climate. It is also implied by the United Nations Framework Convention on Climate Change. That treaty, to which the United States is a party, requires that the burden of reducing emissions of greenhouse gases be shared equitably, with due consideration to the historical fact and current reality that developed countries have been and are responsible for most emissions. A per-capita norm is a minimal interpretation of this treaty. When joined to the goal of being reasonably sure to limit temperature rise to the range of 2 to 2.4 degrees Celsius by 2050, the UNFCCC implies a zero-CO_2 economy for the United States.

Finding 2: A hard cap on CO_2 emissions – that is, a fixed emissions limit that declines year by year until it reaches zero – would provide large users of fossil fuels with a flexible way to phase out CO_2 emissions. However, free allowances, offsets that permit emissions by third party reductions,[2] or international trading of allowances, notably with developing countries that have no CO_2 cap, would undermine and defeat the purpose of the system. A measurement-based physical limit, with appropriate enforcement, should be put into place.

A hard cap on CO_2 emissions is recommended for large users of fossil fuels, defined as an annual use of 100 billion British thermal units (Btu) or more – equal to the delivered energy use of about 1,000 households. At this level, users have the financial resources to be able to track the market, make purchases and sales, and evaluate when it is most beneficial to invest in CO_2 reduction technologies relative to purchasing credits. This would cover about two-thirds of fossil fuel use. Private vehicles, residential and small commercial use of natural gas and oil for heating, and other similar small-scale uses would not be covered by the cap. The transition in these areas would be achieved through efficiency standards, tailpipe emissions standards, and other standards set and enforced by federal, state, and local governments. Taxes are not envisaged in this study, except possibly on new vehicles that fall far below the average efficiency or emissions standards. The hard cap would decline annually and be set to go to zero before 2060. Acceleration of the schedule would be possible, based on developments in climate impacts and technology.

The annual revenues that would be generated by the government from the sale of allowances would be on the order of \$30 billion to \$50 billion per year through most of the period, since the price of CO_2 emission allowances would tend to increase as supply goes down. These revenues would be devoted to ease the transition at all levels – local, state, and federal – as well as for demonstration projects and research and development.

Finding 3: A reliable U.S. electricity sector with zero-CO_2 emissions can be achieved without the use of nuclear power or fossil fuels.

The U.S. renewable energy resource base is vast and practically untapped. Available wind energy resources in 12 Midwestern and Rocky Mountain states equal about 2.5 times the entire electricity production of the United States. North Dakota, Texas, Kansas, South Dakota, Montana, and Nebraska each have wind energy potential greater than the electricity produced by all 103 U.S. nuclear power plants. Solar energy resources on just one percent of the area of the United States are about three times as large as wind energy, if production is focused in the high insolation areas in the Southwest and West.

Just the parking lots and rooftops in the United States could provide most of the U.S. electricity supply. This also has the advantage of avoiding the need for transmission line expansion, though some strengthening of the distribution infrastructure may be needed. Wind energy is already more economical than nuclear power. In the past two years, the costs of solar cells have come down to the point that medium-scale installations, such as the ones shown in Chapter 3, are economical in sunny areas, since they supply electricity mainly during peak hours.

The main problem with wind and solar energy is intermittency. This can be reduced by integrating wind and solar energy together into the grid – for instance, wind energy is often more plentiful at night. Geographic diversity also reduces the intermittency of each source and for both combined. Integration into the grid of these two sources up to about 15 percent of total generation (not far short of the contribution of nuclear electricity today) can be done without serious cost or technical difficulty with available technology, provided appropriate optimization steps are taken.

Solar and wind should also be combined with hydropower – with the latter being used when the wind generation is low or zero. This is already being done in the Northwest. Conflicts with water releases for fish management can be addressed by combining these three sources with natural gas standby. The high cost of natural gas makes it economical to use combined cycle power plants as standby capacity and spinning reserve for wind rather than for intermediate or baseload generation. In other words, given the high price of natural gas, these plants could be economically idled for some of the time and be available as a complement to wind power. Compressed air can also be used for energy storage in combination with these sources. No new technologies are required for any of these generation or storage methods.

