# Nuclear Energy- Appendix

## Current Status

There are 104 reactors in the US, each delivering roughly a Gigawatt of capacity (roughly enough to power ~1 million American homes). Of these, 69 are pressurized water reactors (PWR), and 35 are boiling water reactors (BWR). These provide 19.6% of the nation's total electricity.

Illinois is ranked first in the United States in terms of nuclear capacity, with 47.8% of our energy generated by nuclear power. Eleven reactors located at six sites, each with roughly 1 Gigawatt capacity produce this nuclear power. All of the plants are owned and run by Exelon Corporation. Of these reactors, 4 are Westinghouse Pressurized Water Reactors (PWRs) and 7 are General Electric Boiling Water Reactors (BWRs).

**Table 1: Nuclear Reactors in Illinois**

| Reactor | Type | Capacity (MW) | 2008 Generation (MWh) | 2006-2008 3-year Average Capacity Factor (%) | Avg # of employees |
|---|---|---|---|---|---|
| **Braidwood 1** | Westinghouse PWR | 1,178 | 10,462,944 | 96.6 | 830 |
| **Braidwood 2** | Westinghouse PWR | 1,152 | 9,323,212 | 96.0 | |
| **Byron 1** | Westinghouse PWR | 1,164 | 9,733,362 | 95.0 | 850 |
| **Byron 2** | Westinghouse PWR | 1,136 | 9,624,164 | 95.8 | |
| **Clinton 1** | GE BWR | 1,043 | 8,549,903 | 94.9 | 680 |
| **Dresden 2** | GE BWR | 867 | 7,468,202 | 95.2 | 700 |
| **Dresden 3** | GE BWR | 867 | 6,916,643 | 94.9 | |
| **LaSalle 1** | GE BWR | 1,118 | 8,883,902 | 94.0 | 800 |
| **LaSalle 2** | GE BWR | 1,120 | 9,964,662 | 99.4 | |
| **Quad Cities 1** | GE BWR | 867 | 7,490,109 | 92.9 | 660 |
| **Quad Cities 2** | GE BWR | 867 | 6,734,591 | 91.2 | |
| **Total** | | 11,379 | 95,151,694 | 95.1 | 4520 |

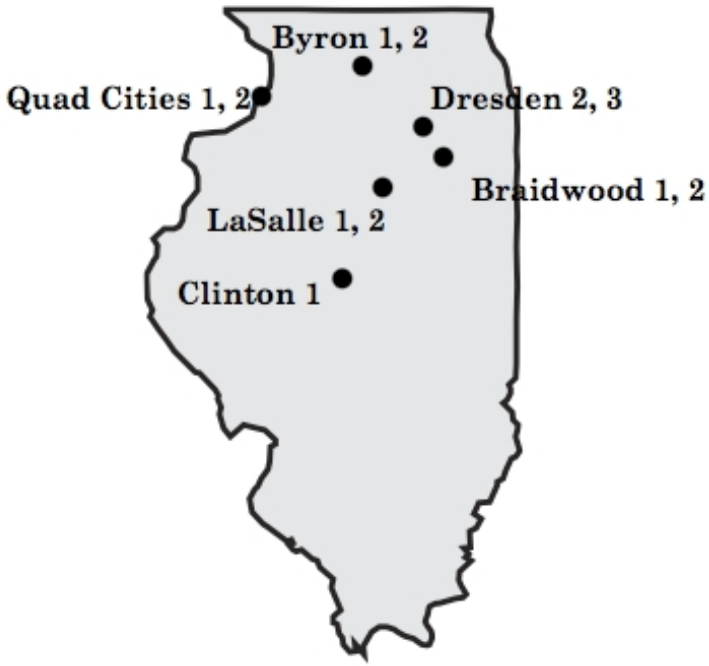



**figure 1: Locations of Illinois' Nuclear Reactors, taken from www.nei.org**

**Interest In Nuclear Energy**

There is a renewed interest in nuclear energy, both to meet growing needs for new energy capacity and because of its benefits as mature, effectively carbon-neutral source of electricity. The Department of Energy (DOE) has already received 31 new license applications, which is a new high. While none of these licenses have yet been approved, the private-sector interest is promising.

