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ENERGY TRANSITIONS AND THE FUTURE OF NUCLEAR ENERGY: A CASE FOR SMALL MODULAR REACTORS

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ABSTRACT

The world is undergoing a global energy transition that will transform societies from fossil-fuel dependency towards clean energy solutions to meet future energy demand. An assumption is that nuclear energy, as a low-emissions energy source, could play a vital role in a clean, low-carbon future. Most reactors operating in the United States today are large custom-made reactors (LRs). Because of unfair risk-perceptions and the forced internalization of negative externalities, LRs and nuclear energy industry have long-struggled to compete with other energy sources.

The deployment of Small Modular Reactors (SMRs) make up for many of the inherent problems that exist in the traditional focus of the nuclear industry. SMRs offer technological advancements and potential opportunities to overcome certain obstacles of the dreaded licensing

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process that has hampered nuclear growth in the United States. In the context of the current energy transition and the problems of conventional reactors, the case for the deployment of SMRs presents an opportunity for the next nuclear renaissance in the United States.

INTRODUCTION

A. *Energy Transition: A Brief Overview*

Transitioning from fossil fuels to alternative energy sources is arguably one of the most significant challenges facing modern society to date.¹ In the special report “Global Warming of 1.5 °C” the International Panel on Climate Change (“IPCC”) claims it is necessary to reduce global carbon emissions by 45 percent from 2010 levels by 2030,² and net zero must be reached by 2050, to mitigate the effects of climate change.³ The scientific consensus of human activities’ effect on climate change,⁴ has spurred a global effort to reduce greenhouse gas emissions (“GHGs”). This has been labeled as the “energy transition.”⁵ The problem of reducing emissions becomes further difficult considering that world demand for energy is expected to increase at least until the year 2050,⁶ and the current cheapest source of reliable energy remains carbon-based.⁷ Global demand for oil has also seen a steady increase despite efforts to reduce fossil-fuel dependency.⁸

¹ Mike Munsell, *Energy Transition in 4 Charts, A Peek at Wood Mackenzie’s Latest Outlooks for Solar, Wind Energy Storage and Carbon Emissions*, GREEN TECH MEDIA (Aug. 19, 2019), https://www.greentechmedia.com/articles/read/the-energy-transition-in-charts_

² Intergovernmental Panel on Climate Change [IPCC], *Global Warming of 1.5°C*, at 12, Valerie Masson-Delmotte (IPCC Working Group, Co-Chair) et al. (2018), https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf. See also Climate Reality Project, *2030 or Bust: 5 Key Takeaways from the IPCC*, CLIMATE REALITY PROJECT (Oct. 18, 2018, 9:35 AM), <https://www.climateRealityProject.org/blog/2030-or-bust-5-key-takeaways-ipcc-report>. The IPCC is an intergovernmental organization consisting of over 195 member states, that assess the current scientific data on climate change to find objective and accurate scientific data.

³ Intergovernmental Panel on Climate Change, *supra* note 2, at 12

⁴ NAT’L AERONAUTICS & SPACE ADMIN., *SCIENTIFIC CONSENSUS: EARTH’S CLIMATE IS WARMING*, <https://climate.nasa.gov/scientific-consensus/>.

⁵ “The energy transition is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century. At its heart is the need to reduce energy-related CO₂ emissions to limit climate change.” Int’l Renewable Energy Agency [IRENA], *Energy Transition*, <https://www.irena.org/energytransition> (last visited Mar. 9, 2020).

⁶ ENERGY INFO. ADMIN., *EIA PROJECTS NEARLY 50% INCREASE IN WORLD ENERGY USAGE BY 2050, LED BY GROWTH IN ASIA*, (2019), <https://www.eia.gov/todayinenergy/detail.php?id=41433>.

⁷ See *Levelized Cost of Energy*, LAZARD (Nov. 7, 2019), <https://www.lazard.com/perspective/lcoe2019>. Both Coal and Gas Combined Cycle remain more expensive than nuclear on a Levelized Cost of Energy (LCOE) comparison.

⁸ *EIA’s International Energy Outlook Shows Demand for Fossil Fuels Increasing*, INST. FOR ENERGY RESEARCH (Sep. 30, 2019),

There are many climate and non-climate related costs associated with the combustion of fossil fuels.⁹ It is estimated that the annual non-climate related external damages from the 406 coal-fired power plants in the United States result in costs of tens of billion USD.¹⁰ Thus, one study has found that considering non-GHG air pollution, both oil and coal-fired power plants are a net negative on a cost basis for society, but not gas.¹¹

The effects of climate change will also generate high costs for society and the global economy at large.¹² According to the *Stern Review* commissioned by the British government, models have shown that the impact of climate change may have a grave impact on global GDP.¹³ Similar research shows that the United States will incur high costs from the effects of climate change as well.¹⁴ Since these models are attempting to predict the future, there is also a real risk of cost escalation because the effects of climate change are not yet fully understood.¹⁵ Acknowledging the reality of these costs has fueled the global effort to reduce dependency on fossil fuels, and in turn, led to a global ambition for a cleaner future. However, the energy transition and efforts by nation-states have not yet been proven successful enough to generate sufficient

<https://www.instituteforenergyresearch.org/international-issues/eias-international-energy-outlook-shows-demand-for-fossil-fuels-increasing/>.

⁹ *Air Pollution from Fossil Fuels Costs \$ Billion Per Day, New Research Finds*, YALE ENV'T. 360 (Feb. 12, 2020), <https://e360.yale.edu/digest/air-pollution-from-fossil-fuels-costs-8-billion-per-day-new-research-finds>. See also Roger Pielke, *Every Day 10,000 People Die Due To Air Pollution From Fossil Fuels*, FORBES (Mar. 10, 2020), <https://www.forbes.com/sites/rogerpielke/2020/03/10/every-day-10000-people-die-due-to-air-pollution-from-fossil-fuels/#447394b52b6a>.

¹⁰ Report Examines Hidden Health and Env't. Costs of Energy Prod. and Consumption, NAT'L ACAD. OF SCI. (Oct. 19, 2009), <https://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12794>.

¹¹ See Nicholas Z. Muller et al., *Environmental Accounting for Pollution in the United States Economy*, 101 AM. ECON. REV. 1649, 1665 (2011).

¹² Renee Cho, *How Climate Change Impacts the Economy*, COLUM. UNIV. EARTH INST.: STATE OF THE PLANET (June 20, 2019), <https://blogs.ei.columbia.edu/2019/06/20/climate-change-economy-impacts/>.

¹³ NICHOLAS STERN, *THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW* (Cambridge Univ. Press ed., 2007). "By 2050, models suggest a plausible range of costs from -2% (net gains) to +5% of GDP, with this range growing towards the end of the century, because of the uncertainties about the required amount of mitigation, the pace of technological innovation and the efficiency with which policy is applied across the globe. Critically, these costs rise sharply as mitigation becomes more ambitious or sudden." *Id.* at 249.

¹⁴ Dana Nuccitelli, *Climate Change Could Cost the U.S. Economy Hundreds of Billions a Year by 2090*, YALE CLIMATE CONNECTIONS, (Apr. 29, 2019) <https://www.yaleclimateconnections.org/2019/04/climate-change-could-cost-u-s-economy-billions/>.

¹⁵ STERN, *supra* note 13, at 249.

hope to reduce most of the impact of climate change.¹⁶ Hence, the world faces a tremendous and time-pressured task to create a future that is less dependent on fossil-fuels.¹⁷

B. Nuclear Energy and the Energy Transition

Energy is defined as the ability to do work; it is a prime mover of civilizations and essential to get anything done.¹⁸ Without energy, no work could be completed, and with unlimited energy the potential for human civilization should, in theory, be endless.¹⁹ Out of all energy sources that can be harnessed by humans, nuclear energy is the most efficient.²⁰ A nuclear reaction has around 100 million times more energy than a chemical reaction,²¹ making the energy density of nuclear energy unrivaled in comparison to fossil-fueled energy.

Nuclear energy is both a clean and reliable source of power as nuclear power plants do not emit harmful emissions.²² It is estimated that the carbon footprint of nuclear energy is similar to wind and solar energy.²³ Coal-fired power plants, on the other hand, emit both criteria pollutants toxins and GHG emissions.²⁴ Gas plants are a cleaner source

¹⁶ United Nations Env't Programme, *Emissions Gap Report 2019*, 1 Doc. DEW/2263/NA (2019).

¹⁷ NAT'L AERONAUTICS AND SPACE ADMIN.: GLOBAL CLIMATE CHANGE, VITAL SIGNS OF THE PLANET, *Is it too late to prevent climate change?*, <https://climate.nasa.gov/faq/16/is-it-too-late-to-prevent-climate-change/> (last visited Sep, 10, 2019). See also Georg Kell, *The Energy Transformation Is Not Happening Fast Enough*, FORBES (Sep. 11, 2019), <https://www.forbes.com/sites/georgkell/2019/09/11/the-energy-transformation-is-not-happening-fast-enough/#40b52f4a23da>.

¹⁸ See VACLAV SMIL, *ENERGY AND CIVILIZATION: A HISTORY 1* (The MIT Press, 2017).

¹⁹ See generally FREDERICK COTTRELL, *ENERGY AND SOCIETY: THE RELATION BETWEEN ENERGY, SOCIAL CHANGE, AND ECONOMIC DEVELOPMENT* (1955).

²⁰ OFFICE OF NUCLEAR ENERGY, *Nuclear 101: How Does a Nuclear Reactor Work?* (May 19, 2020), <https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work>. OFFICE OF NUCLEAR ENERGY, *Nuclear Power is the Most Reliable Energy Source and It's Not Even Close* (Apr. 22, 2020), <https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close>.

²¹ SAMUEL GLASSTONE & ALEXANDER SESONSKE, *NUCLEAR REACTOR ENGINEERING* 143 (Van Nostrand Reinhold Company, 1967).

²² JOEL B. EISEN ET AL., *ENERGY, ECONOMICS AND THE ENVIRONMENT* § 7 at 2 (5th ed. 2019); NUCLEAR ENERGY INST., *What is Nuclear Energy?*, <https://www.nei.org/fundamentals/what-is-nuclear-energy> (last visited Mar, 9, 2020).

²³ EISEN et al., *supra* note 22, at 37.