Baseload power can be provided by geothermal and biomass-fueled generating stations. Intermediate loads in the evening can be powered by solar thermal power plants which have a few hours of thermal energy storage built in.

Finally, new batteries can enable plug-in hybrids and electric vehicles owned by fleets or parked in large parking lots to provide relatively cheap storage. Nanotechnology-based lithium-ion batteries, which Altairnano has begun to produce, can be deep discharged far more times than needed simply to operate the vehicle over its lifetime (10,000 to 15,000 times compared to about 2,000 times respectively).

Since the performance of the battery is far in excess of the cycles of charging and discharging needed for the vehicle itself, vehicular batteries could become a very low-cost source of electricity storage that can be used in a vehicle-to-grid (V2G) system. In such a system, parked cars would be connected to the grid and charged and discharged according to the state of the requirements of the grid and the charge of the battery in the vehicle. Communications technology to accomplish this via wires or wireless means is already commercial. A small fraction of the total number of road vehicles (several percent) could provide sufficient backup capacity to stabilize a well designed electricity grid based on renewable energy sources (including biomass and geothermal).

One possible configuration of the electric power grid is shown in Figure 5-6 in Chapter 5. A large amount of standby power is made available. This allows a combination of wind and solar electricity to supply half or more of the electricity without affecting reliability. Most of the standby power would be supplied by stationary storage and/or V2G and by combined cycle power plants for which the fuel is derived from biomass. Additional storage would be provided by thermal storage associated with central station solar thermal plants. Hydropower use would be optimized with the other sources of storage and standby capacity. Wind energy can also be complemented by compressed air storage, with the compressed air being used to reduce methane consumption in combined cycle power plants. Storage on the energy supply-side can be combined with storage on the demand-side and a smart grid approach in which demand can be adjusted to more closely match renewable energy supply.

With the right combination of technologies, it is likely that even the use of coal can be phased out, along with nuclear electricity. However, we recognize that the particular technologies that are on the cutting edge today may not develop as now appears likely. It therefore appears prudent to have a backup strategy. The carbon dioxide from coal-fired power plants can be captured at moderate cost if the plants are used with a technology called integrated gasification combined cycle (IGCC). Carbon capture and sequestration may also be needed for removing CO_2 from the atmosphere via biomass.

Finding 4: The use of nuclear power entails risks of nuclear proliferation, terrorism, and serious accidents. It exacerbates the problem of nuclear waste and perpetuates vulnerabilities and insecurities in the energy system that are avoidable.

Commercial nuclear technology is being promoted as a way to reduce CO_2 emissions, including by the U.S. government. With Russia, the United States has also been promoting a scheme to restrict commercial uranium enrichment and plutonium separation (reprocessing) to the countries that already have it. (These are both processes that can produce nuclear-weapons-usable materials.) This is a transparent attempt to change the Nuclear Non-Proliferation Treaty (NPT) without going through the process of working with the signatories to amend it. The effort will undermine the treaty, which gives non-nuclear parties an "inalienable right" to commercial nuclear technology. In any case, non-nuclear-weapon states are unlikely to go along with the proposed restrictions.

It is not hard to discern that the increasing interest in nuclear power is at least partly as a route to acquiring nuclear weapons capability. For instance, the Gulf Cooperation Council (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates), pointing to Iran and Israel, has stated that it will openly acquire civilian nuclear power technology. In making the announcement, the Saudi Foreign Minister Prince Saud Al-Faisal was quoted in the press as saying "It is not a threat....We are doing it openly." He also pointed to Israel's nuclear reactor, used for making plutonium for its nuclear arsenal, as the "original sin." At the same time, he urged that the region be free of nuclear weapons.[3]

Interest in commercial reprocessing may grow as a result of U.S. government policies. The problems of reprocessing are already daunting. For instance, North Korea used a commercial sector power plant and a reprocessing plant to get the plutonium for its nuclear arsenal. Besides the nuclear weapon states, about three dozen countries, including Iran, Japan, Brazil, Argentina, Egypt, Taiwan, South Korea, and Turkey, have the technological capacity to make nuclear weapons. It is critical for the United States to lead by example and achieve the necessary reductions in CO_2 emissions without resorting to nuclear power. Greater use of nuclear power would convert the problem of nuclear proliferation from one that is difficult today to one that is practically intractable.