In Illinois, Exelon has expressed some interest in increasing nuclear capacity. Clinton is the only site in Illinois that does not have dual reactors. Exelon submitted an application for an Early Site Permit (ESP) to build a new, Generation III Westinghouse PWR (AP1000). Publicly, Exelon has been guarded on the matter of a new plan. It is possible that this is a political calculation, or perhaps motivated by genuine economic or political hesitations on the viability of a new reactor. Either way, it is possible that a policy change in Illinois and at the federal level. could incentivize Exelon to take that step.

In the mean time, Exelon explicitly has plans to upgrade the existing Clinton facility to boost capacity from 1.3 to 1.5 gigawatts. A company spokesperson said, "Clinton is on schedule for 2016". The improvements would include:

- A new metering system to improve monitoring and power output

- Equipment that would allow up to a 20 percent increase in reactor power.
- "Generator rewinds," which involve new copper components to increase capacity.
- Turbine refits, including blades, rotors and casings

## Political Climate

In his February 2010 State of the Union Speech, the first future energy source mentioned by President Obama was nuclear power. Secretary of Energy, Steven Chu has long been a known supporter of nuclear energy as one of the many sources of new future power capacity. While the future of nuclear energy is uncertain, these are promising signs of a changing political climate. Since the 3-Mile Island incident in 1979, America has not built any new reactors. Illinois, in particular has placed an official moratorium on new reactor construction. Any future nuclear reactors in-state will require express support from the state legislature or an amendment to the IL *Public Utilities Act*, lifting the moratorium.

Two policy changes over the last decade, the *Energy Policy Act of 2005* and the *Nuclear Power 2010 Program*, include measures to spur a new nuclear renaissance. Of note is the creation of a new licensing model, the Combined Construction and Operating License (COL), which allows power companies to obtain the operating license and construction permit at the same time (conditional on the plant being built as designed). Steven Chu has suggested an interest in allowing generic plant designs to be licensed separately to expedite the process. There is also talk of making more federal capital construction loans available to incentivize new plant construction.

## Economic Impact

The construction of new nuclear capacity has the potential to generate new jobs, GDP growth, and new tax revenue in three phases: construction, operations, and fuel production.

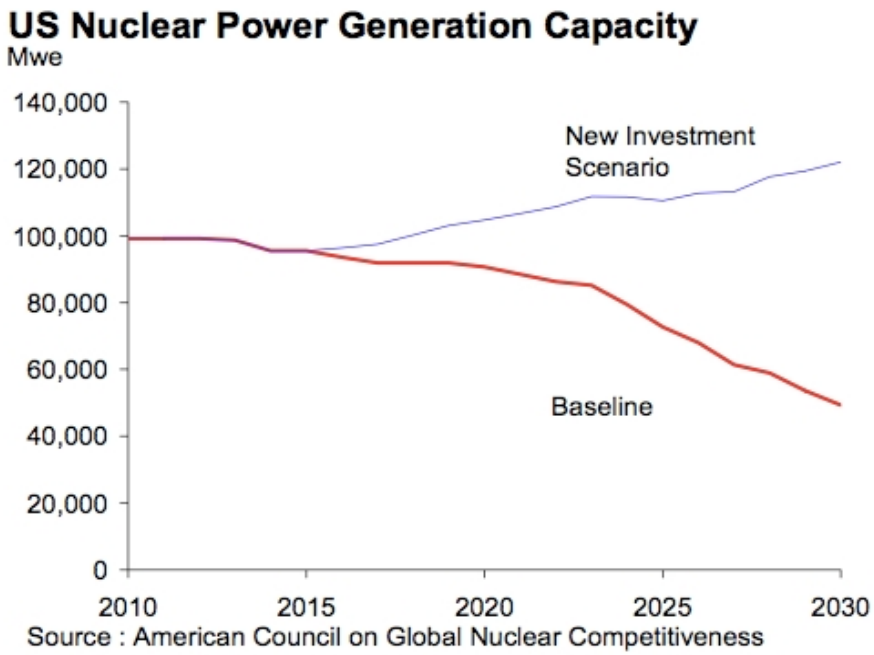
Oxford Economics, the British economic consultancy produced a report for the American Council on Global Nuclear Competitiveness titled *Economic, Employment, and Environmental Benefits of Renewed US Investment in Nuclear Energy*. The report looks at the impacts of US investment in new nuclear capacity, both to replace older facilities and build more capacity. The report looks into a scenario where America invests the funds necessary to build 52 new reactors, 1 new fuel recycling facility, and 4 new enrichment facilities (see Fig. 2). The report is based on the current license applications as well as assumed construction in states with a strong nuclear base. Illinois, for example, is taken to be planning one new reactor (in Clinton) and expected to build 6 additional reactors by 2025. Because of our large nuclear resources, the report anticipates Illinois as building the most new capacity of any state (7 reactors, with Texas coming in 2$^{nd}$ with 6 new reactors).

