NOTE

ECONOMIC SOLUTIONS TO NUCLEAR ENERGY'S FINANCIAL CHALLENGES

*Zachary Robock**

This Note presents a legal, economic, and regulatory roadmap to drive long-term innovation in sustainable energy generation. Next-generation nuclear power, which fundamentally mitigates many safety and nuclear waste issues, is the focus of this Note; however, the economic concepts can be applied to encourage solar, wind, advanced battery, and other sustainable technologies with high up-front costs and low long-term variable costs. Advanced nuclear energy generation is economically competitive on a long-term levelized cost basis, but suffers from a timing issue—a large amount of capital is needed upfront, with repayment over several decades, during which time significant capital costs can accrue (e.g., compounding interest, often at unfavorably high interest rates). This Note offers solutions to offset capital costs in both regulated and deregulated energy markets, including tools to accelerate recognition of future revenue and to reduce interest rates.

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* Zachary Robock (University of Michigan, J.D. 2015, B.A., 2008) is an associate at Jones Day, where his practice focuses on corporate and energy matters. He would like to thank the staff of the *Michigan Journal of Environmental and Administrative Law*, his family, friends, and professors. The views and opinions set forth in this Note are the personal views and opinions of the author and do not necessarily reflect the views or opinions of the law firm with which he is associated.

INTRODUCTION

This Note proposes regulatory and economic solutions to drive major innovation in clean energy generation. There is a particular focus on nuclear energy innovation; however, the economic principles can be applied to any project with high upfront costs and low long-term variable costs, which is the case for many clean energy sources. Part I discusses the importance of nuclear energy in the world's energy supply. Part II explains next-generation nuclear technology (hereinafter "advanced nuclear"), including fundamental safety, waste, and efficiency benefits over today's commercial technologies. Part III details the economic challenges facing nuclear energy innovation. Part IV provides an overview of the regulated and deregulated energy markets in America. Part V proposes solutions to drive innovation in regulated energy markets with traditional regulatory tools, such as rate regulation, Construction Work in Progress allowances, and Integrated Resource Planning. Part VI proposes solutions in deregulated energy markets, including first-loss catalytic capital, securitization of plant assets, and deliberate use of energy and capacity markets. Ultimately, both regulatory models are capable of driving energy innovation. Different tools are required in each, but they work in surprisingly similar ways. Under both models, ratepayers today would incur modest costs in exchange for long-term reliable, clean, carbon-free, and relatively consistently priced energy.

Such costs are an investment with multifaceted returns. Clean energy is a valuable end unto itself for environmental stewardship, public health benefits, and energy independence. While some benefits may not take hold during a single lifetime, others can be realized within years or decades. Furthermore, delayed realization is not a compelling reason to shirk the responsibility to help sustain the planet for future generations. This Note is not about short-term energy band-aids; the motivating vision is to fundamentally advance beyond the fossil fuel age.

Clean energy also presents a means of driving the U.S. economy through the 21st and into the 22nd centuries. New energy technology will be highly valued as countries grapple with eventual fuel shortages and pollution, while derivative technologies should benefit industries from transportation to healthcare and defense. The recent climate accords in Paris reinforce the importance of clean energy in the world economy's future.[1]

Next-generation nuclear power addresses the most important drawbacks of today's nuclear energy—it provides fundamental safety improvements, can consume existing nuclear waste or generate only small amounts of short-lived nuclear waste (depending on the technology), and need not be located near a water source. Nuclear power has long been an important component in avoiding harmful emissions from fossil fuel power generation;[2] however, most commercial nuclear plants in operation today were built thirty to forty years ago, and all rely on designs from the 1960s.[3] Consider other technology built forty years ago—today's iPhone has approximately 12,000 times the computing power of the original Macintosh computer, released in 1976.[4] Nuclear plants are initially licensed for forty years, after which time they should have recovered their upfront costs plus reasonable profit and should be decommissioned as an improved fleet of power stations comes online.[5] However, this is not the trend in the United States. Forty-year-old nuclear plants are currently receiving twenty-year licensing extensions, and there is already talk of additional twenty-year renewals, for a total lifetime of eighty years.[6]

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1. *See, e.g.*, Coral Davenport, *Nations Approve Landmark Climate Accord in Paris*, N.Y. Times (Dec. 12, 2015), http://www.nytimes.com/2015/12/13/world/europe/climate-change-accord-paris.html ("[T]he deal could be viewed as a signal to global financial and energy markets, triggering a fundamental shift away from investment in coal, oil and gas as primary energy sources toward zero-carbon energy sources like wind, solar and nuclear power.").

2. World Nuclear Ass'n, *Greenhouse Gas Emissions Avoided*, Nuclear Basics, http://www.world-nuclear.org/nuclear-basics/greenhouse-gas-emissions-avoided.aspx (last visited Mar. 22, 2016); Nuclear Energy Inst., *U.S. Nuclear Generating Statistics*, Knowledge Center, http://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Generating-Statistics (last updated May 2015) (providing that, for the last twenty-five years, nuclear energy has provided approximately 20% of United States energy).

3. Steven Goldberg & Robert Rosner, Nuclear Reactors: Generation to Generation 4 (2011).

4. 60 Minutes, *Inside Apple*, CBS News (Dec. 20, 2015), http://www.cbsnews.com/news/60-minutes-apple-tim-cook-charlie-rose (interview by Charlie Rose with Tim Cook, CEO, Apple, in New York, N.Y.).

5. U.S. Nuclear Regulatory Comm'n, Fact Sheet on Reactor License Renewal 1 (2012), http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.pdf; Matthew Wald, *Power Plants Seek to Extend Life of Nuclear Reactors for Decades*, N.Y. Times (Oct. 19, 2014), http://www.nytimes.com/2014/10/20/business/power-plants-seek-to-extend-life-of-nuclear-reactors.html.

6. *See, e.g.*, U.S. Nuclear Regulatory Comm'n, *supra* note 5; Nancy Slater-Thompson, U.S. Energy Info. Admin., *Almost All U.S. Nuclear Plants Require Life Extension Past 60 Years to Operate Beyond 2050*, Today in Energy (Dec. 8, 2014), https://www.eia.gov/todayinenergy/detail.cfm?id=19091.

This process is driven by short-term economics—the vast majority of nuclear power costs are upfront construction costs. Once online, nuclear plants have very low, very stable operating costs, so current operators can earn substantial profit margins once initial costs are paid off. And constructing new nuclear plants, especially those with fundamental technological improvements, is a risky and expensive endeavor. Notwithstanding these challenges, investing in new technology is critical from a safety, environmental, and long-term economic standpoint. Making such investments economically attractive is the focus of this Note.

I. The Need for Nuclear Energy

Next-generation nuclear power should be a key component of America's energy supply. It is the only carbon-free energy source capable of supplying reliable baseload electricity, which today is produced mainly by coal and other fossil fuels.[7] Despite some high-profile accidents, nuclear power has a very impressive safety and environmental record, especially in the United States, and especially compared to coal, oil, and natural gas.[8] That said, the nuclear technology in commercial operation today is antiquated—plant designs and construction typically date back to the 1960s and 70s and generate substantial long-lived nuclear waste. Next-generation nuclear technology, discussed *infra* in Part II, can significantly improve on many deficiencies in today's nuclear plants in terms of efficiency, safety, and waste production.

Unlike coal or natural gas plants, nuclear reactors do not produce greenhouse gases or pollutants that contribute to climate change, acid rain, smog, respiratory illnesses, and mercury deposits, among other impacts.[9] Other lifecycle impacts of fossil fuels—from exploration, pit mining, drilling, hydraulic fracturing, leaks, and spills—only exacerbate these ecological and human health harms. Renewable energy sources can mitigate these impacts but come with their own environmental, economic, and reliability concerns.

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7. *See, e.g.*, U.S. Energy Info. Admin., *Competition Among Fuels for Power Generation Driven by Changes in Fuel Prices*, Today in Energy (July 13, 2012), http://www.eia.gov/todayinenergy/detail.cfm?id=7090 (providing that, historically, coal and nuclear supplied most of the baseload power in the United States, supplemented by hydropower in some areas).

8. *See* World Nuclear Ass'n, *Safety of Nuclear Power Reactors*, Information Library, http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx (last updated Aug. 2015); James Conca, *How Deadly Is Your Kilowatt Hour? We Rank the Killer Energy Sources*, Forbes (June 10, 2012), http://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/#21302e7249d2.

9. *See, e.g.,* Fred Bosselman et al., Energy, Economics and the Environment 211 (3d ed. 2010).

Biofuels, for example, can be grown on polluted soil to absorb toxins,[10] but the pesticides and fertilizer necessary to grow such crops on an industrial scale typically end up damaging waterways.[11] Furthermore, burning biofuels still releases greenhouse gases, as does manufacturing fertilizer.[12] Biofuels are a good supplemental energy source, but they are not necessarily carbon neutral (especially on a large commercial scale),[13] and do not present an independent long-term energy solution.

Wind and solar are beneficial energy sources and should be encouraged; however, for grid stability and reliability purposes, "[a]s the U.S. incorporates greater amounts of intermittent renewable resources into the nation's generation mix, the need to maintain diversity in the baseload power portfolio is critical."[14] A recent study by researchers from the National Oceanic

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10. For example, *jatropha curcas* is a crop that can be grown on polluted soil to absorb toxins that result from mining operations or other industrial processes, and its oil seeds can be processed into biofuels. *See* Fang-Chih Cheng et al., *Phytoremediation of Heavy Metal Contaminated Soil by Jatropha Curcas*, 23 Ecotoxicology 1969 (2014). After approximately ten years, the soil becomes suitable for crops. *Id.*

11. *See, e.g.*, David Biello, *Fertilizer Runoff Overwhelms Streams and Rivers—Creating Vast "Dead Zones"*, Sci. Am. (Mar. 14, 2008), http://www.scientificamerican.com/article/fertilizer-runoff-overwhelms-streams/.

12. Alt. Fuels Data Ctr., U.S. Dept. of Energy, U.S. Life Cycle Greenhouse Gas Emissions of Biofuels (2010), http://www.afdc.energy.gov/data/10328 (providing that over a full lifecycle analysis?accounting for carbon absorbed in growth?most forms of biofuel are not carbon neutral or negative, with the admitted exception of switchgrass ethanol, which fixes carbon into the soil in which it grows); Robert Sanders, *Fertilizer Use Responsible for Increase in Nitrous Oxide in Atmosphere*, Berkeley News (Apr. 2, 2012), http://news.berkeley.edu/2012/04/02/fertilizer-use-responsible-for-increase-in-nitrous-oxide-in-atmosphere.

13. *See, e.g.*, Kelsi Bracmort, Cong. Research Serv., R41603, Is Biopower Carbon Neutral? 3–6 (2015); *Biofuel Is Not Carbon Neutral*, Ecoworld (Feb. 12, 2007), http://www.ecoworld.com/energy-fuels/biofuel-is-not-carbon-neutral.html.

14. Mathew J. Morey et al., Ensuring Adequate Power Supplies for Tomorrow's Energy Needs 60 (2014). There are several ways to stabilize variable generation from intermittent renewables. One argument is that reliable quick-response generation is necessary to stabilize unpredictable generation from intermittent renewables; however, natural gas is the main source of reliable quick-response generation (as is hydroelectric, but this is a limited resource); nuclear cannot cycle up and down quickly. Andreas Pickard & Gero Meinecke, Siemens AG Energy, The Future Role of Fossil Power Generation 7–8 (2011). A second argument is that improving energy storage capabilities can help stabilize energy generation with intermittent renewables—batteries or other storage mechanisms can be charged with nuclear energy and quickly supply energy to the grid as needed. *See generally* Rachel Carnegie et al., State Util. Forecasting Grp., Utility Scale Energy Storage Systems: Benefits, Application and Technologies (2013) (discussing the application of technologies for energy storage). Another factor in stabilization is the issue of reliability; nuclear is very reliable whereas wind and solar are dependent on uncontrollable environmental factors. *See* World Nuclear Ass'n, *Renewable Energy and Electricity*, Information Library, http://world-nuclear.org/information-library/energy-and-the-environment/renewable-energy-and-electricity.aspx (last updated Feb. 26, 2016).

and Atmospheric Administration and University of Colorado Boulder that "pushes the envelope" shows that "intermittent renewables plus transmission can eliminate *most* fossil-fuel electricity."[15] In other words, even with an overhaul of the long-term transmission grid in the United States, intermittent renewables cannot entirely displace fossil fuels, even in a scenario that "pushes the envelope." Another source of reliable baseload electricity is needed.

