# THE NEW NUCLEAR? SMALL MODULAR REACTORS AND THE FUTURE OF NUCLEAR POWER

*Bruce R. Huber*

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## INTRODUCTION

One might be surprised to find an article on nuclear power[1] in the inaugural volume of a journal focused on emerging technology. Nuclear power plants have existed for over half a century and represent a sizeable fraction of the world's electricity generation.[2] The nuclear power industry is not emerging, but mature–and perhaps even overmature.[3]

But there is news to report. In August of 2019, the U.S. Nuclear Regulatory Commission (NRC) held a final hearing on a proposal by the Tennessee Valley Authority (TVA) to locate a new nuclear power facility at its Clinch River site in central Tennessee.[4] Earlier that year, the NRC noted its support for the proposal in an Environmental Impact Statement; a site permit is likely forthcoming.[5] Why are the TVA and the NRC moving forward with a new nuclear plant at a time when nuclear power is otherwise in dire straits? Because both entities believe that the proposed plant may avoid the

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* Professor of Law, Notre Dame Law School. This article is dedicated to the inaugural editors and staff of the Notre Dame Journal on Emerging Technologies. Your commitment to this enterprise has been a joy to behold.

[1] Let alone two. *See* Don Howard, *The Moral Imperative of Green Nuclear Energy Production*, 1 NOTRE DAME J. EMERGING TECH. 64 (2020).

[2] MASS. INST. TECH., THE FUTURE OF NUCLEAR ENERGY IN A CARBON-CONSTRAINED WORLD: AN INTERDISCIPLINARY MIT STUDY 29 (2018) (nuclear energy presently accounts for roughly 10% of the world's electricity).

[3] As this article will explain, nuclear power plants have struggled against severe economic headwinds principally wrought by low natural gas prices, leading many to conclude that nuclear power's heyday is behind us. *See, e.g.*, Diane Cardwell, *The Murky Future of Nuclear Power in the United States*, N.Y. TIMES, Feb. 18, 2017. *See also* Per F. Peterson, Michael R. Laufer & Edward D. Blandford, *Nuclear Freeze: Why Nuclear Power Stalled–and How to Restart It*, 93 FOREIGN AFF. 27, 27 (2014) (noting that other regulated industries have experienced technological transformations while the nuclear industry has stagnated).

[4] Transcript of Commission Hearing on Early Site Permit for the Clinch River Nuclear Site: Section 189A of the Atomic Energy Act Proceeding (Public Meeting), Aug. 14, 2019. *See also* Jeremy Dillon & Kristi E. Swartz, *NRC Holds First Hearing for Small Modular Reactor Site*, ENERGYWIRE, Aug. 15, 2019.

[5] Kristi E. Swartz, *TVA's Plan for Small Reactors Clears Federal Hurdle*, ENERGYWIRE, Apr. 9, 2019.

industry's travails by employing a so-called small modular reactor (SMR).[6]

SMRs bear little external resemblance to the reactors within the existing fleet of nuclear power plants: they are a fraction of the size; they can be powered up and down in response to changes in demand; and they can be manufactured centrally, rather than on-site.[7] It is too soon to tell, of course, whether SMRs represent the future of the nuclear power industry, let alone whether they can save that industry from its present woes. But in an era in which electricity markets are in flux,[8] and in which fossil fuels are increasingly disfavored in public policy,[9] SMRs may have an important role to play. Their potential depends entirely on their ability to overcome the industry's most serious vulnerability: namely, the high capital costs associated with the construction of new nuclear power plants.

This article explores SMRs. It begins by explaining the regulatory and economic structure of the electricity sector in the United States. It then describes the current state of nuclear power before examining SMRs in particular—how they differ from conventional nuclear reactors, what regulatory issues they will confront, and what factors will most directly shape their long-term potential.

## I. NUCLEAR POWER: SOME ECONOMIC AND REGULATORY CONTEXT

The crisis facing nuclear power is fundamentally economic.[10] To understand this crisis, one need only grasp that (1) nuclear power is generally more expensive than its competitors, and that (2) in the United States today, the market decides which power plants to use. There are important qualifications to these broad claims, of course. But for all the public discussion about the risks of nuclear calamity or the benefits of carbon-free electricity, the central fact is simply that nuclear power plants are being

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[6] Although the TVA's proposal is the only SMR-based site application presently before the NRC, there is another initiative in the works, to be located in Idaho, which may achieve commercial power deliveries more rapidly. *See* Carlos Anchondo, *Nation's First Small Reactor Project Moves Forward*, ENERGYWIRE, July 22, 2019.

[7] *Id.*; *see also* Adrian Cho, Smaller, *Safer, Cheaper: One Company Aims to Reinvent the Nuclear Reactor and Save a Warming Planet*, SCI. MAG., Feb. 21, 2019.

[8] *See generally* Joshua C. Macey & Jackson Salovaara, *Rate Regulation Redux*, 168 U. PA. L. REV. (forthcoming 2020) (describing difficulties associated with wholesale electric market structures).

[9] *See, e.g.*, Associated Press, *Gov. Gavin Newsom Signs Bill Limiting Oil & Gas Development*, L.A. TIMES, Oct. 12, 2019.

[10] *See* MASS. INST. TECH., *supra* note 2, at 11 ("[T]he prospects for the expansion of nuclear energy remain decidedly dim in many parts of the world. The fundamental problem is cost.").

slaughtered in the marketplace, thanks mostly to inexpensive natural gas.[11] This section will expand briefly on this background.

### *A. Electricity, Regulation, and Markets*

A casual reader of American energy news might conclude that power generation is centrally planned by some government agency. Debates about energy are often framed as a contest among competing energy sources, as though public officials somewhere have complete control over the deployment of those sources and sit waiting to be convinced that, say, wind power is superior to coal power.[12] Thus a great deal of writing about energy emphasizes, for example, the environmental attributes or social benefits of some energy technology.[13] Nuclear power, like all the rest, is evaluated in the public square on the basis of its carbon footprint, its waste stream, its vulnerability to accidents, and so forth.[14]

In reality, the market decides. The mix of electricity sources on the grid today is determined largely in a competitive market, that is to say, by economic decisions made by myriad private actors all across the country.[15] There is no central planner; government acts primarily as a regulator, not a proprietor, and increasingly it wields its regulatory heft not to preselect a favored form of electric generation, but to preserve the reliability of the grid and to maintain effective markets.[16] As with many markets, different actors make different decisions for different reasons, but price tends to

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[11] *See, e.g.*, Michael Scott, *Future of U.S. Nuclear Power Fleet Depends Mostly on Natural Gas Prices, Carbon Policies*, U.S. ENERGY INFO. ADMIN., May 8, 2018: TODAY IN ENERGY, May 8, 2018; ELECTRIC POWER RES. INST., EXPLORING THE ROLE OF ADVANCED NUCLEAR IN FUTURE ENERGY MARKETS: ECONOMIC DRIVERS, BARRIERS, AND IMPACTS IN THE UNITED STATES (2018).