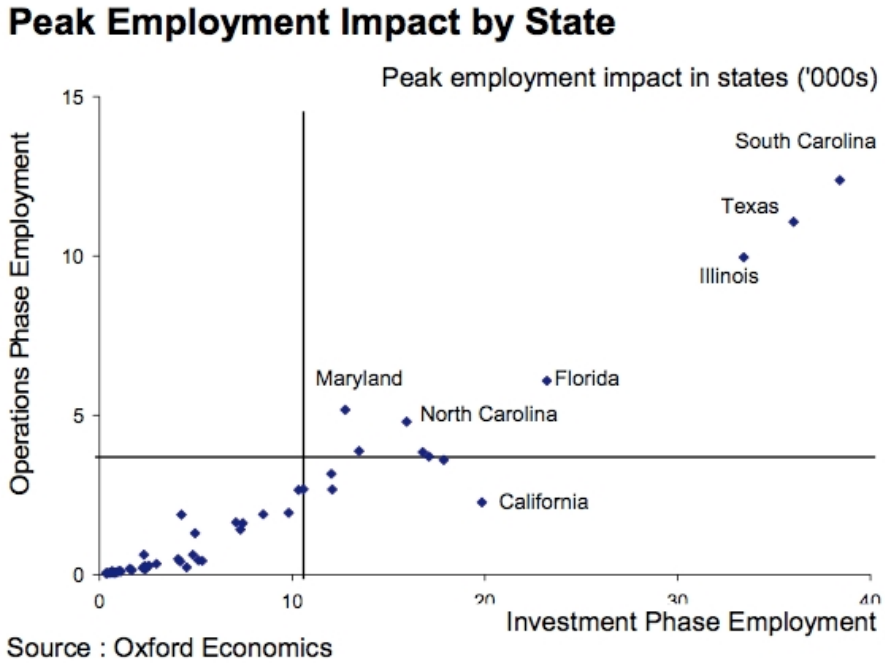
Nation-wide, the report estimates that 82,000 direct jobs, 74,000 indirect jobs, and 112,000 induced jobs will be generated during the construction phase, contributing a total value added of $33.6 billion dollars. During the operations phase, there will be 54,000 direct

jobs, 9,000 indirect jobs, and 33,000 induced jobs, with a total value added of $11.8 billion. Many of these jobs will be highly technical, and the nuclear experience, infrastructure, and expertise maintained and developed during this investment would keep America competitive in the world nuclear market.

On a state level, the report concludes that states with the most highly developed nuclear infrastructure and capital will reap the largest economic benefits. The report singles out Illinois as one of the states expected to make among the largest gains in employment and value-added, both during the investment and operations phase. Assuming 7 new reactors, Figure 4 shows that peak employment is expected to reach 30,000 jobs during the investment phase (mostly construction and manufacturing), and 10,000 jobs during the operations phase. Figure 5 shows that cumulative value added would reach $32.4 billion during the investment phase and $8.9 billion during the operations phase.

The above study is likely optimistic. During the operations phase, the report assumes roughly 1,200 new jobs per reactor (including indirect employment). Looking at Table 1, direct employment for dual reactor sites never exceeds 900 and the employment differential between 1 and 2 reactors is a few hundred jobs. Nonetheless, even 500 new jobs due to the operation of a new Clinton reactor would be a small victory. And, 1200 new jobs per site could be a realistic estimate if we build wholly new nuclear plants. During the investment phase, the report estimates that Illinois will create 33,400 new jobs, roughly 4,800 per reactor. Half of those jobs (2,400 per reactor) are involved with construction and are likely guaranteed in any scenario with new, in-state construction. The remaining 2,400 jobs are in manufacturing and will depend on the level of nuclear investment in states outside of Illinois.