²⁴ Emily Hammond & David B. Spence, *The Regulatory Contract in the Marketplace*, 68 VAND. L. REV. 141, 158 (2016).

of energy than coal-fired plants but still remain a great contributor to GHG emissions.²⁵

At the time of writing, nuclear power makes up around 19.7% of US energy mix.²⁶ There are 96 commercial reactors operating in the US,²⁷ and globally, there are 452 reactors.²⁸ While the US power grid remains dominated by a fleet of both coal and gas-fired power plants²⁹ there is an emerging trend of increasing renewable sources.³⁰ However, it remains unlikely for coal and gas-fired power plants to reach below double digits in the generation mix anytime soon.³¹

It has been decades since the US last saw a thriving nuclear industry, and most plants currently belong to an old era.³² However, the clean nature of nuclear energy amid the current energy transition could make it a competitive component in both climate policy and strategy.³³ The energy markets are incredibly dynamic, subject to constant and fundamental change, and as history has taught us, predicting the future of energy markets has proven to be a challenging task.³⁴ However, the

²⁵ ENERGY INFO. ADMIN., *Natural Gas Explained, Natural Gas and the Environment*, <https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php> (last visited Sep. 23, 2019).

²⁶ ENERGY INFO. ADMIN., *Frequently Asked Questions (FAQs): What is U.S. Electricity Generation by energy source*, ENERGY INFO. ADMIN., <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3> (last visited Feb. 27, 2020).

²⁷ ENERGY INFO. ADMIN., *Frequently Asked Questions (FAQs): How Many Nuclear Power Plants are in the United States, and Where Are They Located?*, <https://www.eia.gov/tools/faqs/faq.php?id=207&t=3> (last visited Dec. 30, 2019).

²⁸ INT. ENERGY AGENCY, *Nuclear*, <https://www.iea.org/fuels-and-technologies/nuclear> (last visited Feb. 27, 2020).

²⁹ ENERGY INFO. ADMIN., *What is U.S. Electricity Generation by Energy Source?*, ENERGY INFO. ADMIN., <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3> (last visited Feb. 27, 2020).

³⁰ *Id.*

³¹ EISEN et al., *supra* note 22, at 284.

³² OFFICE OF NUCLEAR ENERGY, *What's the Lifespan for a Nuclear Reactor? Much Longer Than You Might Think*, <https://www.energy.gov/ne/articles/whats-lifespan-nuclear-reactor-much-longer-you-might-think> (last visited Apr. 16, 2020).

³³ Michael E. Stern and Margaret M. Stern, *Does Nuclear Power Have a Future Symposium: Electric Power in a Carbon Constrained World*, 32 UTAH ENVTL. L. REV. 431 (2012).

³⁴ For example, considering the recent “Shale Revolution” few to no scholars predicted that this would give rise to resurgence of American hydrocarbon production. See generally RUSSELL GOLD, *THE BOOM: HOW FRACKING IGNITED THE AMERICAN ENERGY REVOLUTION AND CHANGED THE WORLD* (Simon & Schuster, 2014). Furthermore, in the 1970’s nuclear energy was predicted to become “[t]oo cheap to meter” because of efficiency levels. Thomas Wellock, *“Too Cheap to Meter”: A History of the Phrase* (June 3, 2016), <https://public-blog.nrc-gateway.gov/2016/06/03/too-cheap-to-meter-a-history-of-the-phrase/>.

energy transition and the effort to reduce the dependency of fossil-fuels has created many exciting opportunities and trends that could, in the long-run, benefit nuclear energy.

I. THE CURRENT STATE OF NUCLEAR ENERGY IN THE UNITED STATES

High costs associated with nuclear power has sidelined nuclear reactors in the US energy transition as a critical and reliable alternative to conventional fossil fuels.

Proponents for nuclear reinvigoration have a wide variety of arguments in support of nuclear energy ranging from climate change to energy security benefits.³⁵ However, these types of arguments have been trumped by the unresolved concerns of nuclear proliferation, radioactive waste disposal concerns, economic costs, and the opinion that the effects of climate change and energy security are not as imminent to necessitate investment into nuclear energy.³⁶

Energy products are, in economic terms, perfect substitutes, meaning that energy sources compete on price and no other features.³⁷ Because of the different risk perceptions, nuclear energy has higher costs than many other types of energy sources.³⁸ The nuclear industry has long struggled to compete with both coal and gas-fired power plants, and today some estimations even predict that the nuclear industry could be completely phased out by market forces around the year 2050.³⁹ Similar concerns have been raised by the industry that without reform, nuclear power plants will not be economically viable.⁴⁰ In light of the current state of

³⁵ See INT'L ATOMIC ENERGY AGENCY, *Climate Change and Nuclear Energy 2016*, (2016), <https://www-pub.iaea.org/MTCD/Publications/PDF/CCANPI6web-86692468.pdf>.

³⁶ Justin Gundlach, *What's the Cost of a New Nuclear Power Plant? The Answer's Gonna Cost you: A Risk-Based Approach to Estimating the Cost of New Nuclear Plants*, 18 N.Y.U. ENV'T L. J. 600, 601 (2011).

³⁷ Gokul Iyer et. al, *Implications of Small Modular Reactors for Climate Change Mitigation*, ENERGY ECONOMICS, 45, 146 (2014); see also Matthias Kahlkul et al., *Learning or lock-in: Optimal Technology Policies to Support Mitigation*, RESOURCE & ENERGY ECONOMICS, 34, 34-57 (2012).

³⁸ The Levelized Cost of Energy (LCOE) holds nuclear energy as very expensive in comparison to other energy sources. See Lazard, *Lazard's Levelized Cost of Energy Analysis, Version 13.0* (2019), <https://www.lazard.com/perspective/lcoe2019/>.

³⁹ See generally Peter A. Bradford, *How to close the US nuclear industry: Do nothing*, BULLETIN OF ATOMIC SCIENTISTS (2013).

⁴⁰ NUCLEAR ENERGY INST. [NEI], *NEI to Wall Street Analysts: Power Market Flaws Must Be Corrected, 'Significant Movement' Underway to Better Monetize Value of Nuclear Power Plants* (Feb. 12, 2015, 8:33 AM), <https://www.globenewswire.com/news->

the nuclear industry, the possibility of a second nuclear renaissance looks bleak. Nevertheless, the low emission basis of nuclear energy, in conjunction with a scientific consensus on the realities of climate change, has sparked industry attention to the clean capabilities of nuclear reactors.⁴¹ Some commentators go even further, arguing that without nuclear energy, mitigation of climate change is not possible.⁴²

The nuclear industry has struggled when relying on political support. The current gridlock in Congress makes the prospect of federal support for nuclear energy unlikely, and as of this writing, federal administrations have shown minimal interest in promoting nuclear energy, based on potential climate benefits.⁴³ Climate change legislation that would benefit nuclear energy has also proven to be very difficult to pass through the political process.⁴⁴

However, there has been some recent political developments that could benefit nuclear energy. The Nuclear Energy Innovation Capabilities Act (“NEICA”) was recently signed by President Trump as an effort to promote efficiency in the licensing and regulatory process of nuclear power in the United States.⁴⁵ Furthermore, the Senate Energy and Natural Resource Committee recently approved a key piece of legislation for the development of advanced nuclear reactors in the US.⁴⁶ Another exciting development has been the first EU-US High-Level Industry

release/2015/02/12/705928/10119964/en/NEI-to-Wall-Street-Analysts-Power-Market-Flaws-Must-Be-Corrected.html/.

⁴¹ RAYMOND L. MURRAY, NUCLEAR ENERGY: AN INTRODUCTION TO THE CONCEPTS, SYSTEMS, AND APPLICATIONS OF NUCLEAR PROCESSES 481–82 (6th ed. 2009).

⁴² CNN, *Top climate change scientists’ letter to policy influencers* (Nov. 3, 2013, 8:12 AM), <https://www.cnn.com/2013/11/03/world/nuclear-energy-climate-change-scientists-letter/index.html/>. The International Energy Agency (IEA) stated that it would be next to impossible to fulfill the global commitments to the United Nations Paris Agreement, in the Energy Outlook 2019, “double globally within 20 years to meet the two-degree Celsius Climate Target.” Rudiger Tscherning, Ablawg.ca, *Small Modular (Nuclear) Reactors in Canada – Small Steps Towards Realization* (Dec. 3, 2019), <https://ablawg.ca/2019/12/03/small-modular-nuclear-reactors-in-canada-small-steps-towards-realization/>.

⁴³ EISEN, *supra* note 22, at 422–23.

⁴⁴ “Opposition from Republicans and coal-state Democrats has left the prospect of climate change legislation bleak in subsequent congresses.” *Id.* at 321.

⁴⁵ World Nuclear News [WNN], *US nuclear innovation act becomes law* (Jan. 17, 2019), <https://www.world-nuclear-news.org/Articles/US-nuclear-innovation-act-becomes-law/>.

⁴⁶ TSCHERNING, *supra* note 42; *See also* U.S. Senate Comm. on Energy & Natural Resources, *Murkowski, Booker, and 13 Colleagues Reintroduce the Nuclear Energy Leadership Act*, REPUBLICAN NEWS (May 27, 2019), <https://www.energy.senate.gov/public/index.cfm/2019/3/murkowski-booker-and-13-colleagues-reintroduce/>.

Meeting on the Development of Small Modular Reactors (“SMRs”).⁴⁷ Many factors, such as energy security, international polity, and economics, are a driving force behind these legislative and political initiatives.⁴⁸ However, whether or not these political actions are sufficient to assist the nuclear industry remains to be seen.

Local climate initiatives have proven to be very effective and could potentially benefit nuclear energy. States and local utilities play a crucial role in overseeing the implementation of climate change resolutions and promoting low-carbon energy solutions.⁴⁹ For example, The New York Independent Systems Operator (“NYISO”) has considered implementing a carbon price into its operation of the wholesale electricity market.⁵⁰ Similarly, in California and other states, comparable initiatives have been implemented.⁵¹ Thus, local climate action could potentially benefit nuclear energy as a clean source of reliable energy.

One of nuclear energy’s core problem is that it is burdened with a unique set of issues that encumbers the prospect of development and deployment of new reactors.⁵² Also, since the issue of radioactive waste disposal has not yet been satisfactorily resolved in the US environmentally, many challenges to nuclear energy development remain.⁵³ Furthermore, nuclear energy projects are fraught with litigation constraints under the National Environmental Protection Act (“NEPA”), procedural challenges, and general environmental litigation.⁵⁴

⁴⁷ European Comm., *EU-U.S. high-level forum on small modular reactors* (Oct. 21, 2019), https://ec.europa.eu/info/events/eu-us-high-level-forum-small-modular-reactors-smr-2019-oct-21_en/.