[12] *See, e.g.*, Kevin Crowley, *Big Oil Prepares to Defend Big Gas as Climate Week Begins*, BLOOMBERG, Sept. 22, 2019 (presenting arguments for and against natural gas).

[13] *Id.*

[14] *See, e.g.*, Joshua S. Goldstein, Staffan A. Qvist & Steven Pinker, *Nuclear Power Can Save the World*, N.Y. TIMES, Apr. 6, 2019.

[15] There are numerous publicly owned power systems, but over 75% of generating capacity is privately owned. Federally owned generating units, such as the large hydroelectric dams on the Columbia and Colorado Rivers, generally sell their power to distributors through market transactions and thus may face competition from private generators. The local distribution market is also largely private. *See generally* OFFICE OF ELEC. DELIVERY AND ENERGY RELIABILITY, U.S. DEPT. OF ENERGY, DOE/OE-0017, UNITED STATES ELECTRICITY INDUSTRY PRIMER (2015).

[16] *Id.* at 24-25 (describing the responsibilities of the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC)). The bogeyman, of course, is the Enron scandal and crisis of the early 2000s. *See generally* BETHANY MCLEAN & PETER ELKIND, THE SMARTEST GUYS IN THE ROOM: THE AMAZING RISE AND SCANDALOUS FALL OF ENRON (2003).

dominate other variables.

It was not always this way. There was a time when the price signals associated with various fuel sources were significantly less relevant than they are today. In the (good? bad?) old days, there were no wholesale markets for electricity. Utilities generated their own power and faced no direct competition. They proposed new power plants to state utilities commissions; those commissions reviewed such proposals and generally approved them, allowing their costs to be passed on to ratepayers pursuant to carefully scrutinized rate schedules.[17] Commissioners looked hard at rate designs, but rarely second-guessed utilities' fuel decisions: if a utility claimed that a certain fuel choice would most economically serve its customers' needs, the commission seldom analyzed this choice independently.[18] Even relatively expensive plants could be justified if the utility could defend its view that, in the long run, the plant would be cost-effective.[19]

This was the context when commercial nuclear power first came on the scene in the United States. Utilities were pursuing greater economies of scale, and large nuclear plants appeared in many cases to offer the best way forward. Although capital costs were high, fuel and other operating costs would be low; some expected that nuclear power soon would be "too cheap to meter."[20] Orders were placed for nearly three hundred commercial reactors nationwide.

Problems arose almost immediately. Often these problems are narrated in terms of safety and catastrophe; the 1979 mishap at the Three Mile Island plant in Pennsylvania typically looms large in both popular and academic accounts of nuclear energy's early years.[21] But the more enduring difficulty, one that emerged even before 1979, was that plant construction costs

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[17] *See generally* William T. Gormley, Jr., The Politics of Public Utility Regulation (1983).

[18] *See, e.g.*, Richard J. Pierce, Jr., *Completing the Process of Restructuring the Electricity Market*, 40 WAKE FOREST L. REV. 451, 453-54 (2005) (describing regulatory complacency as a consequence of declining electricity prices).

[19] Moreover, economists concluded that cost-of-service regulation led to a systematic overinvestment in capital assets. *Id.* at 456-57. This line of research stemmed largely from one of the most-cited economics articles ever written: Harvey Averch & Leland L. Johnson, *Behavior of the Firm Under Regulatory Constraint*, 52 AM. ECON. REV. 1052 (1962).

[20] *Abundant Power from Atom Seen*, N.Y. TIMES, Sept. 17, 1954, at 5 (quoting Lewis L. Strauss, Chairman, Atomic Energy Comm'n, Address at the Twentieth Anniversary of the National Association of Science Writers (Sept. 16, 1954)).

[21] *See, e.g.*, Nathan Hultman & Jonathan Koomey, *Three Mile Island: The Driver of US Nuclear Power's Decline?*, 69 BULL. OF THE ATOMIC SCIENTISTS 63 (2013) (noting that forty percent of all reactor cancellations between 1960-2010 occurred before the Three Mile Island incident). *See also* JOHN L. CAMPBELL, COLLAPSE OF AN INDUSTRY: NUCLEAR POWER AND THE CONTRADICTIONS OF U.S. POLICY (1988) (detailing an array of factors that contributed to the failure of commercial nuclear energy).

exceeded estimates, and forecasted growth in electricity demand failed to materialize[22] The energy crises of the early 1970s spurred policies and investments that favored efficiency and conservation over new electricity supply, and did so at precisely the time that utilities were realizing that nuclear plants were significantly more costly than they first expected. Utilities had, to some extent, bought a pig in a poke. The "too cheap to meter"[23] expectation had no basis in actual commercial experience with completed nuclear plants.

Costs in all categories were vastly in excess of early projections: costs associated with reactor design, site preparation, regulatory compliance, raw materials, and so forth. Plant after plant was scrapped. Of the three hundred orders for commercial nuclear reactors, fully half were cancelled.[24] Public utilities–once regarded as the model of stability, paying reliable dividends to investors for decades on end–were in turmoil.[25] Utilities commissions were forced to make extraordinary decisions about whether to allow utilities to charge ratepayers for half-built nuclear plants now sitting idle. Lawsuits abounded. Utilities investors were spooked as they realized (seemingly for the first time) that commissions could, in fact, decline to pass along costs to ratepayers.

In a sense, these shock waves still reverberate around the industry today. The nuclear industry has never fully recovered from this economic reality check, even though it took place years before nuclear energy production peaked. Certainly, the enthusiasm for nuclear power that prevailed in the late 1960s has never returned. But more to the point, in the years following the troubled buildout of the existing nuclear fleet, the regulatory model of the energy sector was itself transformed.