Even the present number of nuclear power plants and infrastructure has created tensions between non-proliferation and the rights countries have under the NPT to acquire commercial nuclear technology. Increasing their number would require more uranium enrichment plants, when just one such plant in Iran has stoked global political-security tensions to a point that it is a major driver in spot market oil price fluctuations. In addition, there are terrorism risks, since power plants are announced terrorist targets. It hardly appears advisable to increase the number of targets.

The nuclear waste problem has resisted solution. Increasing the number of power plants would only compound the problem. In the United States, it would likely create the need for a second repository, and possibly a third, even though the first, at Yucca Mountain in Nevada, is in deep trouble. No country has so far been able to address the significant long-term health, environmental and safety problems associated with spent fuel or high level waste disposal, even as official assessments of the risk of harm from exposure to radiation continue to increase.

Finally, since the early 1980s, Wall Street has been, and remains, skeptical of nuclear power due to its expense and risk. That is why, more than half a century after then-Chairman of the Atomic Energy Commission, Lewis Strauss, proclaimed that nuclear power would be "too cheap to meter," the industry is still turning to the government for loan guarantees and other subsidies. The insurance side is no better. The very limited insurance that does exist is far short of official estimates of damage that would result from the most serious accidents; it is almost all government-provided.

Finding 5: The use of highly efficient energy technologies and building design, generally available today, can greatly ease the transition to a zero-CO_2 economy and reduce its cost. A two percent annual increase in efficiency per unit of Gross Domestic Product relative to recent trends would result in a one percent decline in energy use per year, while providing three percent GDP annual growth. This is well within the capacity of available technological performance.

Before the first energy crisis in 1973, it was generally accepted that growth in energy use and economic growth, as expressed by Gross Domestic Product (GDP), went hand in hand. But soon after, the U.S. energy picture changed radically and economic growth was achieved for a decade without energy growth.

Since the mid-1990s, the rate of energy growth has been about two percent less than the rate of GDP growth, despite the lack of national policies to greatly increase energy efficiency. For instance, residential and commercial buildings can be built with just one-third to one-tenth of the present-day average energy use per square foot with existing technology. As another example, we note that industrial energy use in the United States has stayed about the same since the mid-1970s, even as production has increased.

Our research indicates that annual use of delivered energy (that is, excluding energy losses in electricity and biofuels production) can be reduced by about one percent per year while maintaining the economic growth assumed in official energy projections.

Finding 6: Biofuels, broadly defined, could be crucial to the transition to a zero-CO_2 economy without serious environmental side effects or, alternatively, they could produce considerable collateral damage or even be very harmful to the environment and increase greenhouse gas emissions. The outcome will depend essentially on policy choices, incentives, and research and development, both public and private.

Food crop-based biodiesel and ethanol can create and are creating social, economic, and environmental harm, including high food prices, pressure on land used by the poor in developing countries for subsistence farming or grazing, and emissions of greenhouse gases that largely or completely negate the effect of using the solar energy embodied in the biofuels. While they can reduce imports of petroleum, ethanol from corn and biodiesel from palm oil are two prominent examples of damaging biofuel approaches that have already created such problems even at moderate levels of production.

For instance, in the name of renewable energy, the use of palm oil production for European biodiesel use has worsened the problem of CO_2 emissions due to fires in peat bogs that are being destroyed in Indonesia, where much of the palm oil is produced. Rapid increases in ethanol from corn are already partly responsible for fueling increases in tortilla prices in Mexico. Further, while ethanol from corn would reduce petroleum imports, its impact on reducing greenhouse gas emissions would be small at best due to the energy intensity of both corn and ethanol production, as well as the use of large amounts of artificial fertilizers, which also result in emissions of other greenhouse gases (notably nitrous oxide). All subsidies for fuels derived from food crops should be eliminated.