⁴⁸ See Richard Rhodes & Denis Beller, *The Need for Nuclear Power*, FOREIGN AFFAIRS Vol. 79, No. 1, 30-44 (Jan – Feb. 2000).

⁴⁹ EISEN, *supra* note 22, at 343-351.

⁵⁰ Sue Tierney & Paul Hibbard, *Potential New Carbon Pricing in the NYISO Market, Analysis Group’s Final Report*, NEW YORK INDEPENDENT SYSTEMS OPERATOR [NYISO] (Oct. 3, 2019), <https://www.nyiso.com/documents/20142/8524371/2%20Potential%20New%20Carbon%20Pricing%20in%20the%20NYISO%20Market.pdf/e257e203-26b1-f316-fa04-c4d246fb3d1c/>.

⁵¹ Many states and local governments have implemented initiatives to promote renewable energy and reduce carbon emissions. EISEN, *supra* note 22, at 819; Felix Mormann, *Enhancing the Investor Appeal of Renewable Energy*, 42 ENVTL. L. 681, 694 n. 85 (2012). Many states further have so-called renewable portfolio standards (RPS). See EISEN, *supra* note 22, at 819 (for an overview of local initiatives).

⁵² HELEN COOK, *THE LAW OF NUCLEAR ENERGY* 305 (2013).

⁵³ The YUCCA Mountain controversy has led to difficulty in acquiring long-term waste facilities in the United States. For a good overview of contemporary litigation concerning waste-disposal of radioactive waste. See *In re Aiken County*, 725 F.3d 255 (D.C. Cir. 2013).

⁵⁴ EISEN, *supra* note 22, at 438.

There have also been concerns that nuclear energy has a difficult time competing with other forms of renewable energy that receive federal and state support through subsidies.⁵⁵ Renewable energy producers have long benefited from a production tax credit. This tax credit does not benefit the nuclear industry since it requires actual production of energy.⁵⁶

Other market conditions such as the abundant supply of natural gas in the United States as a result of the recent shale-fracking “revolution” has led many nuclear power providers to cancel future plants due to long-term risk perspectives and competition concerns.⁵⁷ A plentiful supply of natural gas in combination with the onset of retail customer choice makes it very difficult for the nuclear industry to compete with cheap natural gas from Combined Cycle Gas Turbine (“CCGT”) power plants.⁵⁸ However, as will be discussed below, the energy transition and other climate-related factors could assist nuclear energy to become a competitive energy source.

A. *Internalization of Climate Costs and Negative Externalities*

Both the history and the public perception of nuclear power plants have forced the industry to internalize most of the negative externalities of production.⁵⁹ This can be compared to the fossil-fuel industry, which has borne few to none of the social costs from its production and energy generation.⁶⁰ The substantial investment risk embedded in nuclear energy projects has created hesitation from investors to finance.⁶¹

If both coal and gas-fired power plants are forced to internalize some of the climate-related and social costs caused by the combustion of fossil fuels, this will make carbon-based energy more expensive.⁶² So far, few

⁵⁵ Repka, *infra* note 62, at 10251.

⁵⁶ Bradford, *supra* note 39, at 16.

⁵⁷ *Id.* at 2.

⁵⁸ *Id.*

⁵⁹ Hammond, *supra* note 24, at 25 (providing details and comparisons to other fuels).

⁶⁰ Matthew L. Wald, *Fossil Fuels' Hidden Costs Is in Billions Study Says*, N.Y. TIMES, (Oct. 19, 2019), <https://www.nytimes.com/2009/10/20/science/earth/20fossil.html/>. See generally NATIONAL RESEARCH COUNCIL, HIDDEN COSTS OF ENERGY (National Academic Press, 2010).

⁶¹ EISEN, *supra* note 22, at 452 (“Perceptions about nuclear power relate to its financial viability as well as to its political feasibility. Plagued by the experience of cost overruns and regulatory and litigation-related delays during the construction phase in the 1980s and early 1990s, investors have been hesitant to back new nuclear construction”).

⁶² See MIT, THE FUTURE OF NUCLEAR POWER, AN INTERDISCIPLINARY MIT STUDY (2009) (study showing that a price on carbon and internalization of social costs from fossil-fuel combustion could make nuclear energy more competitive again). See also David A.

initiatives have been successful in attempting to push the cost of climate change upon the fossil-fuels industry, and the prospect of federal climate change regulation seems unlikely in the near future.⁶³

A higher price tag on carbon would not only drastically increase the cost-competitiveness of nuclear energy but could also spark a renewed interest in the research and development of nuclear energy.⁶⁴ In the European Union (“EU”), pricing carbon emissions has helped spur nuclear reinvigoration.⁶⁵ Many ideas to price carbon emissions have been put forward, such as a carbon-tax or the direct pricing of emissions, but none have gained any traction to have a sufficient impact on climate change.⁶⁶ One interesting idea is mandatory carbon capture and sequestration (“CCS”)⁶⁷ technologies that could drastically increase the cost of fossil-fueled power plants.⁶⁸ However, CCS technology has not yet been proven to be cost-effective enough to enable regulators to enforce the use of such technology.⁶⁹ CCS technology is an essential tool against climate change and has been recognized by the IPCC as a vital component to mitigate the effects of climate change.⁷⁰

Nuclear energy does not create the large amount of emissions that gas-fired power plants do without CCS technology, and to compete effectively, the costs of emissions must be internalized by the gas-fired

Repka & Tyson R. Smith, *Deep Decarbonization and Nuclear Energy*, 48 ELR 10244, 10256 (2018) (discussing the benefit of carbon-pricing for the nuclear energy industry).

⁶³ Coral Davenport & Mark Landler, *Trump Administration Hardens Its Attack on Climate Science*, N.Y. TIMES (May 27, 2019), <https://www.nytimes.com/2019/05/27/us/politics/trump-climate-science.html> (claiming Trump administration has provided little effort to increase climate change legislation).

⁶⁴ Repka, *supra* note 62, at 10252.

⁶⁵ MATTI KOJO & TAPIO LITMANEN, INTRODUCTION IN *THE RENEWAL OF NUCLEAR POWER IN FINLAND* 25–26 (Matti Kojo & Tapio Litmanen eds., 6th ed. 2009).

⁶⁶ For a good overview of carbon pricing See Narassimhan, et al., *Carbon pricing in practice: a review of existing emissions trading systems*, 18 J. CLIMATE POL’Y 967 (April 17, 2018).

⁶⁷ See STEPHEN A. RACKLEY, *CARBON CAPTURE AND STORAGE* (Elsevier Butterworth Heinemann, 2nd ed. 2017).

⁶⁸ Arnold W. Reitze Jr., *Electric Power in a Carbon Constrained World*, 34 WM. & MARY ENVTL. L. & POL’Y REV. 821, 855 (2010).

⁶⁹ This is based on the fact that CCS technology remains too expensive to become competitive on the electrical grid. However, estimates show that advanced nuclear energy can be cost-competitive with baseload technologies, when assuming life-span, and social costs is reflected in the cost of generating electricity. Int’l Energy Agency & Nuclear Energy Agency, *Projected Costs of Generating Electricity* 14 fig. ES.1 (2015 ed.).

⁷⁰ GLOBAL CCS INSTITUTE, *Carbon capture and storage remains essential to beating climate change* (Oct. 8, 2018), <https://www.globalccsinstitute.com/news-media/press-room/media-releases/carbon-capture-and-storage-remains-essential-to-beating-climate-change/>.

power plant providers.⁷¹ If the cost of this type of harm is internalized by the fossil fuels industry, alongside other non-climate related costs of combustion, then nuclear energy would become a more competitive source of energy.

B. *Nuclear Energy and the Baseload Rubric*

If the energy transition, from fossil-based fuels to clean sources of energy could result in a phase-out of both coal and gas-fired power plants, there is a real risk of the power grid becoming unreliable.⁷² Most power grids in the United States follow a baseload rubric.⁷³ Baseload power is “the minimum amount of electric power delivered or required over a given period of time at a steady rate.”⁷⁴ Due to the around the clock reliability of coal, gas, and nuclear energy these sources make up a large portion of baseload generation in the United States. In a nuclear power plant, the fission chain reaction is difficult to start and stop, and for economic reasons, the marginal cost of nuclear power is meager, making it a great candidate as a baseload provider.⁷⁵

Some generous energy models support the idea of an electrical grid consisting of renewable energy in conjunction with battery storage capabilities.⁷⁶ However, the baseload rubric is entrenched into existing “patterns of consumption, investment, and regulation,”⁷⁷ and as such is unlikely to be replaced. Thus, nuclear energy is important to ensure reliability on the energy grid, in particular in a time of growing renewable energy generation.⁷⁸ Proponents of renewable energy argue that battery technology can resolve the issues of intermittency. However, apart from a few optimistic energy models, the baseload rubric is

⁷¹ See generally MIT, *supra* note 62; see also Repka, *supra* note 62.

⁷² EISEN, *supra* note 22, at 423.

⁷³ EIA, *Electricity Explained*, <https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php> (last visited Aug. 31, 2020).

⁷⁴ EIA, *Glossary*, <https://www.eia.gov/tools/glossary/index.php?id=B> (last visited Jan. 2, 2020).

⁷⁵ EISEN, *supra* note 22, at 415.

⁷⁶ Neanda Salvaterra, *Giant Batteries Supercharge Wind and Solar Plans*, WALL ST. J. (Aug. 16, 2019), <https://www.wsj.com/articles/giant-batteries-supercharge-wind-and-solar-plans-11565535601>.

⁷⁷ Gundlach, *supra* note 36 at 613.

⁷⁸ EISEN, *supra* note 22, at 415-416.

unlikely to change.⁷⁹ Instead, it seems more likely that renewable energy's place is to provide peak load demand.⁸⁰

Nuclear power plants are the cleanest source of reliable baseload generation available.⁸¹ However, nuclear energy could be a key component in assisting a clean future by providing baseload power where the constraints of intermittency caused by a more renewable energy-based grid.⁸²

II. PUBLIC PERCEPTION OF NUCLEAR ENERGY

The future of nuclear energy in the United States depends on the ability of the nuclear industry and policymakers to overcome the public perception of nuclear energy as harmful and dangerous.⁸³ A dark history and recurring accidents assisted in shaping a negative public perception of nuclear energy that goes back to the discovery of nuclear energy's remarkable potential. Nuclear energy was born out of the wrath of war, and the discovery of its energy potential was only realized after mass destruction.⁸⁴ As a result, deep-rooted fear and cultural opposition to nuclear energy developed and remains deeply entrenched in modern society.⁸⁵

⁷⁹ See Jacobson et al., *100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World*, JOULE (2017). Note: Jacobson, et al. have received critique based on specific assumptions made in their roadmap. Robert Fares, *Landmark 100 Percent Renewable Energy Study Flawed, Say 21 Leading Experts* (June 23 2017), <https://blogs.scientificamerican.com/plugged-in/landmark-100-percent-renewable-energy-study-flawed-say-21-leading-experts/>.