Beginning in the 1970s and 1980s, the energy sector underwent a massive restructuring.[26] This restructuring was part of a wave of deregulatory activity catalyzed by the ideas of Chicago-school economists.[27] It resulted

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[22] Hultman & Koomey, *supra* note 21.

[23] N.Y. TIMES, *supra* note 20.

[24] *See generally* Richard J. Pierce, Jr., *The Regulatory Treatment of Mistakes in Retrospect: Canceled Plants and Excess Capacity*, 132 U. PA. L. REV. 497 (1984).

[25] *See* CAMPBELL, *supra* note 21, at 92-109 (describing the investment crisis facing utilities in the wake of nuclear's collapse).

[26] *See generally* Bernard S. Black & Richard J. Pierce, Jr., *The Choice Between Markets and Central Planning in Regulating the U.S. Electricity Industry*, 93 COLUM. L. REV. 1339 (1993); KARL MCDERMOTT, EDISON ELEC. INST., COST OF SERVICE REGULATION IN THE INVESTOR-OWNED ELECTRIC UTILITY INDUSTRY: A HISTORY OF ADAPTATION, 17-18 (2012); RICHARD F. HIRSH, POWER LOSS: THE ORIGINS OF DEREGULATION AND RESTRUCTURING IN THE AMERICAN ELECTRIC UTILITY SYSTEM 33-54 (1999).

[27] *See generally* MARTHA DERTHICK & PAUL J. QUIRK, THE POLITICS OF DEREGULATION (1985). The word "restructuring" is often used in the energy industry over and against the word

in a series of decisions by the Federal Energy Regulatory Commission (FERC), Congress, and state governments.[28] Although the changes were piecemeal, the animating thrust was the same: treating utilities as regulated monopolies, and shielding them from competition, was no longer seen as economically defensible, at least as to electricity *generation*. Different generating sources, it was now thought, should be able to compete on price. In the past, utilities commissioners would decline to pass utilities' costs on to ratepayers only in the most extreme circumstances, as with the canceled nuclear plants described above. In the restructured energy sector, wholesale electricity would be bought and sold on interconnected, regional markets. Rather than approve individual wholesale rate filings, regulators would now allow wholesale rates to be set by the marketplace. Owners of power plants, whether nuclear or coal or natural gas, would have to compete on price.

Thus, there are today in the U.S. a handful of regional wholesale power markets, run by independent grid operators, in which an unending stream of auctions dictate not only the wholesale price of energy, but also the dispatch sequence of specific power plants.[29] Plant owners across the region bid their plants into these marketplaces and agree to abide by their results. The variable that drives dispatch, of course, is price.[30]

### *B. Nuclear Power Today*

In these regional wholesale markets, nuclear power struggles to compete. As many readers will know, the domestic energy revolution associated with the dramatic rise of hydraulic fracturing has brought to market enormous quantities of natural gas and petroleum. Natural gas was already

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"deregulation." The word choice reflects the fact that while the late 1900s saw a great deal of genuine deregulatory activity in various US economic sectors, such as in the trucking, airline, and telecommunications industries, the scheme that has emerged in electricity still depends on a thoroughgoing regulatory presence, even as constructed markets establish energy prices and structure grid operations.

[28] The most prominent enactments include the Public Utility Regulatory Policies Act of 1978 (Pub. L. No. 95-617, 92 Stat. 3117), the Energy Policy Act of 1992 (Pub. L. No. 102-486, 106 Stat. 2776); FERC Order 888, issued in 1996 (75 FERC ¶ 61,080); and a host of state legislation that carried out restructuring at the state level. *See generally* Pierce, *supra* note 18.

[29] *See generally* Richard J. Campbell, Cong. Research Serv., R43093, ELECTRICITY MARKETS–RECENT ISSUES IN MARKET STRUCTURE AND ENERGY TRADING (2016).

[30] This is a simplification, but only a slight one. The price bid by plant owners is, of course, partly a function of public policies that affect that price (some of which are explicitly designed to affect price, and others of which affect price only indirectly). And plant owners may at times make strategic bids that reflect less their immediate costs of operation than their mid- or long-term strategic aspirations.

the fuel of choice for new electric generating stations through much of the 1990s, but the increase in gas production over the last decade (see Figure 1) has made the situation even more stark.

Domestic gas prices have remained quite low in recent years, and utilities continue to invest heavily in gas-fired generation as a result. Moreover, utility-scale investments in wind and solar generation have been substantial over the same time period. As depicted in Figure 2, these three types of electric generation–natural gas, wind, and solar–represent the overwhelming majority of recent additions to electric generating capacity nationwide.

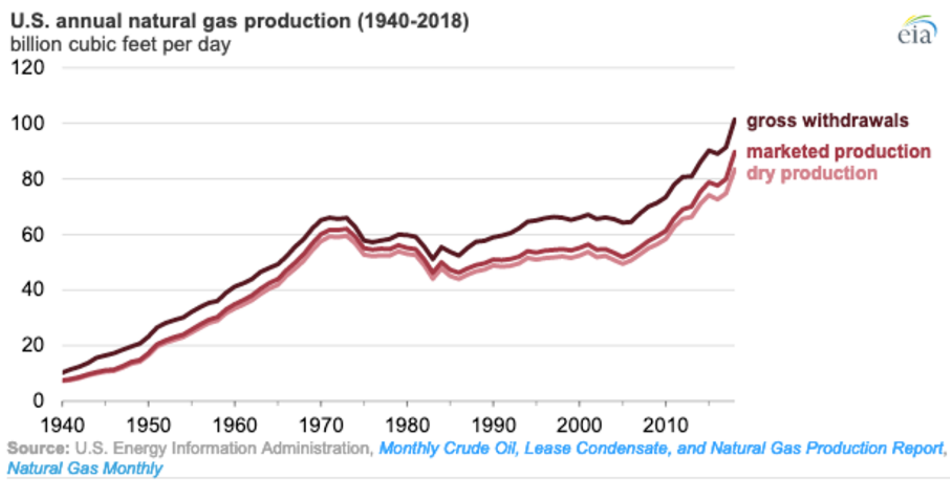


Figure 1[31]

[31] Emily Geary, *U.S. Natural Gas Production Hit a New Record High in 2018*, TODAY IN ENERGY (Mar. 14, 2019), https://www.eia.gov/todayinenergy/detail.php?id=38692.