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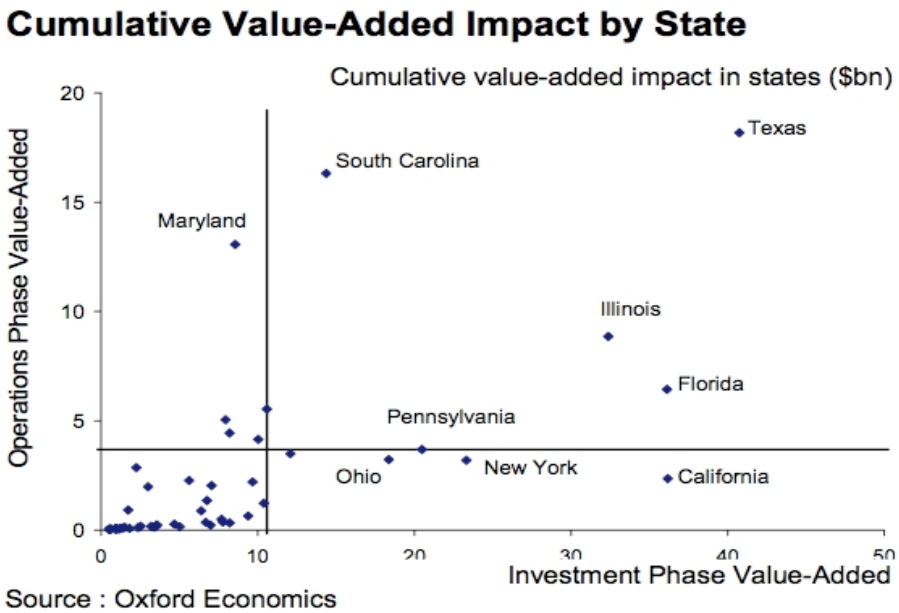



**Figure 2 (upper left):** Assumed Investment Scenario in Oxford Economics study

**Figure 3 (upper right):** Peak impact from new nuclear investment. Illinois makes large gains in both the investment and operations phase.

**Figure 4 (left):** Cumulative value added impact of new nuclear investment. Illinois makes large gains in both the investment and operations phase.

## Economic Feasibility of Nuclear Power

Critics of nuclear power often point out that new nuclear reactors will be costlier than those past, and that we really cannot know how expensive they will be. This is a legitimate and very important consideration. However, while a great deal of uncertainty applies to the cost of nuclear power, many of the same uncertainties also apply to the future costs of power in general. The sources of these uncertainties include:

- **Cost of carbon:** A simple carbon tax could actually push the cost of fossil fuels above that of nuclear power or any other source of green energy.
- **Potentially drastic changes in demand:** There are many factors that could affectIf, for example, America were to quickly adopt electric cars, the demand for electricity would greatly increase.
- **Status of energy-grid infrastructure:** The ability for intermittent sources of renewable energy to address our bulk power needs will require substantive changes to our electrical grid. It is the hope of this commission that these changes happen. However, timing is everything, and a good measure of carbon-neutral, constant-baseload power will be useful in hedging greenhouse risks over the next decade.
- **Variability in technological advancement:** Any model for future costs needs to leave room for both evolutionary and transformative advances and technology. The degree of optimism in this regard can have an impact on the predicted costs.

- **Policy changes:** Nuclear power, without incentives, is often compared against other power sources with large subsidies and tax breaks. Policy changes at the federal and state level can have effects on cost at the tens of percent level. In many cases, this makes the difference between what is viable and what is not.
- **Discount rates:** How do upfront costs, like the capital costs of nuclear power, spread over the lifetime of a reactor?
- **Lifetime:** What is the lifetime of a nuclear reactor or, for that matter, the turbines in a wind farm or the photovoltaic cells in a solar array?

Upon simple review of the standard literature, one finds that it is possible to choose data from any combination of legitimate reports to make any energy source appear cheaper than another. One can very easily compare the most optimistic predictions of one power source against the most skeptical predictions of another. This is dangerous, especially since different estimates are typically based on economic models with different assumptions.