In contrast, biomass that has high efficiency solar energy capture (~five percent), such as microalgae grown in a high-CO_2 environment, can form a large part of the energy supply both for electricity production and for providing liquid and gaseous fuels for transport and industry. Microalgae have been demonstrated to capture over 80 percent of the daytime CO_2 emissions from power plants and can be used to produce up to 10,000 gallons of liquid fuel per acre per year. Some aquatic plants, such as water hyacinths, have similar efficiency of solar energy capture and can be grown in wastewater as part of combined water treatment and energy production systems.

Water hyacinths have been used to clean up wastewater because they grow rapidly and absorb large amounts of nutrients. Their productivity in tropical and subtropical climates is comparable to microalgae – up to 250 metric tons per hectare per year. They can be used as the biomass feedstock for producing liquid and gaseous fuels. There are also other high productivity aquatic plants, such as duckweed, that grow in a wider range of climates that can be used for producing biofuels.

Prairie grasses have medium productivity, but can be grown on marginal lands in ways that allow carbon storage in the soil. This approach can therefore be used both to produce fuel renewably and to remove CO_2 from the atmosphere.

Finally, solar energy can be used to produce hydrogen; this could be very promising for a transition to hydrogen as a major energy source. Techniques include photoelectrochemical hydrogen production using devices much like solar cells, high-temperature, solar-energy-driven splitting of water into hydrogen and oxygen, and conversion of biomass into carbon monoxide and hydrogen in a gasification plant.

Finding 7: Much of the reduction in CO_2 emissions can be achieved without incurring any cost penalties (as, for instance, with efficient lighting and refrigerators). The cost of eliminating the rest of CO_2 emissions due to fossil fuel use is likely to be in the range of \$10 to \$30 per metric ton of CO_2.

Table 9-1 shows the estimated costs of eliminating CO_2 from the electricity sector using various approaches.

Table 9-1: Summary of costs for CO_2 abatement (and implicit price of CO_2 emission allowances) – Electricity sector (based on 2004 costs of energy)

CO_2 source	**Abatement method**	**Phasing**	**Cost per metric ton CO_2, \$**	**Comments**
Pulverized coal	Off-peak wind energy	Short-term	A few dollars to $15	Based on off-peak marginal cost of coal.
Pulverized coal	Capture in micro-algae	Short- and medium-term	Zero to negative	Assuming price of petroleum is >$30 per barrel.
Pulverized coal	Wind power with natural gas standby	Medium- and long-term	Negative to $46	Combined cycle plant idled to provide standby. Highest cost at lowest gas price: $4/mn Btu
Pulverized coal	Nuclear power	Medium- to long-term	$20 to $50	Unlikely to be economical compared to wind with natural gas standby.
Pulverized coal	Integrated Gasification Combined Cycle (IGCC) with sequestration	Long-term	$10 to $40 or more	Many uncertainties in the estimate at present. Technology development remains.
Natural gas standby component of wind	Electric vehicle-to-grid	Long-term	Less than $26	Technology development remains. Estimate uncertain. Long-term-natural gas price: $6.50 per million Btu or more.

Notes:

1. Heat rate for pulverized coal = 10,000 Btu/kWh; for natural gas combined cycle = 7,000 Btu/kWh.
2. Wind-generated electricity costs = 5 cents per kWh; pulverized coal = 4 cents per kWh; nuclear = 6 to 9 cents per kWh.
3. Petroleum costs $30 per barrel or more.
4. CO_2 costs associated with wind energy related items can be reduced by optimized deployment of solar and wind together.

Further, the impact of increases in costs of CO_2 abatement on the total cost of energy services is low enough that the overall share of GDP devoted to such services would remain at about the present level of about 8 percent or perhaps decline. It has varied mainly between 8 and 14 percent since 1970, hitting a peak in 1980. It dropped briefly to about 6 percent in the late 1990s when oil prices tumbled steeply, hitting a low of about $12 per barrel in 1998.

