Before the United States House of Representatives
Committee on Energy and Commerce
Subcommittee on Energy, Climate, and Grid Security

Nuclear Energy:
Pathways and Requirements for Global Scale-Up, and the Role of U.S. Policy

Testimony of Armond Cohen, Executive Director, Clean Air Task Force, Inc.

April 18, 2023

SUMMARY OF TESTIMONY

It is the best of times and the worst of times for nuclear energy. On the one hand, numerous studies, and a growing chorus of government leaders, energy and climate thinkers, and environmental organizations are concluding that nuclear energy could be critical path to managing climate change while doubling global electricity consumption and decarbonizing fuel, bolstering energy security and reliability, and moderating energy transition costs. There are more than 50 advanced nuclear companies in the U.S. alone offering promising new designs after a multi-decade innovation drought and the recent passage of the Infrastructure Investment and Jobs Act, Inflation Reduction Act, and funding of programs established in the Energy Act of 2020 have established programs and provided resources to maintain our country's existing zero carbon nuclear fleet and to help develop and demonstrate the next generation of reactor technologies. On the other hand, nuclear energy has stagnated globally, and recent custom-built large light water projects such as the Vogtle 3 and 4 plants in Georgia, a half decade late and two times over budget, have rightly led critics to question whether nuclear energy is a viable pathway; only China is building nuclear energy in significant amounts, and even its efforts are short of climate scale and speed.

To change course and have nuclear energy make a meaningful contribution, we need a radical rethink of how we conceive, build, regulate, and finance this technology. Tinkering with current institutional arrangements will not do the job. We need an overhauled industrial and regulatory ecosystem that produces and delivers standardized, commoditized cost competitive ***products*** rather than costly and risky multi-decade ***projects***. These products – think of Boeings, not cathedrals – must be cost-competitive ($4,000/kw or less), with low-risk delivery times of 3-5

years, easy to license globally, financeable on near-normal commercial terms, suitable for deployment in the developing world where most emissions and energy demand will come from, and capable of decarbonizing sectors such as fuels and industrial heat as well as electricity.

The U.S. can be at the center of this transformative effort. But more ambitious action is needed at home, and on the global stage, to create a global nuclear ecosystem that can deliver hundreds of Gigawatts per year, roughly ten times the current global build rate.

Elements of a transformative strategy include:

- Public-private collaboration to enable a commoditized product ecosystem, with maximum standardization and recategorization of nuclear and non-nuclear grade components;
- Public policies that drive large orders enabling repeat deployment of standardized designs;
- A strategic Earth Shot program to drive nuclear capex costs below $4,000/kw;
- An innovation program targeted at nuclear energy applications for zero carbon fuel production and industrial heat;
- New global initiatives to facilitate multi-national design certification, as well as providing the resources to enable the licensing nuclear reactors in newcomer countries, and establishment of an International Bank for Nuclear Infrastructure to catalyze global expansion;
- Provision of a "sandbox" environment to allow for live, time-bound demonstration and testing of new nuclear energy designs under regulatory oversight;
- Reform of U.S. Nuclear Regulatory Commission ("NRC" or "Commission") licensing practices for new advanced designs, to focus on performance in order to realize the promises of previous acts of Congress;

- Take measures to establish a new model for low dose radiation standards in order to support appropriate safety regulation;
- Measures to ensure socially and environmentally responsible uranium sourcing;
- A whole-of-government program to facilitate re-use of retired fossil generation sites for new nuclear build;
- Measures to ensure availability of high assay low enriched uranium ("HALEU") to support advanced technology deployment; and
- Establishment of a new national regime for managing nuclear waste.

Chairman Duncan, Ranking Member DeGette, and Honorable Members of this Sub-Committee, Good afternoon. My name is Armond Cohen. I am Executive Director of the Clean Air Task Force ("CATF"), a non-profit environmental organization dedicated to pushing the technology and policy changes needed to achieve a zero-emissions, high-energy planet at an affordable cost. We appreciate the opportunity to testify today. I will note that CATF is funded entirely by private philanthropic donations and accepts no support from governments or energy companies.

It is the best of times and the worst of times for nuclear energy. On the one hand, numerous studies, and a growing chorus of government leaders, climate thinkers, and environmental organizations are concluding that nuclear energy could be critical path to managing climate change while doubling global electricity consumption and decarbonizing fuel, bolstering energy security and reliability, and moderating energy transition costs. There are more than 50 advanced nuclear companies in the U.S. alone offering promising new designs after a multi-decade innovation drought, and the passage of the Infrastructure Investment and Jobs Act, Inflation Reduction Act, the CHIPS and Science Act, and funding of programs established in the Energy Act of 2020 have put in place programs and provided resources to maintain our country's existing zero carbon nuclear fleet and to help develop and demonstrate the next generation of reactor technologies. On the other hand, nuclear energy has stagnated globally, and recent more traditional design projects such as the Vogtle 3 and 4 pressurized water reactors in Georgia, a half decade late and two times over budget, have rightly led critics to question whether nuclear energy is a viable pathway; only China is building nuclear energy in significant amounts, and even its efforts are short of climate scale and speed.

Let's review the evidence concerning where we are and where we need to be.[1]

I. The Case for Nuclear Energy as a Critical Part of a Decarbonized Global Energy System

A. A decarbonized energy system will need lots of clean firm, 24/7/365 power

Most analyses of global decarbonization pathways assume that, even with increased end use energy efficiency, the world will need to double or even triple its electric power output by midcentury[2] to facilitate the electrification of transport and industry and buildings as well as meet the incremental traditional demand arising from increasing energy access in the developing world. [3] The future energy growth beyond 2050 will likely be more dramatic than even these projections indicate; 13% of the world's population currently lives without electricity, and 40% of the global population (3 billion people) do not have access to clean fuels for cooking. There is a greater than ten-fold difference in energy use per capita between regions globally, even

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[1] This testimony does not address the need to preserve and maintain America's existing nuclear energy plants, including relicensing for 60 and 80 years where it is safe to do so. Doing this is important for climate and environmental reasons, as well as to maintain the infrastructure and skills for further buildout. See Lyssa M. Freese et al., *Nuclear power generation phase-outs redistribute US air quality and climate-related mortality risk*, Nature Energy, Apr. 10, 2023, https://www nature.com/articles/s41560-023-01241-8, at 1 (loss of America's nuclear plants would result in "increases in $PM_{2.5}$ and ozone that lead to an extra 5,200 annual mortalities" and "[c]hanges in CO_2 emissions [that] lead to an order of magnitude higher mortalities throughout the twenty-first century, incurring US$11–180 billion of damages from 1 year of emissions.").

[2] The International Energy Agency ("IEA") World Energy Outlook estimates electricity demand will increase by 150%, from 28,000 TWh in 2021 to 73,000 TWh in 2050 under the net zero scenario. This includes conservative estimates of population growth and continued limits to energy access in developing countries. IEA, *World Energy Outlook 2022*, at 44 (2022), https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

[3] Recent analysis suggests that even these studies have vastly underestimated likely future energy demand, especially in the developing world. A recent paper analyzed the level of energy demand growth in Africa and South Asia contained in the Intergovernmental Panel on Climate Change scenarios and found that these scenarios essentially freeze per capita consumption in those regions at current levels or even a decrease! *See generally* Tejal Kanitkar et al., *Equity Assessment of Global Mitigation Pathways in the IPCC Sixth Assessment Report* (2022), https://osf.io/p46ty.

embedded into future demand projections in the International Energy Agency ("IEA") sustainable development scenario (Figure 1).