⁸⁰ See Gundlach, *supra* note 36, at 612.

⁸¹ *Id.* at 603.

⁸² “Despite many concerns about nuclear power, it fills a critical need for electricity reliability by providing steady baseload power, comprising 20 percent of US electricity generation. Its lifecycle carbon emissions are comparable to hydro and wind power, making it an essential player in climate change policy.” Emily Hammond, *Nuclear Power, Risk, and Retroactivity*, 48 VAND. J. TRANSNAT’L L. 1059, 1063 (2015).

⁸³ Wouter Poortinga & Nick F. Pidgeon, *Trust, the asymmetry principle, and the role of prior beliefs*, 24 RISK ANALYSIS 1475, 1475–86; Paul Slovic, *Perception of Risk and the Future of Nuclear Power*, 9 ARIZ. J. INT’L AND COMP. L. 191, 191–98 (1992); Paul Slovic, *Perceived Risk, Trust, and Democracy*, 13 RISK ANALYSIS 675, 675–682 (1993).

⁸⁴ “[N]uclear energy was conceived in secrecy, born in war, and first revealed to the world in horror. No matter how much proponents try to separate the peaceful from the weapons atom, the connection is firmly embedded in the minds of the public.” K.R. Smith, *Perception of Risks Associated with Nuclear Power*, 4 ENERGY ENV’T MONITOR 1, 61–62 (1988).

⁸⁵ See Spencer R. Weart & Allan M. Winkler, *Nuclear Fear: A History of Images*, 42 PHYSICS TODAY 7, 70 (1988).

The question of nuclear energy's future is a complex and often morally complicated issue rather than a consideration and evaluation of technological possibilities.⁸⁶ Given the existence of widespread distrust in nuclear technology, these objections cannot be dismissed in favor of technocratic arguments.⁸⁷ It has been difficult to resolve disagreements around nuclear energy by relying on empirical evidence.⁸⁸ The argument that there have been few accidents and catastrophic events involving nuclear power plants has not gained any traction.⁸⁹ Neither has the argument that reactor safety and advancement of technological features make past accidents extremely unlikely.⁹⁰ The complexity of nuclear energy has afforded it a special place within the perception literature; these unique traits make it a challenging and complex energy source to manage socially as well as politically.⁹¹

A. *A Brief Overview of Nuclear Power Plant Accidents*

The first major accident involving a nuclear power plant was the Three Mile Island ("TMI") accident, which occurred as a result of human error related to the plant's safety analysis.⁹² There were no deaths directly related to the accident, and, there were few or even zero latent cancer effects as a result of the aftermath of TMI.⁹³ However, the cost to society from increased regulation resulting in reduced operations from other reactors was enormous.⁹⁴

The second major accident involving a nuclear power plant was the 1986 meltdown of the Chernobyl reactor. This accident was a result of the subordination of public health and safety within a militaristic system leading to an unsafe reactor.⁹⁵ In comparison to the TMI accident,

⁸⁶ Ralph Berger, 11 *Reader NE 161 Nuclear Power Engineering* 334, 334–56 (2011).

⁸⁷ See David B. Spence & Frank Cross, *A Public Choice Case for the Administrative State*, 89 *GEO. L.J.* 97, 99–100 (2000).

⁸⁸ "Beliefs about the catastrophic nature of nuclear power are a major determinant of public opposition to that technology. That is not a comforting conclusion because the rarity of catastrophic events makes it extremely difficult to resolve disagreements by recourse to empirical evidence." Slovic et al., *Facts and Fears: Understanding Perceived Risk*, in *The Perception of Risk* 137, 150–51 (2000).

⁸⁹ *Id.*

⁹⁰ *Id.*

⁹¹ Slovic, *supra* note 88, at 192.

⁹² For a good overview of the accident itself see J. Samuel Walker, *Three Mile Island: A Nuclear Crisis in Historical Perspective*, 69(3) *BULLETIN OF THE ATOMIC SCIENTISTS* 63 (2004). See also *In re TMI Litigation*, 193 F.3d 613 (3d Cir. 1999).

⁹³ EISEN, *supra* note 22, at 428.

⁹⁴ *Id.*

⁹⁵ Smith, *supra* note 84, at 3.

Chernobyl had much more significant effects on human health and the environment by sending waves of radiation into neighboring countries.⁹⁶ However, it is essential to note that the reactor type used at Chernobyl could, by default, not be sited in the United States.⁹⁷ The effects of the Chernobyl accident were global, and the aftermath involved significant social, political, and economic issues.⁹⁸ Many of the health-related effects of Chernobyl, similar to the TMI accident, were lower than initially expected.⁹⁹

The last major nuclear power plant accident to occur was the 2011 Fukushima Daiichi Nuclear Power Plant (“Fukushima”) disaster resulting in stigmatization, and once again, world-wide repercussions for the nuclear industry.¹⁰⁰ After the accident, opposition to nuclear energy found new breeding ground, leading to some nations curtailing their nuclear power generation fleet.¹⁰¹ However, considering similar risks to the US nuclear fleet, regulators found that the continuance of operations would not “pose an imminent risk to public health and safety.”¹⁰² It should be noted that all of these accidents involved reactors that were constructed in the 1970s, and that the advancement of reactor technology has been significant since.¹⁰³

Another factor that affects the public perception of nuclear energy is the lack of safe storage for nuclear waste in the United States.¹⁰⁴ Studies show that radioactive waste is a significant cause of social and political distrust in nuclear technology.¹⁰⁵ The lack of a national facility that can handle radioactive waste is a hamper to the development of nuclear

⁹⁶ See E. Cardis & M. Hatch, *The Chernobyl accident – an epidemiological perspective*, 23 CLIN ONCOL (R COLL RADIOL) 251, 253 (2011).

⁹⁷ Smith, *supra* note 84, at 3. One author has described the Reaktor Bolshoy Moshchnosti Kanalnyy (“RBMK”) as a “monument to the folly of placing political ideology before public health and safety.” *Chernobyl Accident and its Consequences*, NUCLEAR ENERGY INST. (May 2019), <https://nei.org/resources/fact-sheets/chernobyl-accident-and-its-consequences> (last visited June 22, 2020).

⁹⁸ *Id.*

⁹⁹ EISEN, *supra* note 22, at 430.

¹⁰⁰ Iyer et al., *supra* note 37, at 146.

¹⁰¹ See Lincoln L. Davies, *Beyond Fukushima: Disasters, Nuclear Energy, and Energy Law*, 2011 BYU L. REV. 1937, 1937–38 (2011).

¹⁰² See DR. CHARLES MILLER ET AL., U.S. NUCLEAR REG. COMM’N, RECOMMENDATIONS FOR ENHANCING REACTOR SAFETY IN THE 21ST CENTURY: THE NEART-TERM TASK FORCE REVIEW OF INSIGHTS FROM THE FUKUSHIMA DAI-ICHI ACCIDENT vii (2011); see also, Hammond, *supra* note 82, at 1065.

¹⁰³ EISEN, *supra* note 22, at 421.

¹⁰⁴ *Id.* at 416.

¹⁰⁵ Paul Slovic et al., *Perceived Risk, Trust, and the Politics of Nuclear Waste*, 254 SCI. 1603–1607 (1991).

technology, and yet another factor limiting the development of reactor technology in the United States.¹⁰⁶

B. *Public Perception and Nuclear Energy*

Unfortunately, events like TMI, Chernobyl, and Fukushima reinforce the entrenchment of negative notions associated with nuclear technology.¹⁰⁷ Public perception of risk can halt nuclear energy growth.¹⁰⁸ Even if nuclear energy has a proven safety record, human-beings are far from rational economic actors.¹⁰⁹ After TMI and Chernobyl, public opinion of nuclear energy saw a drastic shift.¹¹⁰ After Fukushima, these fears were once again exacerbated,¹¹¹ causing Germany to initiate a phase-out of its entire commercial reactor fleet.¹¹²

These past accidents have led to an amplified process of risk assessment, creating a difficult hurdle for the industry to develop and advance new reactor technology.¹¹³ For example, investment costs for current commercial reactors have increased as a result of greater perception of risk.¹¹⁴ Following these accidents safety requirements have been enhanced, thereby increasing construction periods and costs for the nuclear industry.¹¹⁵

¹⁰⁶ Repka, *supra* note 62, at 10263.

¹⁰⁷ Slovic, *supra* note 83, at 190.

¹⁰⁸ Iyer et al., *supra* note 37, at 146.

¹⁰⁹ Hammond, *supra* note 82, at 1065.

¹¹⁰ See generally, Toby Bolsen & Fay Lomax Cook, *The Polls—Trends: Public Opinion on Energy Policy: 1974-2006*, 72 PUBLIC OPINION QUARTERLY 364 (2008); Nathan Hultman & Jonathan Koomey, *Three Mile Island: The Driver of US nuclear power's decline?*, 69 BULLETIN OF THE ATOMIC SCIENTISTS 63 (2013).

¹¹¹ See generally, MIT CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH, THE FUTURE OF NUCLEAR POWER AFTER FUKUSHIMA. MIT CTR. FOR ENERGY AND ENVTL. POL'Y RES. (2012); see also, Ioannis N. Kessides, *The Future of the Nuclear Industry Reconsidered: Risks, Uncertainties, and Continued Promise*, 48 ENERGY POL'Y 185 (2012).

¹¹² Iyer, *infra* note 131, at 5.

¹¹³ EISEN, *supra* note 22, at 416.

¹¹⁴ See generally M.V. Ramana, *Nuclear Power: Economic, Safety, Health, and Environmental Issues of Near-Term Technologies*, 34 ANN. REV. OF ENV'T AND RESOURCES 127 (2009).

¹¹⁵ See generally, Pedro Carajilescov et al., *Construction time of PWRs*, 55 ENERGY POL'Y 31(2013); see also Jonathan Koomey & Nathan E. Hultman, *A reactor-level analysis of busbar costs for US nuclear plants, 1970-2005* 35 ENERGY POL'Y 5630 (2007).