Other than nuclear, options for reliable baseload capacity are principally coal and natural gas. Natural gas currently enjoys low prices and burns cleaner than coal, but it is still a fossil fuel with harmful emissions, and methane leaks across the natural gas supply chain, still poorly understood, may undermine its climate change benefits.[16] Furthermore, natural gas is largely obtained through fracking that may harm groundwater,[17] and its prices are historically volatile.[18] Natural gas is good in the short term to wean off of coal, but an overreliance on it will pose substantial challenges over the long term.

There is an escalating need for new energy capacity, especially baseload capacity. New EPA clean air regulations are leading to increased closures of coal plants.[19] This loss of electric generation has not yet led to energy shortages, but only because of the decline in energy demand caused by the recent recession.[20] As the economy—and energy demand—recovers, energy adequacy is becoming increasingly uncertain.[21] EPA regulations appear likely to get increasingly stringent, leading to additional old plant closures.[22] Moreover, if the EPA's Clean Power Plan rule survives judicial re-

15. Univ. of Co. Boulder, *Rapid, Affordable Energy Transformation Possible, Study Says*, PHYS.ORG (Jan. 25, 2016), http://m.phys.org/news/2016-01-rapid-energy.html (emphasis added) (discussing Alexander E. MacDonald et al., *Future Cost-Competitive Electricity Systems and Their Impact on US CO2 Emissions*, NATURE CLIMATE CHANGE (Jan. 25, 2016)).

16. *See* Envtl. Def. Fund, *Extensive Research Effort Tackles Methane Leaks*, WHAT WE DO, https://www.edf.org/climate/methane-studies (last visited Mar. 22, 2016).

17. News Release, U.S. Envtl. Prot. Agency, EPA Releases Draft Assessment on the Potential Impacts to Drinking Water Resources from Hydraulic Fracturing Activities (June 4, 2015), http://yosemite.epa.gov/opa/admpress.nsf/21b8983ffa5d0e4685257dd4006b85e2/b542d827055a839585257e5a005a796b!OpenDocument.

18. *See* ERIN MASTRANGELO, U.S. ENERGY INFO. ADMIN., AN ANALYSIS OF PRICE VOLATILITY IN NATURAL GAS MARKETS 5 (2007).

19. *Power Plant Closures*, INST. FOR ENERGY RESEARCH, http://instituteforenergyresearch.org/topics/policy/power-plant-closures/ (last visited Mar. 22, 2016).

20. PUB. SECTOR CONSULTANTS, ELECTRIC RELIABILITY IN MICHIGAN: THE CHALLENGE AHEAD 18 (2014), http://www.pscinc.com/LinkClick.aspx?fileticket=CUGsO5sdBOs%3D&tabid=75.

21. *See generally* MOREY ET AL., *supra* note 14, at 30–60.

22. *See* U.S. ENVTL. PROT. AGENCY, FACT SHEET: CLEAN POWER PLAN & CARBON POLLUTION STANDARDS KEY DATES (2014), https://www.epa.gov/sites/production/files/2015-01/documents/20150107fs-key-dates.pdf. *But see* Greg Stohr and Jennifer Diouhy, *Obama's Clean Power*

view, each state must submit a plan for reducing greenhouse gas emissions to target levels set by the federal government.[23] Nuclear power can be an important part of those state plans.[24]

That said, nuclear power has its own environmental concerns—namely, uranium mining, waste disposal and storage, and the risk of nuclear accident. The proliferation of nuclear energy also increases the risk of nuclear terrorism, either through a nuclear explosion or a dirty bomb.[25] Advanced nuclear is not a perfect silver bullet, but it is carbon-free and reliable, and many of the environmental and safety concerns with current nuclear energy can be addressed and substantially reduced by advancing nuclear technology, as discussed throughout this Note.

II. Introduction to Generation IV Advanced Nuclear

A central tenet of this Note is that nuclear power needs to *advance*, not stagnate or disappear.[26] The nuclear industry is at a critical juncture—invest in fundamental, long-term design improvements and drive the clean energy industry, or keep a low bottom line and trudge along with inefficient, antiquated technology until eventually becoming obsolete. Advanced nuclear promises improvements in safety, efficiency, and the reduction, elimination or even consumption of nuclear waste, as discussed below in Section II.A.

Today's nuclear power plants are considered Generation II (or "Gen II").[27] Gen I plants were the earliest prototypes and proof of concept, built in the 1950s and early 60s.[28] Today's Gen II designs were the first commer-

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Plan Put on Hold by U.S. Supreme Court, Bloomberg (Feb. 9, 2016) (discussing the stay on implementation of the Clean Power Plan, pending additional judicial review).

23. *See* U.S. Envtl. Prot. Agency, Fact Sheet: Clean Power Plan: Flexible Approach to Cutting Carbon Pollution 2 (2014), http://www.epa.gov/sites/production/files/2014-05/documents/20140602fs-plan-flexibilty.pdf; U.S. Envtl. Prot. Agency, Fact Sheet: Clean Power Plan National Framework for States 1 (2015), http://www.epa.gov/sites/production/files/2014-05/documents/20140602fs-setting-goals.pdf.

24. *See* Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64,662, 64,901–02 (Oct. 23, 2015) (to be codified at 40 C.F.R. pt. 60) (explaining that new nuclear power can be factored into a state's plan for meeting Clean Power Plan requirements, but existing nuclear power and nuclear plants under construction may not be included).

25. *See, e.g.*, Joe Cirincione, *The Risk of a Nuclear ISIS Grows*, Huffington Post (Oct. 7, 2015. A dirty bomb is a conventional explosive laced with radioactive materials.

26. A recent nuclear construction project underway in Georgia is the first new nuclear construction in the United States in 30 years. *See* Michael Reilly, *U.S. Starts Building First Nuclear Reactor in 30 Years*, New Scientist (Apr. 29, 2015), https://www.newscientist.com/article/mg21829116-600-us-starts-building-first-nuclear-reactors-in-30-years/.

27. Goldberg & Rosner, *supra* note 3.

28. *Id.* at 3.

cial reactor designs and date back to the 1960s.[29] The Generation III and III+ designs in the pipeline today offer improvements over the current fleet, but they are still "essentially Gen II reactors," in that they utilize the same fuel and coolant, employ similar backup safety principles, and result in substantial long-lived radioactive waste.[30] On the other hand, Gen IV, or "advanced nuclear" designs, present fundamentally improved technologies over Gen II and III, especially with regard to safety, efficiency, and nuclear waste minimization.[31]

Air travel provides a good analogy. Early airplane technology involved wooden frames and propellers.[32] Upgrading to metal frames and propellers was a design improvement over wooden parts, but still relied on the same underlying propeller technology—much like Gen II to Gen III. However, the change from propellers to jet engines was a fundamental design shift—similar to a design shift to Gen IV reactors.[33] The newest plant under construction in the U.S. today is Gen III+ technology, akin to building an airplane with a metal propeller (versus wood), but still shy of a jet engine.[34]

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29. *Id.* at 4.

30. *Id.* at 6 (referring specifically only to Gen-III). *But see id.* at 7 (describing III+ as evolutionary development over III, which themselves are just improvements to II).

31. GENERATION IV INT'L FORUM, https://www.gen-4.org/gif/jcms/c_9260/public (last visited Mar. 2, 2016) (providing a very helpful graphic explaining the differences in nuclear generations); MICHAEL FOX, WHY WE NEED NUCLEAR POWER 112 (2014) ("Generation IV reactors are not just evolutionary improvements in existing designs but involve new technologies.").

32. *Just the Facts: 1903 Wright Flyer I*, WRIGHT BROS. AEROPLANE CO., http://www.wright-brothers.org/Information_Desk/Just_the_Facts/Airplanes/Flyer_I.htm (last visited Mar. 22, 2016).

33. The analogy continues in terms of public perception of air travel and nuclear power. High profile accidents in both nuclear and air travel weigh heavily on the human psyche. Air travel is statistically the safest form of travel—safer than walking, riding a bike, driving, or taking a bus or train. Peter Jacobs, *12 Reasons Flying is Still the Safest Way to Travel*, BUS. INSIDER (Jul. 9, 2013, 5:23 PM), http://www.businessinsider.com/flying-is-still-the-safest-way-to-travel-2013-7. But every bump of turbulence brings white knuckles and nervous sideways glances. People often applaud whenever a plane lands safely. How often do passengers applaud a bus driver for arriving safely or receive a pat on the back for walking safely to a destination? Similarly, nuclear power has the *lowest death rate per kilowatt hour of any energy source in the world*, including wind, solar, hydro, and other renewables. Conca, *supra* note 8. The United States is the world leader in nuclear power production and has had zero deaths in its operating history. World Nuclear Ass'n, *Nuclear Power in the U.S.A.*, COUNTRY PROFILES, http://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx (last updated Feb. 23, 2016); World Nuclear Ass'n, *supra* note 8.

34. *See AP1000 Nuclear Power Plant*, WESTINGHOUSE, http://www.westinghousenuclear.com/New-Plants/AP1000-PWR (last visited Mar. 2, 2016); *Vogtle 3 & 4 Project Overview*, GEORGIA POWER, https://www.georgiapower.com/about-energy/energy-sources/nuclear/overview.cshtml (last visited Mar. 22, 2016).

Gen IV reactors are not some far-off theoretical technology; several have been successfully operated, accumulating approximately 400 total reactor-years of experience,[35] and there is increasing domestic and international momentum in advanced nuclear energy. In 2011, thirteen countries, including the United States, extended an agreement to focus their research and development efforts on six Gen IV reactor designs: Gas Cooled Fast Reactor; Lead-Cooled Fast Reactor; Molten Salt Reactor; Supercritical Water-Cooled Reactor; Sodium-Cooled Fast Reactor; and Very High Temperature Reactor.[36] The first fleet of commercial Gen IV reactors are expected in 2030–2040.[37]

Companies in the United States are actively pursuing advanced nuclear technologies. For example, FLiBe Energy is based in Alabama and headed by Kirk Sorenson, a former NASA scientist and the former Chief Nuclear Technologist at Teledyne Brown Engineering. FLiBe is developing a thorium-fueled molten salt reactor.[38] TerraPower is chaired by Bill Gates (of Microsoft), and is developing a standing wave reactor—a version of a sodium-cooled fast reactor—designed by Pavel Hejzlar, who previously worked as the principal research scientist and program director for the Advanced Reactor Technology Program and Center for Advanced Nuclear Energy Systems at MIT.[39] Transatomic Power, based in Boston, was founded by recent MIT PhD graduates to develop a molten salt reactor specifically intended to consume existing nuclear reactor waste, without re-enrichment.[40] A team involving University of Michigan nuclear engineers recently developed a mechanism to simulate reactor materials' integrity under the stresses of molten salt fast reactions, which should help drive critical R&D.[41] Finally, among other initiatives, the Obama administration recently

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35. World Nuclear Ass'n, *Fast Neutron Reactors*, INFORMATION LIBRARY, http://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx (last updated Oct. 2015). From 1965 through 1968, a thorium-fueled molten salt reactor was successfully operated at Oak Ridge National Laboratory and decommissioned after achieving its proof-of-concept objectives. NEIL ENDICOTT, THE WEINBERG FOUND., THORIUM-FUELLED MOLTEN SALT REACTORS 4 (2013), http://www.the-weinberg-foundation.org/wp-content/uploads/2013/06/Thorium-Fuelled-Molten-Salt-Reactors-Weinberg-Foundation.pdf.

36. *See generally* Charter of the Generation IV International Forum, *opened for signature* June 7, 2001.

37. GENERATION IV INT'L FORUM, https://www.gen-4.org/gif/jcms/c_9260/public (last visited Mar. 2, 2016); FOX, *supra* note 31.

38. *See generally Our Technology and Vision*, FLIBE ENERGY, http://flibe-energy.com/ (last visited Mar. 22, 2016).

39. *See generally* TERRAPOWER, http://terrapower.com/ (last visited Mar. 22, 2016).

40. *See generally* TRANSATOMIC POWER, http://www.transatomicpower.com/ (last visited Mar. 22, 2016).

41. *Nuclear Reactor Reliability: Fast Test Proves Viable*, UNIV. OF MICH. (Aug. 20, 2014), http://ns.umich.edu/new/releases/22343-nuclear-reactor-reliability-fast-test-proves-viable.

committed $40 million to two companies involved in advanced nuclear research, X-energy and Southern Company.[42]

Internationally, India, which has substantial reserves of thorium, an alternative to uranium fuel, has been aggressively developing its nuclear power industry with a long-term plan toward advanced nuclear reactors, including a Gen IV prototype expected to come online in 2016.[43] France has historically generated most of its power from nuclear energy and is pursuing three Gen IV technologies.[44] China is similarly increasing its nuclear power resources while developing advanced nuclear to meet future needs.[45]

On the other hand, the technology still has hurdles to overcome. More research and testing are needed to confirm the long-term integrity of materials used to contain the reaction.[46] For example, some proposed salts can react poorly with water (sodium is flammable in contact with water), but others, such as FLiBe (a mixture of lithium fluoride and beryllium), are more stable.[47] Notably, many of the technological hurdles to commercialization can be studied and addressed simultaneously, rather than needing to go sequentially.[48] Therefore, more upfront funding can accelerate the timeline for development.