In this section we look at four major analyses regarding the economics of nuclear energy. These reports are among the most cited and were chosen to represent skeptical, moderate, and optimistic perspectives on the viability of nuclear. The 2007 *Nuclear Power Fact-Finding Report* by the Keystone Center was unable to resolve the viability of nuclear and is included in this section because it is often cited by critics of nuclear energy and therefore deserves to be considered. Likewise, we include the results of a report by the financial consultancy Lazard Ltd are included because they are among the most skeptical. *The Future of Nuclear Power*, a widely recognized, cross disciplinary MIT report gives moderate price estimates, and the result of a University of Chicago study, commissioned by the Department of Energy gives fairly optimistic numbers.

Particular to nuclear power, capital costs are very high. The costs of waste management, insurance, and decommissioning are indeterminate. It is risky to assume the liability for such a large upfront cost, without guarantees that the reactor will become operational and profitable. These issues all play in to the questions of nuclear viability. Most of the major reports on the cost of nuclear power concede this point. The question is whether these costs are too large to overcome, through policy change or streamlining of the civil construction. The MIT report acknowledges this, but concludes that *plausible* policy and technological changes could make nuclear viable and recommends that it be kept as a serious option. The Keystone report leaves the question open. Figure 5, shows the Levelized Cost of Energy (LCOE) estimates of these four reports. Figure 6 compares these nuclear prices with those of several solar and coal estimates. Figure 6 is not presented to imply the viability of nuclear, so much as to show that the costs of nuclear are close enough that they *could* become competitive.

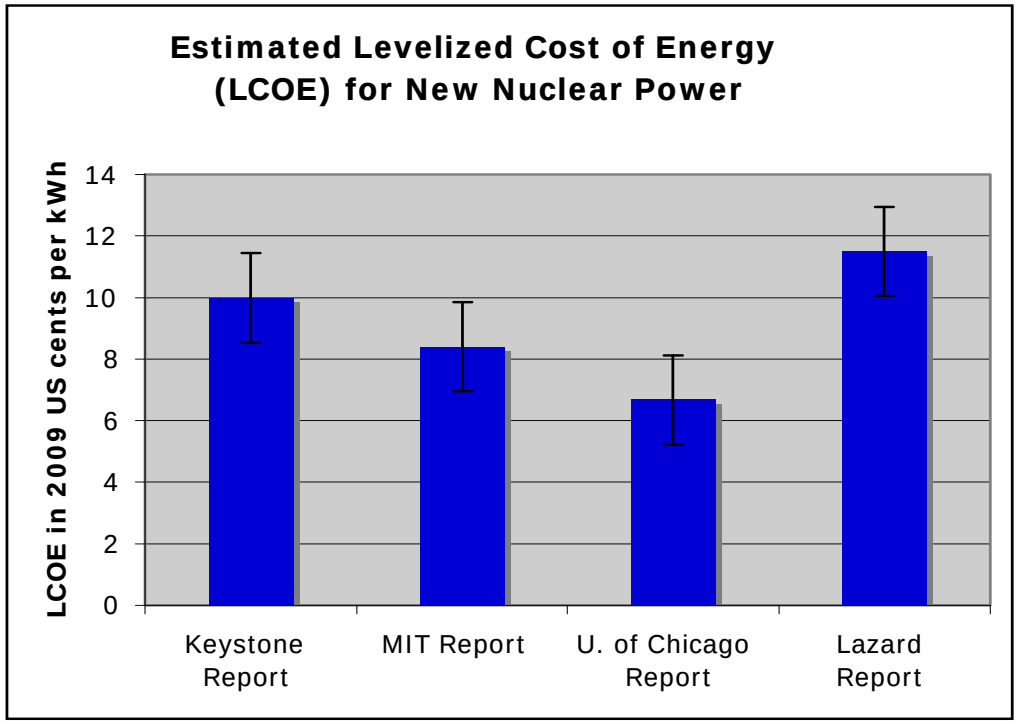
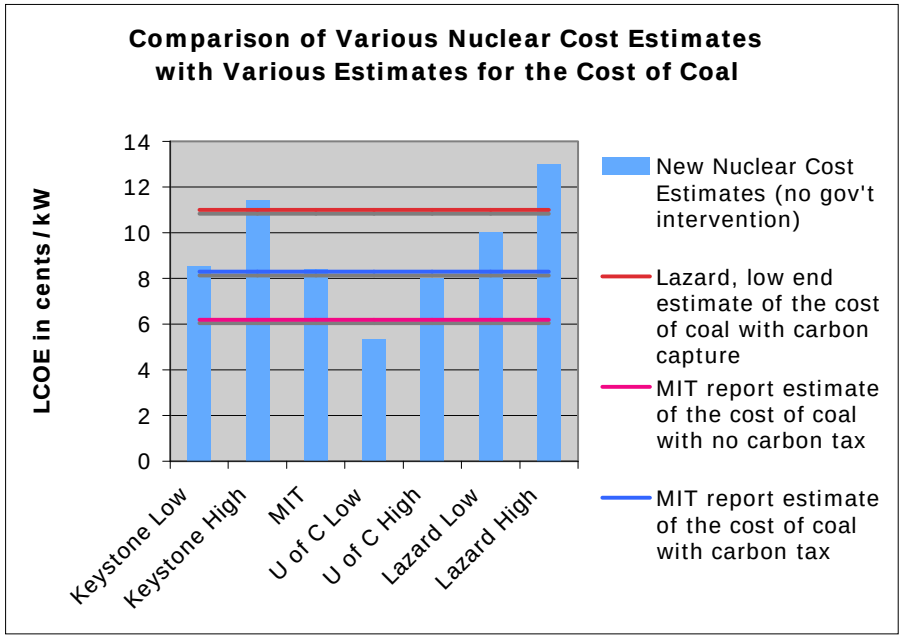