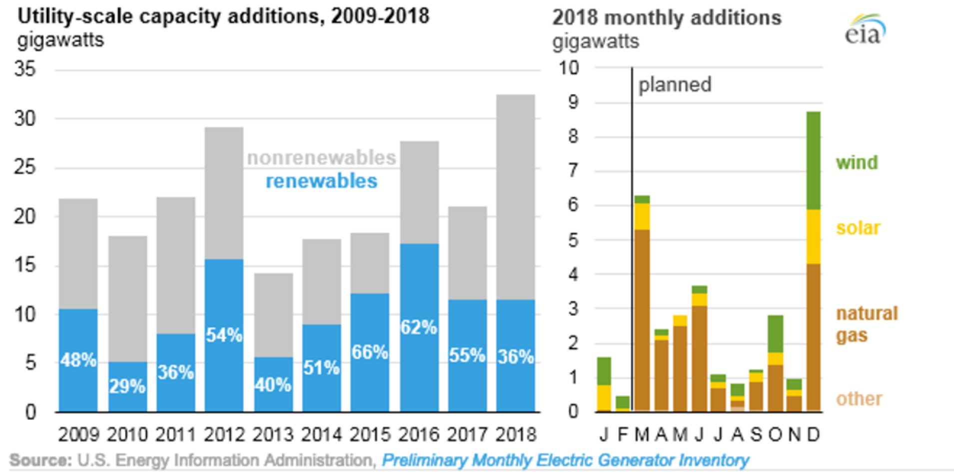


Figure 2[32]

Just as importantly, even *existing* nuclear power plants–plants for which the bulk of capital costs have already been recovered–are proving uneconomical in present market conditions. A handful of plants have already closed in recent years, prior to their license expiration.[33] And others are slated to close, having been regularly underbid by less expensive competitors not only in power markets but also in capacity markets.[34] As to power markets, some estimate that half to two-thirds of the U.S. nuclear fleet may already be operating at a loss as electricity prices fall in wholesale

[32] Ray Chen, *Natural Gas and Renewables Make Up Most of 2018 Electric Capacity Additions*, TODAY IN ENERGY (May 7, 2018), https://www.eia.gov/todayinenergy/detail.php?id=36092.

[33] *See, e.g.*, Jacey Fortin, *Three Mile Island Nuclear Power Plant Is Shutting Down*, N.Y. TIMES (May 8, 2019, 10:34 AM), https://www.nytimes.com/2019/05/08/us/three-mile-island-shut-down.html.

[34] *See, e.g.*, Jeff Brady, *More Than Half of the Nation's Nuclear Power Plants Are at Risk of Closing*, NPR (June 12, 2018, 5:10 AM), https://www.npr.org/2018/06/12/618812542/more-than-half-of-the-nation-s-nuclear-power-plants-are-at-risk-of-closing. As to capacity markets, *see, e.g.*, Gavin Bade, *PJM Loses a Quarter of its Nuke Capacity in Latest Power Auction*, UTILITYDIVE (May 23, 2018), https://www.utilitydive.com/news/pjm-loses-a-quarter-of-its-nuke-capacity-in-latest-power-auction/524247. Regional system operators facilitate not only purchases of power, but also capacity markets in which the region buys commitments from electric generators to provide generating capacity during a future time period. Such markets are thought to guarantee a margin of safety during times of peak demand, and to overcome the "missing money" problem that accompanies rate caps in power markets. *See generally* Macey & Salovaara, *supra* note 8.

markets.[35] Capacity markets are designed to assure sufficient electric generating capability in a future time period, and as such can serve to supplement revenues from power markets. But even in these markets, nuclear has fared poorly as of late.

Nuclear power's economic woes have troubled many lawmakers, especially in jurisdictions in which nuclear generation has been abundant and in which plant retirements would necessitate increased fossil fuel combustion. Legislators in Illinois, Ohio, New York, New Jersey, and Pennsylvania have enacted bills providing financial assistance to nuclear power plants in order to maintain their viability in the relevant wholesale markets.[36] These laws are essentially direct subsidies to nuclear facilities, and they are generally justified to voters in terms of maintaining a diverse mix in power generation, preserving the state's nuclear power industry, and keeping greenhouse gas emissions to a minimum.[37] To date, laws of this sort have survived judicial challenge.[38] But the very existence of such subsidy schemes makes nuclear energy's circumstances painfully clear: without significant nonmarket aid, nuclear power is generally not competitive in wholesale power markets, notwithstanding its desirable attributes.[39]

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[35] *See* Geoffrey Haratyk, Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options, 110 ENERGY POLICY 150 (2017). *See also* Jesse D. Jenkins, What's Killing Nuclear Power in U.S. Electricity Markets? Drivers of Wholesale Price Declines at Nuclear Generators in the PJM Interconnection, (Mass. Inst. of Tech. Ctr. for Energy and Envtl. Policy Research, CEEPR WP 2018-001, 2018), http://ceepr.mit.edu/files/papers/2018-001.pdf.

[36] *See, e.g.*, Monique Garcia, *Legislature Passes ComEd Rate Hike to Bail Out Nuclear Power Plants, But Little Else*, CHI. TRIB. (Dec. 1, 2016, 10:07 PM), https://www.chicagotribune.com/politics/ct-bruce-rauner-comed-exelon-rate-hike-met-1203-20161201-story.html; Jessie Balmert, *Ohio Gov. Dewine Signs Bill to Bail Out Nuclear Plants, Slash Renewable Energy*, CIN. ENQUIRER, (July 23, 2019, 9:29 AM), https://www.cincinnati.com/story/news/politics/2019/07/23/ohio-nuclear-bailout-set-final-vote/1802640001; Patrick McGeehan, *New York State Aiding Nuclear Plants With Millions in Subsidies*, N.Y. TIMES (Aug. 1, 2016), https://www.nytimes.com/2016/08/02/nyregion/new-york-state-aiding-nuclear-plants-with-millions-in-subsidies.html.

[37] *See, e.g.*, Kris Maher, *Nuclear-Bailout Bills in Pennsylvania, Ohio Take Heat Over Cost*, WALL STREET J. (Apr. 29, 2019, 7:00 AM), https://www.wsj.com/articles/nuclear-bailout-bills-in-pennsylvania-ohio-take-heat-over-cost-11556535601.