A. *Safety Improvements*

Next generation nuclear technologies offer several inherent safety advantages over older reactor designs, including low-pressure operation and passive cooling that eliminates the need for battery or diesel backups. Ex-

42. Henry Fountain, *U.S. Acts to Spur Development of High-Tech Reactors*, N.Y. TIMES (Jan. 19, 2016), http://www.nytimes.com/2016/01/20/science/advanced-nuclear-reactors-department-of-energy.html.

43. World Nuclear Ass'n, *Nuclear Power in India*, COUNTRY PROFILES, http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/India (last updated Feb. 26, 2016).

44. World Nuclear Ass'n, *Nuclear Power in France*, COUNTRY PROFILES, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx (last updated Feb. 2015).

45. World Nuclear Ass'n, *Nuclear Power in China*, COUNTRY PROFILES, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx (last updated Feb. 23, 2016).

46. DAVID E. HOLCOMB ET AL., OAK RIDGE NAT'L LAB., FLUORIDE SALT-COOLED HIGH TEMPERATURE REACTOR TECHNOLOGY DEVELOPMENT AND DEMONSTRATION ROADMAP, at xvi–xix (2013).

47. *Liquid-Fluoride Reactors*, FLIBE ENERGY, http://flibe-energy.com/?page_id=872 (last visited Mar. 22, 2016).

48. HOLCOMB ET AL., *supra* note 46, at xv ("[T]he required tasks can largely be performed in parallel, resulting in a resource- as opposed to a schedule-constrained development path. Thus, the key development challenge is not overcoming specific technological deficiencies but obtaining the financial lift necessary to mature technologies with a payoff two or more decades in the future.").

isting nuclear technology is akin to a car with the accelerator stuck at full throttle that must be actively contained. Advanced nuclear is the inverse. The reaction must be actively encouraged; if power is lost, the reaction will fizzle out due to its natural thermodynamic properties.[49] This is both a challenge and a benefit to the technology.

Gen II and III light water reactors (LWRs) use water as both a coolant and heat transfer medium. LWRs must be highly pressurized in order to keep the water liquid. LWRs operate most efficiently at 500 to 600 degrees Fahrenheit, yet water boils at 212 degrees.[50] To keep the water liquid at these high temperatures, the reactor must be pressurized to 1,000 to 2,000 pounds per square inch (for reference, a moose weighs about 1,000 pounds[51]), or 75- to 150-times normal atmospheric pressure.[52] This pressure makes for a fairly tenuous situation.[53] Any water that escapes will flash instantly to steam (often radioactive steam), building pressure in the containment vessel. If there is a loss of coolant—as occurred in different ways at Three Mile Island, Chernobyl, and Fukushima—backup systems run by batteries and diesel generators are supposed to keep coolant circulating around the reactor.[54] These failed tragically in Fukushima due to the intensity of the earthquake and tsunami, which dislodged and flooded diesel generators.[55] The batteries worked for a time, but didn't last.[56]

One new safety feature of Gen III reactors is to store emergency water above or nearby the reactor to deploy automatically and without the need for power in the event of a power loss or other loss of coolant.[57] This is an improvement over Gen II, but is hardly a fundamental fix. The water storage could become dislodged by the same event (e.g., earthquake, tsunami, or explosion) that caused the primary coolant or power loss in the first place. Moreover, many passive safety systems rely on intricate fail-safe mecha-

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49. *See* Brookings Inst., *Can Nuclear Energy Save the World?*, YouTube (Dec. 12, 2014), https://www.youtube.com/watch?v=YHwZJPBlwKc (at 1:30–2:00).

50. World Nuclear Ass'n, *Nuclear Power Reactors*, Information Library, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx (last updated Jan. 2016).

51. Alina Bradford, *Moose: Facts About the Largest Deer*, Live Science (Nov. 13, 2014), http://www.livescience.com/27408-moose.html.

52. World Nuclear Ass'n, *supra* note 50.

53. Badaway M. Elsheikh, *Safety Assessment of Molten Salt Reactors in Comparison with Light Water Reactors*, 26 J. Radiation Res. & Applied Sci. 65 (2013) ("The single most volatile aspect of current nuclear reactors is the pressurized water.").

54. *See generally* Fox, *supra* note 31, at 210–12, 214–16, 229–31.

55. Geoff Brumfiehl, *The Meltdown that Wasn't*, 471 Nature 417, 417 (2011).

56. *See id.*

57. *See generally* Int'l Atomic Energy Admin., *Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants*, IAEA Doc. IAEA-TECDOC-1624 (Nov. 2009) (describing various backup coolant systems).

nisms—sensitive valves to detect changes in core pressure, or complex condensation and pressurization systems,[58] which could be dislodged during an earthquake, explosion, tsunami, or other physically disruptive event. In short, regardless of the particular backup system, the high operating pressures and natural tendency for coolant to flash to steam make for an unavoidably tenuous situation, even with passive backup systems.[59]

In comparison, many Gen IV reactors will use molten salts, lead, or sodium (referred to collectively as "salts" for simplicity) for cooling and heat transfer, rather than water.[60] Salts naturally become molten at the high temperatures necessary to run nuclear reactors efficiently, so they need not be highly pressurized. These salts also do not vaporize until extremely high temperatures—sodium boils at roughly 1,600 degrees Fahrenheit[61] and certain fluoride salts boil at roughly 3,000 degrees.[62]

The ability to operate at low pressure enables molten salt reactors to employ a passive emergency cooling mechanism in the event of power loss. During normal operation, the reaction occurs in the reactor core, which has a drain at the bottom, like a sink, as shown in Figure 1.[63] The drain is normally plugged with a stopper comprised of the same salt used as a coolant in the reaction.[64] The salt stopper is actively cooled, keeping the stopper solid.[65] If there is a power loss, the stopper would cease to be cooled and would melt.[66] The reactor contents (molten salt + nuclear fuel) would drain into a reinforced drainage tank designed to passively cool the contents.[67] Unlike water, the salt coolant would not boil away, but would remain in the drain tank and continue to cool the fuel.[68] Moreover, many Gen IV technologies have a strong negative temperature coefficient, meaning that the reaction slows as the temperature rises, thereby naturally cooling the reactor

58. *Id.*

59. Elsheikh, *supra* note 53.

60. *Gen IV Systems*, Generation IV Int'l Forum, https://www.gen-4.org/gif/jcms/c_40465/generation-iv-systems (last visited Mar. 2, 2016).

61. Los Alamos Nat'l Lab., *Periodic Table of the Elements: Sodium*, Chemistry Division, http://periodic.lanl.gov/11.shtml (last visited Mar. 22, 2016).

62. World Nuclear Ass'n, *Molten Salt Reactors*, Information Library, http://www.world-nuclear.org/information-library/current-and-future-generation/molten-salt-reactors.aspx (last updated Jan. 2016).

63. *See, e.g.*, Elsheikh, *supra* note 53, at 63.

64. *Id*. at 66.

65. *Id.*

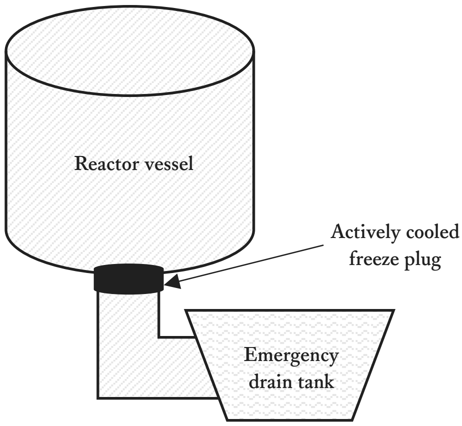
66. *Id.*

67. *Id.*

68. *Id.*

contents in the event of an emergency drainage scenario and substantially reducing the possibility of a meltdown scenario.[69]

FIGURE 1: ADVANCED NUCLEAR EMERGENCY DRAINAGE SYSTEM



B. *Reduction in Nuclear Waste*

Advanced nuclear technologies can also dramatically reduce both the volume and lifespan of radioactive waste, which is one of the critical environmental challenges in nuclear power. Different Gen IV designs reduce nuclear waste in different ways. In order to achieve more complete burnup, some Gen IV designs operate as "fast" reactors,[70] while others utilize innovative fuel mixes and processes.[71] As shown in Figure 2, below, a nuclear reaction occurs when a neutron "bullet" strikes a uranium (or thorium or plutonium) atom, fissioning the atom and releasing: (a) energy/heat; (b) more neutrons; and (c) nuclides, which are the resultant atoms from the

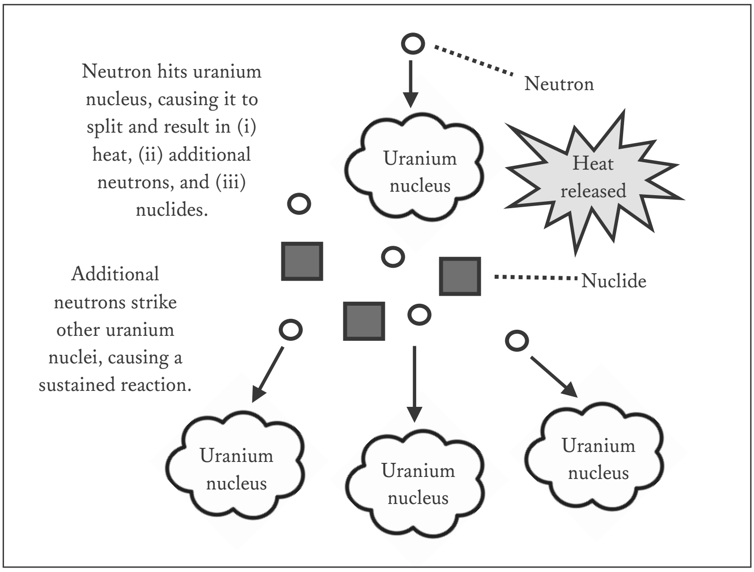
69. World Nuclear Ass'n, *supra* note 34 ("[F]ast reactors have a strong negative temperature coefficient (the reaction slows as the temperature rises unduly), an inherent safety feature, and the basis of automatic load following in many new designs."); World Nuclear Ass'n, *supra* note 61 ("MSRs [Molten Salt Reactors] have large negative temperature and void coefficients of reactivity, and are designed to shut down due to expansion of the fuel salt as temperature increases beyond design limits.").

70. World Nuclear Ass'n, *supra* note 34 (describing the greater burnup capability of fast reactors).

71. *See, e.g.*, *Thorium Fuel Cycle*, FLIBE ENERGY, http://flibe-energy.com/?page_id=874 (last visited Mar. 22, 2016) (describing the reduced potential for transuranic waste due to the use of thorium instead of uranium); *The Science*, TRANSATOMIC POWER, http://www.transatomicpower.com/the-science/ (last visited Mar. 22, 2016) (describing their molten salt reactor, which "produce[s] much less waste per year than a light water reactor, reducing the total volume of waste by 96%").

splitting of the uranium atom.[72] Nuclides are a substantial component of the nuclear waste ultimately generated by nuclear reactions.[73]

FIGURE 2: NUCLEAR REACTION



Gen II and III reactors are all LWR, which operate as thermal, or slow, reactors.[74] The water in these reactors acts as a "moderator," slowing the neutron bullets down in order to maximize the likelihood of a neutron bullet striking another uranium atom.[75] Moderating (slowing) these neutrons reduces their velocity and hence their energy.[76] Lower energy neutrons result in less burnup of the fuel, resulting in substantial amounts of long-lived nuclear waste.[77] In contrast, fast reactors do not moderate neutrons, resulting in fast (high-energy) neutrons, which are capable of more complete burnup (including the nuclides).[78] "Fast reactors hold a unique role in the actinide [i.e., nuclide] management mission because they operate with high

72. *See, e.g.*, BENGT PERSHAGEN, LIGHT WATER REACTOR SAFETY 101–03 (Monica Bowen trans., 1989).