**Figure 5:** Cost estimates for nuclear energy (adjusted for inflation to 2009 prices) by four of the most cited reports on nuclear energy. Three of these reports (Keystone, Lazard, and U of C) give a low and high estimate that varies by a little under 3 cents/kWh. The blue bars represent the average of the low and high estimate, while the error bars include this 3 cent variation.



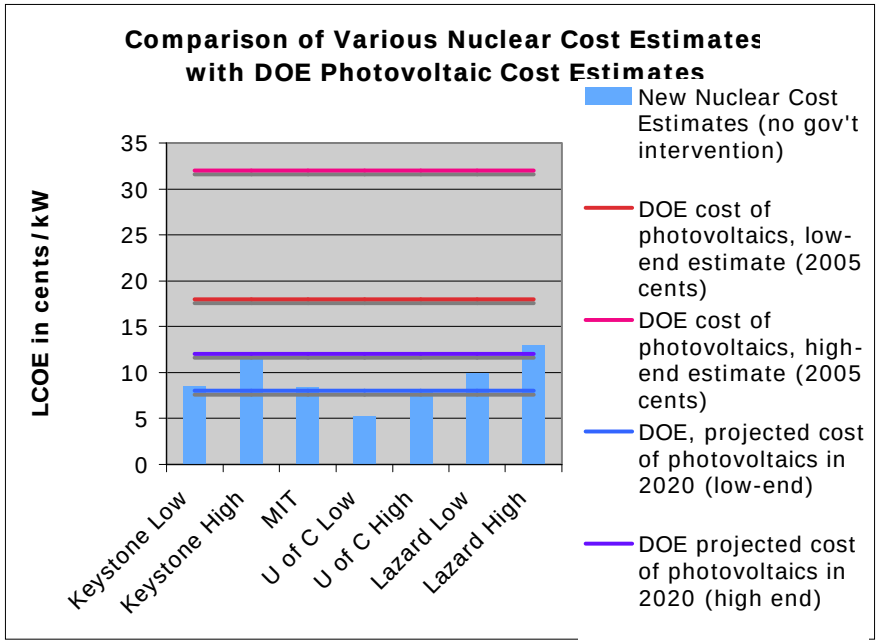




**Figure 6:** Cost comparisons of Nuclear power to those of coal (left) and photovoltaic (right) power.

Many energy experts rightly point out that end-use efficiency is the most cost-effective and simple pathway to reduced carbon emissions and improved industrial efficiency. We agree with that point whole-heartedly. However, efficiency can only go part of the way, since electricity consumption will never go to zero. Our objective is to reduce carbon, *while still providing for our energy needs*. To that end, no single source of power will be a silver bullet. We should pursue a mixed strategy in the mean time. While nuclear energy should be treated with the same reasonable skepticism applied to all other energy sources, it should also be given the same measure of healthy optimism. Like solar and wind power, new economic instruments, policy changes, and technological innovations can transform a renewed nuclear industry and bring down costs.