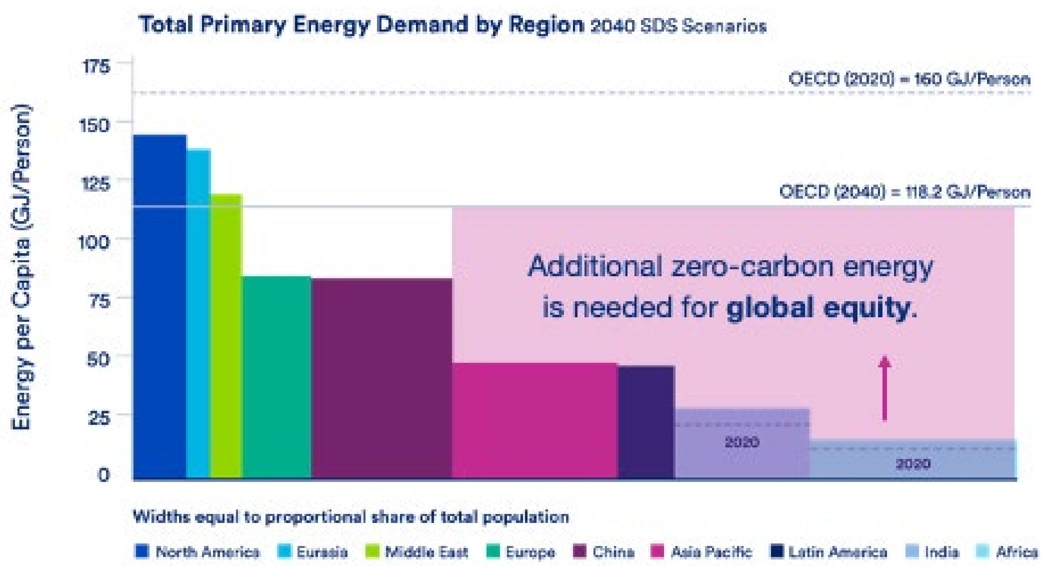

Figure 1: Projected energy demand by region in International Energy Sustainable Development Scenario vs Regional Population. Sources: CATF from IEA and World Bank data.

To decarbonize the grid, we must also replace existing unabated fossil fuel systems and retiring nuclear generation with clean energy and then double or triple the total. In the United States, this

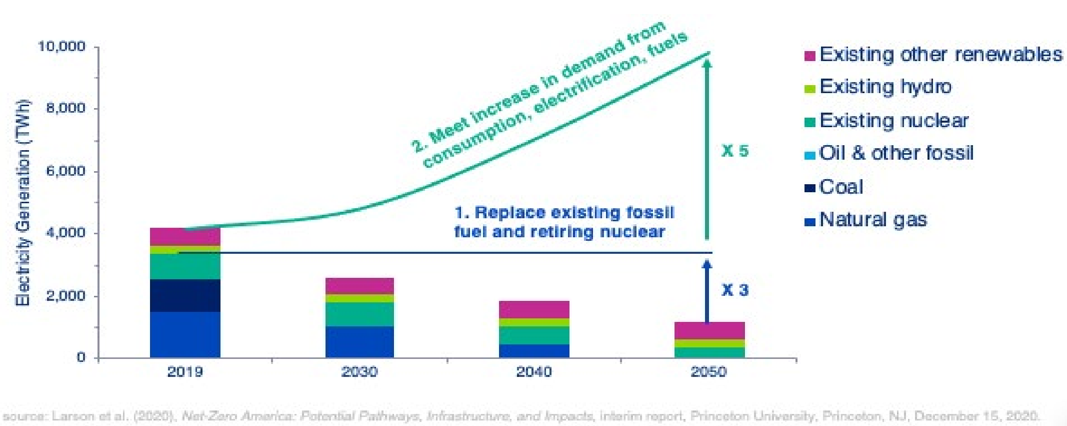

Figure 1: U.S. example representing the twofold challenge of decarbonization: replacing existing fossil fuels while adding more capacity to meet additional demand. Source: as cited in figure.

twofold challenge will require an eight-fold increase in the generation currently met by zero carbon sources (Figure 2).[4]

Most studies assume that a substantial portion of this electricity will be provided from renewables such as wind and solar.

Meeting this additional demand while simultaneously decarbonizing the grid and maintaining reliability will be an enormous challenge, a challenge that underscores the importance of preserving and extending the life of the existing domestic nuclear fleet. Wind and solar energy will likely be a cornerstone of this future expanded electricity grid, though premature retirement of the existing nuclear fleet could lead to increased energy generation from coal, gas, and oil.[5] While currently accounting for about 10% of U.S. electricity, costs of wind and solar have declined dramatically over the last decade,[6] and are now cost competitive on a commodity energy-only basis[7] with traditional electricity sources in most regions.[8] We need to continue to develop these resources as quickly as possible to realize our climate goals. Most modeling studies demonstrate future decarbonized electricity systems will likely be powered substantially, if not predominantly by these variable renewable sources.

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[4] Data from Eric Larson et al., Princeton University, *Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report* (2020), https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf.
[5] Freese et al., *supra* note 1, at 1.
[6] Wind and solar costs from Lazard, *Lazard's Levelized Cost of Energy Analysis – Version 15.0* (2021), https://www.lazard.com/media/sptlfats/lazards-levelized-cost-of-energy-version-150-vf.pdf.
But see, Bloomberg New Energy Finance, Battery Price Survey (Dec. 6, 2022), https://about.newenergyfinance.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/ (noting that battery prices rose from 2021-2022).
[7] As discussed below, this cost parity – sometimes called the "levelized cost of energy" ("LCOE") – does not include the additional costs of reliability and back up.
[8] National Renewable Energy Laboratory, *Annual Technology Baseline 2020* (2020), https://atb.nrel.gov/electricity/2020/.

But we likely cannot rely on wind, solar, and battery storage alone. These resources are weather dependent, varying in output by a factor of two or more depending on the hour, day, and season and are not available on demand to match the electricity load (Figure 3A).[9] Even if we were able to supply all or nearly of our electricity from these sources (and I discuss below some constraints to deployment of those resources rapidly at assumed scale), maintaining reliability and containing costs in such a system is likely to require substantial amounts of non-weather-dependent, always-available zero carbon power.

In theory, continental scale seamless transmissions grids could smooth out peak generation requirements, but only to a point. Figure 3B shows that wind output is highly correlated across the continental United States on a weekly and seasonal basis. Additionally, wind and solar capacity factors are subject to climate change risks, such as less rain to power hydro facilities,[10] wildfire smoke obscuring sunlight from reaching solar panels,[11] and potentially declining wind speeds.[12]

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[9] *See generally* Dan Tong et al., *Geophysical constraints on the reliability of solar and wind power worldwide*, Nature Commc'n, Oct. 22, 2021, https://www nature.com/articles/s41467-021-26355-z, at .

[10] U.S. Energy Information Admin. ("EIA"), *Drought effects on hydroelectricity generation in western U.S. differed by region in 2021*, Today in Energy (Mar. 30, 2022), https://www.eia.gov/todayinenergy/detail.php?id=51839.

[11] U.S. EIA., *Smoke from California wildfires decreases solar generation in CAISO*, Today in Energy (Sept. 30, 2020), https://www.eia.gov/todayinenergy/detail.php?id=45336.

[12] Jim Robbins, *Global Wind Speeds: are they falling due to climate change?*, energypost (Oct. 14, 2022), https://energypost.eu/global-wind-speeds-are-they-falling-due-to-climate-change/.

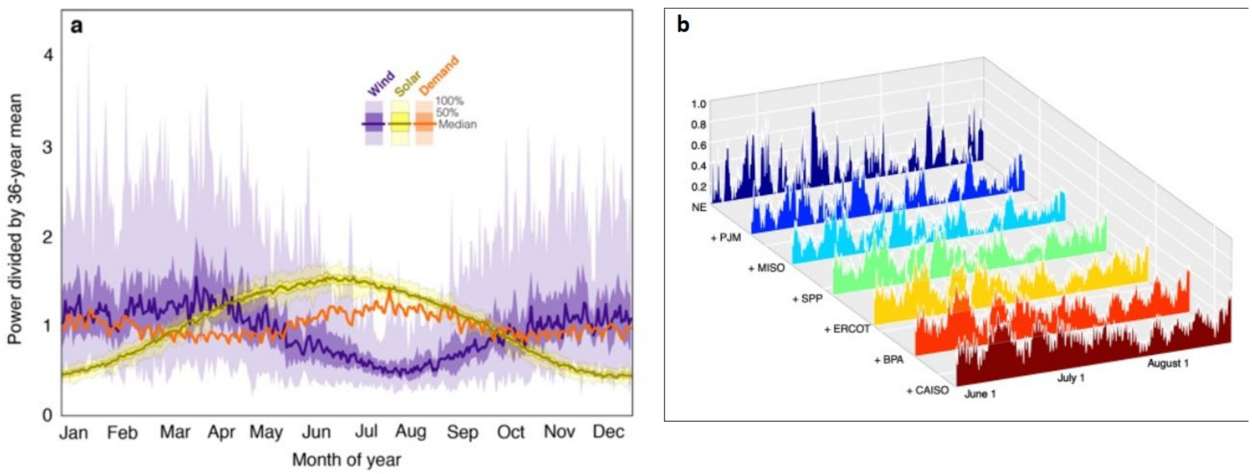

Figure 3: A) Representation of the variable nature of wind and solar by week, season, and year in the United States, and B) Wind capacity factors showing composite average output across the continental United States in one summer, as outputs are successfully added to the average, starting in New England and moving across the nation to California.[13]

Maintaining reliability and containing costs in a decarbonized electricity system will therefore also likely require substantial amounts of non-weather-dependent, always-available zero carbon power to complement this variable renewable energy; academic and industry studies consistently show that the key to achieving such a transition in a timely and affordable manner hinges on allowing "clean firm" generation technologies to complement wind, solar, and storage within the electricity mix.[14] Clean firm generation sources, such as geothermal energy, hydrogen combustion, biomass and gas with carbon capture, and nuclear, can provide electricity at any hour of the day, any day of the year regardless of season or weather.