73. Unfissioned uranium, plutonium, and/or thorium atoms (depending on the fuel mix) are also substantial components of nuclear waste. *See e.g.*, *What is Nuclear Waste?*, WHATISNUCLEAR.COM, http://www.whatisnuclear.com/articles/waste.html (last visited Mar. 22, 2016).

74. GOLDBERG & ROSNER, *supra* note 3, at 4–11.

75. World Nuclear Ass'n, *supra* note 50.

76. *Id.*

77. *Id.*

78. World Nuclear Ass'n, *supra* note 35.

energy neutrons that are more effective at fissioning actinides [nuclides]."[79] By more completely consuming the fuel and nuclides, fast reactors substantially reduce the volume of nuclear waste generated.

Importantly, the waste that is generated will decay to safe levels in approximately 300 years, compared with the 300,000 years it will take for nuclear waste from today's thermal reactors to decay to safe levels.[80] Fast reactors can even be used to consume existing nuclear "waste" as a beneficial power source.[81] The ability to utilize existing nuclear waste can eliminate or reduce the need to mine for uranium, thereby reducing environmental damage from mining and from long-term waste disposal.[82]

Fast reactors are not the only way that Gen IV reactors aim to substantially reduce long-lived nuclear waste. Molten salt reactors operate as thermal, not fast, reactors, but are able to achieve almost complete burnup of the uranium fuel by using uranium dissolved in liquid salt, rather than solid uranium pellets surrounded by water.[83] This allows for (1) filtration of the uranium-salt mixture, thereby removing certain fission products that would otherwise slow the reaction down; and (2) the continuous addition of fuel.[84] With proper filtration, the liquid fuel can remain in the reactor for decades, enabling much more complete burnup. This process can also utilize existing nuclear waste as fuel, thereby not only minimizing future nuclear waste, but actually reducing the current stockpile.[85]

III. What Is Holding Advanced Nuclear Back? Overview of Costs

What is holding nuclear power back from the "jet age"? Simply put, "[c]osts remain the biggest hurdle for the nuclear industry."[86] Once opera-

79. *Sodium Cooled Fast Reactors*, Generation IV Int'l Forum, https://www.gen-4.org/gif/jcms/c_9361/sfr (last visited Mar. 22, 2016).

80. Andrew Tarantolo, *Fast-Acting Nuclear Power Reactor Will Power Through Piles of Plutonium*, Gizmodo (Nov. 7, 2014, 11:40 AM), http://gizmodo.com/fast-acting-nuclear-reactor-will-power-through-piles-of-1655683450.

81. William H. Hannum et al., *Smarter Use of Nuclear Waste*, Sci. Am., Dec. 2005, at 84–85.

82. *Id.* at 91 (providing that there would "be no need to mine any more uranium ore for centuries" if today's thermal nuclear plants were all replaced by fast reactors).

83. Transatomic Power, Technical White Paper 11–12 (2014), http://www.transatomicpower.com/wp-content/uploads/2015/04/transatomic-white-paper.pdf.

84. *Id.* at 11.

85. *Id.* at 6.

86. Toni Johnson, *Nuclear Power Expansion Challenges*, Council on Foreign Relations: Renewing America (Mar. 18, 2011), http://www.cfr.org/united-states/nuclear-power-expansion-challenges/p16886; *see also* Ian Hutchinson, Letter to the Editor, *Cost of Nuclear Energy is Misrepresented*, MIT Faculty Newsl., Nov./Dec. 2010, at 24 ("[T]he main issues for new

tional, a nuclear plant can produce electricity at a marginal cost below that of electricity from fossil fuels.[87] However, high start-up costs (and the associated cost of capital), long repayment periods, and regulatory uncertainty put nuclear power at an investment disadvantage.[88] Advanced nuclear should prove even more operationally efficient than existing plants, but entails even higher upfront costs, given the research and development necessary to safely commercialize the technology.[89]

The levelized cost of advanced nuclear is competitive with other forms of generation.[90] Table 1, below, shows that advanced nuclear can have levelized costs competitive with natural gas (with carbon capture) and with coal (with or without carbon capture).[91] Including carbon capture in future energy prices is appropriate given the increasing trend of carbon regulation. While it may take decades before carbon capture is required on every fossil fuel plant, advanced nuclear is still several decades away from commercialization. Hence, levelized cost comparisons are most relevant for anticipated future prices and technology, not today's. Moreover, the cost of nuclear energy is largely (if not entirely) internalized,[92] unlike fossil fuel, which has major negative externalities from carbon and other pollutants emitted.[93]

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reactors are to demonstrate that their actual capital construction costs can be kept within acceptable bounds, by building on budget and schedule, and to convince the capital markets that the big outlay is a manageable financial risk."); Charles D. Ferguson et al., *A U.S. Nuclear Future?*, 467 NATURE 391, 392 (2010).

87. NUCLEAR ECON. CONSULTING GRP., NUCLEAR POWER & SHORT-RUN MARGINAL COST 1–2 (2014), http://nuclear-economics.com/wp-content/uploads/2014/10/2014-10-01-NECG-Commentary-2-Nuclear-Power-SRMC.pdf (explaining that short-run marginal cost of nuclear is zero); U.S. ENERGY INFO. ADMIN., LEVELIZED COST AND LEVELIZED AVOIDED COST OF NEW GENERATION RESOURCES IN THE ANNUAL ENERGY OUTLOOK 2014 (2014).

88. Johnson, *supra* note 86 (citing J. DEUTCH ET AL., MIT ENERGY INITIATIVE, UPDATE OF THE MIT 2003 FUTURE OF NUCLEAR POWER (2009), http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf).

89. *See* GOLDBERG & ROSNER, *supra* note 3, at 14–16 (discussing the costs and benefits of Generation IV nuclear reactors).

90. U.S. ENERGY INFO. ADMIN., *supra* note 87.

91. Note that Table 1 uses estimates for levelized cost beginning in 2019, and it includes additional costs of carbon emissions of 3% of capital costs (roughly equivalent to $15 per metric ton of carbon emitted). *Id.*

92. *See also* Nuclear Energy Inst., *Disposal*, ISSUES & POLICY, http://www.nei.org/issues-policy/nuclear-waste-management/disposal (last visited Mar. 22, 2016) (including approximately $29 billion already paid into the Nuclear Waste Fund); World Nuclear Ass'n, *The Economics of Nuclear Power*, INFORMATION LIBRARY, http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx (last updated Sept. 2015); Hutchinson, *supra* note 86.

93. *See, e.g.*, Joe Confino, *Al Gore: Oil Companies 'Use our Atmosphere as an Open Sewer'*, THE GUARDIAN (Jan. 21, 2015, 2:06 PM), http://www.theguardian.com/sustainable-business/2015/jan/21/al-gore-lord-stern-oil-companies-fossil-fuels-climate-change.

Only by internalizing costs of both generating sources can there be a fair comparison of levelized costs.[94]

TABLE 1: LEVELIZED COSTS OF ENERGY PRODUCTION ($/MWH)[95]

	Capital costs (construction + financing)	Variable O/M (including fuel)	Total levelized cost
Advanced nuclear	71	11	96
Natural gas (advanced combined cycle with carbon capture)	30	55	91
Conventional coal	60	30	95
Coal gasification with carbon capture	97	38	147

As shown in Table 1, the primary expense in advanced nuclear is capital cost, which is comprised largely of construction and financing costs.[96] Critically, the estimates in Table 1 use a 30-year lifecycle for estimating costs, but nuclear plants are designed to run for at least 40 years.[97] If the lifecycle analysis from Table 1 is extended to 40, 50, 60 years, the levelized cost of advanced nuclear will decline precipitously as one-time upfront construction costs are spread over a longer time period. Variable costs of

94. Some may argue that the risk of nuclear accident is nonetheless externalized to society. That is true to some extent, but then so are the risks of coal ash spills, fracking fluid leaks, or other fossil fuel-related accidents. Moreover, the nuclear industry collectively holds approximately $12 billion in accident insurance, more than enough to cover the $1 billion in costs from a relatively modest accident like the one that occurred at Three Mile Island, though admittedly shy of the $100 billion estimated cost of cleaning up Fukushima. *Nuclear Liability Insurance (Price-Anderson Act)*, NAT'L ASS'N OF INS. COMM'R & THE CTR. FOR INS. POLICY & RESEARCH, http://www.naic.org/cipr_topics/topic_nuclear_liability_insurance.htm (last updated Jan. 5, 2016). Others may argue that the storage costs of spent nuclear fuel are externalized; however (a) there is approximately $29 billion currently in the Nuclear Waste Fund, which has been funded by a one-tenth of one cent toll on every kilowatt-hour of electricity produced at nuclear plants pursuant to the Nuclear Waste Policy Act of 1983; and (b) the advanced nuclear technology proposed in this Note would generate relatively small amounts of nuclear waste, and some technologies can actually consume existing waste. Nuclear Energy Inst., *supra* note 91.

95. U.S. ENERGY INFO. ADMIN., *supra* note 87. Note that the term "advanced nuclear" here reflects its use by the EIA and does not necessarily reflect Gen IV. The EIA does not further define "advanced nuclear" in its estimates. Also, note that capital costs and variable costs are not the only two components to total levelized cost, which is why the first two columns do not add up to the third column. Fixed operating and maintenance costs and transmission investments also contribute some costs. For full details, see *id.*

96. U.S. ENERGY INFO. ADMIN., UPDATED CAPITAL COST ESTIMATES FOR UTILITY SCALE ELECTRICITY GENERATING PLANTS, at app. B (2013).

97. *See, e.g.*, U.S. NUCLEAR REGULATORY COMM'N, *supra* note 5.

nuclear are very low and very stable.[98] The same is not true for natural gas, which has substantial variable costs, even in the current climate of low natural gas prices.[99] Natural gas prices can be volatile,[100] and any sustained increase in natural gas pricing could make advanced nuclear even more economically attractive in terms of long-term levelized cost.

The upshot is that the capital problem with advanced nuclear is mainly one of timing, not levelized costs. More specifically, there are three critical challenges to financing nuclear energy projects. First, simply obtaining the billions of dollars necessary for an advanced reactor is a substantial hurdle. Capital cost estimates range from as little as $1.7 billion[101] to around $5 billion[102] and up. A recent Gen III nuclear construction project underway in Georgia (the first new nuclear construction in the U.S. in 30 years[103]) is estimated to cost around $4 billion per reactor (Georgia is building two 1,110 megawatt (MW) reactors side by side, for a total cost around $8 billion).[104] Second, obtaining billions of dollars will entail significant financing costs since few, if any, companies can bootstrap such a project.

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98. Nuclear Energy Inst., *Electricity Supply*, WHY NUCLEAR ENERGY?, http://www.nei.org/Why-Nuclear-Energy/Reliable-Affordable-Energy/Electricity-Supply (last visited Mar. 22, 2016) ("Nuclear energy has tremendous price stability because fuel accounts for just 31 percent of production costs. Fuel costs are closer to 80 or 90 percent when electricity is produced by burning coal or natural gas. This makes electricity from fossil-fuel plants highly susceptible to fluctuations in coal and gas prices."); *see also* NUCLEAR ECON. CONSULTING GRP., *supra* note 86 (explaining that short-run marginal cost of nuclear is zero); NUCLEAR MATTERS, 5. NUCLEAR BENEFITS: ECONOMIC ENGINES 2 (2014), http://www.nuclearmatters.com/resources/document/Nuclear-Matters-Economic-Engines.pdf (the fifth in a series of fact sheets by Nuclear Matters); U.S. ENERGY INFO. ADMIN., *supra* note 87, at 6, 10.

99. SOFYA ALTERMAN, OXFORD INST. FOR ENERGY STUDIES, NATURAL GAS PRICE VOLATILITY IN THE U.K. AND NORTH AMERICA 23–25 (2012).

100. *Id.*

101. Kevin Bullis, *Safer Nuclear Power, at Half the Price*, MIT TECH. REV. (Mar. 12, 2013), https://www.technologyreview.com/s/512321/safer-nuclear-power-at-half-the-price/ ("[Transatomic] estimates that it can build a plant based on such a reactor for $1.7 billion . . . .").

102. World Nuclear Ass'n, *supra* note 35 (citing a 2010 estimate for a 600 megawatt sodium-cooled fast reactor at 4.286 billion Euros).

103. Reilly, *supra* note 26.

104. Press Release, The White House, Obama Administration Announces Loan Guarantees to Construct New Nuclear Power Reactors in Georgia (Feb. 16, 2010), https://www.whitehouse.gov/the-press-office/obama-administration-announces-loan-guarantees-construct-new-nuclear-power-reactors; GEORGIA POWER, THIRTEENTH SEMI-ANNUAL VOGTLE CONSTRUCTION MONITORING REPORT 6 (2015) (providing a total capital and financing cost of $6.113 billion). For a detailed treatment of how to estimate advanced nuclear costs, see generally Econ. Modeling Working Grp., Generation IV Int'l Forum, *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*, GIF/EMWG/2007/004 (Revision 4.2 Sept. 26, 2007), https://www.gen-4.org/gif/upload/docs/application/pdf/2013-09/emwg_guidelines.pdf.