[38] *See, e.g.*, Coalition for Competitive Electricity v. Zibelman, 906 F.3d 41 (2d Cir. 2018), *cert. denied*, 139 S.Ct. 1547 (2019) (upholding New York's Zero Emissions Credit program); Electric Power Supply Ass'n. v. Star, 904 F.3d 518 (7th Cir. 2018), *cert. denied*, 139 S.Ct. 1547 (2019) (upholding Illinois's program). The principal legal argument against such subsidies is that they are preempted by the Federal Power Act.

[39] *See* STEVE CLEMMER ET AL., UNION OF CONCERNED SCIENTISTS, THE NUCLEAR POWER DILEMMA: DECLINING PROFITS, PLANT CLOSURES, AND THE THREAT OF RISING CARBON EMISSIONS, (2018), https://www.ucsusa.org/sites/default/files/attach/2018/11/Nuclear-Power-

To be clear, there remain sizeable regions in which electric generation remains under cost-of-service regulation. In these areas, utilities have greater economic freedom, in that state regulations allow (or require) commissioners to consider variables other than price. In a number of states, then, especially in the west and the south, private utilities do not face market competition and thus retain a privileged position in decisions about electricity supply.[40] It remains possible for utilities to persuade state commissioners that relatively expensive forms of electricity generation will best serve ratepayers' interests. As we will see, it is these regions that are likely to serve as the proving ground for SMR technology. Commissioners may allow operators of both new and existing plants to recover costs from ratepayers even for plants that would not be economical in competitive conditions. Indeed, the only new nuclear power plants the United States has seen in recent years are located in these regions.[41]

Even in these jurisdictions, however, there are profound headwinds. In South Carolina, a traditionally regulated state, utilities were forced in 2017 to abandon two unfinished nuclear reactors due to missed deadlines, cost overruns, and other economic pressures.[42] The project led to a bankruptcy filing by the lead contractor and, despite being less than halfway completed, still accounts for 18% of the rates charged to the utilities' residential customers.[43] Despite the absence of direct market competition, these utilities became convinced that they could not plausibly gain regulatory approval for the rate burdens that would be placed on customers if the projects were brought to completion.[44]

There is one additional aspect of nuclear power's context that must be

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Dilemma-full-report.pdf (concluding, inter alia, that more than one-third of existing nuclear power plants are unprofitable or scheduled to close).

[40] *See generally* Francisco Flores-Espino et al., Nat'l Renewable Energy Lab., NREL/TP-6A20-67106, *Competitive Electricity Market Regulation in the United States: A Primer* (2016) (map on p. 4 depicts the coverage of wholesale markets).

[41] When a new reactor went live at Watts Bar, Tennessee, in 2016, it was the first since 1996. *See* Sara Hoff & Marta Gospodarczyk, *First new U.S. Nuclear Reactor in Almost Two Decades Set to Begin Operating*, TODAY IN ENERGY (June 14, 2016), https://www.eia.gov/todayinenergy/detail.php?id=26652. The only other reactor construction project still underway is at Plant Vogtle, Georgia. Both Georgia and Tennessee are still traditionally regulated, cost-of-service jurisdictions.

[42] *See, e.g.*, Brad Plumer, *U.S. Nuclear Comeback Stalls as Two Reactors Are Abandoned*, N.Y. TIMES (July 31, 2017), https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html.

[43] *Id.*

[44] In fact, the debacle involving the abandoned nuclear plants has led to calls for deregulation in South Carolina. *See, e.g.*, Brian Murray, *Reforming The Carolinas' Power Markets: Producing A Panacea Or A Pandora's Box?*, FORBES (Oct. 11, 2019, 1:29 PM), https://www.forbes.com/sites/brianmurray1/2019/10/11/reforming-the-carolinas-power-markets-producing-a-panacea-or-a-pandoras-box.

mentioned. The United States, like many other countries, has not arrived at a long-term solution for its handling of spent nuclear fuel (SNF, or "nuclear waste," as it is sometimes called). In fact, no solution is in sight.[45] Practically, this means that spent fuel continues to accumulate at plants around the country, while taxpayers pay out billions to cover the federal government's liability for breach of its contractual obligations to collect waste from plant operators.[46] The mothballed Yucca Mountain facility remains an occasional focus of legislators' inquiry, but the quantity of spent fuel awaiting disposal now exceeds Yucca Mountain's designed capacity in any event.[47] Quite apart from the private costs of nuclear power, then–those costs borne by privately-owned utilities or non-utility generators–are a set of public costs which entail a political calculus all their own. The ongoing failure of the federal government to dispose of spent nuclear fuel looms over the industry nationwide. In the past, proponents of nuclear power could plausibly rely on federal promises to remove spent fuel. Today's nuclear advocates cannot maintain this position with a straight face.[48] Instead, they face persistent opposition from would-be neighbors of proposed nuclear facilities, neighbors who quite understandably resist the idea of having untold quantities of radioactive material stored nearby for decades to come.

## II. WHY SMRS MIGHT HELP

It should by now be clear that if nuclear power is to make a comeback in the United States, its economic proposition must be overhauled. Either nuclear power must become less expensive, or policies must be imposed that improve nuclear power's standing relative to its competitors–policies such as a carbon tax or an expansion of the subsidies described above. These two paths are not entirely disconnected; the political viability of pro-nuclear policy may well turn on the nuclear power sector's ability to achieve clear, convincing, long-run cost reductions. The remainder of this article will discuss whether SMRs can achieve such reductions where previous reactor

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[45] *See generally* Bruce R. Huber, *Checks, Balances, and Nuclear Waste*, 48 ARIZ. ST. L.J. 1169 (2017).

[46] *See generally* Cong. Research Serv., RL33461, Civilian Nuclear Waste Disposal (2018).

[47] At present, there are roughly 80,000 metric tons of spent fuel at commercial nuclear plants around the United States. The intended capacity of the Yucca Mountain facility is 70,000 tons. *Id.* at 17.