Nevertheless, on a per KWh basis, nuclear energy is the least dangerous out of all energy sources,¹¹⁶ with no deaths directly associated with generating power from nuclear energy.¹¹⁷ It is also imperative to note that current nuclear facilities undergoing construction and regulation are much safer in comparison to coal and gas-fired power plants.¹¹⁸ One study found that the likelihood of a severe accident at a nuclear power plant resulting in five or more deaths is approximately a millionth that of the safest hydrocarbon-based energy source.¹¹⁹ Furthermore, some of the new generation reactors can even be waste and proliferation-resistant.¹²⁰ This means that certain new types of reactors can utilize existing waste, and the reactor itself cannot be used to produce weapons-grade uranium. In effect, this new technology would alleviate existing security concerns surrounding the production of energy from nuclear processes.¹²¹ Apart from power plants, nuclear reactor technology has been applied in many different areas from submarines, icebreakers, aircraft carriers, and space technology.¹²²

The nuclear industry must distill both public trust and confidence in the nuclear process.¹²³ As the industry tries to regain public trust, hopefully new reactor technology can assist in the re-emergence of a fruitful nuclear industry. Furthermore, time will tell whether advanced reactor technology can overcome the negative public perceptions that haunt the industry.

¹¹⁶ James Conca, *How Deadly Is Your Kilowatt? We Rank The Killer Energy Sources*, FORBES (June 10, 2012), <https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/#39997629709b>.

¹¹⁷ Hannah Ritchie, *What Are the Safest Sources of Energy?* (Feb 10, 2020), <https://ourworldindata.org/safest-sources-of-energy#:~:text=Nuclear%20energy%20is%20by%20far,38%20times%20fewer%20than%20gas.>

¹¹⁸ *Id.*

¹¹⁹ *Id.*

¹²⁰ TerraPower's generation IV traveling wave reactor ("TWR") is also designed to eliminate the possibility of certain severe accidents; it uses depleted uranium for fuel and has features that render it proliferation-resistant. Repka, *supra* note 62, at 10247.

¹²¹ Iyer et al., *supra* note 37, at 7; *see also* Son H. Kim & Jae Edmonds, THE JOINT GLOBAL CHANGE RES. INST., THE CHALLENGES AND POTENTIAL OF NUCLEAR ENERGY FOR ADDRESSING CLIMATE CHANGE (2007).

¹²² Tscherning, *supra* note 46.

¹²³ *See generally*, Alvin M. Weinberg, *The Maturity and Future of Nuclear Energy*, 64 AM. SCIENTIST 16 (1976).

III. THE ISSUES OF CUSTOM-MADE CONVENTIONAL LARGE REACTOR FACILITIES

Commercial nuclear facilities operating in the United States are large, complex, and often custom-made.¹²⁴ Guided by the principle of economies of scale, the nuclear industry has continued to invest and focus on building large reactors and power plants.¹²⁵ Large power plants have a unique construction fitted to a specific location. Because of size and licensing constraints, these projects are incredibly costly and time-consuming.¹²⁶ It can take several decades to construct a conventional nuclear power plant in the United States today.¹²⁷ Arguably, many of the issues plaguing the development of nuclear energy relate to the lack of standardization and design efficiency within the current reactor fleet.

Most of the current commercial reactor fleet operating in the United States were built in the 1970s, with many having been subject to severe licensing and cost constraints.¹²⁸ For example, the Tennessee Valley Authority (“TVA”) Watts Bar 1 reactor came into effect in 1996 but was ordered in 1970.¹²⁹ The latest reactor to come online in the United States was the Watts Bar 2.¹³⁰ Moreover, as recently witnessed by the 2016 Westinghouse bankruptcy, the conventional nuclear power plant continues to face many problems.¹³¹ The economics of the conventional

¹²⁴ “The plants in the 1970s and 80s were custom plants, designed and constructed in a post-three mile island regulatory environment of significant change. Interest rates were high, and there usually was no allowance for recovery of capital costs until commercial operation” Repka, *supra* note 62, at 10260.

¹²⁵ See, B. Mignacca & G. Locatelli, *Economics and finance of Small Modular Reactors: A systematic review and research agenda*, 118 RENEWABLE & SUSTAINABLE ENERGY REV. 1, 5 (2019).

¹²⁶ Erik Slobe, *The Nuclear Regulatory Commission’s Next Steps in Encouraging Innovations in Nuclear Energy*, 80 UNIV. OF PITT. L. REV. 753, 754 (2019).

¹²⁷ See Christopher Groskopf, *The United States’ Newest Nuclear Power Plant has Taken 43 Years to Build*, QUARTZ (May 11, 2016), <https://qz.com/681753/the-united-states-newest-nuclear-power-plant-has-taken-43-years-to-build/>.

¹²⁸ EISEN, *supra* note 22, at 421.

¹²⁹ *Id.*

¹³⁰ Staff Report, *Watts Bar power ascension tests completed*, CHATTANOOGA TIMES FREE PRESS, (Oct. 3, 2016), <https://www.timesfreepress.com/news/business/aroundregion/story/2016/oct/03/watts-bar-power-ascension-tests-completed/389869/>.

¹³¹ James Conca, *Westinghouse Bankruptcy Shakes The Nuclear World*, FORBES, (MAR. 31, 2017), <https://www.forbes.com/sites/jamesconca/2017/03/31/westinghouse-bankruptcy-shakes-the-nuclear-world/#1deb5e102688>; See also Anthony Michael Sabino & Michael J. Abatemarco, *Westinghouse Chapter 11 Bankruptcy: National Security Also an Issue*, 33 NATURAL GAS & ELECTRICITY 8 (2017). Other countries have also faced major difficulties with licensing constraints and cost-overruns affecting the nuclear industry. See Inkeri Ruuska et al., *A New Governance Approach for Multi-firm Projects:*

nuclear power plants began to falter in the 1970s, even before the TMI accident.¹³² At the time, this was contrary to public belief, as it was a general thought that the efficiency of nuclear energy would lead to almost free energy in the future.¹³³ Instead, the price of nuclear energy has increased drastically since.¹³⁴

The large conventional power plant is associated with the negative public perception of nuclear energy. All of the significant and well-known accidents have involved LR facilities, creating a deep distrust for this type of nuclear technology. The focus on LR's by the nuclear industry should be re-thought as the nuclear businesses and politicians try to regain public trust and acceptance of nuclear technology.

A. *Small Modular Reactors*

The future of nuclear energy would greatly benefit from the deployment of Small Modular Reactors ("SMRs").¹³⁵ Compared to large reactor facilities, SMRs can be produced in a factory setting, and rid many of the hidden costs carried by the current reactor fleet.¹³⁶ For their novelty and potential, SMRs have been praised by both industry, government, and academia for their potential benefits.¹³⁷ Over one billion of private capital has already been invested in advanced reactor technology.¹³⁸ Yet, no "truly modular" SMR has been built so far.¹³⁹ The Office of Nuclear Energy has recognized the benefits of SMRs as part of its strategy for the future development of clean, safe, and affordable nuclear energy.¹⁴⁰

Lessons from Olkiluoto 3 and Flamanville 3 Nuclear Power Plant Projects, 29 INTERNATIONAL JOURNAL OF PROJECT MANAGEMENT 64, (2011), and Inkeri Ruuska et al., *Dimensions of Distance in a Project Network: Exploring Olkiluoto 3 Nuclear Power Plant Project*, 27 INT'L J. OF PROJECT MGMT. 142, (2009).

¹³² EISEN, *supra* note 22, at 421.

¹³³ See generally WELLOCK, *supra* note 35.

¹³⁴ LAZARD, *supra* note 7.

¹³⁵ *Advances in Small Modular Reactor Technology Developments*, IAEA 1 (2018). IAEA definition: "newer generation reactors designed to generate electric power up to 300MW, whose components and systems can be shop fabricated and then transported as modules to sites for installation as demand arises."

¹³⁶ *Id.* at forward.

¹³⁷ See Iyer et al., *supra* note 37, at 144; Tristano Sainati et al., *Small Modular Reactors: Licensing Constraints and the Way Forward*, 82 ENERGY 1092, 1094 (2015).

¹³⁸ Samuel Brinton, *The Advanced Nuclear Industry*, THIRD WAY (June 15, 2015), <https://www.thirdway.org/report/the-advanced-nuclear-industry>.

¹³⁹ MIGNACCA, *supra* note 125, at 12.

¹⁴⁰ OFFICE OF NUCLEAR ENERGY, ADVANCED SMALL MODULAR REACTIONS (SMRS), <https://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors>.

SMRs are defined as reactors with a generation capacity of less than 300 MWe,¹⁴¹ a small size reactor in comparison to the conventional commercial reactors operating in the United States.¹⁴² There are many different types of SMRs, and advanced reactors currently under development,¹⁴³ designed for a multitude of different purposes and applications.¹⁴⁴ Most designs are based on the widely proven Light Water Reactor (“LWR”), including Pressurized Water Technology (“PWR”), and Boiling Water Reactor (“BWR”).¹⁴⁵ Others are advanced reactor designs, including gas-cooled, and cooled by liquid metal or salt.¹⁴⁶ Some of these reactors belong to the so-called fourth generation of reactors.¹⁴⁷ Nevertheless, since most of the licensing process in the United States have involved reactors of LWR or PWR, it is unlikely that the first wave of SMRs will be different.¹⁴⁸

1. *The benefits of small modular reactors*

A revolutionizing benefit of SMRs is their modularity, meaning the ability to construct these reactors or parts of the reactors in a controlled factory setting and then install, module by module, at the desired location.¹⁴⁹ The smaller size of SMRs enables them to be transported by both trucks and railroads, which significantly improves construction efficiency.¹⁵⁰ The ability to produce nuclear reactors in a factory is a

¹⁴¹ See *Small Nuclear Power Reactors*, WORLD NUCLEAR ASSOCIATION (Nov. 2019), <https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx>.

¹⁴² *US Operating Nuclear Reactors*, WORLD NUCLEAR ASSOCIATION, <https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/appendices/nuclear-power-in-the-usa-appendix-1-us-operating-n.aspx>.

¹⁴³ For a good overview and summary, see *Small Modular Reactors*, IAEA, <https://www.iaea.org/topics/small-modular-reactors>, (Jan. 2, 2020).

¹⁴⁴ MIGNACCA, *supra* note 125, at 1; and, Giorgio Locatelli et al., *Generation IV Nuclear Reactors: Current Status and Future Prospects*, 61 ENERGY POLICY 1503, 1503–10(2013).