Compounding interest will add significant costs to an already expensive project. Moreover, debt funding of advanced nuclear will probably require interest rate premiums given the substantial risks—strict regulations, new technology, minimal track record, and uncertain energy prices.[105] Third, the repayment period can be up to 30 years or more, longer than many sources of capital are willing to wait.[106]

IV. Brief Overview of United States Energy Markets

The balance of this Note will explore the three core nuclear financing challenges discussed in Part III, *supra*, and propose solutions under the two prevailing energy regulation models: (a) a market in which regulated utilities own generation assets with rate regulation; and (b) a market in which independent power producers (IPPs) own generation assets without rate regulation. Historically, all energy markets were regulated, but beginning in the early 1970s and accelerating in the 1990s, certain legislative, judicial, and regulatory actions allowed states to deregulate their energy markets.[107]

In a regulated energy market, public utilities are vertically integrated and own all three major aspects of energy production—energy generation (i.e., power plants), energy transmission (i.e., power lines that transmit energy from the power plant to the neighborhood), and distribution (i.e., power lines from the street to the house, including billing). As discussed further *infra*, energy rates in a regulated market are determined by a public service commission (PSC) according to a particular formula and methodology.

The specific contours of deregulated energy markets can vary by state, but deregulation generally means that public utilities are prohibited from owning generation assets.[108] They can and are still involved in transmission

105. *See Cost of Capital*, Investopedia, http://www.investopedia.com/terms/c/costofcapital.asp (last visited Mar. 22, 2016) ("In general, newer enterprises with limited operating histories will have higher costs of capital than established companies with a solid track record, since lenders and investors will demand a higher risk premium for the former.").

106. Energy Fair, The Financial Risks of Investing in New Nuclear Power Plants 2 (2012).

107. Robin Deliso, *Regulated and Deregulated Energy Markets, Explained*, EnergySmart (June 27, 2014), http://www.energysmart.enernoc.com/regulated-and-deregulated-energy-markets-explained/.

108. *See, e.g.*, Me. Stat. tit. 35-A § 3204 (2010) (requiring utilities to divest all generation assets, with some exceptions including nuclear power plants); *see also* Consumers Energy, DTE Energy, & Mich. Elec. & Gas Ass'n, Joint Response from Consumers Energy, DTE, and MEGA to Electric Choice Questions 18 and 19 (2013), https://www.michigan.gov/documents/energy/Electric_Choice_Questions_18_and_19_response_from_DTE_Consumers_and_MEGA_419093_7.pdf (responding to questions posed by the Michigan Agency for Energy "to educate the citizens of Michigan about electric choice," Mich. Agency for

and distribution, but cannot own generation assets in that state.[109] One motivation behind deregulation is to foster competition in the generation of energy by giving customers a choice in their energy providers.[110] In deregulated markets, energy prices are not determined by a PSC; they are determined by market forces, although some rate caps and controls still exist.[111]

The takeaway for this Note in the regulated versus deregulated market debate is not that one is better than the other in terms of energy innovation. Rather, both are capable of fostering innovation; however, different tools are required in each. Direct regulatory policy is required in regulated markets, whereas deliberate market structures and temporary incentives will help foster innovation in deregulated markets.

V. Energy Innovation in a Regulated Energy Market

Despite the levelized cost competitiveness discussed above, many utilities are hesitant to invest in new nuclear generation. The top ten investor-owned utilities in the United States range in market capitalization from approximately $18 billion to $50 billion.[112] Bootstrapping advanced nuclear construction—estimated to cost anywhere from $1.7 billion to $5 billion, and up[113]—is out of the question for all but the absolute largest utilities, which even then probably have insufficient cash on hand. Traditional regulatory tools can help mitigate these issues, driving advanced nuclear energy development and construction. This section will first explain the mechanics and incentives of government-regulated electricity rates. It will next recommend a regulatory allowance called Construction Work in Progress (CWIP), which can help offset compounding interest costs. The section concludes by suggesting a regulatory management regime called Integrated Resource Planning (IRP) which can help incentivize investment at the outset and provide sufficient long-term revenue for utilities that make the necessary investments in advanced nuclear. These concepts, in and of themselves, are not particularly novel; the purpose of this section is to ex-

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Energy, *Electric Choice*, Energy Policy Reports, https://www.michigan.gov/energy/0,4580,7-230-72200_68204_54287—,00.html (last visited Mar. 22, 2016)); Steve Ferrey, The New Rules: A Guide to Electric Market Regulation 164, 319 (2000).

109. Ferrey, *supra* note 108; *Deregulation*, JustEnergy, https://www.justenergy.com/energy-explained/deregulation/ (last visited Mar. 22, 2016).

110. *Deregulation*, JustEnergy, *supra* note 109.

111. *Id.*

112. *Largest Electric Utilities in the U.S. in 2015, Based on Market Value*, Statista, http://www.statista.com/statistics/237773/the-largest-electric-utilities-in-the-us-based-on-market-value/ (last visited Mar. 22, 2016).

113. *See* Bullis, *supra* note 100; World Nuclear Ass'n, *supra* note 35.

amine the challenges and present a path to advanced nuclear in a traditional regulated market.

A. *Traditional Rate Regulation*

The way that electricity prices are determined in a regulated energy market provides incentives for capital investments; however, such incentives do not necessarily incentivize *innovation*. A regulated utility in a regulated market charges customers rates approved by a PSC according to a cost-of-service formula. The rates are determined using the formula $O + B(r) = R$, in which O = operating expenses, B = base rate, r = rate of return, and R = revenue requirement.[114] More specifically, O stands for operating costs, which are typically defined as expenses consumed within one year. B represents a utility's capital investments—its property, plant, and equipment. Lowercase r stands for the rate of return on capital assets that the utility is entitled to earn, typically around 10%.[115] Note that while capital assets, B, earn a rate of return, operating expenses, O, do not. R represents the total amount of revenue that the utility needs to collect from ratepayers. Roughly speaking, R divided by the number of kilowatt-hours of electricity projected for the upcoming year will yield the price per kilowatt-hour of electricity charged to ratepayers.

A utility with both generation and distribution capabilities still must separate these two functions pursuant to FERC Order 888.[116] The generation arm produces power and sells it through the energy markets or bilateral power purchase agreements (PPAs).[117] Similarly, the distribution arm has to buy power either through energy markets or PPAs. The cost of purchasing energy through either means is incorporated into the rate formula as an operating expense on which the utility will *not* earn a rate of return. However, the utility does still earn a rate of return on capital assets that it owns, including power generation facilities.

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114. Bosselman et al., *supra* note 9, at 65.

115. Coley Girouard, *How Do Electric Utilities Make Money?*, Advanced Energy Economy: Advanced Energy Perspectives (Apr. 23, 2015, 2:05 PM), http://blog.aee.net/how-do-electric-utilities-make-money (providing that the average return on equity for United States utilities is approximately 10%).

116. FERC Order 888 requires a utility that owned generation and transmission assets to essentially deal with itself at arms-length, such that utility-owned generation would need to compete with Independent Power Producers (IPPs) on an even playing field, without discriminatory tariffs toward the IPPs. 18 C.F.R. pt. 35 (2012).

117. For an explanation of energy markets, see generally Fed. Energy Regulatory Comm'n, Energy Primer (2015) and Matthew J. Morey, Power Market Auction Design Rules and Lessons in Market Based Control for the New Electric Industry (2001).

The return-on-capital-investment aspect provides a financial incentive for utilities to invest in generation. Moreover, the increased likelihood of cost recovery and price stability from rate regulation reduces uncertainty surrounding the project's likely success, which should reduce the interest rate premium required for an advanced nuclear construction.

Despite rate regulation's incentives for capital investment, there are powerful competing economic forces against investment in innovative energy sources. Investment in advanced nuclear requires major upfront investment and entails substantial financing costs. Many generation assets operating today have already been paid in full and generate electricity at very low marginal costs, especially nuclear. Owners of such plants can be quite content simply selling this power into the market well above marginal costs[118] and are hesitant to put billions of dollars at risk in new investments.[119] This is particularly problematic for new nuclear energy given its high upfront costs, discussed *supra* in Part III.

Several policy tools can help push through the stagnating inertia of cheap electricity from outdated plants. First, more stringent carbon and pollution regulations will help push old fossil fuel plant operators to invest in new technology. Second, the NRC is currently extending existing 40-year nuclear plant licenses for another 20 years, and there is talk of one day extending for *another* 20 years (for a total of 80 years).[120] The NRC should commit now to refusing the second round of license extensions to deliver a clear policy message to drive innovation while providing plant operators with 20 years to prepare alternate plans.[121] Finally, as proposed below, Construction Work in Progress allowances and Integrated Resource Planning, discussed *infra*, would bring both policy and economic factors to bear in regulated markets to incentivize capital investment in innovative and socially responsible generation sources.

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118. This is true given the Dutch auction nature of many wholesale energy markets. *See, e.g*, MOREY, *supra* note 117, at 4.

119. *See* Wald, *supra* note 5.

120. *See* U.S. NUCLEAR REGULATORY COMM'N, *supra* note 5; Wald, *supra* note 5.

121. It is appropriate to refuse further licensing extensions because these plant operators have received their initially anticipated 40 years of useful life out of the plants, plus an extra 20 years to earn profits. One feature of the regulatory compact is that once cost recovery and reasonable profit have been achieved, old technology should be retired so new technology can benefit from the same process. Without this turnover, incumbent operators will receive a windfall and technological advances will be delayed. In another 40–60 years, plant operators of advanced nuclear should have recovered costs and earned reasonable profits. New and improved technology will likely be available and should be implemented.

B. *Construction Work in Progress*

An allowance for Construction Work in Progress (CWIP) would incentivize advanced nuclear by permitting utility companies to begin billing ratepayers for construction costs when construction begins, rather than wait until the plant comes online.[122] This can save billions in financing costs by limiting compounding interest.[123] Without CWIP, the utility must pay compounding interest on its original principal loan plus the accruing interest. Consider if the original loan was for $100 at 10% interest. After the first interest period (say, one month), the outstanding balance would be $110 ($100 principal plus $10 interest). After the second month, the balance would be $121 ($110 principal/interest plus $11 interest). After the third month, it would be $133.10 ($121 principal/interest plus $12.10 interest). By the fourth month, it would be $146.41 ($133.10 principal/interest plus $13.31 interest). Not only does the balance increase each month, but the amount of interest owed each month grows exponentially as the balance grows. The first month was $10, then $11, then $12.10, then $13.31. Imagine these numbers are millions and billions of dollars and it should be clear how the cost of capital snowballs.

Under a CWIP regime, the growth in interest payments would be limited and perhaps eliminated, depending on the administration of CWIP. Rather than interest growing from $10 to $11, $12.10, $13.31 and so on, interest payments would remain constant at $10, or perhaps even shrink from $10 down to $9, $8, etc. This adjustment would save substantial sums on the cost of capital for the project. Each ratepayer would chip in a small amount of money to finance the project in real-time, offsetting the otherwise exponential cost of borrowing. Ratepayers' rates would increase earlier than they would absent a CWIP regime, but the overall additional cost is less because of the avoided interest payments that would have otherwise accrued between the beginning of construction and the plant coming online.

Critics of CWIP argue that what the ratepayers gain from reduced long-term electricity rates, they sacrifice in return on investment that could be earned if their money was otherwise invested from the time of payment to project completion. This ignores the bigger picture. First, the amount in question is not huge—if 1.8 million customers chipped in to offset the interest on a $1 billion project with a 10% annual interest rate, for example, there

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122. *See* Nuclear Energy Inst., Construction Work in Progress: An Effective Financial Tool to Lower the Cost of Electricity (2012), http://www.nei.org/CorporateSite/media/filefolder/CWIP.pdf?ext=.pdf.