[48] So many federal assurances have been broken that federal courts now disallow the NRC from relying on projected dates of repository completion in its environmental assessments involving nuclear waste storage. *See* New York v. Nuclear Regulatory Comm'n, 681 F.3d 471 (D.C. Cir. 2012).

designs have failed.[49]

The core attributes of SMRs are suggested by their name: they are small, and they are modular. These attributes are related, and they are at the heart of SMRs' economic promise. The commercial nuclear power industry has long relied on economies of scale. Given the enormous expense associated with constructing a safe nuclear reactor, utilities have assumed that such plants should be made as large as possible in order to distribute their capital costs as widely as possible.[50] The entire first wave of nuclear power plants took such logic for granted, and nearly all of these plants operate at roughly the same scale, bearing a nameplate electric generating capacity of around one gigawatt.[51]

SMRs represent a thorough rejection of this logic. To proponents of SMRs, the enormous scale of existing nuclear plants has been their Achilles' heel. Their massiveness has required on-site construction; has resisted standardization and modularization; has invariably necessitated expensive, site-specific modifications to plant design; and ultimately has led to the cost overruns that have imperiled the industry.[52] The future, according to these proponents, is small, and modular.[53]

To understand the SMR proposition, one must examine the major causes of cost overruns at existing and abandoned nuclear power plants. If there is a single factor most responsible for the high cost of nuclear plant construction, it is that most plants are functionally first-of-a-kind.[54] In any

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[49] For a thorough account of the economic difficulties confronted by first-generation reactor designs, *see* CAMPBELL, *supra* note 21.

[50] More generally, economies of scale have long driven efficiency-enhancing operational and regulatory initiatives. *See, e.g.*, STEPHEN BREYER & PAUL MACAVOY, ENERGY REGULATION BY THE FEDERAL POWER COMMISSION 93 (1974) ("[T]he most efficient way to make electricity usually is to install the largest generator that technology permits . . . ."). However, some analysts argue that the nuclear power industry has not only failed to deliver economies of scale but is actually characterized by *dis*economies of scale. *See generally* FRANÇOIS LÉVÊQUE, THE ECONOMICS AND UNCERTAINTIES OF NUCLEAR POWER 43–63 (2015). "The cost per [megawatt] of installed capacity is no lower for the construction of the largest reactors. Why? Because they are not just scaled-up replicas of their predecessors. They are more complex, fitted with more parts and components, often of a different design. Some research even shows diseconomies of scale …" *Id.* at 45.

[51] Utilities settled on this as the optimal size for a nuclear power plant by roughly the early 1970s. *See generally* PAUL JOSKOW & RICHARD L. SCHMALENSEE, MARKETS FOR POWER: AN ANALYSIS OF ELECTRICAL UTILITY DEREGULATION 51–54 (1983).

[52] *See generally* MASS. INST. TECH., *supra* note 2, at 31–58.

[53] "[U]nless nuclear research moves away from the present model of large, non-modular plants and gigantic construction projects, the costs of nuclear technology will likely continue to rise, which is a serious drawback in the competition between nuclear power and other electricity-generating technologies." LÉVÊQUE, *supra* note 50, at 63.

[54] The engineering economics literature distinguishes between first-of-a-kind (FOAK) and nth-of-a-kind (NOAK) construction projects.

class of major construction project, there are countless efficiencies and opportunities for cost reduction that emerge as that sort of project is repeated again and again. Contractors develop expertise. Mistakes are discovered and then accounted for and avoided in future iterations.[55] Supply chains develop and mature. Competition emerges for parts and labor, driving down costs.[56] So-called "nth-of-a-kind" projects, in contrast to first-of-a-kind projects, benefit enormously from all these efficiencies and iterative improvements, yielding facilities that conform more closely to their owners' expectations in terms of both cost and performance.

But first-of-a-kind projects are an entirely different beast. In such projects, builders are confronted with new and unsolved problems. Unexpected hurdles and inadequate supply chains introduce delay, and delays cause cost overruns in two ways. First, they can significantly increase the financing costs associated with a new plant.[57] Construction loans are carried longer; interest payments multiply; revenues are pushed off into the future. For an expensive plant, a year of delay can add well over a hundred million dollars to the cost of financing the plant.[58] Second, delays can dramatically increase the labor costs associated with a construction project as work crews remain on the job site, waiting for managerial or engineering problems to be solved. Specialized "craft labor" costs in particular can easily swell.[59]

The existing fleet of nuclear power plants in the United States were

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[55] Examples of these issues can be found in accounts describing the construction of Plant Vogtle in Georgia, the only ongoing construction of a new nuclear generator. *See, e.g.*, Sonal Patel, *How the Vogtle Nuclear Expansion's Costs Escalated*, POWER (Sept. 24, 2018), https://www.powermag.com/how-the-vogtle-nuclear-expansions-costs-escalated.

[56] For example: "[T]wo decades ago there were about 400 suppliers of nuclear plant components and 900 so-called nuclear stamp, or N-stamp, certifications from the American Society of Mechanical Engineers. Today there are fewer than 80 suppliers in the U.S. and fewer than 200 N-stamp certifications." DAVID SCHLISSEL & BRUCE BIEWALD, SYNAPSE ENERGY ECONOMICS, NUCLEAR POWER PLANT CONSTRUCTION COSTS 6 (2008).

[57] *See* U. OF CHI., THE ECONOMIC FUTURE OF NUCLEAR POWER: A STUDY CONDUCTED AT THE UNIVERSITY OF CHICAGO S-4 (Aug. 2004) (interest payments during plant construction may represent as much as 25% of the total project cost).

[58] At the Plant Vogtle project in Georgia, the cost of delayed completion is estimated at $1.2 million per day. *See Economics of Nuclear Power,* WORLD NUCLEAR ASSOCIATION, https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx (last updated Sept. 2019).

[59] *See, e.g.*, Patel, *supra* note 55 (describing, among other problems, how "project contractors were forced to repair welds on [reactor components] that were found to be the wrong type of weld" (internal quotes omitted)).

almost all, for practical purposes, first-of-a-kind projects.[60] Yes, there were common reactor designs, and engineering and construction expertise developed as plants were completed. But an influential MIT report summarized this wave of construction this way:

> The track record for the construction costs of nuclear plants completed in the U.S. during the 1980s and early 1990s was poor. Actual costs were far higher than had been projected. Construction schedules experienced long delays, which, together with increases in interest rates at the time, resulted in high financing charges. . . . The challenge facing the U.S. nuclear industry lies in turning plausible reductions in capital costs and construction schedules into reality. Will designs truly be standardized, or will site-specific changes defeat the effort to drive down the cost of producing multiple plants?[61]