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[13] *See* Jesse Jenkins, Analysis of wind output correlation across continental U.S. (2017), unpublished, available on request).

[14] A review of 7 national studies found the average clean firm power share to be 35% of the projected net-zero generation mix. *See* The NorthBridge Group, *Review and Assessment of Literature on Deep Decarbonization in the United States: Importance of System Scale and Technological Diversity* 11 (2021), https://www.catf.us/wp-content/uploads/2021/06/NorthBridge_Deep_Decarbonization_Literature_Review.pdf.

In addition to reliability, clean firm generation is critical to the energy transition for several reasons:

1. **Reduces the need for over-built capacity of wind and solar**

An electricity system without firm and dispatchable generation requires wind and solar capacity to be sized to meet the largest seasonal and daily load. During times of peak wind and solar, this

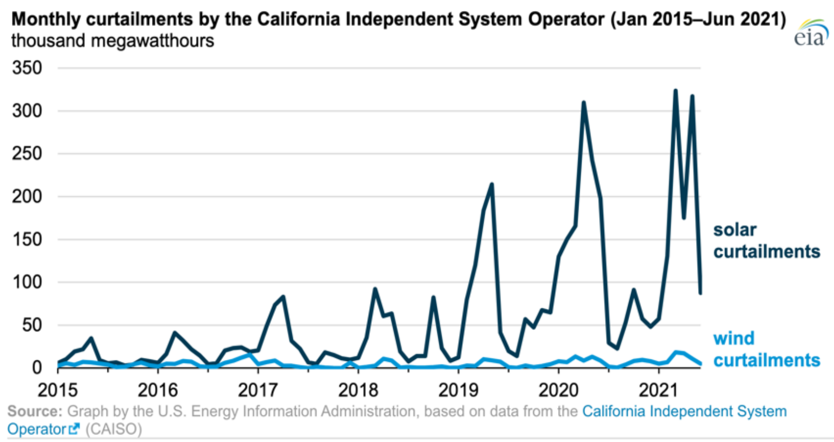

Figure 4: Monthly curtailments of wind and solar in CAISO from 2015 to 2021.

results in excess generation beyond what is needed to balance the load. Some of this excess generation could be used to replenish storage and may be used to generate hydrogen via electrolysis. However, much of this oversupply would likely be curtailed (i.e., purposefully shut down). For example, Figure 4 shows historical curtailment of wind and solar in the California Independent System Operator ("CAISO") system.[15] This excess installed capacity of wind and solar would be expensive, use more land and critical minerals, and increase transmission requirements – all significant challenges described more below.

[15] U.S. EIA, *California's curtailments of solar electricity generation continue to increase*, Today in Energy, (Aug. 24, 2021), https://www.eia.gov/todayinenergy/detail.php?id=49276.

2. **Reduces the need for expensive, rarely called upon, long duration storage capacity**

Short duration storage can typically provide electricity for 4-hour periods. However, there are likely to be prolonged periods, from multi-day to even monthly, of shortages throughout a typical year (Figure 5).[16] Therefore, storage needs to be sized to peak annual required state of charge, not peak daily demand. In this example, meeting this “energy gap” and maintaining reliability in this system without clean firm power would therefore require installation of extensive storage capacity (33 TWh of storage) to meet the 68 day shortage period. This storage build out would require extensive infrastructure at high cost, most of which is only used one time per year.

[16] Jesse Jenkins, Princeton University (2019), unpublished analysis performed for CATF, available on request.

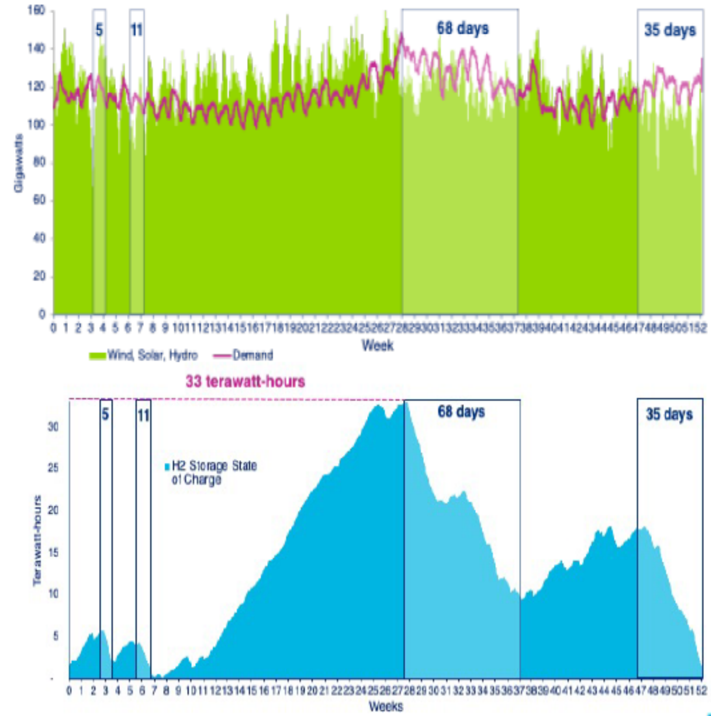

Figure 5: a simulated year of wind, solar, and hydro generation for the Western Interconnection showing periods of shortage based on a typical demand pattern (top), and the associated long duration storage state of charge needed to address the energy gap (below).

3. **Reduces the mileage and quantity of new transmission lines needed to be built**

Due to the dispersed nature of the variable renewable generators, each cluster, and occasionally individual plants, require a transmission line to connect to the main ("bulk") transmission line. A recent study of California found that a grid relying exclusively on dispersed variable sources that would need to be balanced would triple the amount of transmission required versus a system with clean firm power such as nuclear energy,[17] yet California is presently only permitting a few

[17] *See* Jane Long, et al, *Clean Firm Power is the key to California's Carbon-Free Energy Future, Issues in Science and Technology* (2021), https://www.edf.org/sites/default/files/documents/LongCA.pdf.

such lines per decade, with recent average delay times of 10 years.[18] Similar decade long wait times have been observed in the UK.[19] Planning and building these transmission lines takes time, and most transmission planning entities have not been equipped, staffed, and funded properly to evaluate these interconnection requests in an efficient manner. The costs of these infrastructure upgrades also make the ultimate project cost uncertain but likely to increase as the best sites with easier access to transmission lines are used up and could offset any additional decreases in wind and solar technology costs.

4. **Reduces reliance on wide-spread and consistent demand-side shifting to maintain reliability**

The variable nature of wind and solar throughout the day would require a transformation in how we use our electricity. In today's grid, electricity generation is adjusted throughout the day to meet our demand. In a wind and solar grid without firm generation, the opposite must be true; even with a high degree of storage, we would have to adjust our demand to follow the wind and solar daily generation patterns. This is often called 'demand flexibility,' and includes industrial, commercial, and residential measures such as reducing factory output at times of low sun or wind, controlling when electric vehicles are charged, and turning on/off heating, cooling, and refrigeration to match the load. While this is theoretically possible, it would take an immense amount of operational oversight and an unproven degree of societal participation and behavioral modifications coupled with stringent government policies. Including clean firm generation in the

[18] Alex Breckel et al., *Growing the Grid: A Plan to Accelerate California's Clean Energy Transition* 11 (2022), https://cdn.catf.us/wp-content/uploads/2022/10/11081420/growing-grid-plan-accelerate-californias-clean-energy-transition.pdf.
[19] Gil Plimmer, *Renewables projects face 10-year wait to connect to electricity grid*, Financial Times (May 8, 2022) https://www.ft.com/content/7c674f56-9028-48a3-8cbf-c1c8b10868ba.

grid mix drastically reduces the reliance on these demand side flexible measures by being able to ramp up electricity supply to meet demand, as fossil generation does in our current grid.