123. *Id.* (estimating that allowances for CWIP will save Georgia ratepayers approximately $2 billion in financing costs on two nuclear reactors currently under construction, or approximately 15% of the projected total cost).

would be approximately $8.3 million in monthly interest payments. Customers' rates would increase by about $5 per month or $60 per year.[124] Assuming a customer invested that $60 elsewhere instead of paying it toward CWIP, he would be lucky to earn 1% annually in a savings account, and a long-term average of 6–7% in the market with more risky investments.[125]

Second, consider what ratepayers gain. By paying early at a rate of $5 per month or $60 per year, ratepayers would offset $8.3 million in monthly interest, or $104.7 million in annual interest. Now, $8.3 million times 12 months only equals $99.6 million. The difference between $104.7 million and $99.6 million is $5.1 million, which represents the compounded interest avoided by making interest payments every month. Dividing $5.1 million across 1.8 million customers equals $2.83 per customer. So, by paying about $60 per year to offset the utility's interest, ratepayers can save $2.83 per ratepayer per year in avoided interest, or about 5% annual return. Absent the CWIP, the $60 *and* the $2.83 would be paid by ratepayers in the future. With CWIP, only the $60 is paid and the $2.83 can be avoided. Compare that 5% to the 1% or less the ratepayer would have earned by keeping their money in a savings account or 7% in the stock market. While 5% is not as good as the "average" rate of return on stock market investment, there are other factors involved: this is a relatively small sum of money for which market returns are negligible in terms of long-term finances, and gradually funding long-term energy solutions will be less disruptive to customers than potential price shocks from climate or energy emergencies.

Consider also that a new advanced nuclear plant would reduce carbon emissions and other pollutants, reduce coal mining and natural gas fracking, and provide macroeconomic stimulus through technology innovations.[126] Recent studies provide estimates of the social cost of releasing one ton of

124. $8.3 million divided by 1.8 million customers equals roughly $5 per month. Multiplied by 12 months, the total reaches $60.

125. *See, e.g.*, *National Highest Money Market Account Rates – Best Savings Rates*, BANKRATE, http://www.bankrate.com (last visited Mar. 22, 2016); Trent Hamm, *Average Stock Market Return: Where Does 7% Come From*, THE SIMPLE DOLLAR (Sept. 12, 2014), http://www.thesimpledollar.com/where-does-7-come-from-when-it-comes-to-long-term-stock-returns.

126. *See* U.S. ENVTL. PROT. AGENCY, ASSESSING THE MULTIPLE BENEFITS OF CLEAN ENERGY 140–41 (2011), https://www3.epa.gov/statelocalclimate/documents/pdf/epa_assessing_benefits.pdf. While jobs would be lost in fossil fuel industries, they would be gained elsewhere: directly in the nuclear industry; less directly through derivative applications of nuclear-related research and development; and generally through the economic stimulus generated by disruptive energy technology.

carbon dioxide into the air that range from $37 to $220 per ton.[127] In Michigan, for example, three nuclear plants avoided the release of 26.85 million metric tons of carbon dioxide, which would have imposed social costs of $993 million to $5.9 billion based on the savings per ton discussed in those studies.[128] This does not account for other pollutants released by burning fossil fuels and their effects on public health and the environment, nor the environmental costs of mining for coal and fracking for natural gas.[129]

The upshot of all this is not to put a specific cost avoidance price tag on nuclear development; that would be impossibly speculative. The point is that modest investments today, spread gradually across all ratepayers, can have reverberating long-term benefits. In purely financial terms, these investments avoid interest-on-interest, benefiting ratepayers in long-term cost avoidance. Expanding the calculus to account for environmental, public health, and job creation benefits, the modest CWIP costs borne today should provide generous multifaceted returns to ratepayers. This concept—long-term benefits through modest near-term investments—is demonstrated nicely by CWIP, and is a running theme throughout this Note's proposals.

C. *Integrated Resource Planing and Certificates of Necessity*

An Integrated Resource Plan (IRP) is a centralized plan organized by a PSC to anticipate future energy demand and regulate future energy supply with an ultimate goal of ensuring that future energy needs are met at prices reasonable to the consumer, but high enough for generators to recover their costs and earn a reasonable profit.[130] Historically, IRPs considered only load forecasting and least-cost generation, but today's plans consider additional factors, including environmental protection and demand-side man-

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127. Ker Than, *Estimated Social Cost of Climate Change Not Accurate, Stanford Scientists Say*, STANFORD (Jan. 12, 2015), http://news.stanford.edu/pr/2015/pr-emissions-social-costs-011215.html.

128. BOSSELMAN ET AL., *supra* note 9, at 210; Nuclear Energy Inst., *Emissions Avoided by the U.S. Nuclear Industry (State by State)*, KNOWLEDGE CENTER, http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Environment-Emissions-Prevented/Emissions-Avoided-by-the-US-Nuclear-Industry (last updated May 2015).

129. *See generally* Nickolas Z. Muller & Robert Mendelsohn, *Weighing the Value of a Ton of Pollution*, 33 REGULATION 20, 25 (2010).

130. *See generally* FRANK C. GRAVES ET AL., EDISON ELEC. INST., RESOURCE PLANNING AND PROCUREMENT IN EVOLVING ELECTRICITY MARKETS 3 (2004) ("Some state policy makers, concerned about the past price instability and the future resource adequacy in the restructured wholesale markets, are expressing a renewed interest in old regulatory tools, such as Integrated Resource Planning (IRP)."); TENN. VALLEY AUTH., ENERGY VISION 2020: INTEGRATED RESOURCE PLANNING ch. 2 (1995), http://152.85.5.80/environment/reports/energyvision2020/; *see also* Peter Maloney, *Marginal Success*, U.S. POWER MARKETS, Dec. 2013, at 49, 51–52.

agement.[131] A properly designed IRP seeks to ensure reliable energy, at reasonable costs for both ratepayers and power generators, while also considering policy factors such as environmental protection. An IRP is the essence of a regulatory compact in which free market competition is limited by government regulators in order to balance the competing desires of reliability, innovation, and economics.[132]

A key component of an IRP is the Certificate of Necessity (CON), which is issued by the PSC to a power generator proposing to construct a new power plant, expand an existing plant, or enter into a long-term PPA. The specifics of certification can vary by state or region, but CONs generally aim to provide assurance by the PSC that the capital expended in new generation or construction may be recovered from ratepayers pursuant to the rate regulation discussed in *supra* Section V.A on traditional rate regulation.[133] Such assurances may be provided explicitly[134] or may be implicit from a CON that certifies a "need" for the proposed generation, but stops short of an assurance of recovery.[135] Certifying a need for the proposed generation is a way to limit the supply of electricity to avoid an oversaturation of the marketplace and unsustainably low energy prices that could drive generators out of business and ultimately lead to electricity shortages and higher prices.[136]

CONs thus encourage investment in innovative generation methods by reducing the investment risk at the outset. However, even for a CON that assures recovery of costs, some investment risk persists because the assurance generally extends only to the proposed budgeted amount—cost overruns cannot necessarily be recovered from ratepayers.[137] CONs are provided after extensive consideration by the PSC of the proposed generation, alter-

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131. GRAVES ET AL., *supra* note 130, at 6.

132. Karen Gould, Integrated Resource Planning for Electric Power, slide 18 (Aug. 3–7, 2009), http://pubs.naruc.org/pub/5383B7D3-2354-D714-51CA-BF2EB9D711D7 (providing that "[r]egulation substitutes for competition" and "[a]ttempts to mimic a perfectly competitive market as much as possible").

133. *See, e.g.*, MICH. COMP. LAWS § 460.6s(3) (2008).

134. *Id.* § 460.6s(3)(d) (explaining that one type of CON provides an assurance that the estimated purchase or capital costs "will be recoverable in rates from the electric utility's customers").

135. *Id.* § 460.6s(3)(a) (explaining that another type of CON is "[a] certificate of necessity that the power to be supplied as a result of the proposed construction, investment, or purchase is needed").

136. Low energy prices may sound nice in the short term, but prolonged energy prices below generation costs would drive generators out of business, especially clean energy generators with the highest internalized environmental costs, and leave the cheapest energy generators, which often have high externalized environmental costs.

137. *See* MICH. COMP. LAWS. § 460.6s(6).

native generation methods, and competitive landscape.[138] New or expanding generation sources are not required to obtain a CON prior to construction, but it is certainly advantageous to do so to ensure that costs can be recovered from ratepayers.[139]

Advanced nuclear is a risky investment proposition given the sheer amount of capital required, extended payback period, and lack of track record. Such risks entail substantial financing costs, which compound to make the project even riskier. Issuance of a CON would reduce the investment risk at the outset, thereby incentivizing advanced nuclear construction by utility companies, which would have assurance of cost recovery from ratepayers.[140] The inclusion of environmental and policy considerations in an IRP would further incentivize investment by utilities in nuclear and other renewable energy sources.

Despite the regulated nature of an IRP, the process to obtain a CON ensures that only the most competitive projects receive a CON. An "IRP is about choosing the lowest cost among alternatives of like benefits but different costs, typically where the alternatives are mutually exclusive and customized."[141] In other words, an IRP should balance the priorities of reliability, environmental concern, and cost—both near-term and long-term—and choose from least-cost options within each category in a competitive process. There would be competition among different advanced nuclear technologies and other energy generation technologies that provide comparable environmental, reliability, and economic benefits. As discussed throughout this Note, advanced nuclear hits on all three categories—it produces reliable power, is environmentally responsible, and is cost efficient over the long term.

VI. Energy Innovation in a Deregulated Energy Market

Advanced nuclear construction projects in a market without utility-owned generation face the same three core challenges identified above that plague regulated utilities: (a) the need to raise billions of dollars upfront; (b) compounding interest at a likely interest-rate premium; and (c) a long repayment horizon. Additionally, IPPs lack the regulatory tools discussed

138. *See id.* § 460.6s(11)(f).

139. *See, e.g.*, *id.* § 460.6s(1) (providing that the utility "may" submit an application for a CON); *id.* § 460.6s(8) (providing that if the commission denies the CON, the utility may continue construction without the assurances of a CON).

140. However, the cost recovery assurances from a CON generally only apply to budgeted costs. The typical utility is responsible for overruns, thereby limiting the potential moral hazard. *See id.* § 460.6s(6).

141. Graves et al., *supra* note 130.

above that could incentivize advanced nuclear in a regulated market.[142] So, IPPs need to raise money from the capital markets using free-market principles.

This section lays out three suggestions that can help encourage capital-intensive innovation by IPPs. First, catalytic first-loss capital can help reduce investment risk, thereby incentivizing investment from a wider range of sources and reducing the cost of capital. Second, securitization of plant assets can improve the liquidity of investments. Third, adjustments to the way in which energy markets operate can enable earlier recognition of future power sales, helping to address the capital timing issue.

Free market purists may take issue with the government assistance proposed, but this would ignore the government assistance that led to the current status quo. Early nuclear technology would not have been possible without the support of major government programs during the 1960s.[143] And fossil fuels also have enjoyed a long history of government subsidies.[144] Completely eliminating government assistance from energy innovation essentially amounts to a new barrier to market entry that even Chicago School adherents would agree provides an unfair advantage.[145]

A. *Catalytic First-Loss Capital*

Catalytic first-loss capital (CFLC) is a tiered capital deployment strategy designed to stimulate investment in promising—yet unproven—ventures by temporarily using government funds to improve the risk-return profile, thereby incentivizing others to invest.[146] Absent CFLC (or rate reg-

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142. Recall that IPP stands for Independent Power Producer. IPPs are typically large utility companies that operate as regulated utilities in some states and as IPPs in other states. Jun Ishii, *From Investor-Owned Utility to Independent Power Producer*, 27 ENERGY J. 65, 66 (2006).

143. Comprehensive Nuclear-Test-Ban Treaty Org., *Manhattan Project*, HISTORY OF NUCLEAR TESTING, http://www.ctbto.org/nuclear-testing/history-of-nuclear-testing/manhattan-project/ (last visited Mar. 22, 2016) (providing that the Manhattan Project, which was funded by the United States government and played an important role in the development of nuclear energy, cost nearly $2 billion, or approximately $34 billion in 2016 dollars).

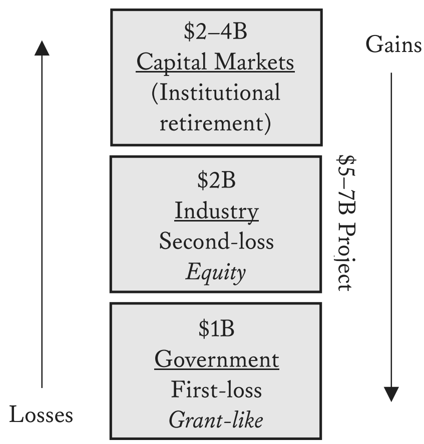
144. Jeff Johnson, *Long History of U.S. Energy Subsidies*, 89 CHEMICAL & ENGINEERING NEWS 30, 30 (2011) (providing that "[t]he first 15 years . . . are critical to developing new technologies," and, further, that "oil and gas subsidies, including tax breaks and government spending, were about five times as much as aid to renewables during their first 15 years of development").