¹⁴⁵ See WNA, *supra* note 147.

¹⁴⁶ Jasmina Vujčić et al., *Small Modular Reactors: Simpler, Safer, Cheaper?*, 45 ENERGY 288, 290, 292, 295 (2012); see also LOCATELLI, *supra* note 144.

¹⁴⁷ *Id.* at 288.

¹⁴⁸ U.S. NRC, *BACKGROUND ON NEW NUCLEAR PLANT DESIGNS*, (2020).

¹⁴⁹ See WNA, *supra* note 90; See also, OFFICE OF NUCLEAR ENERGY, *BENEFITS OF SMALL MODULAR REACTORS (SMRs)* (The term “modular” in the context of SMRs, refers to the ability to fabricate major components of the nuclear steam supply system in a factory environment and ship to the point of use...) [hereinafter Benefits].

¹⁵⁰ Benito Mignacca, Ahmad Hasan Alawneh, & Giorgio Locatelli, *Transportation of Small Modular Reactor Modules: What do the Experts Say?*, UNIVERSITY OF LEEDS, May 2019, at 1–2.

great advantage economically,¹⁵¹ that could also generate significant learning benefits for the nuclear industry.¹⁵² Modularization can also assist the standardization efforts of nuclear design.¹⁵³

Many SMR designs offer safety and passive security systems, making these reactors suitable to provide reliable off-grid power to smaller communities without prior experience of nuclear construction and generation.¹⁵⁴ SMRs could also be used in remote locations of commercial activity requiring a lot of energy, such as mining and fossil fuel extraction.¹⁵⁵

SMR technology is scalable and, in contrast to LRs, load following rather than functioning only as a baseload provider.¹⁵⁶ This is an essential aspect of SMRs as these reactors can be constructed as a multi-module large capacity power plant,¹⁵⁷ and also scaled to meet different kinds of energy demands.¹⁵⁸ The load following and co-generation aspect of SMRs is revolutionizing as the nuclear industry has today been restricted by providing generation compatible with LRs.¹⁵⁹

The benefits of SMRs are abundant, including better design features, shorter construction times,¹⁶⁰ and lesser siting costs.¹⁶¹ Any economic loss by the smaller reactor size not being able to utilize economies of scale can be made up of benefits of modularity,¹⁶² economies of

¹⁵¹ MIGNACCA *supra* note 125, at 5-6; WNA, *supra* note 90, at 6. It has been estimated that with the doubling of cumulative output, construction costs could decrease of up to 70-90%. LOCATELLI, *supra* note 144.

¹⁵² See M.D. Carelli, et al., *Economic Features of Integral, Modular, Small-to-medium Size Reactors*, 52 PROG. NUCL. ENERGY 403, (2010).

¹⁵³ LOCATELLI, *supra* note 144, at 1.

¹⁵⁴ *Id.* at 7.

¹⁵⁵ *Id.*

¹⁵⁶ See Giorgio Locatelli, et al., *Cogeneration: an Option to Facilitate Load Following in Small Modular Reactors*, 97 PROG. NUCL. ENERGY 153, 154-155 (2017). Also, conventional large reactors can suffer damages from the cost of having to ramp up and down their load capacity. See EISEN, *supra* note 22, at 767 n.5.

¹⁵⁷ VUJIĆ et al., *supra* note 150, at 1. "SMRs offer simpler, standardized, and safer modular design by being factory-built, requiring smaller initial capital investment, and having shorter construction times. The SMRs could be small enough to be transportable, could be used in isolated locations without advanced infrastructure and power grid, or could be clustered in a single site to provide a multi-module, large capacity power plant".

¹⁵⁸ ONE, *supra* note 149.

¹⁵⁹ Locatelli, et al., *Load Following by Cogeneration: Options for Small Modular Reactors, gen IV Reactor and Traditional Large Plants*. In 25th international conference on nuclear engineering. Shanghai, China: ICONE 25; 2017; see also Locatelli, et al., *Load following with Small Modular Reactors (SMR): A real options analysis*, 80 ENERGY 41, 41-42(2014).

¹⁶⁰ See Sainati, *supra* note 137, at 1093.

¹⁶¹ See WNA, *supra* note 141, at 2.

¹⁶² See Iyer et al., *supra* note 37, at 145.

multiples,¹⁶³ co-siting economies,¹⁶⁴ and scalability.¹⁶⁵ Overall, it is likely that SMRs will face a lower financial risk than large reactors.¹⁶⁶

The attractiveness of SMRs as an investment is mostly based on the principle of modular deployment.¹⁶⁷ Undoubtedly, SMRs will face unique problems by nature,¹⁶⁸ but there is much exciting financial opportunity for investors who are interested in financing SMRs in comparison to large reactors.¹⁶⁹ Many of the benefits inherent in SMR deployment are in direct response to the faults of the large conventional reactors currently operating.¹⁷⁰ Furthermore, because of the perceived risk of conventional nuclear facilities, insurance premiums have been extraordinarily high for specific projects.¹⁷¹ If SMRs are not perceived to be on the same risk level, then insurance costs could drastically be reduced. These qualities suggest that SMRs could overcome some of the barriers traditionally faced by the nuclear industry in utilizing principles of project finance.¹⁷²

¹⁶³ Locatelli & Mancini, *A Framework for the Selection of the Right Nuclear Power Plant*, 50 INT J. PROD. RES. 474, 4753–4766 (2012); see also, Boarin et al., *Financial Case Studies on Small – and Medium-size Modular Reactors*, 178 NUCLEAR TECH. 218–232 (2012); see also Boarin et al., *Economics and Financing of Small Modular Reactors (SMRs)*, in HANDBOOK OF SMALL MODULAR NUCLEAR REACTORS 239–277 (M.D. Carelli and D.T. Ingersoll, Elsevier eds.) (2015); See also Trianni, et al., *Competitiveness of Small-medium Reactors: A Probabilistic Study on the Economy of Scale Factor*, in INT’L CONG. ON ADVANCES IN NUCLEAR POWER PLANTS (2009) in Proceedings of Int’l. Conf. of Nuclear Power Plants 2009.

¹⁶⁴ Mignacca, *supra* note 125, at 1.

¹⁶⁵ Sainati, *supra* note 137, at 1093.

¹⁶⁶ Iyer et al., *supra* note 37, at 147.

¹⁶⁷ Carelli et al., *Economic Features of Integral, Modular, Small-to-medium Size Reactors*, 52 PROGRESS IN NUCLEAR ENERGY 403, 403–414 (2010). See also Locatelli, et al., *Small Modular Reactors: A Comprehensive Overview of their Economics and Strategic Aspects*, 73 PROGRESS IN NUCLEAR ENERGY 75, 75– 83 (2014).

¹⁶⁸ For example, there have been very few studies on decommissioning. See Mignacca, *supra* note 125.

¹⁶⁹ Mignacca, *supra* note 125, at 3.

¹⁷⁰ “Overall we can point out the following advantages of SMRs: (1) Power generating systems for areas difficult to access or without infrastructure for transportation or fuel; (2), Modular concept that reduced the amount of work on-site, makes it simpler and faster to construct; (3) Long-life cycle and reduced need for refueling (perhaps every 10-15 years); (4) Design simplicity; (5) Passive safety; (6) Expanded potential siting options since more sites are suitable for SMRs; (7) Smaller nuclear island and footprint of the whole nuclear power plant; (8) Low operation and maintenance costs; (8) Low operation and maintenance costs; (9) Lower initial costs and risks; and (10) Proliferation resistance.” Vujic et al., *supra* note 146, at 289.

¹⁷¹ OFFICE OF PUBLIC AFFAIRS, BACKGROUND ON NUCLEAR INSURANCE AND DISASTER RELIEF, (2019).

¹⁷² Repka, *supra* note 62, at 10257.

Other benefits of SMRs include safety features, ranging from size to advanced technological improvements.¹⁷³ Wide-scaled SMR deployment could also have great socio-economic benefits, including job growth that would benefit local communities.¹⁷⁴ SMRs have furthermore been recognized as essential for energy security, and as cost-effective in the fight against the effects of climate change¹⁷⁵ as the low emissions basis of SMRs makes this technology a lucrative alternative to traditional nuclear power production.¹⁷⁶

The nuclear industry is now at an exciting crossroads; many of the current reactors are subject to the prolonging of their licensing to operate.¹⁷⁷ Some of these nuclear projects can have a life-span of up to 80 years.¹⁷⁸ Thus, rather than extending the life-span of these conventional reactors, SMRs should be recognized as an exciting alternative to the next deployment of reactors.

2. *Current market for SMR's*

Because of the misguided principle of economies of scale, the nuclear industry has focused on constructing LRs and not yet built any SMRs.¹⁷⁹ However, many companies ranging from start-ups to mature energy companies are investing and participating in the development of SMRs.¹⁸⁰ One company at the forefront of SMR deployment in the US is NuScale, a company that has been trying to build a 60 MWe SMR based on PWR technology.¹⁸¹ NuScale's reactor is an integrated module, factory manufactured and transportable to the desired location.¹⁸² The reactor also has new safety features providing a high level of proliferation resistance and safety value.¹⁸³ It can also be constructed as a

¹⁷³ See generally Vujic, *supra* note 146.

¹⁷⁴ Repka, *supra* note 125, at 10265.

¹⁷⁵ Iyer, et al., *supra* note 37, at 152 (“We find that the costs of achieving a 2° degree target are lower with SMRS than without.”).

¹⁷⁶ BENEFITS, *supra* note 149.

¹⁷⁷ *Id.*

¹⁷⁸ *Id.*

¹⁷⁹ See Mignacca, *supra* note 125, at 1.

¹⁸⁰ See Repka, *supra* note 62, at 10248 (explaining different companies currently developing SMR technology).

¹⁸¹ NUSCALE, <https://www.nuscalepower.com/about-us>, (last visited Sept. 3, 2020).

¹⁸² “Nuscale is an integrated module, factory manufactured, transportable by rail, truck or barge, with dimensions of 15 m by 4.5 m, and the weight of 400 tons. It also has a robust seismic design with its structure composed almost entirely out of concrete, with well arranged shear walls and diaphragms which provide high rigidity. . . .” Vujic et al., *supra* note 146, at 291.