5. **Increases the speed of the energy transition**

Mitigating the worst effects of climate change relies on us rapidly decarbonizing the energy system. Meeting our energy demand with renewables alone would delay the transition due to the sheer number of projects that would need to be sited to install enough wind and solar capacity. Siting will only become more difficult as wind and solar cumulative capacity increases due to competing land uses, fewer amenable land owners, increasing distance from bulk transmission, and increasing public opposition (Figure 6), as is further discussed below.

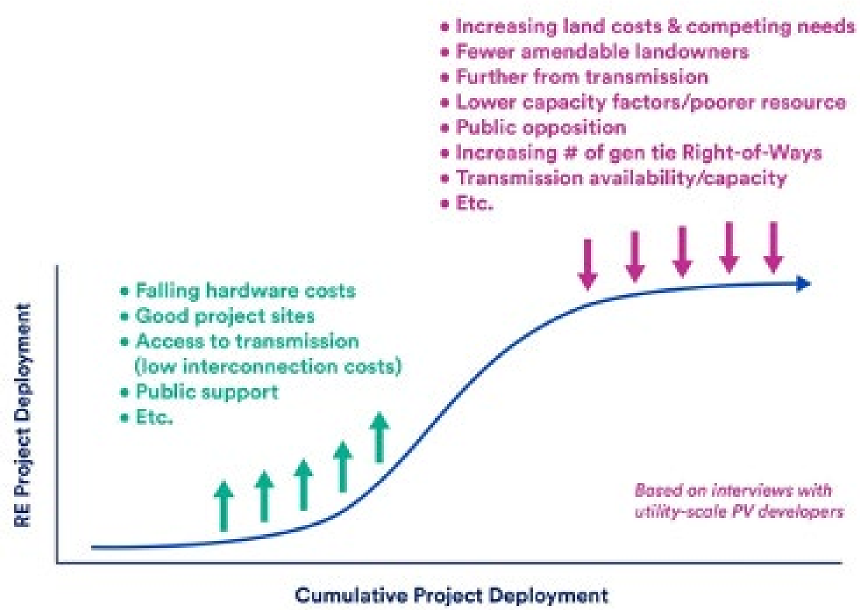

Figure 6: Figurative cumulative project deployment curve demonstrating decreasing pace of wind and solar deployment as a function of increasing cumulative deployment.[20]

As a result of the above wind and solar challenges and associated benefits of clean firm generation supporting wind and solar on the grid reduces the total transition cost and time horizon by between 60-110% depending upon the modeling study and scenario specifications and assumptions.[21] For example, a 2021 EPRI study found that a 100% renewable scenario would cost $500B to $800B more than a technology diverse net-zero scenario, for 2050 and 2035 time horizons, respectively.[22] A study of the 100% carbon free electricity pathways in California harmonized assumptions across three different models and found supplementing wind, solar, and

[20] CATF, based on unpublished work by Lucid Catalyst; figure available on request.

[21] *See*, *e.g.*, Nestor Sepulveda et al., *The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation*, Joule, Oct. 17, 2018, https://www.researchgate.net/publication/327480033_The_Role_of_Firm_Low-Carbon_Electricity_Resources_in_Deep_Decarbonization_of_Power_Generation; Christopher Clack, Bipartisan Policy Center, *Modeling Renewable Energy, Clean Technologies and Electrification for Deep Decarbonization Future* (2019), https://vibrantcleanenergy.com/wp-content/uploads/2019/05/BPPC-VCE_RevCF-_31May2019.pdf; Ejeong Baik et al., *What is different about different net-zero carbon electricity systems?*, Energy & Climate Change Jul. 10, 2021, https://www.sciencedirect.com/science/article/pii/S2666278721000234; James Williams et al., *Carbon Neutral Pathways for the United States*, AGU Advances, Jan. 14, 2021, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020AV000284; and Jamil Farbes et al., Evolved Energy Research, *Federal Policy for Low-Carbon, High-Renewables Electricity* (2020), file:///Users/toddwarshawsky/Downloads/Policy_LowCarbonElectricity_20201111.pdf.

[22] Geoffrey Blanford et al., Electric Power Rsch. Inst., *Powering Decarbonization: Strategies for Net-Zero CO2 Emissions* 3 (2021), https://www.epri.com/research/products/3002020700.

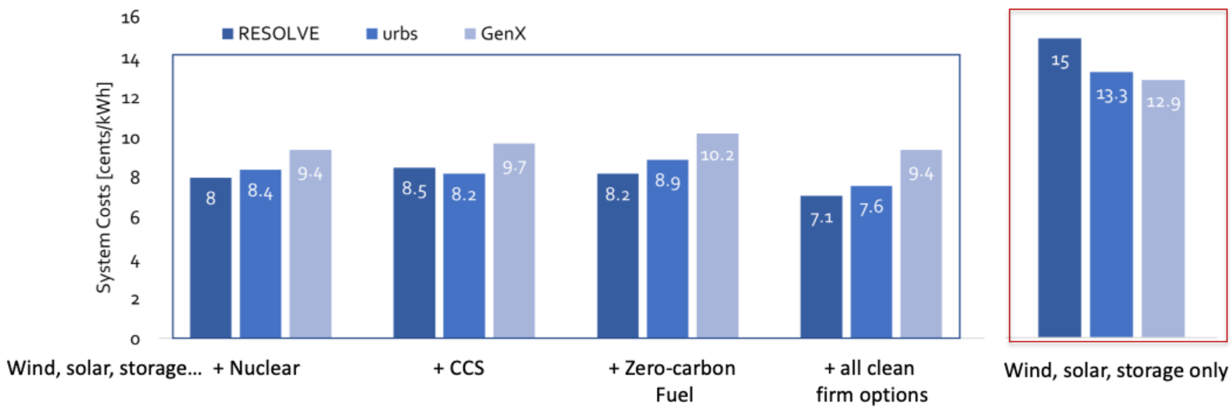

Figure 7: Results from three different models of the California electricity system comparing the decarbonized electricity system cost with clean firm generation vs. wind, solar, and storage only.

storage with clean firm generation could as much as cut in half the clean electricity grid system costs (Figure 7).[23]

B. Nuclear energy, if available at scale, would minimize the costs of a decarbonized energy system

There are several pathways to a completely decarbonized energy system and numerous analyses have been conducted to assess their viabilities. Results vary widely, but what most tend to have in common is a recognition that a full transition without nuclear energy is highly improbable, being much less reliable or cost prohibitive. The IEA, for example, found in its Net Zero Emissions Scenario by 2050 ("NZE") that nuclear power capacity would need to double to reach the 2050 target.[24] Conversely, reducing nuclear energy's role in the transition would make reaching ambitions more challenging and more expensive. IEA showed this in its low nuclear case version of the NZE, projecting average electricity bills would go up by more than $20 billion every year through 2050.

[23] Baik et al., *supra* note 21, at 5.
[24] IEA, Nuclear Power and Secure Energy Transitions 8 (2022), https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions/executive-summary.

But the IEA's model is just one of many that optimize systems to include significant nuclear growth in a decarbonized economy, even without improvements to current nuclear technology and business models. The Organisation for Economic Co-operation and Development's Nuclear Energy Agency ("NEA") in 2022 looked at several of the most prominent emission reduction models, including that of the IEA, (see Figure 8) and all necessitated very high growth in nuclear, most more than two-times current global capacity. Importantly, the NEA noted "none of the pathways project particularly aspirational scenarios for nuclear innovation."[25] Some researchers, however, have modeled projected declines in nuclear costs, and the results speak volumes about the potential for nuclear energy to contribute to decarbonization goals.

[25] Organisation for Economic Co-operation and Development, Nuclear Energy Agency, *Meeting Climate Change Targets: The Role of Nuclear Energy* 16 (2022), https://www.oecd-nea.org/jcms/pl_69396/meeting-climate-change-targets-the-role-of-nuclear-energy.