Ultimately, the criticism of nuclear power being too costly is irrelevant to the recommendations of this commission, since we are not asking the state itself to make the ultimate decision. It is not the job of Illinois or any government to decide whether or not to build new nuclear plants; That decision ultimately rests with the power companies. Our task is merely to implement sound policies to maximize the number of viable or potentially viable energy sources. Our other goal is to do so in a way that can promote economic growth in state. Surely, we should remove unnecessary roadblocks to nuclear power. We should also bear in mind that very reasonable financial incentives can be used on the state and federal level to help make nuclear viable, just as strong tax credits and subsidies have been helping with the growth of wind and solar.

**Environmental Benefits of Nuclear Power**

The Oxford Economics study concluded that with the construction of 7 new reactors, Illinois would see the largest $CO_2$ reduction of any state in America, which they estimate to be 66 Mt. This assumes nuclear to replace 96% of coal-based non-nuclear power and 3% of the natural gas share. Nation wide, the construction of 52 reactors would reduce $CO_2$ by 450 Mt, an 11% reduction in the carbon output of electricity production and a 5% reduction in total $CO_2$

***Carbon Footprint of Nuclear:***

The process of nuclear fission is entirely carbon neutral, making nuclear energy an ideal form of power production in terms of greenhouse emissions. Nonetheless, over the lifecycle of a nuclear reactor, there is a small carbon footprint, driven primarily by:

- the energy cost of extracting and refining the Uranium fuel (~40% of the total)
- construction (~10%)
- operation (~20%, including the fossil-fuel backup generators used during down-time)
- waste processing and containment (~10%)
- decommissioning (~20%).

There is some contention regarding the exact size of the carbon footprint over a reactor lifetime, with estimates ranging from 1.4 grams of equivalent $CO_2$ per kW-hour to 288 grams per kWh.

Benjamin Sovacol, a research fellow at the National University of Singapore recently analyze more than 100 studies and published his findings in the August issue of *Energy Policy*, and featured in Nature, online. He suggests a mean value of around 66 grams per kWh to be a reasonable approximation. This is much smaller than the footprint for natural gas plants (443 $gCO_2e$/kWh) and scrubbed coal-fire plants (960 $gCO_2e$/kWh) Stacked against other green power sources, such as photovoltaics (32 $gCO_2e$/kWh) and onshore wind farms, at (10 $gCO_2e$/kWh), nuclear energy has a small and competitive footprint.

Illinois currently receives just over 50% of its current energy from nuclear power, making Illinois a leading producer of nuclear power in the country. Nuclear power plays an important role in Illinois's energy infrastructure and this role will become even more critically important in the future. Nuclear power is carbon-neutral, safe and dependable. A thriving nuclear power industry provides dependable energy generation, which is particularly important in balancing the fluctuating energy generation of wind and solar energy. Nuclear power also provides high paying jobs in a variety of fields, including skilled trades, engineering and science. Illinois has benefited enormously from its early adoption of nuclear power. However, Illinois's nuclear energy capacity is aging and becoming increasingly outdated. Illinois needs to lead the country in a "nuclear energy renaissance".

Nuclear power also provides high paying jobs in a variety of fields, including skilled trades, engineering and science. A report by Oxford Economics singles out Illinois as one of the states expected to make among the largest gains in employment and new income, should America make modest strides to build new nuclear capacity. The report projects the impact of building 7 new reactors in

Illinois over the next 30 years. It predicts the creation of 30,000 new jobs $32.4 billion in value-added to Illinois during the construction phase, and 10,000 jobs with $8.9 billion in value-added during the operational phase of the reactors*[1]*.

Illinois has set ambitious goals for the construction of new green energy capacity. Yet, these goals, even if met, fall far short of the magnitude of $CO_2$ reductions necessary to stem global climate change. Wind and solar power, while very promising, are not yet mature enough to handle all of our power needs alone. Nuclear energy is a mature technology with comparable carbon footprint (66 grams/kWh, compared with 960 g/kWh for coal and 32 g/kWh for solar) *[2,3]* and a much lower cost (30$/MWh compared with 29$/MWh for coal and 150$/MWh for solar) *[4]*. While many of the renewable energy sources provide only intermittent power, nuclear energy is capable of delivering constant and controllable baseload power, making it more compatible with the current grid. Illinois must continue to develop its solar and wind, but we cannot afford to neglect any viable and mature form of carbon-neutral energy. In the US alone, there have been 31 license applications to build new reactors *[5]*. If the rest of the country and the world embrace nuclear energy, we cannot afford to lose the competitive edge Illinois would have in the nuclear economy. Nuclear energy should play a role in our long-term energy plans.