Finding 8: The potential for energy efficiency is considerably greater than assumed in the reference scenario in many areas. Greater efficiency, greater use of electricity, and use of hydrogen derived from wind (and possibly solar) energy would greatly reduce the land impacts associated with large-scale biofuel production.

The opportunities for greater efficiency beyond the reference scenario discussed in Chapter 6 help reduce the requirement for liquid and gaseous biofuels in 2050 from about 35 quadrillion Btu to 20 to 25 quadrillion Btu. A significant fraction of this fuel requirement can be met by electrolytic hydrogen from wind and possibly direct solar hydrogen production, provided there is adequate early emphasis on commercialization of hydrogen. Distributed hydrogen production and use of hydrogen in internal combustion engines are the closest to practical application. Reducing liquid and gaseous biofuels requirements to the 10 to 15 quadrillion Btu range would largely resolve the most important anticipated environmental impact of the reference scenario – land use for biofuels. In the preferred renewable future, only about 2 to 3 percent of the land area of the U.S. would be needed for energy supply.

Finding 9: The transition to a zero-CO_2 system can be made in a manner compatible with local economic development in areas that now produce fossil fuels.

Fossil fuels are mainly produced today in the Appalachian region, in the Southwest and West and some parts of the Midwest and Rocky Mountain states. These areas are also well-endowed with the main renewable energy resources – solar and wind. Federal, state and regional policies, designed to help workers and communities transition to new industries, therefore appear to be possible without more major physical movement or disruption of populations than has occurred in post-World War II United States. It is recognized that much of that movement has been due to dislocation and shutdown of industries, which causes significant hardship to communities and workers. Some of the resources raised by the sale of CO_2 allowances should be devoted to reducing this disruption. For instance, the use of CO_2 capture technologies, notably microalgae CO_2 capture from existing fossil fuel plants, can create new industries and jobs in the very regions where the phase-out of fossil fuels would have the greatest negative economic impact. Public policy and direction of financial resources can help ensure that new energy sector jobs that pay well are created in those communities.

B. Recommendations: The Clean Dozen

The 12 most critical policies that need to be enacted as urgently as possible for achieving a zero-CO_2 economy without nuclear power are as follows.

1. Enact a physical limit of CO_2 emissions for all large users of fossil fuels (a "hard cap") that steadily declines to zero prior to 2060, with the time schedule being assessed periodically for tightening according to climate, technological, and economic developments. The cap should be set at the level of some year prior to 2007, so that early implementers of CO_2 reductions benefit from the setting of the cap. Emission allowances would be sold by the U.S. government for use in the United States only. There would be no free allowances, no offsets and no international sale or purchase of CO_2 allowances. The estimated revenues – approximately $30 to $50 billion per year – would be used for demonstration plants, research and development, and worker and community transition.
2. Eliminate all subsidies and tax breaks for fossil fuels and nuclear power (including guarantees for nuclear waste disposal from new power plants, loan guarantees, and subsidized insurance).
3. Eliminate subsidies for biofuels from food crops.
4. Build demonstration plants for key supply technologies, including central station solar thermal with heat storage, large- and intermediate-scale solar photovoltaics, and CO_2 capture in microalgae for liquid fuel production (and production of a high solar energy capture aquatic plants, for instance in wetlands constructed at municipal wastewater systems).
5. Leverage federal, state and local purchasing power to create markets for critical advanced technologies, including plug-in hybrids.
6. Ban new coal-fired power plants that do not have carbon storage.
7. Enact at the federal level high efficiency standards for appliances.
8. Enact stringent building efficiency standards at the state and local levels, with federal incentives to adopt them.
9. Enact stringent efficiency standards for vehicles and make plug-in hybrids the standard U.S. government vehicle by 2015.
10. Put in place federal contracting procedures to reward early adopters of CO_2 reductions.
11. Adopt vigorous research, development, and pilot plant construction programs for technologies that could accelerate the elimination of CO_2, such as direct electrolytic hydrogen production, solar hydrogen production (photolytic, photoelectrochemical, and other approaches), hot rock geothermal power, and integrated gasification combined cycle plants using biomass with a capacity to sequester the CO_2.
12. Establish a standing committee on Energy and Climate under the U.S. Environmental Protection Agency's Science Advisory Board.