Organisation	Scenario	Publication year	Climate target	Role of nuclear technologies		Description	Role of nuclear energy by 2050	
				Large Generation III	Nuclear Innovation		Capacity (GW)	Nuclear growth (2020-50)
IAEA (2021b)	High Scenario	2021	2°C	Included	Not included	Conservative projections based on current plans and industry announcements.	792	98%
IEA (2021c)	Net Zero Scenario (NZE)	2021	1.5°C	Included	Not included in the quantitative model, although the potential of HTGR and nuclear heat are acknowledged in the report narrative	Conservative nuclear capacity estimates. NZE projects 100 gigawatts more nuclear energy than the IEA sustainable development scenario.	812	103%
Shell (2021)	Sky 1.5 Scenario	2021	1.5°C	Included	Not specified	Ambitious estimates based on massive investments to boost economic recovery and build resilient energy systems.	1 043	160%
IIASA (2021)	Divergent Net Zero Scenario	2021	1.5°C	Included	Not specified	Ambitious projections required to compensate for delayed actions and divergent climate policies.	1 232	208%
Bloomberg NEF (2021)	New Energy Outlook Red Scenario	2021	1.5°C	Included	Explicit focus on SMRs and nuclear hydrogen	Highly ambitious nuclear pathway with large-scale deployment of nuclear innovation.	7 080	1670%

Figure 8: Role of nuclear technologies in various decarbonization models.

Studies conducted for the DOE also support the idea of nuclear innovations leading to a large share of nuclear energy in the future clean energy mix. For example, the Pacific Northwest National Laboratory ("PNNL") found that "reduction of nuclear capital costs and increased nuclear competitiveness resulted in significant nuclear power expansion and carbon emissions mitigation even without an explicit carbon mitigation policy."[26] Moreover, by adding net zero policies, nuclear buildout becomes much higher under PNNL's various scenarios, reaching 50%

[26] Son Kim, PNNL, *Scenarios of Nuclear Energy Use in the United States for the 21st Century* 35 (2022), https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/FY22_PNNL_Nuclear_Scenario_Report.pdf.

of U.S. electricity by 2100. Notably, this was also due to nuclear power plants' exceptional longevity.

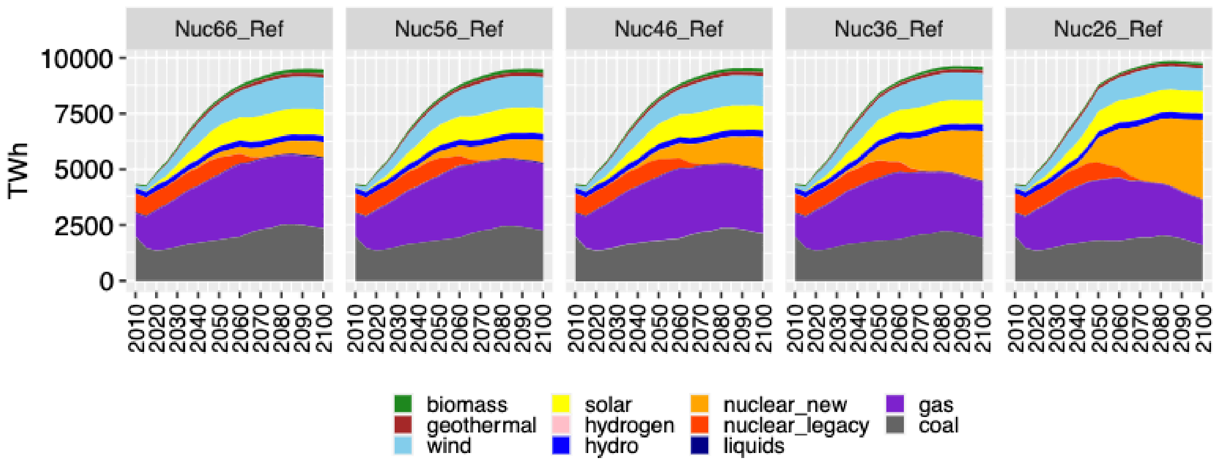

Figure 9: Technology shares in a decarbonized economy.

Another study for the DOE performed for the ARPA-MEITNER Program, modeled advanced reactor prospects—specifically high-temperature advanced reactors, with optional thermal energy storage—in four major U.S. power markets in 2034, finding wide opportunity for market rate of return for advanced nuclear plants that can reduce capital costs below $3000/kW, and a large share of final electricity production.[27] Importantly, advanced reactors reduced total system costs in each market modeled, and their flexibility even allowed higher penetration of renewables (when paired with thermal storage) and improved grid performance. These results are also significant because they show positive advanced nuclear performance in competitive power markets, in contrast to regulated markets where nuclear has historically fared better.

[27] *See generally* Eric Ingersoll et al., Lucid Catalyst, *Cost & Performance Requirements for Flexible Advanced Nuclear Plants in Future U.S. Power Markets* (2020), https://www.lucidcatalyst.com/_files/ugd/2fed7a_a1e392c51f4f497395a53dbb306e87fe.pdf

The value of nuclear energy in decarbonization is especially clear when taking into account the challenge of deep decarbonization and constraints on deploying weather-dependent renewables. Evidence to support this assertion is mounting both internationally and domestically. For instance, Carbon Free Europe analyzed 2050 net zero pathways for the EU and UK and determined that nuclear energy becomes one of the biggest primary energy sources in those regions in scenarios where it is allowed.[28] The only scenario where nuclear was not included, that of 100% renewables, was considerably more expensive, costing more than EUR 80 Billion more than the baseline scenario (see Figure 10).

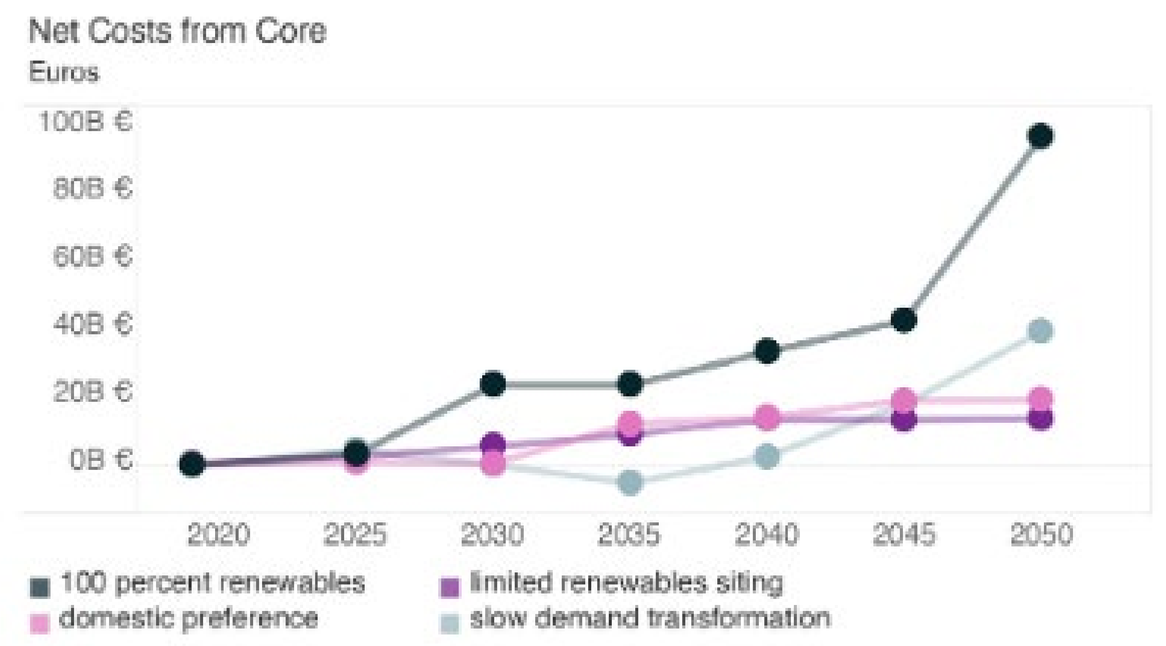

Figure 10: Costs of various energy scenarios for Europe (see text).