Advocates of SMR designs regard first-of-a-kind engineering costs as endemic to large, gigawatt-size reactors. In this view, experience proves that large projects invariably encounter site-specific engineering challenges that cause predictable delays, driving up financing and other costs.[62] The answer is to relinquish whatever economies of scale may be associated with large plants, and move instead towards small reactor designs–reactors with an output of, say, under 300 megawatts.[63] More reactors would be required to achieve the same energy output as could be obtained by a large reactor design, but the iterative process of production, it is thought, will drive down manufacturing costs enough not only to offset any lost economies of scale, but to yield a new equilibrium in which the net, levelized cost of nuclear power is competitive with other forms of generation.[64] In short, nth-of-a-kind production is much cheaper, and SMRs are expected to benefit from this "economy of multiples."[65]

Small reactor designs could drive down manufacturing costs in several ways. First, modularity relies upon factory construction of plant components, leaving only the assembly of completed modules for the actual reactor emplacement. Factory construction, in turn, brings with it a host of efficiencies. It enables a more stable, specialized workforce than would be

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[60] "Apart from Bechtel, which built twenty-four reactors, the experience of engineering firms and operators was limited to building just a few nuclear plants." LÉVÊQUE, *supra* note 50, at 49.

[61] MASS. INST. TECH. ENERGY INITIATIVE, UPDATE OF THE MIT 2003 FUTURE OF NUCLEAR POWER: AN INTERDISCIPLINARY MIT STUDY 8 (2009), available at https://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

[62] *See generally* LÉVÊQUE, *supra* note 50, at 43–63.

[63] *Id.* at 61–63.

[64] *See generally* Robert Rosner & Stephen Goldberg, U. of Chi., Energy Pol'y Inst. at Chi., *Small Modular Reactors - Key to Future Nuclear Power Generation in the U.S.* 15–22 (2011).

[65] Int'l Atomic Energy Agency [IAEA], *Deployment Indicators for Small Modular Reactors: Methodology, Analysis of Key Factors and Case Studies* at 10, IAEA Doc. IAEA-TECDOC-1854 (2018).

possible at most power plant sites. It allows for greater control over the construction environment than is achievable during on-site construction. Both of these factors help improve the quality of manufacture and reduce costly imperfections. Modularity may also improve the likelihood of standardization, which enables yet further efficiencies.[66] Standardization in design translates into standardization of parts, and thus the possibility of competition among suppliers.[67]

As compared to a small number of large reactors, a large number of small reactors requires more iteration. More iteration leads to greater opportunities for learning effects and economies of serial production.[68] Conventional wisdom would say: why build eight small reactors instead of one big one?[69] The SMR answer is, in effect, that in building those eight small reactors, the industry will have already acquired eight times the experience in how to build those reactors most economically. Given the extraordinary first-of-a-kind costs incurred by existing plants, the counterintuitive SMR approach appears to make some economic sense.

Along with their diminished size and enhanced modularity, SMR designs incorporate passive safety features that are generally simpler and considerably less expensive than their forebears. Reactor safety–obviously a preeminent concern in regard to any installment, large or small–has conventionally relied on redundancy. Multiple, complex systems were engineered and then duplicated within each plant, on the plausible theory that vital systems, especially those systems designed to cool an overheating reactor, must be backed up or perhaps doubly backed up. But advanced nuclear designs dispense with many redundant systems, systems that failed to

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[66] *See generally* Michel Berthélemy & Lina Escobar Rangel, *Nuclear Reactors' Construction Costs: The Role of Lead-Time, Standardization and Technological Progress*, 82 ENERGY POL'Y 118 (2015). Of course, standardization and innovation tend to work against each other; standardization often leads to technological path dependence or "lock in" that perpetuates inefficiencies. Some argue that early nuclear development in the United States was characterized by lock in with respect to light water reactor technology. *See* Robin Cowan, *Nuclear Power Reactors: A Study in Technological Lock-in*, 50 J. ECON. HIST. 541 (1990).

[67] James Conca, *Can't All Nuclear Just Get On The Same Page?*, FORBES (Mar. 12, 2015, 6:00 AM) https://www.forbes.com/sites/jamesconca/2015/03/12/cant-all-nuclear-just-get-on-the-same-page/#1b567b3331d0 ("But nowhere else does this standardization concept have more potential than with small modular reactors (SMRs))".

[68] "Learning effects" are a major contributor to cost reductions within a particular technology over time. *See* LÉVÊQUE, *supra* note 50, at 43. *See also* BAHMAN ZOHURI & PATRICK MCDANIEL, ADVANCED SMALLER MODULAR REACTORS: AN INNOVATIVE APPROACH TO NUCLEAR POWER 58 (2019) ("The economy of scale is replaced [in SMRs] with the economy of serial production of many small and simple components and prefabricated sections").

[69] Many SMR vendors envision installations in which multiple small reactors are "batched" and housed side-by-side. *See* ZOHURI & MCDANIEL, *supra* note 68, at 92.

prevent catastrophic meltdowns at Fukushima, for example.[70] In place of electrical pumps that need electricity and thus backup generators, such as those that failed at Fukushima, advanced reactor cooling systems rely instead on passive safety systems that require neither electricity nor human control.[71] Such systems may be triggered by rising heat levels and rely on gravity to distribute cooling water from a holding tank elevated above the reactor plane. By eliminating pumps and the generators that power them, passive designs also reduce the cost of construction while improving the safety rating of the relevant reactor. In some cases, this also has the happy consequence of reducing the size of the impact zone associated with a particular generator.[72] This reduction also reduces the cost of emergency planning, driving down costs yet further.

## III. WHAT'S NEXT?

The proof, of course, is ultimately in the pudding. The viability of SMRs will be decided not in the laboratory but in the marketplace. And in order to reach the marketplace, SMR vendors will need to gain regulatory approval for their reactor designs. For the moment, this does not appear to be an insuperable barrier. The most advanced SMR design in the United States is being developed by a company called NuScale. NuScale's reactor is in the midst of a multi-phase, multi-year process of design certification.[73]

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[70] "Inherent or full passive safety depends only on physical phenomena such as convection, gravity, or resistance to high temperatures, not on functioning of engineered components. Because small reactors have a higher surface area to volume (and core heat) ratio compared with large units, a lot of the engineering for safety (including heat removal in large reactors) is not needed in the small ones." *Id.* at 143–44.