¹⁸³ *Id.*

multi-module power plant.¹⁸⁴ NuScale has submitted a design certification (“DC”) application for its reactor, which is still under review by the NRC.¹⁸⁵ SMR use is also anticipated from other companies. For example, since 2016 a local utility in Utah has attempted to acquire a license to site such a reactor and become the first customer of SMR technology.¹⁸⁶ The first US SMR Boiling Water Reactor (“BWR”) is now under development.¹⁸⁷ Internationally there have been many initiatives as well to develop and deploy SMR technology.¹⁸⁸

3. *SMRs and the NRC licensing regime*

The nuclear industry is predominantly regulated by the Nuclear Regulatory Commission (“NRC”),¹⁸⁹ while the Department of Energy (“DOE”) plays a minor role in research and development of nuclear energy.¹⁹⁰ A core feature of the work undertaken by the NRC is to certify and approve reactor designs.¹⁹¹ There are currently two licensing pathways for nuclear power plants: part 50, and part 52.¹⁹² Part 52 was created as an attempt to standardize and streamline the heavily criticized part 50 licensing regime,¹⁹³ under which all current reactors are licensed.¹⁹⁴ Many critiques had reached the NRC and about the regulatory framework under part 50 being slow, bureaucratic,

¹⁸⁴ “A 540 MWe power plant could be comprised of 12 independent 45 MWe modules, each with its own dedicated steam generator.” *Id.*; see also Ingersoll, et al., *Nuscale Small Modular Reactor for Co-generation of Electricity and Water*, 340 *DESALINATION* 84, 85–86 (2014).

¹⁸⁵ *Design Certification Application*, NRC (May 14, 2020),

<https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html>.

¹⁸⁶ Dan Yurman, *Utah Utility Selects Idaho Site for NuScale SMR*, NEUTRON BYTES (Aug. 12, 2016), <https://neutronbytes.com/2016/08/12/utah-utility-selects-idaho-site-for-nuscale-smr/>; UTAH ASSOCIATED MUNICIPAL POWER SYSTEMS (UAMPS) CARBON FREE POWER PROJECT (CFPP), <https://www.nuscalepower.com/projects/carbon-free-power-project> (last visited June 2020).

¹⁸⁷ Office of Nuclear Energy, *First U.S. Small Modular Boiling Water Reactor Under Development* (Feb. 19, 2020), [https://www.energy.gov/ne/articles/first-us-small-modular-boiling-water-reactor-under-development#:~:text=BWRX%2D300%20small%20modular%20reactor.&text=GE%20Hitachi%20\(GEH\)%20is%20expanding,development%20in%20the%20United%20States](https://www.energy.gov/ne/articles/first-us-small-modular-boiling-water-reactor-under-development#:~:text=BWRX%2D300%20small%20modular%20reactor.&text=GE%20Hitachi%20(GEH)%20is%20expanding,development%20in%20the%20United%20States).

¹⁸⁸ For international development of SMR technology see Tscherning, *supra* note 46.

¹⁸⁹ 10 C.F.R. §1.1(a) (2018).

¹⁹⁰ DOE, *Nuclear*, <https://www.energy.gov/science-innovation/energy-sources/nuclear>.

¹⁹¹ *Id.*

¹⁹² *Id.*

¹⁹³ EISEN, *supra* note 22, at 435.

¹⁹⁴ *Id.* at 435.

complicated, and requiring double regulation, leading to an outcry for reform from members of the industry.¹⁹⁵

Part 52 introduced the Combined License (“COL”) to mitigate the effect of double regulation that exists in part 50.¹⁹⁶ Under part 52, the licensee has the voluntary option to apply for a DC. If approved, the NRC will issue a standard DC in the form of a rule that is added as an appendix to part 52 and is valid for fifteen years.¹⁹⁷ The DC enables companies seeking a COL to entirely avoid design issues, or at least resolve these types of issues early in the licensing process.¹⁹⁸ Hence, this is an attempt to resolve many of the problems inherent in part 50 licensing regime. Other applicants in the COL process can use already pre-approved and certified nuclear power plant designs.¹⁹⁹

The COL licensing process offers other benefits for the licensee to streamline the regulatory procedure. Alongside the DC, a licensee could apply for an Environmental Site Permit (“ESP”) for the proposed siting location. Similar to the DC, the ESP is valid for 10-20 years from the date that it is issued and may be renewed for an additional period.²⁰⁰ Also new to part 52 is the Inspections, Tests, Analyses, and Acceptance Criteria (“ITAAC”).²⁰¹ If all ITAAC tests are passed related to siting, no party can raise last-minute objections related to the project.²⁰²

IV. STANDARDIZATION, NUCLEAR VENDORS, AND "OFF-THE-SHELF-NUCLEAR"

Lack of design standardization is a significant factor hampering the development of nuclear energy in the United States.²⁰³ The current reactor fleet exists of unique, large, custom-made power plants, and some of the issues with these plants could be resolved by design standardization.²⁰⁴ To achieve greater standardization of the commercial

¹⁹⁵ EISEN, *supra* note 22, at 436.

¹⁹⁶ *Id.*

¹⁹⁷ *Id.* at 445.

¹⁹⁸ *Id.*

¹⁹⁹ 10 C.F.R. § 52.43 (2019).

²⁰⁰ “Once an ESP is issued for a specific site, the holder of the ESP may “bank” that site for future construction of a new nuclear power plant. The ESP is valid from 10-20 years from the date it is issued and may be renewed for an additional 10 to 20 years. EISEN, *supra* note 22, at 437.

²⁰¹ *Id.* at 33.

²⁰² *Id.*

²⁰³ Mignacca, *supra* note 125, at 7.

²⁰⁴ Gundlach, *supra* note 80, at 2.

nuclear power fleet, the concept of “Off-the-shelf-nuclear,” is particularly noteworthy.²⁰⁵

This concept refers to the ability of nuclear energy providers to purchase reactor designs from reactor vendors that have been pre-approved by the NRC.²⁰⁶ Some companies could act as nuclear vendors selling pre-approved designs to other companies looking to site and build a nuclear power plant.²⁰⁷ To make this happen, the nuclear vendor must first acquire a DC from the NRC. If one company could push-through the dreaded licensing regime of nuclear power plants, then other companies could then buy that design pre-approved.

A reactor vendor system could generate enormous benefits to the nuclear industry, and it could significantly improve the licensing process.²⁰⁸ Furthermore, new projects could capitalize on the experience of already completed projects.²⁰⁹ If multiple projects move forward at a similar time, the benefit of synergies between projects could be utilized by the nuclear industry.²¹⁰ SMRs, in particular, are interesting as they incorporate many features that could assist in creating more efficient design certification.²¹¹

A nuclear vendor cannot merely build and ship a standard plant that is pre-approved without the buyer and operator taking over responsibility.²¹² If it were possible for an international reactor vendor to ship standard SMR technology that is pre-approved internationally

²⁰⁵ “Off-the-shelf,” a term most likely coined by Admiral Hyman G. Rickover in a speech delivered before Congress on June 5, 1953: *AEC Authorizing Legislation: Hearings Before the Joint Committee on Atomic Energy*, 1702 (1970) (stating that “[a]n academic reactor or reactor plant almost always has the following basic characteristics: (1) it is simple; (2) it is small; (3) it is cheap; (4) it is light; (5) it can be built very quickly; (6) it is very flexible in purpose; (7) very little development will be required; it will use off-the-shelf components; (8) the reactor is in the study phase; it is not being built now; on the other hand a practical reactor can be distinguished by the following characteristics: (1) it is being built now; (2) it is behind schedule; (3) it requires an immense amount of development on apparently trivial items; (4) it is very expensive; (5) it takes a long time to build because of its engineering development problems; (6) it is large; (7) it is heavy; (8) it is complicated”).

²⁰⁶ EISEN, *supra* note 22.

²⁰⁷ Sainati, *supra* note 137, at 1093; *see also* Tronea, *European quest for standardization of nuclear power reactors*, 52 *PROG. NUCL. ENERG.* 159-63 (2010).

²⁰⁸ Sainati, *supra* note 137, at 1094.

²⁰⁹ “Standard plant designs could significantly simplify the licensing and construction of new plants, by allowing new projects to capitalize on the experience of lead projects.” Repka, *supra* note 62, at 10259.

²¹⁰ *Id.*

²¹¹ Mignacca & Locatelli, *supra* note 125, at 7; *see also* Ramana et al., *Licensing Small Modular Reactors*, 61 *ENERGY J.* 555, 555-64 (2013).

²¹² Sainati, *supra* note 137, at 1093-94.

merely, then this would be a fantastic opportunity for the nuclear industry.²¹³ There is a long-standing debate over international harmonization of nuclear-licensing processes; however, because of the heterogeneity in national legal systems, an international licensing and approval process becomes extremely difficult to achieve for nuclear technology.²¹⁴

A. *Costs of Licensing, A Case for Nuclear Vendors*

Licensing a nuclear power plant is a highly costly and time-consuming venture.²¹⁵ Historically, receiving a DC from the NRC costs tens of millions of dollars.²¹⁶ For example, the DC process for the AP1000 reactor took almost four years, resulting in fees of more than \$45 million,²¹⁷ and General Electric's ESBWE Reactor took more than nine years and application fees of around \$68 million.²¹⁸ It is a fair estimate to assume that a conventional custom-made nuclear power plant can cost billions to construct with licensing fees of around \$50-70 million.²¹⁹ The high costs of licensing a nuclear power plant could be related to the fee structure of the NRC, which in itself is a deterrent for the development of innovative nuclear designs.²²⁰ It should be noted that many of these costs are based on the economics of licensing conventional LR's and could, therefore, be an inaccurate representation of advanced nuclear technology such as SMR's.²²¹

B. *Small Modular Reactors and Public Perception*

Increased perception of need and benefit of nuclear power could increase public tolerance of nuclear energy.²²² The mass-deployment and many benefits of SMR's over LR's could alleviate the focus on potential danger and harm²²³ and assist in furthering the public acceptance of

²¹³ *Id.* at 1094–95.

²¹⁴ *Id.*

²¹⁵ EISEN, *supra* note 22, at 819.

²¹⁶ NRC, *New Reactors Business Line Fee Estimates* (2020),

<https://www.nrc.gov/reactors/new-reactors/new-licensing-files/nro-fee-transformation-data.pdf>.

²¹⁷ Repka, *supra* note 62, at 10258.

²¹⁸ *Id.*

²¹⁹ *Id.*

²²⁰ Slobe, *supra* note 126, at 754.

²²¹ *Id.*

²²² Slovic, *supra* note 88, at 196.