[28] Ben Haley et al., Carbon Free Europe, *Summary for Policymakers: Analysis of Net-Zero Pathways for the EU and UK* 5 (2022), https://www.carbonfreeeurope.org/modeling/Summary-for-Policymakers-Analysis-of-Net-Zero-Pathways-for-the-EU-and-UK.pdf.

E3 performed a similar analysis in Washington State, which mandated zero-emission electricity by 2045.[29] After considering different combinations of resources, it concluded that "achieving deep emissions reductions from the electric sector is achievable at manageable cost, provided that firm capacity is available to avoid the infrequent but large electricity shortages that can occur on highly renewable grids." Significantly, this required extended use of Washington's only existing nuclear power plant and build out of small modular reactors, finding approximately 5 GW of SMRs deployed in the region by 2045. (See Figure 11.)

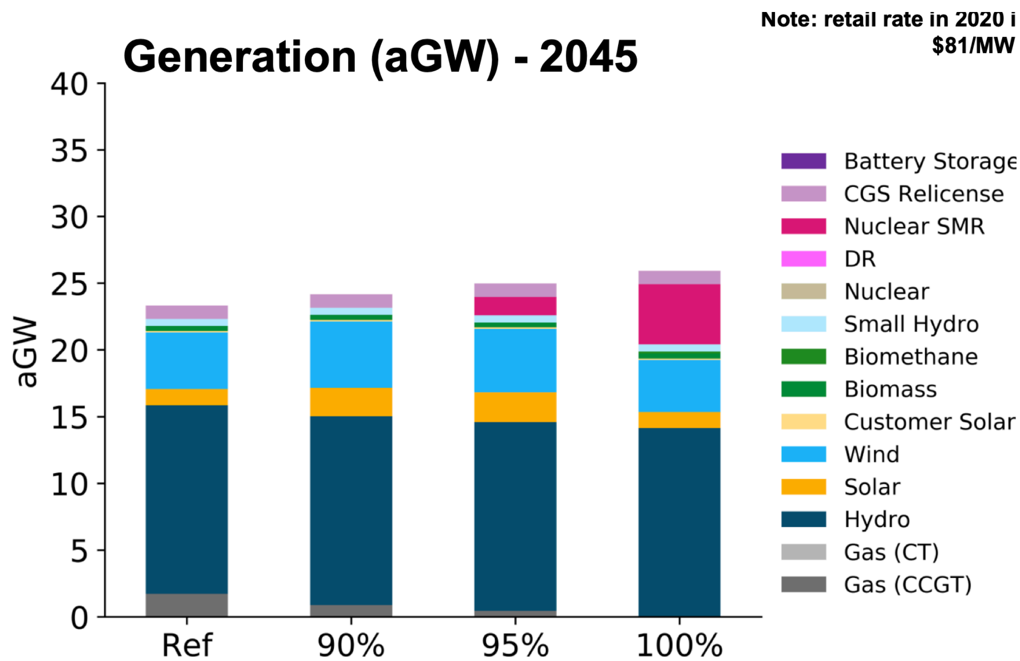

Figure 11: CGS = Columbia Generation Station, Washington State's only nuclear power plant.

A global analysis by McKinsey and Company finds a similarly large need for nuclear energy to meet net-zero targets when considering the difficulties in scaling up renewables to meet

[29] Dan Aas et al., Energy+Environmental Economics, *Pacific Northwest Zero-Emitting Resources Study* 54 (2020), https://www.ethree.com/wp-content/uploads/2020/02/E3-Pacific-Northwest-Zero-Emitting-Resources-Study-Jan-2020.pdf

projected global energy demand.[30] McKinsey accounts for factors like land scarcity and raw material and transmission limitations, concluding that to meet global goals by 2050 an additional 400-800 GW of new nuclear plants could be required. This would amount to 10-20% of global energy demand at that point. However, to meet these projections, McKinsey notes that deliberate action must be taken across the supply chain and in the realms of finance and regulation, to ensure nuclear plants can be built on time and at cost. (See Figure 12).

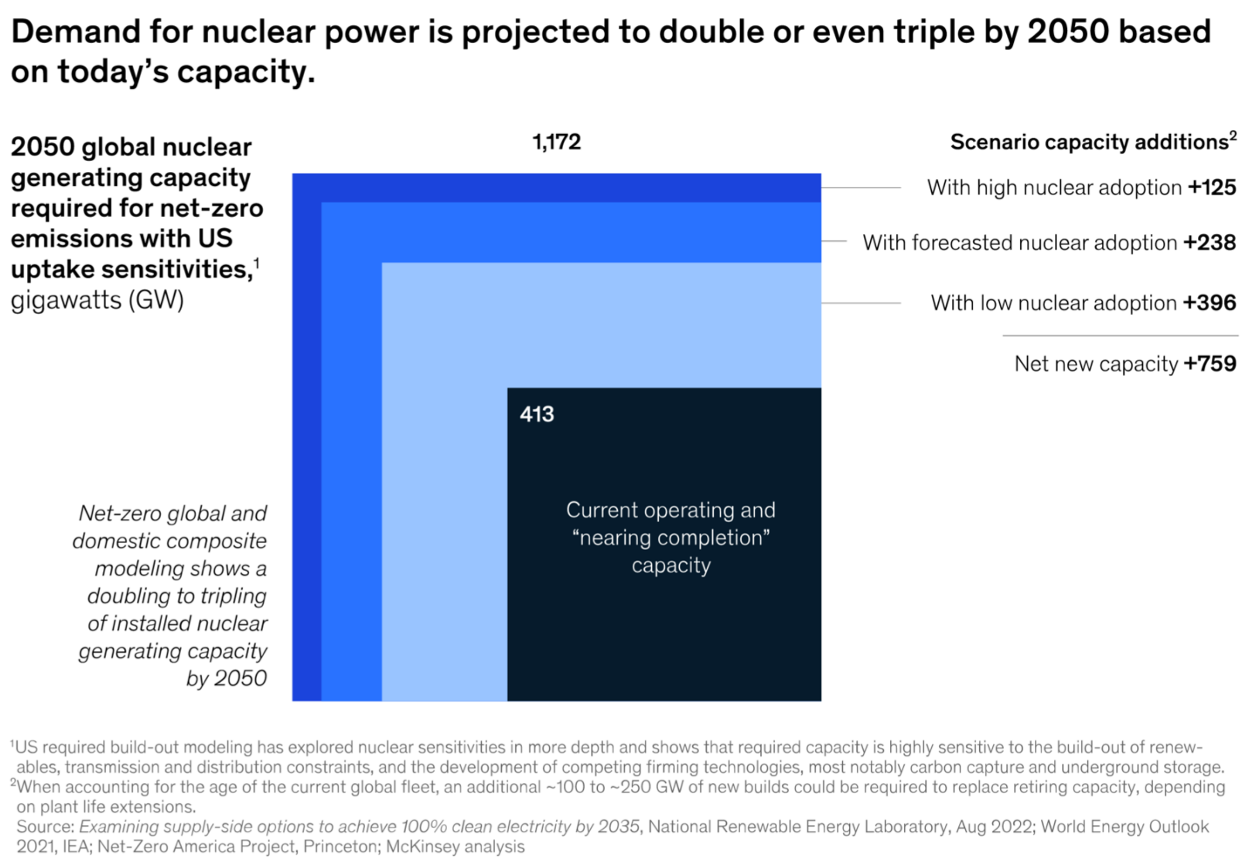

Figure 12 – Demand for Nuclear Power is Projected to Double or Even Triple by 2050.

C. Nuclear energy deployment could help reduce the land use and grid infrastructure barriers facing the buildout of a zero-carbon energy system

[30] *See generally,* Chad Cramer et al., McKinsey & Co., *What will it take for nuclear power to meet the climate challenge?* McKinsey & Co., (Mar. 21, 2023), https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/what-will-it-take-for-nuclear-power-to-meet-the-climate-challenge#/.

Decarbonizing the energy system while meeting the growing energy demand requires constructing massive amounts of clean energy infrastructure. Expectations are high for the role that wind and solar resources may play in our clean energy future, and for good reason: they are low-cost, easy to construct, and produce no harmful local emissions.

But they are also considerably more land-consuming than more power dense sources such as nuclear. Technologies that use less land for comparable electricity production offer a major siting advantage by reducing conflict inherent in conversion of large swaths of land. According to the U.S. Department of Energy, nuclear power is nearly 20 times more land efficient than wind and nearly 300 times more than solar (see Figure 13 below).