145. DAN CRANE, ANTITRUST 35 (2014) ("One of the key tenets of the Chicago School is that only expenses incurred by new entrants but not by incumbents should be considered entry barriers.").

146. Much of the discussion of catalytic first-loss capital in this Note is based on AMIT BOURI & ABHILASH MUDALIAR, GLOBAL IMPACT INV. NETWORK, CATALYTIC FIRST-LOSS CAPITAL (2013).

ulation), an investment in unproven advanced nuclear energy would be too risky for most institutional capital market participants. Any that did participate would likely require extraordinary interest rate premiums. Some venture capital firms might be willing to invest, but venture capital alone is unlikely to provide the billions necessary to finance advanced nuclear.[147] CFLC can adjust the risk profile by structuring investments into different tiers with different risk/reward outcomes tailored to meet the needs of each participant in the tier.[148] This would enable advanced nuclear projects to tap into $18 *trillion* in institutional retirement funds (pension funds, IRAs, 401(k) plans, etc.).[149] Expanding the pool of financing should help to raise the money necessary, and at a lower interest rate.

FIGURE 3: STRUCTURE OF A CATALYTIC FIRST-LOSS CAPITAL TRANSACTION



147. *The Daily Startup: Venture Investors Back Nuclear Energy After a Lull*, WALL ST. J.: VENTURE CAPITAL DISPATCH (Aug. 15, 2014, 9:31 AM), http://blogs.wsj.com/venturecapital/2014/08/15/the-daily-startup-venture-investors-back-nuclear-energy-after-a-lull/. In 2014, venture firms invested $1.5 million and $2 million, respectively, in Helion Energy Inc. and Transatomic Power Corp, which are startup nuclear energy companies. *Id.* Such small amounts of money would certainly help advanced nuclear companies, but are insufficient for even a Prototype of Helion's proposed generator, which it estimates would cost between $30–50 million. *Id.* The article also notes that there was no venture fund investment in nuclear in 2013 or 2012, and only $2.87 million total in 2011. *See also* Katie Fehrenbacher, *How Startups Can Save Nuclear Tech*, FORTUNE (July 6, 2015) (providing that there are a number of nuclear startups with modest funding success, but acknowledging the shortfall between venture funding and the billions needed for commercialization).

148. *Id.* at 3–4.

149. TOWERS WATSON, GLOBAL PENSION ASSETS STUDY 2014, at 6 (2014). This Note is certainly not proposing that all $18 trillion be invested in advanced nuclear. One-tenth of one percent (0.1%) of this value would be $18 billion, a potentially transformational amount of capital for advanced nuclear.

Figure 3 illustrates the structure of CFLC for a $5–7 billion project. First, an organization—traditionally government, a foundation, or other non-governmental organization—contributes $1 billion in "first-loss" capital. This money is often viewed as a grant, though there is strong potential for repayment over the long-term. Second, participants from the nuclear industry[150] invest in the venture through equity interests, which traditionally serve a first-loss purpose, but here serve as second-loss capital. With these first- and second-loss tiers in place, the risk profile of the venture is substantially reduced for top-tier participants. The venture can seek additional financing from the capital markets, including the $18 trillion in institutional retirement accounts.

The specific instrument for institutional funds to invest in CFLC would likely be commercial debt instruments. Without the government's CFLC, these investments would probably be too risky for institutional investors, which are often constrained by certain risk-adjusted return management policies on their investments.[151] However, the CFLC essentially serves as a partial loan guarantee, thereby improving the risk-adjusted return profile to enable institutional investment.

Gains and losses are applied inversely. As the project comes online and begins to make money, the top-tier debt will be paid off with modest interest.[152] This is consistent with "normal" (i.e., non-CFLC) public debt issuance—debtholders enjoy relatively little risk due to their claim priority, and therefore receive only modest returns.[153] In the case of CFLC, the outcome should be the same as a non-CFLC debt issuance in a more traditional (i.e., less risky) energy investment. *That is the whole point*—the first-loss government capital reduces the risk of the debt offering to be in line with traditional debt offerings.[154]

Once debtholders are paid off, dividends will flow to the nuclear industry equity holders; specifically, companies already engaged in the ownership, operation, and construction of nuclear plants. As discussed above, utility companies in one state often own generation assets in other states, where they function as IPPs, rather than regulated utilities.[155] These partici-

150. These nuclear participants would probably be IPPs that operate other nuclear plants, either at regulated utilities or IPPs (depending on the states in which they operate).

151. Dorothy Franzen, *Managing Investment Risk in Defined Benefit Pension Funds* 48 (OECD, Working Papers on Insurance and Private Pensions No. 38, 2010) ("In the United States, 'prudence' is interpreted along the lines of financial economics, i.e. maximising risk-adjusted returns.").

152. *See* Bouri & Mudaliar, *supra* note 146, at 8–9.

153. *See id.*

154. *See id.*

155. *See* Ishii, *supra* note 142.

pants took on a substantial risk by investing $2 billion in equity capital, subordinated to public debtholders, and they should enjoy the commensurate reward of owning a nuclear power plant that can generate electricity for 40 or more years with very low marginal costs. Notably, these are precisely the participants that *should* own advanced nuclear plants since they will be the ones with the expertise to operate the plants.

The notion of tapping institutional retirement funds may raise some eyebrows, but consider what these funds are currently doing. CalPERS, the California Public Employees' Retirement System, is one of the largest pension funds in the world, managing over $300 billion in assets at the end of 2014.[156] Of that $300 billion, approximately $15 billion was held in publicly issued corporate debt similar to the debt proposed in this Note.[157] The money raised by these corporate bonds helps to finance capital-intensive projects (like building new energy generation). CalPERS holds debt in companies ranging from Verizon Wireless to Hawaiian Airlines to the Wynn casinos, including $85 million in Duke Energy,[158] the largest utility in the United States.[159] CalPERS even has $600 million invested in a fund specifically designed to target North American power investments.[160] In short, the CFLC debt suggested in this Note is generally consistent with the business-as-usual investing of institutional retirement funds. Of course, risks remain (as with any investment in corporate bonds), but the risks under this CFLC structure should be no different than the risks already present under the status quo use of institutional retirement funds.[161]

Importantly, government CFLC is meant to be *catalytic* and temporary, not a permanent financing structure for nuclear power. A primary problem with investment in advanced nuclear right now is its uncertainty and lack of track record. CFLC helps to get the first handful of projects off the ground by providing a risk-mitigating counterbalance, while still requiring the ultimate beneficiaries to put skin in the game. Once several advanced nuclear projects with CFLC have been completed, there will (hopefully) be a track record of success such that subsequent projects will require decreasing

156. Cal Pub. Emps.' Retirement Sys., Comprehensive Annual Investment Report: Fiscal Year Ended June 30, 2014, at 3 (2014).

157. *Id.* at 46 (providing, under the "Corporate Bonds" heading, a tally of approximately $15 billion).

158. *Id.* at 21.

159. N.Y. Times, *Markets: Utilities – Electric*, Business Day, http://markets.on.nytimes.com/research/markets/usmarkets/industry.asp?industry=59111 (last visited Mar. 22, 2015).

160. Press Release, Harbert Mgmt. Corp., HMC Affiliate Gulf Pacific Power, LLC Acquires Interest in New York City Power Plant (Oct. 18, 2013), http://www.harbert.net/wp-content/uploads/2013/10/GPP-Astoria-Energy-II-Press-Release.pdf.

161. *See* Bouri & Mudaliar, *supra* note 146.

amounts of CFLC in order to provide investors with acceptable risk profiles, eventually eliminating the need for government CFLC altogether.

B. *Securitization*

A long repayment period is an additional issue for advanced nuclear. A huge amount of money is needed upfront, with ultimate repayment and profit to occur over decades. Even with strategies to mitigate the levelized cost of capital, there still may be a timing issue for many investors. The securitization aspect of publicly-issued CFLC debt of advanced nuclear projects can provide a path to monetization for investors even before the plant comes online, and well before the potential 30–40 years required for repayment from energy revenue.[162]

Securitization refers to the process of dividing an asset or company into shares that can be bought and sold as a security, thereby providing some liquidity to the investment.[163] Consider the benefits of securitizing a venture to build a hypothetical advanced nuclear plant, Jet Nuclear. Early on, when Jet Nuclear is in its infancy, the resale value of that debt would be discounted due to the various project risks (technology, regulatory, etc.). As Jet Nuclear progresses—clearing regulatory and construction milestones—the resale value of that debt will increase as the project risks decline. On one hand, the holder of that debt should want to keep the debt as Jet Nuclear shows increasing promise. But the holder may have other liquidity or strategic needs and may want to sell Jet Nuclear debt to another investor in order to monetize her initial gains. The buying investor may not have been interested in the risk of Jet Nuclear debt at the outset, but with certain milestones already attained, the risk may be reduced to acceptable levels for that buyer.[164]

162. The concepts discussed in this section are similar to the strategies employed by SunEdison and other solar yieldco's. SunEdison is facing potential bankruptcy, reportedly due to mismanagement of its rapid growth. In essence, SunEdison's securitization of its solar assets worked too well—raising approximately $10 billion—and its management was unable to maintain sufficient oversight and quality standards. *See, e.g.*, Liz Hoffman, *Inside the Fall of SunEdison, Once a Darling of the Clean-Energy World*, Wall St. J. (Apr. 14, 2016).

163. *See Securitization*, Investopedia, http://www.investopedia.com/ask/answers/07/securitization.asp (last visited Mar. 22, 2016); *How Does Securitization Increase Liquidity?*, Investopedia, http://www.investopedia.com/ask/answers/042115/how-does-securitization-increase-liquidity.asp (last visited Mar. 22, 2016).

164. During the recent mortgage-backed security recession, this strategy was irresponsibly employed through derivative positions in an unsuccessful attempt to diversify the risk out of mortgage-backed securities. This Note makes no argument for securitization as a means of diversification. However, there is one securitization lesson from the recent recession that does apply—liquidity risk. Just because something *can* be securitized (i.e., divided

The converse also applies. Perhaps there is a moderate investment risk at the outset, and Jet Nuclear fails to reach certain milestones in time. The value of the debt goes down and the initial debt holder wants to cut its losses. A more risk-tolerant buyer may see value in the depressed debt and be willing to buy it from the initial debt holder at a discount. The initial buyer still takes a loss (as can happen with any investment), but is not stuck holding the debt long-term.

Securities in advanced nuclear ventures can be sold as registered public securities or as exempt private offerings. Public registration is costly and increases potential regulatory enforcement liability,[165] but this cost should be manageable relative to the overall project cost and would likely provide the most liquidity. On the other hand, private offering options include a Rule 506 offering under Regulation D, a Rule 144 offering, or a Rule 144A offering, although restrictions on resale could limit the liquidity from such private offerings.[166]

C. *Energy and Capacity Markets*

There are two priorities for advanced nuclear that are more important than maximizing profit: (a) offsetting high upfront costs by early monetization of future energy production and capacity; and (b) decreasing uncertainty at the time of investment by increasing the predictability of future revenue. Without these two considerations, an advanced nuclear project may never get off the ground, and there will be no profit to maximize. To achieve these priorities, advanced nuclear generators can and should transact in the existing capacity and energy markets—specifically, capacity sales, exchange-traded electricity futures, and exchange-traded electricity options.[167]

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into shares, bought, and sold), doesn't mean that there will always be a market for that product. Without willing buyers, the security is not worth anything.

165. *See* 15 U.S.C. § 77k(a) (2012).

166. 17 C.F.R. § 230.506 (2015) (providing, in general, for a private placement offering to accredited investors); 17 C.F.R. § 230.144 (2015) (providing, in general, for the sale of restricted or controlled securities); 17 C.F.R. § 230.144A (2015) (providing, in general, for a private placement offering to qualified institutional investors).

167. *See, e.g.*, *Capacity Market (RPM)*, PJM, http://learn.pjm.com/three-priorities/buying-and-selling-energy/capacity-markets.aspx (last visited Mar. 4, 2016); Adam James, *How a Capacity Market Works*, THE ENERGY COLLECTIVE (June 14, 2013), http://www.theenergycollective.com/adamjames/237496/energy-nerd-lunch-break-how-capacity-market-works-and-why-it-matters.

1. Capacity Markets

The difference between energy and capacity is that energy is the power *actually* produced, sold, and consumed, whereas capacity is a prepaid commitment to be ready to produce energy at some point in the future.[168] For example, a generator would sell capacity into the market in January of Year 1 and collect $*X* in exchange for a commitment to produce *Y* amount of power during January of Year 2. In January of Year 2, the generator would actually produce *Y* amount of energy (if necessary based on grid demand) and sell that energy for $*Z*, a price determined by real-time market forces. So the generator would collect revenue twice—once in Year 1 when selling capacity and once in Year 2 when selling the energy ($*X* + $*Z*).