AFTERWORD

by Dr. Helen Caldicott

The climate crisis has put the Earth in the intensive care unit. In the past few years I have experienced an acute sense of urgency to do my part to set it on the road to recovery. I have not felt such urgency since the threat of nuclear war between United States and the Soviet Union hung over the planet in the early 1980s, a threat incidentally that has not diminished, with thousands of Russian and US .nuclear warheads still on high alert, ready to be fired in minutes.

The Nuclear Policy Research Institute sponsored an energy conference in 2006 to which I invited some of the world's most experienced and able people in the energy field to ascertain whether they shared my sense of urgency about the state of the planet. This two day discussion dissected out the ecological and medical dangers of a fossil-fueled, nuclear-fueled energy system and explored the possibilities of a vibrant renewable energy economy.

Among the speakers were S. David Freeman and Arjun Makhijani. David's speech was extraordinarily inspiring as he raised the distinct possibility that all energy could be obtained from present-day technology without the use of fossil fuel or nuclear power. I could hardly believe my ears. This was an entirely new scenario that had never before been seriously entertained.

Dr. Makhijani agreed that the world was facing an ecological crisis and that the scale of the problem was escalating rapidly as grim news about climate alterations continued unabated. But was a renewable energy policy technically and economy feasible without nuclear power?

Arjun, one of the most capable scientists in environmental work, did not want to advocate something that he thought would only be feasible at an unbearably high cost. In his view, cost was part of the feasibility equation.

Several months of discussions took place before a plan of action eventuated. We agreed to initiate a comprehensive in-depth study to examine these questions. Dave Freeman and I would serve on an Advisory Board, along with other members from academia, industry, and the economic justice movement. To enable Arjun to focus entirely on the study, I agreed to accept the task of fundraising.

Wisconsin's Nuclear Reactors: A Legacy of Waste with No Safe Solution

Wisconsin is home to the Point Beach nuclear plant, with 2 reactors in Manitowoc County, and a test nuclear reactor at UW-Madison. The federal government estimates that a major accident at one of Wisconsin's nuclear plants could cost over $40 billion in property losses.

The Kewaunee Power Station, located on the shores of Lake Michigan 27 miles south of Green Bay, ceased operations in May 2013 after its owner, Dominion, could not find a buyer for its expensive power (nuclear can't compete with the decreasing cost of natural gas, wind and even solar). Decommissioning this plant will take over 60 years.

Unfortunately, because there is no safe, permanent federally-licensed repository for nuclear waste, tons of dangerous, radioactive spent fuel is being "temporarily" stored at Kewaunee (and at Point Beach and Minnesota plants), posing risks to Lake Michigan and the Mississippi River.

Wisconsin's nuclear moratorium requires utilities to show that building a new nuclear plant will benefit ratepayers and that a safe, federally licensed site is available to permanently store resulting radioactive waste. ***If cost and waste safeguards are gutted, Wisconsin could be subjected to more expensive, risky nuclear power, and revive Wisconsin's pristine Wolf River Batholith as a potential waste storage site.***

Clean energy can create thousands of family-supporting jobs now and protect our environment for future generations.

A 2009 BlueGreen Alliance report found that Wisconsin could create 35,000 jobs by increasing renewable energy requirements to 25% by 2025. **Germany already has 32,000 MW of solar and employed over 280,000 in clean energy jobs.**

Since Wisconsin utilities started investing 1.2% of their revenues in energy efficiency through Focus on Energy in 2001, we've created over 16,000 jobs, saved over $1.68 billion in energy costs, and reduced carbon dioxide emissions by over 5 billion pounds.

Investing in renewable energy and efficiency will fight climate change and reduce the billions that Wisconsin sends out of state annually for fossil fuels and uranium, **without the risk of catastrophic accidents or the burden of safely storing nuclear waste for thousands of years.**

Demand Safe, Clean Energy for Wisconsin!