Support the construction of new nuclear capacity as part of its future energy portfolio by including nuclear energy as a "carbon-neutral" energy source to augment the state's renewable energy goals, supporting Exelon's plans for a capacity upgrade to the single Clinton reactor *[6]*, supporting and incentivizing a possible new Generation III reactor at the Clinton site or elsewhere and considering additional new plants and reactor sites

In reaction to the Three Mile Island incident 30 years ago, Illinois placed a moratorium on the construction of new nuclear reactors. Since then, the nuclear industry and nuclear technology have moved far past this unfortunate accident. With 3 additional decades of operational experience in America and worldwide, the current generation of nuclear power plants ("Generation II") have developed hundreds of redundant systems, passive safety features, and failsafe features to prevent human error and reactor failure. These reactors have proven themselves capable of operating safely and cleanly *[7]*. Since the dawn of the nuclear age, not a single American has died from civil nuclear energy; compared with over 3,000 US coal mining deaths alone since the 1940s. It is due time that America and Illinois move on. There are enough obstacles to a nuclear renaissance at the federal level. We do not need any additional obstacles at the state level. The first step towards and progressive position on nuclear energy would be to lift that ban on the state-level.

Illinois is uniquely poised not only to lead in the construction of new nuclear capacity, but also in the development of new nuclear technology. "Generation IV" nuclear reactors are classified as the next, entirely new paradigm for nuclear power. These technologies are matured well beyond proof-of-principles, with several working demonstration reactors in operation worldwide. Generation IV reactors include technologies that can recycle spent fuel, break down radioactive waste into safer elements, and even generate (or "breed") new fuel from otherwise unusable isotopes. They also include radically safer reactor designs. Illinois has a lion-share of human resources and expertise in advance reactor technologies, between its national laboratories (such as Argonne and Fermilab), and its research universities. Illinois has long had a problem with commercializing its advanced technical know-how, and should take pro-active steps to encourage the commercial development of advanced nuclear technology in state.

Set goals to build the first commercial Generation IV nuclear reactor in the US by 2030. Continue to work closely with and invest in those public and private research institutions with expertise in Generation III and Generation IV reactors.

With the Obama Administration proposing possible cancellation of the Yucca Mountain repository – tapped as America's future long-term waste storage facility – the future of nuclear waste management is somewhat indeterminate *[8]*. The amount of waste produced by nuclear energy is miniscule (averaging to much less than 40 grams per person, per year in America *[9]*), and a majority of spent fuel (~95%) removed from nuclear reactors consists of relatively benign isotopes of naturally occurring Uranium. Nonetheless, the remaining 5% consists of dangerous, and highly radioactive waste products *[10]*. While, Yucca Mountain may be cancelled, the idea of deep underground burial is still considered safe, having withstood the test of very conservative environmental impact studies and earning the endorsement of the National Academy of the Sciences *[11,12]*. Future, Generation IV "fast-neutron" reactors can break down radioactive waste into safer components and even "breed" more fissionable fuel from spent fuel. This could remove the need for long-term waste storage and increase rather than deplete our national store of nuclear fuel. The key point is that there are many possible safe options that could become available not so far in the future. In the interim, the status quo (on-site storage) is sufficient until better options become available. To make this option of on-site storage more viable, safe, and cost-effective will require some intentional planning at the state level, and some reform to the federal level (to the Nuclear Waste Policy Act of '82). In-state experts have already considered these issues *[13]*, and Illinois can really help take the lead on this issue. Policy clarity is one of the most important steps to incentivizing private interest in new reactor construction. The most significant obstacle to new nuclear capacity is political and public will. Much of this stems from fear and misunderstanding of the science behind nuclear energy. Effective communication and education can make great strides to bridge that gap. By ommunicating a strong message in support of domestic nuclear energy by lobbying the federal government to support nuclear, communicating support to private industry and educating the public on the benefits, risks, and data on nuclear power, new nuclear power can become a part of Illinois future.

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