There are two main benefits to generators from capacity markets. First, they allow for some monetization of future power generation in Year 1, as demonstrated by the above example. Second, they provide for a second revenue stream, beyond just energy sales, to compensate for the "missing money" problem—a well-documented phenomenon in which prices paid to energy suppliers are below the levels needed to sustain existing generation and incentivize new entry.[169] This subsection will focus mainly on the first benefit. While the second benefit is important, it is beyond the scope of this Note.

Capacity markets typically operate up to three years in advance, though some markets are limited to only a few months.[170] There are typically adjustment periods near the time of actual capacity need, during which time excess capacity can be resold into the market to be purchased by entities with a projected shortfall in capacity.[171]

Extending capacity markets beyond three years—to, say, 40 years[172]—would enable clean energy generators to monetize more of their capacity earlier in the plant's life.[173] In Year 1 of a project (or pre-construction), the generation plant could sell capacity for the next 40 years, receiving substantial revenue to offset high construction and interest costs and mitigate the

168. *See, e.g.*, sources cited *supra* note 167.

169. *See, e.g.*, PETER J. MAKOVICH ET AL., POWER SUPPLY COST RECOVERY BRIDGING THE MISSING MONEY GAP (2013).

170. PJM, *supra* note 167.

171. *See Forward Capacity Market*, ISO NEW ENGLAND, http://www.iso-ne.com/markets-operations/markets/forward-capacity-market (last visited Mar. 4, 2016).

172. Forty years is somewhat arbitrary, but was chosen to reflect the current license period of a nuclear power plant. The important point is to significantly extend markets to better reflect the lifetime of the generation assets for which the markets are supposed to provide price signals. *See generally* Maloney, *supra* note 130.

173. It would also encounter potential issues and risks, addressed in Subsection VI.C.3, *infra*.

capital timing problem discussed in Part III, *supra*, similar to the benefits of CWIP.

This would also send more accurate price signals to indicate when new generation should be built, somewhat akin to an IRP and CON, discussed in Section V.C. *supra*.[174] Long-term price signals would provide increased certainty in Year 1 (or pre-construction) that future energy from that generation asset would be needed and purchased by the market at a high enough price to warrant construction in the first place. Such price signals would help encourage investment by reducing uncertainty at the outset about the future energy sales and revenue from that plant.

There would be increased costs to ratepayers by extending the capacity markets. Load serving entities (LSEs)[175] purchase capacity to satisfy regulatory and consumer demands for reliability.[176] These costs are currently passed on to ratepayers in their energy bills.[177] Thus, the early monetization realized by advanced nuclear would be funded by ratepayers. But this is comparable to CWIP, discussed *supra* in Section V.B., for regulated utilities. Recall the long-term benefits to ratepayers from paying a modest amount early—offsetting compounding interest, plus driving clean-energy innovation to reduce climate change and fossil fuel pollution while also stimulating the economy.

In sum, the primary benefit of extending capacity markets further into the future is that it would provide earlier monetization of future energy capacity, which would encourage investment in advanced nuclear and other renewable energy technologies with high upfront costs by offsetting compounding financing costs. A second benefit is that it would help provide long-term price signals to reduce investment risk at the outset. The downside for consumers is that there would be increases in current energy bills as future energy capacity is paid for today, rather than further down the road. However, as discussed in the CWIP section, paying early does not necessarily mean paying more. Consider credit card or student loan debt—these

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174. Elec. Power Supply Assoc., Getting the Best Deal for Electric Utility Customers, at v (2004).

175. *Load Serving Entities*, ERCOT, http://www.ercot.com/services/rq/lse (last visited Mar. 22, 2016) (providing that "[l]oad serving entities (LSEs) provide electric service to end-users and wholesale customers," and further explaining that "LSEs include the competitive retailers (CRs) that sell electricity at retail in the competitive market," which include "(1) a retail electric provider (REP), which contracts with qualified scheduling entities to provide scheduling services for their load customers, or (2) a municipally owned utility or co-operative that opts to offer customer choice (an opt-in entity)").

176. Adam James, *How a Capacity Market Works*, The Energy Collective (June 14, 2013), http://theenergycollective.com/adamjames/237496/energy-nerd-lunch-break-how-capacity-market-works-and-why-it-matters.

177. *Id.*

costs would come due at some point, but the longer the delay in payment, the higher the ultimate balance.

2. Exchange-Traded Energy Futures and Options

Exchange-traded energy futures and options are standardized derivative contracts, primarily traded on the New York Mercantile Exchange (NYMEX).[178] An energy option refers to a contract in which the generator/seller commits to sell *X* amount of power at $*Y* cost on *N* date in the future, but only if the buyer chooses to exercise the option.[179] It is very similar to capacity, except that there is a fixed price term (a strike price). The buyer pays a fee upfront, $*Z*, for the *option* to buy *X* amount of energy at $*Y* cost on *N* date.[180] If the market price on *N* date is higher than $*Y* (the strike price), then the buyer would exercise its option and pay the seller $*Y* for *X* amount of energy. If the market price on *N* date is lower than $*Y*, then the buyer would decline to exercise the option, and would instead buy energy on the open market.[181] In this case, the generator/seller could bid its energy into the real-time market, while still keeping $*Z* in revenue from the initial sale of the option.

The benefits of energy options for advanced nuclear are similar to those provided by capacity markets—early monetization and better price signals for future power needs. There is an additional benefit in the slightly increased predictability of future energy prices. Because there is a known strike price for the option, *Y*, the generator knows that it won't sell energy higher than *Y*, though it may sell lower if the market goes down. This is not ideal—the seller would prefer to know the minimum price that it will receive for a guaranteed amount of power, but knowing a ceiling still provides some predictability that is helpful for projecting revenues and reducing investment risk. A negative forecast can also discourage unnecessary or unprofitable construction, thereby avoiding bad investments that would create negative precedent for advanced nuclear.

An energy future is a contract in which the seller or generator agrees to sell, and the buyer agrees to purchase, *X* amount of power for $*Y* on *N* date. The futures contract differs from an option in that the buyer is obligated to

178. *See generally* GREGORY PRICE, CME GROUP, STREAMLINING THE NYMEX POWER SLATE (2015); Shijie Deng & Shmuel S. Oren, *Electricity Derivatives and Risk Management*, 31 ENERGY 940, 942 (2006).

179. Deng & Oren, *supra* note 178, at 944–45; *Options Contract*, INVESTOPEDIA, http://www.investopedia.com/terms/o/optionscontract.asp (last visited Mar. 22, 2016).

180. *Options Contract*, INVESTOPEDIA, *supra* note 179.

181. *Id.*

purchase.[182] Therefore, the buyer generally would not pay anything upfront, eliminating the early monetization benefit.[183] However, energy futures can provide substantial certainty about the amount and price of guaranteed future energy sales, thereby encouraging investment in advanced nuclear by enabling more reliable projections of future revenue.[184]

Buyers of energy options and futures would likely be LSEs or energy-intensive industries that want to hedge their risks against future energy price spikes.[185] For example, energy costs comprise twenty to forty percent of the cost of manufacturing steel.[186] Who knows what energy prices will be like in ten years, let alone forty years? Energy options and futures can provide some certainty.

Exchange-traded energy products are generally preferable to over-the-counter (OTC)[187] products because exchange-traded products reduce transaction costs and information asymmetries. For example, an OTC participant would need to spend time shopping around to several sellers comparing prices and terms—transaction costs. Or, the buyer would just accept the first seemingly reasonable offer—a likely information asymmetry.[188] Direct contracting in this way is also likely to produce non-standardized contracts, which would be difficult to resell or unwind if necessary.[189] Trading standardized energy contracts on an exchange provides more trans-

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182. *Futures Contract*, NASDAQ, http://www.nasdaq.com/investing/glossary/f/futures-contract (last visited Mar. 4, 2016).

183. *See* Reem Heakal, *Futures Fundamentals: Characteristics*, INVESTOPEDIA, http://www.investopedia.com/university/futures/futures4.asp (last visited Mar. 4, 2016) (discussing margin requirements for trading in futures contracts, which could require some upfront payment by the energy *generators* in order to enter a futures contract).

184. Deng & Oren, *supra* note 178, at 942 (noting that "these power contracts play the primary roles in offering future price discovery and price certainty to generators and LSEs").

185. Note that energy would not literally be delivered from seller to buyer. Instead, the parties would generally "cash settle." Assuming the market price is higher than the strike price, the seller would sell its power into the market, collect its revenue, then pay the buyer the difference between market and strike price. *Id.* at 944.

186. WORLD STEEL ASS'N, FACT SHEET: ENERGY USE IN THE STEEL INDUSTRY (2015), https://www.worldsteel.org/publications/fact-sheets/content/02/text_files/file0/document/fact_energy_2014.pdf.

187. Int'l Swaps & Derivatives Ass'n, OTC Derivatives: Benefits to U.S. Companies, Slide 2, 9 (May 2009) (providing that an OTC derivative transaction occurs outside of a centralized exchange, often bilaterally between parties).

188. *Information Asymmetry*, INVESTOPEDIA, http://www.investopedia.com/terms/a/asymmetricinformation.asp (last visited Mar. 4, 2016) ("A situation in which one party in a transaction has more or superior information compared to another.").

189. INT'L SWAPS & DERIVATIVES ASS'N, TREASURY'S PROPOSAL MANDATING CLEARING OF "STANDARDIZED" SWAPS 2 (2009) ("[C]ontract standardization and the fungibility created by the clearinghouse guarantee facilitates trading and price discovery.").

parency (mitigating information asymmetry), improves efficiency (mitigating transaction costs), and produces fungible contracts that could be resold (improving liquidity) or unwound if desired.[190]

3. Risks

Counterparty risk is present in any of the three energy contracts discussed above. There is risk that one side or the other will not pay (or exist) ten or forty years down the road when the contract comes due. This risk can be mitigated through a surety bond, insurance, or margin calls on exchange-traded products, which, admittedly, have the downside of increasing transaction costs. For generators, another mitigating factor in the event that a buyer no longer exists is the ability to simply sell that energy into the then-existing energy markets. For buyers of energy and capacity, the counterparty risk that the seller (advanced nuclear generator) may go bankrupt or otherwise not deliver energy as previously agreed upon will probably manifest as a discount on the contract price proportional to the buyer's concerns about the seller's future prospects. For the seller, this is acceptable so long as the agreed upon price allows for sufficient future revenue, early monetization, and improved predictability.

In the event that energy prices plummet, the buyer could attempt to invoke the "just and reasonable" doctrine to legally escape the terms of the contract.[191] However, the *Mobile-Sierra* presumption of validity in energy contracts negotiated by two sophisticated actors should mitigate the concern of a court condoning a breach due to unjust or unreasonable rates.[192]

Conclusion

Collective action is essential to meaningful innovation in energy generation. As both a moral imperative and pragmatic necessity, ratepayers should begin to gradually foot this bill now, rather than let economic, environmental, and public health costs continue to accrue for future generations. Modest investments today should provide long- and short-term benefits across society—baseload diversity, reliability, energy independence, and environmental stewardship, to name a few. Moreover, clean energy presents an important means of driving the world economy through the 21st

190. *Id.*

191. *See* United Gas Pipe Line Co. v. Mobile Gas Serv. Corp., 350 U.S. 332 (1956); Fed. Power Comm'n v. Sierra Pac. Power Co., 350 U.S. 348 (1956). The *Mobile-Sierra* doctrine was clarified in *Morgan Stanley Capital Group, Inc. v. Public Utility District No. 1 of Snohomish County*, 554 U.S. 527 (2008), and refined in *NRG Power Marketing v. Maine Public Utilities Commission*, 558 U.S. 165, 174–75 (2010).

192. *See Mobile Gas*, 350 U.S. 332; *Sierra Pacific Power*, 350 U.S. 348.

and into the 22nd centuries, ideally with the United States leading the way. Such technology will be highly valued as countries grapple with fuel shortages and pollution, while derivative technologies in materials science, radiology, software, and construction (among others) can drive innovation in healthcare, defense, manufacturing, transportation, and other critical industries. Developing clean, renewable energy is poised to be the primary challenge for coming generations and requires solutions on a societal and intergenerational scale. The proposals in this Note are intended to make such investments economically attractive in order to facilitate long-term benefits for future generations while also stimulating near-term economic growth and environmental stewardship.