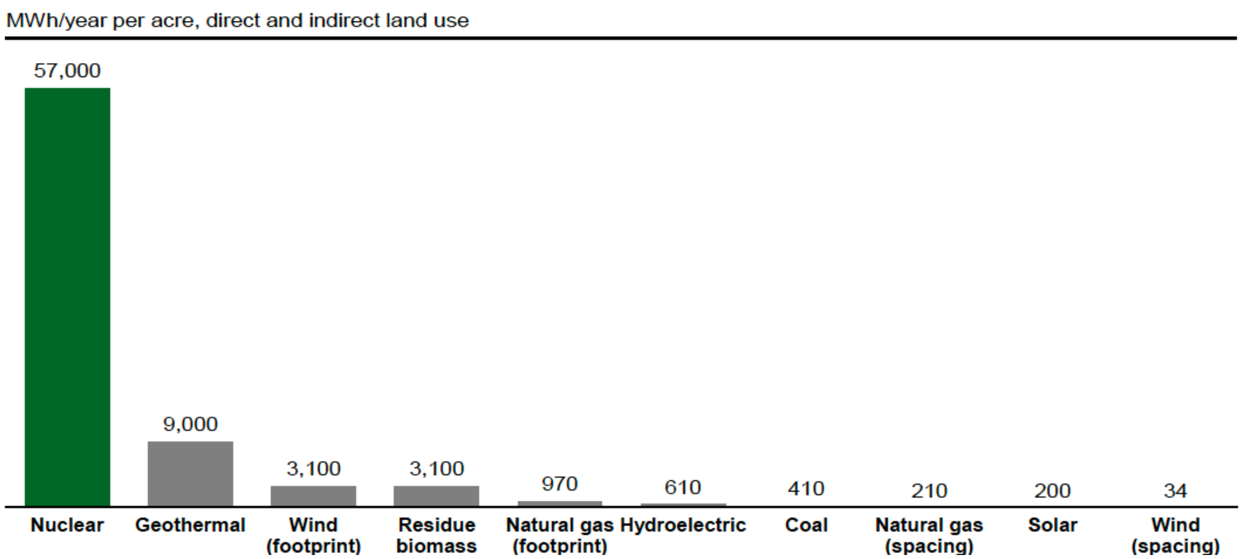

Figure 13: Land use efficiency of electricity generating technologies.[31]

[31] U.S. Dep't of Energy, *Pathways to Commercial Liftoff: Advanced Nuclear* 11 (2023), https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB-0329-Update.pdf.

Clean energy studies tend to anticipate enormous and rapid deployment: a high electrification scenario in the *Princeton Net-Zero America Study* finds that reaching economywide net-zero greenhouse gas emissions in next three decades would require that the United States increase annual wind and solar additions by a factor of four to supply half the U.S. electricity by 2030 and 85-90% of generation by 2050.[32] The scenario that excludes all but wind and solar resources in 2050 requires adding more capacity annually than was built in the entire world in 2020.

And yet, there are no guarantees that these resources could reach their full deployment potential. Projects face persistent and growing land use, community acceptance, grid interconnection, and transmission access challenges. And in some places, these barriers have already led to a *slowing* of clean energy deployment in the past several years, just as policy expectations and grid modeling suggest they ought to be *accelerating*. In California, at least 5 GW of new utility-scale solar is needed each year over 20 years to decarbonize the state's economy, but only 2 GW were added to its grid each year between 2013 and 2017. The pace of deployment has fallen by half since then.[33] In 2022, wind and solar capacity expanded 9% nationwide, the lowest rate of growth since 2013.

1. **Land use for generation**

The amount of land that renewable energy resources could occupy is staggering. The *Princeton Net-Zero America Study* found that the total land area impacted by the electricity system would

[32] Larson et al., *supra* note 4, at 87.
[33] *Growing the Grid: A Plan to Accelerate California's Clean Energy Transition*, CATF (Oct. 11, 2022), https://www.catf.us/resource/growing-grid-plan-accelerate-californias-clean-energy-transition/.

increase by a factor of thirteen in their primary scenario, with wind and solar taking up to 590,000 sq-km (227,800 sq-mi) an area roughly equal to the size of IL, IN, OH, KY, TN, MA, CT and RI combined. (See Figure 14 below):

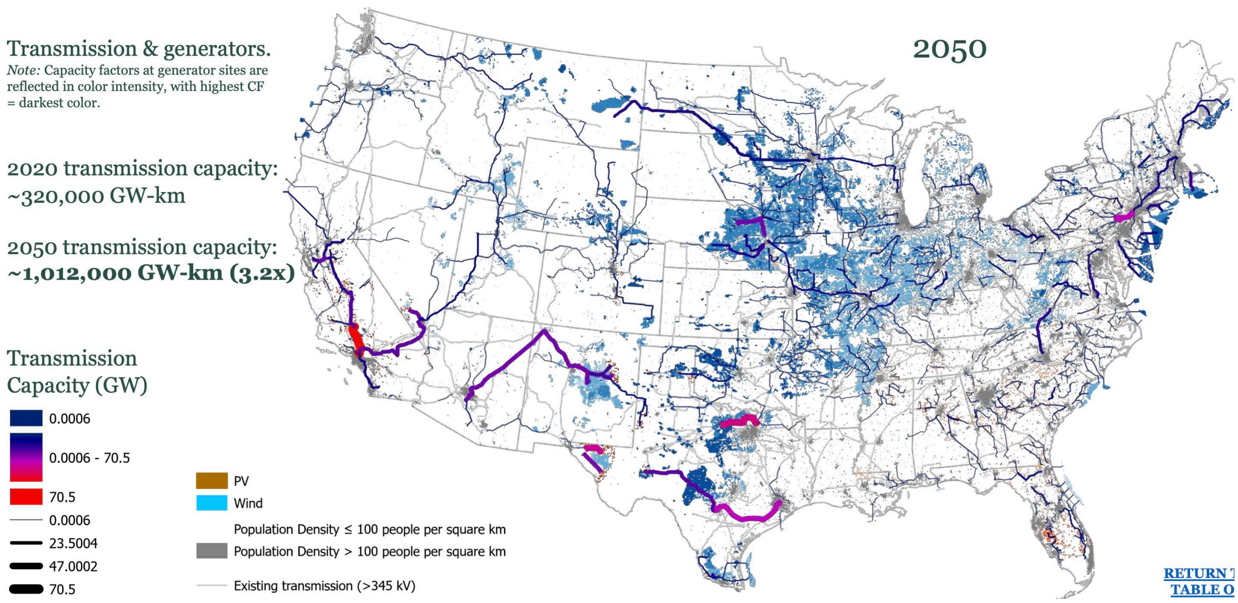

Figure 14: Footprint of a 2050 decarbonized U.S. energy system.[34]

And yet all of the nation's land is in use for some purpose today, requiring complex tradeoffs with every new acre devoted to clean energy.

2. **Community Acceptance**

Perhaps the most formidable obstacle to land use change at the pace and scale imagined by clean energy modeling may be community acceptance. Increasing local opposition to renewable

[34] Larson et al., *supra* note 4, at 137.

energy is not just making projects harder to build, but it is also preventing them from being built at all. Such opposition is slowing the pace of deployment and raising questions about the feasibility of our clean energy deployment expectations.

Wind and solar facilities have faced increasingly unwelcoming communities with concerns over visual impacts, shifting community identify, wildlife impacts, health, and safety. And these concerns are growing in number: in their latest annual report *Opposition to Renewable Energy Facilities in the United States*, researchers at Columbia University's Sabin Center for Climate Chane Law found a 24% increase in the number of contested projects compared to the previous year.[35] In many cases communities stopped projects entirely. In some, policies were changed to prevent similar wind or solar projects from ever being proposed.

The recent growth in project opposition is reflected in the quick cascade of local ordinances and land use polices that severely limit the development of wind and solar. Anticipated levels of wind deployment in Iowa will be near impossible to achieve following a sharp rise in restrictive ordinances and moratoria across the state over last four years. An analysis by ClearPath (see figure 15 below) finds that over half of potential wind project areas in the state could be unavailable for future development under a conservative ordinance adoption scenario.[36] This is in a state that has historically been a leader in wind energy development. Similar stories are playing out across the county.