²²³ *Id.* at 150–51.

nuclear energy and advanced reactor technology.²²⁴ The ability of SMR's to be produced in a factory and installed in remote off-grid locations could hopefully enable local communities to embrace nuclear technology, which is necessary for the development and deployment of nuclear reactors.²²⁵ Smaller societies could, in the future, potentially embrace the benefit of SMR technologies, which could benefit both nuclear investment and reactor advancement.²²⁶ One author stated that the community could potentially embrace SMRs as their "own" reactor, and therefore lead to a change in the willingness to accept nuclear energy.²²⁷ In consideration of the amount of work that one nuclear reactor can do for a community, education initiatives, and public programs for the understanding and benefits of nuclear energy are essential. The public could further embrace the scalability of SMRs and technological advancement of these reactors, to promote both base-load and load-following units.²²⁸

From a public perception viewpoint, nuclear power plant accidents are associated with the LR's. SMRs are safer, use less radioactive fuels, can be hidden from the common eye, and located more strategically to make these reactors safer.²²⁹ For these reasons and more, it is likely that the smaller size and opportunities of SMRs can allow for the nuclear industry to overcome the negative public perception of nuclear energy as harmful and dangerous.

C. *Corporate Demand for Energy and SMRs*

Another area where SMRs could be of benefit is to assist in satisfying the growing corporate demand for energy.²³⁰ The growth of

²²⁴ See Nuclear Energy Agency, SMALL MODULAR REACTORS: NUCLEAR ENERGY MARKET POTENTIAL FOR NEAR-TERM DEPLOYMENT, 29–30 (2017).

²²⁵ Tyson R. Smith, *Nuclear Licensing in the United States: Enhancing Public Confidence in the Regulatory Process*, 18 J. RISK RESEARCH 1099, 1099 (2014) ("The events of Fukushima and elsewhere underscore that public trust is critical to a successful nuclear power program. In short, the public must have confidence in the regulator's ability to protect the public from nuclear power risks.")

²²⁶ *Id.*

²²⁷ *Id.*

²²⁸ *Id.*

²²⁹ Adrian Cho, *Science, Smaller, Safer, Cheaper: One Company Aims to Reinvent the Nuclear Reactor and Save a Warming Planet*, SCIENCE MAG (Feb. 21, 2019), <https://www.sciencemag.org/news/2019/02/smaller-safer-cheaper-one-company-aims-reinvent-nuclear-reactor-and-save-warming-planet>.

²³⁰ Herman K, Trabish "How Utilities are Meeting Rising Corporate Demand for Renewables", UTILITY DIVE (Dec. 14, 2015), <https://www.utilitydive.com/news/how->

data centers around the world has been part of the substantial increase in demand for corporate energy.²³¹ Globalization and smart-technology have resulted in increasing interconnectivity around the world.²³² The surge in global internet and data usage, alongside the digitalization of the economy, has led to a drastic increase in cloud computing.²³³ According to some estimations, “the cloud” will consume around 20% of global energy consumption.²³⁴ From another perspective, the amount of energy that will be used by data facilities is similar to the amount used by the airline industry.²³⁵

There are over 500,000 data centers around the world today.²³⁶ Many of these centers are located in remote locations and often use diesel generators to provide a reliable power supply.²³⁷ As a result, the amount of emissions from these facilities is enormous.²³⁸ Thus, every time we go online shopping, stream videos, use social media, and more, there is a toll taken on the environment, and the more digital the world becomes, the more damage the environment takes.²³⁹

utilities-are-meeting-rising-corporate-demand-for-renewables/410717/ (December 14, 2015).

²³¹ Dardus et al., *Energy Consumption in Cloud Computing Environments*, In Pan African Conference on Science, Computing and Telecommunications (PACT), at 1 (2017), <https://su-plus.strathmore.edu/bitstream/handle/11071/5181/Energy%20consumption%20in%20cloud%20computing%20environments.pdf?sequence=1&isAllowed=y>.

Even with efficiency measures in place, data centers will still consume a large amount of global energy demand: Masanet, et al., *Recalibrating Global Data Center-use Estimates*, SCIENCE MAG (Feb, 28, 2020), <https://science.sciencemag.org/content/367/6481/984>.

²³² See generally James R. Faulconbridge & Jonathan V. Beaverstock, KEY CONCEPTS IN GEOGRAPHY, 331–32 (Sage Publications Ltd., 2008); see also Joseph E. Stiglitz, GLOBALIZATION AND ITS DISCONTENTS (2003).

²³³ *What is cloud computing?*, Microsoft, <https://azure.microsoft.com/e-us/overview/what-is-cloud-computing/> (last visited August 20, 2020).

²³⁴ Naomi Xu Elegant, *The Internet Cloud Has a Dirty Secret*, FORTUNE (Sep. 2019), <https://fortune.com/2019/09/18/internet-cloud-server-data-center-energy-consumption-renewable-coal/>.

²³⁵ Fred Pearce, *Energy Hogs: Can World’s Huge Data Centers be Made More Efficient?*, YALE ENV’T. 360 (2018), <https://e360.yale.edu/features/energy-hogs-can-huge-data-centers-be-made-more-efficient> (April 3, 2018).

²³⁶ DATA CENTER KNOWLEDGE, <https://www.datacenterknowledge.com/archives/2011/12/14/how-many-data-centers-emerson-says-500000> (last visited Sept. 3, 2020).

²³⁷ Andy Lawrence, *Data Centers Without Diesel Generators: The Groundwork is Being Laid...*, UPTIME INSTITUTE (Dec. 2019), <https://journal.uptimeinstitute.com/data-centers-without-generators-the-groundwork-is-being-laid/>.

²³⁸ Nicola Jones, *How to Stop Data Centres from Gobbling up the World’s Electricity*, NATURE (Sep. 12, 2018), <https://www.nature.com/articles/d41586-018-06610-y>.

²³⁹ *Id.*

1. *Power Purchase Agreements and ownership of clean energy*

Through so-called Power Purchase Agreements (“PPA”) many data companies have made investments in solar and wind energy.²⁴⁰ Data companies have also acquired ownership of solar and wind farms directly.²⁴¹ The energy strategy employed by these companies seems to be that through PPA’s, and ownership of clean power plants in combination with battery technology, these companies will be able to employ clean energy solutions to their data facilities. However, it should be recognized that PPA’s are not a guarantee for an entirely clean supply of energy.²⁴² Many data companies have further pledged a reduction in the use of diesel generation, but some of them have failed in their ambition to become cleaner.²⁴³

2. *SMRs and data centers*

SMR technology could potentially be an option for reliable on-site energy for data centers. The application of SMR technology to satisfy corporate demand for energy is not a novel idea. In Poland, a company named Synthos has signed a Memorandum of Understanding (“MOU”) with GE Hitachi for the construction of a small modular reactor.²⁴⁴ The purpose of this venture is to acquire clean and reliable electricity.²⁴⁵ Data

²⁴⁰ Daniel Oberhaus, *Amazon, Google, Microsoft: Here’s Who Has the Greenest Cloud*, WIRED (Dec. 10, 2019), <https://www.wired.com/story/amazon-google-microsoft-green-clouds-and-hyperscale-data-centers/>. for an overview of an example PPA, see *Bonneville Power Administration*, Example of a Power Purchase Agreement, *We’ve got the Power, Big Business sees the Promise of Clean Energy*, The Economist (June 2017), <https://www.economist.com/business/2017/06/10/big-business-sees-the-promise-of-clean-energy>.

²⁴¹ Amazon, *Renewable Energy*, AMAZON.com, <https://sustainability.aboutamazon.com/sustainable-operations/renewable-energy>. See Amazon’s climate strategy.

²⁴² EISEN, *supra* note 22, at 768 (noting that “long-term PPAs do not determine which plants actually supply power to the grid”).

²⁴³ Lawrence, *supra* note 249. Will Calvert, *Amazon is Breaking its Renewable Energy Commitments, Greenpeace Claims*, DATA CENTERED DYNAMICS (Feb. 14, 2019), <https://www.datacenterdynamics.com/en/news/amazon-breaking-its-renewable-energy-commitments-greenpeace-claims/>.

²⁴⁴ Jack Unwin, *GE Hitachi to Partner with Synthos on Small Modular Reactor in Poland*, POWER TECHNOLOGY (Oct. 23, 2019), <https://www.power-technology.com/news/ge-hitachi-synthos-poland/>. See also GE Reports, *GE Hitachi Nuclear Energy Announces Small Modular Reactor Technology Collaboration in Poland*, GE NewsRoom (Oct. 21, 2019), <https://www.genewsroom.com/press-releases/ge-hitachi-nuclear-energy-announces-small-modular-reactor-technology-collaboration>.

²⁴⁵ Unwin, *supra* note 244.

companies could potentially follow Synthos and see the potential of applying SMRs to their facilities. Many data companies are highly capitalized and include some of the world's largest organizations; if anyone could assist in SMR development, these companies seem to be a suitable candidate.²⁴⁶

CONCLUSION

Whether nuclear energy will play a role in the energy transition towards a low-carbon future remains uncertain. In comparison to other fuels, unfair risk perceptions have forced the nuclear industry to internalize the negative externalities associated with nuclear energy. Likely, many problems inherent in the production of nuclear energy in the United States are linked to the focus on constructing large reactor facilities. For revitalization of the US nuclear industry to occur, the focus should be placed on the wide-scale deployment of SMRs. These reactors incur many benefits from economic to technological and are designed to make up for many of the existing problems associated with conventional nuclear power plants.

Furthermore, SMRs can theoretically assist energy companies in overcoming many of the dreaded hurdles within the nuclear licensing process, and their application potential is more significant than the siting of conventional custom-made extensive reactor facilities. One example of such potential lies in the combination of SMRs and data facilities to provide a reliable and clean source of energy for data companies to run their data and storage facilities.

If nuclear vendors can push through the licensing regime and then re-sell their reactors "off-the-shelf," this would be a fantastic opportunity for the nuclear industry to be revitalized. In conclusion, significant reactor facilities function and are safe, but reasons remain that challenge efforts to site and construct them. Furthermore, it is important that the nuclear industry takes into account and tries to re-think the negative public perception of large reactor facilities, and this would be best done through the wide-scale deployment of SMR technology.

²⁴⁶ See Nathaniel Bullard, *Tech Investments Are Powering Up Clean Energy*, BLOOMBERG (Sept. 29, 2018), <https://www.bloomberg.com/opinion/articles/2018-09-29/tech-companies-are-big-spenders-on-renewable-energy>.

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