- Sign up for renewable energy with your utility or install solar panels
- Use Energy Star appliances, switch to LED light bulbs, seal-up leaks, and insulate your home
- Write a letter to-the-editor demanding more renewable energy from utilities
- Support strong EPA carbon rules
- Volunteer with the Sierra Club!

SIERRA CLUB
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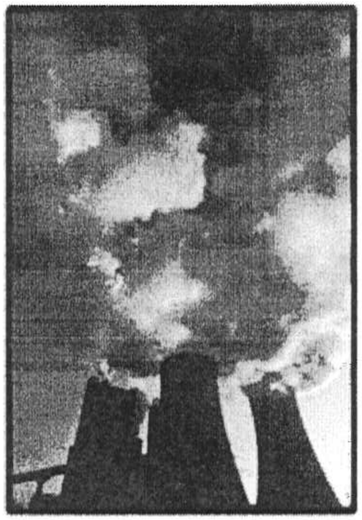
Nuclear Energy: A Bad Bargain for Wisconsin



The case for cleaner, safer, cheaper alternatives

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Nuclear Energy: The Facts

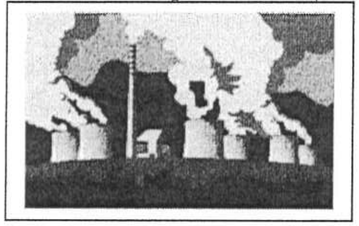
There are 103 nuclear reactors in the United States, supplying about 20% of electricity.

Proponents support nuclear energy due to the lack of carbon dioxide emissions during plant operations. ***But, the uranium mining and enrichment process is very energy intensive. Also, the waste generated is deadly for thousands of years.***

Nuclear reactors are only about 33% efficient. For every 3 units of energy generated by the reactor core, 1 unit of electrical energy goes out to the grid and 2 units of waste heat are released into nearby water bodies. ***Resulting thermal pollution harms aquatic life.***

Mining uranium is a toxic, energy intensive process. 25 tons of uranium is needed to fuel a reactor for one year. This requires 500,000 tons of waste rock and 100,000 tons of toxic mill tailings. ***Tailings consist of thorium, radium, and polonium, all of which have been classified as cancer-causing agents.***

The French have NOT solved the nuclear waste problem. They tout their ability to recycle their nuclear waste, ***but only 1% can be reprocessed into plutonium (MOX) fuel.***



Nuclear Energy: The Risks

Nuclear energy is too risky, too expensive, and too slow to effectively address climate change

Serious accidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima, (2011) show that unacceptable risks related to nuclear energy remain. Integral Fast Reactors still require uranium or plutonium and use explosive, flammable sodium as a coolant.

There is no safe level of radiation. Exposure increases the risk of thyroid cancer, leukemia, and other illnesses, decades after exposure.

Nuclear waste leaks have been documented in France, the Netherlands, Scotland and Washington since 2007. Ontario Power has proposed storing the Bruce Nuclear Generating Station's waste beneath Lake Huron. Other proposals involve shipping radioactive waste across the Great Lakes and the St. Lawrence River, risking our drinking water, tourism, and aquatic resources.

Water contamination related to uranium mining and processing has been documented in **Brazil, Australia, Namibia, Colorado and Texas**.

Nuclear plants are vulnerable to terrorism. Suspected al-Qaeda member, Sharif Mobley, accused of murder in Yemen, worked at 5 US nuclear plants.

Nuclear Energy: The Costs

One of the major drawbacks to nuclear energy is the high cost

Nuclear costs roughly $5,000-$10,000 / kilowatt equaling 10-20 cents per kWh.

Building 100 new nuclear reactors – no matter the design - would take over a decade – too slow to address climate change. They would also require a capital investment ranging from $250 billion to $1 trillion, and only reduce carbon dioxide emissions by 12%.

Not even the CEO of General Electric puts his trust in nuclear

"I don't have to bet my company on any of this stuff. You would never do nuclear. The economics are overwhelming"

Nuclear power has already benefited from over $140 billion in federal subsidies over the last 50 years.

Not only does nuclear energy not adequately reduce carbon dioxide emissions, it has greatly increased the national debt.

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