[71] For example, the marketing materials for NuScale, the leading SMR developer in the United States, boast: "[O]ur advanced SMR design eliminates two-thirds of previously required safety systems and components found in today's large reactors. This . . . design safely shuts down and self-cools, indefinitely with no operator action, no AC or DC power, and no additional water. It is the first self-protecting reactor." *About Us*, NUSCALE, https://www.nuscalepower.com/about-us (last visited Feb. 23, 2020).

[72] In December 2019, the NRC proposed a rule revision pursuant to which the emergency planning zone associated with SMRs could deviate from the norms developed for larger reactors. Larry Pearl, *TVA Gets Nation's First Approval to Potentially Build and Operate Small Modular Nuclear Reactors*, UTILITY DIVE (Dec. 18, 2019) https://www.utilitydive.com/news/tva-gets-nations-first-approval-to-potentially-build-and-operate-small-mod/569298.

[73] Design certification is a regulatory process, carried out by the U.S. NRC, by which reactor designs are vetted and certified for incorporation into applications for operating licenses at nuclear facilities. *See generally* 10 C.F.R. Part 52. *See also NuScale's SMR Design Clears Phase 4 of Nuclear Regulatory Commission's Review Process*, BUSINESSWIRE (Dec. 12, 2019, 3:37 PM) https://www.businesswire.com/news/home/20191212005796/en/NuScale's-SMR-Design-Clears-Phase-4-Nuclear.

If it clears all phases of this process, the reactor may be selected by a utility and incorporated into a plant proposal without additional review of the reactor design itself.[74] Other vendors have not yet announced definite plans to proceed through the certification process. Internationally, there has been additional activity: in Canada, the United Kingdom, China, and elsewhere, utilities have expressed interest in purchasing SMRs as governments have conducted studies to better understand their risks and benefits.

After achieving regulatory clearance, SMR manufacturers will have to demonstrate commercial success. A number of factors–including macroeconomic conditions–will bear on their economic viability,[75] but two in particular are likely to shape the long-term prospects for SMRs. First, reactor orders must be numerous enough to estimate, at least roughly, whether the nth-of-a-kind efficiencies described above will be sufficient to reduce the overall cost curve for a fleet of reactors. It now seems likely that SMRs will in fact be built.[76] But if only a small number of small reactors are constructed, in an important sense, the SMR experiment will have been untried. Since the goal of SMR technology is not merely to improve technical reactor design but also to restructure the economics of reactor production, success cannot truly be assessed until a sufficient number of units are deployed.[77]

Second, the policy climate for nuclear power must evolve so as to create a truly level playing field for electricity generation. A policy environment that disregards greenhouse gas emissions abatement will not adequately incentivize innovation in that direction, and will underestimate substantially the social value of nuclear power generation.[78] As policy shifts to account for carbon emissions, as it must, the benefits of nuclear technology will come into sharper focus. SMR vendors are laboring to create supply chains, to develop technical expertise, and to improve the productive efficiency of their manufacturing processes, but such efforts will be much enhanced by durable policy support for true economic parity between carbon and

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[74] Other permitting processes will remain intact, of course. For example, all new plants must obtain a Combined Operating License in order to operate the plant. *See* 10 C.F.R. Part 52, subpart C. *See generally* MASS. INST. TECH., *supra* note 2, at 117-146.

[75] B. Mignacca & G. Locatelli, *Economics and Finance of Small Modular Reactors: A Systematic Review and Research Agenda*, 118 RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 109519 (2020).

[76] For its part, NuScale has signed its first customer and entered into a handful of MOUs. Interested parties include utilities in Utah, Idaho, Tennessee, and the Czech Republic. *See, e.g.*, Cho, *supra* note 7.

[77] ZOHURI & MCDANIEL, *supra* note 68, at 213 (2019) ("The [levelized cost of energy] for an SMR should decrease with large-scale serial production, which is the key element for proving the competitiveness of SMRs.").

[78] *See generally* MASS. INST. TECH., *supra* note 2, at 95-115.

noncarbon energy sources.[79]

Numerous other factors, of course, will bear upon the global success and commercial deployment of SMRs. Some of these factors cannot be predicted. For example, in the minds of many the timing of the disaster at Fukushima could not have been worse: whatever momentum gathered behind the nuclear renaissance in the United States seemed to dissipate in an instant.[80] But if there is a single takeaway to the present analysis, it is that the ultimate fate of SMRs will turn principally on economic variables.

## CONCLUSION

In today's regulatory environment, cost factors are of the utmost importance. Gone are the days when nuclear power was thought to be "too cheap to meter;"[81] gone too is the willingness of state utility commissioners to rubber-stamp billion-dollar proposals for new plants offered by vertically integrated utilities. Instead, in deregulated jurisdictions, regional grid operators rely on wholesale markets to organize the dispatch sequence for generating units within that region. The units first dispatched are those with the lowest marginal costs. In these markets, wind, solar, and natural gas units can generally underbid nuclear units.[82] Even in those states that maintain conventional cost-of-service regulation, regulators are increasingly attentive to the cost savings that can be attained by diversifying the state's fuel mix and increasing its uptake of renewable energy. By these lights, the outlook for nuclear power is bleak.

But small modular reactors offer more than a ray of hope. A half-century of commercial experience with nuclear power suggests that the most valuable economies associated with nuclear power are not the economies of scale long considered vital. If entities such as NuScale can deliver on their promise, the economies of serial production may prove deeper and more resilient than those chimerical economies of scale. Perhaps size matters,

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[79] Fossil fuels have received various subsidies, both hidden and explicit, for many years, and nearly all industries presently are able to externalize the costs of their carbon emissions. *See generally* Uma Outka, *Environmental Law and Fossil Fuels: Barriers to Renewable Energy*, 65 VAND. L. REV. 1679 (2012).

[80] Interestingly, the regulatory response to the disaster was widely considered to be relatively prompt and proportionate. To assess the precise impact of Fukushima as compared to, e.g., economic variables, would be impossible, but it does seem likely that the disaster substantially diminished the enthusiasm of nuclear advocates around the world. *See generally* Hultman & Koomey, *supra* note 21; Emily Hammond, *Nuclear Power, Risk, and Retroactivity*, 48 VAND. J. TRANSNAT'L L. 1059 (2015).

[81] N.Y. TIMES, *supra* note 20.

[82] All units dispatched are paid the clearing price. Because nuclear plants must always run, they tend to bid low and are price-takers. The result is that they operate at a loss.

but just not the way we thought.