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[35] *See* Hillary Aidun et al., Sabin Center for Climate Change Law, *Opposition to Renewable Energy Facilities in the United States: March 2022 Edition* 2 (2022), https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=1186&context=sabin_climate_change.

[36] ClearPath, *Hawkeye State Headwinds - A Case Study of Local Opposition and Siting Challenges for More Wind Energy in Iowa* 47 (2022), https://clearpath.org/reports/hawkeye-state-headwinds/.

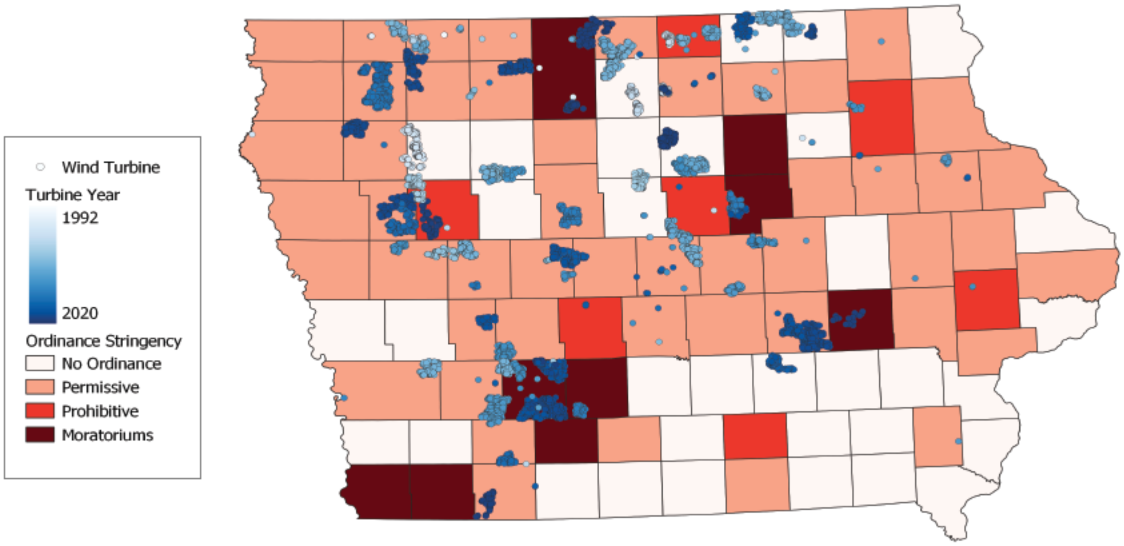

Figure 15: Iowa wind turbines and county wind siting ordinances, 2020.[37]

It is also, of course, true that nuclear energy plants have in the past engendered significant opposition, and twelve states have significant political restrictions in place.[38] Regions will likely vary in their support for this technology, just as they have for renewables. But there is a difference in scale–two hundred 2 Gigawatt clusters of small modular reactors, each in the hundreds of acres, would be equivalent in output to more than 3,000 large wind or solar farms occupying millions of acres. And, historically, many communities have supported nuclear energy because of tax revenue and jobs. How comparative opposition will play out for different technologies is uncertain today, which is a further argument for technology diversification.

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[37] *Id.*
[38] *See*, *States Restrictions on New Nuclear Power Facility Construction* Nat'l Conf. of State Legislatures (Aug. 17, 2021), https://www ncsl.org/environment-and-natural-resources/states-restrictions-on-new-nuclear-power-facility-construction. Some states such as West Virginia are taking action to reverse those bans. Paige Lambermont, *West Virginia is Ending its Nuclear Power Plant Ban*, Catalyst (Feb. 24, 2022), https://catalyst.independent.org/2022/02/24/west-virginia-nuclear-power-ban/.

3. **Transmission Deployment**

Electricity transmission constraints are a persistent and rapidly growing barrier to renewable energy deployment and, absent a paradigm shift in our ability to build large-scale transmission, are likely to persist for decades.

Today, wind, solar, and other clean energy resources waste years waiting to be connected to the grid. As of 2022, approximately 1,260 GW of zero-carbon projects awaited connection to regional grids in the United States – as much generating capacity as currently exists in the country, of *any type.* Projects are also spending more and more time in waiting – the average wait time (5 years in 2022) has more than doubled since 2008. Greater wait times have accompanied substantial increases in annual interconnection requests. Capacity entering queues each year has gone up sevenfold between 2013 and 2022, with 700 GW of capacity requests added in 2022 alone. [39]

Without significant transmission buildout, the number of projects currently in the queue and a growing pile-on of new projects will translate into longer and longer wait times, lower commercialization rates, and an eroding business case for needed clean energy resource development. The *Princeton Net-Zero America Study* found the size of the electricity grid must *triple in the next 30 years* to accommodate a diverse mix of clean energy technologies including advanced nuclear, requiring building new transmission lines a triple the current pace (Figure 16).

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[39] Joseph Rand et al., Lawrence Berkeley National Laboratory ("LBNL") *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2022*, at 6 (2023), https://emp.lbl.gov/sites/default/files/queued_up_2022_04-06-2023.pdf.

Removing clean firm resources like advanced nuclear or CCS from the mix would require increasing the size of the grid by *a factor of five*, quadrupling the nation's historic rate of new transmission additions. (See Figure 16).

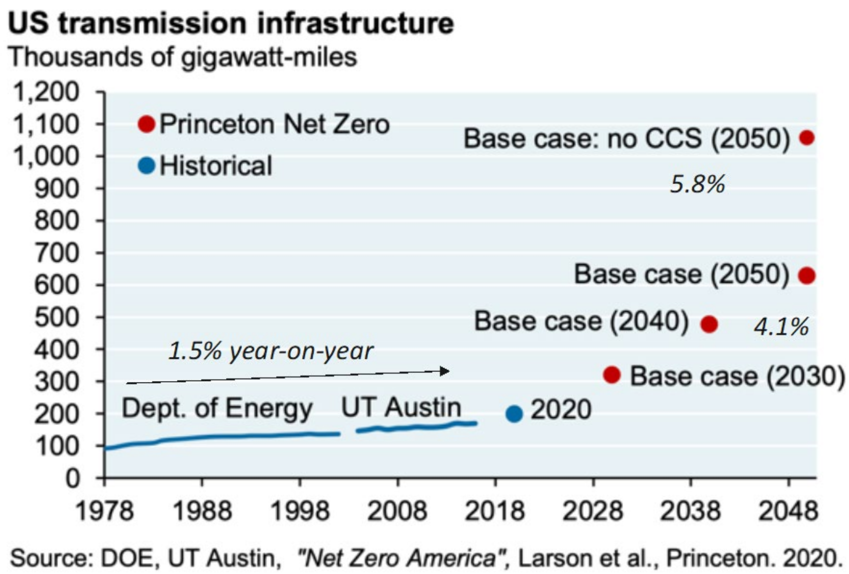

Figure 16: Growth in U.S. transmission capacity, historic and projected.[40]

In sum, nuclear energy has many, many challenges (including siting), but power density – the amount of energy produced within spatial constraints – and the reduced need for electric transmission are decided advantages in a land-constrained world.

[40] Michael Cembalest, J.P. Morgan Asset and Wealth Mgm't, *Eye on the Market: Annual Energy Paper* 16 (11th ed. 2021), https://am.jpmorgan.com/content/dam/jpm-am-aem/global/en/insights/eye-on-the-market/future-shock-amv.pdf.

D. Nuclear energy deployment would reduce the critical minerals and material requirements of a decarbonized energy system[41]

The nature of nuclear energy is to produce a large quantity of amount of energy within a confined space. As a result, even with current Gen III+ designs, which require a substantial amount of concrete and steel for containment and other structures, the overall cement, steel, copper and aluminum requirements for nuclear energy per unit output is orders of magnitude lower than other zero carbon options as shown in Figure 17 below:

[41] While it might seem that the relevant comparison would be between critical minerals for other clean technologies and uranium for nuclear, in fact, uranium is actually very abundant and available in the near term in friendly countries. Totally conventional uranium resources globally are sufficient for around 250 years. Nuclear Energy Agency & Int'l Atomic Energy Agency ("IAEA"), Uranium 2022: Resources, Production, and Demand 135 (2022), https://www.oecd-nea.org/jcms/pl_79960/uranium-2022-resources-production-and-demand?details=true). But, as noted below, responsible sourcing would help ensure this supply can be readily tapped.

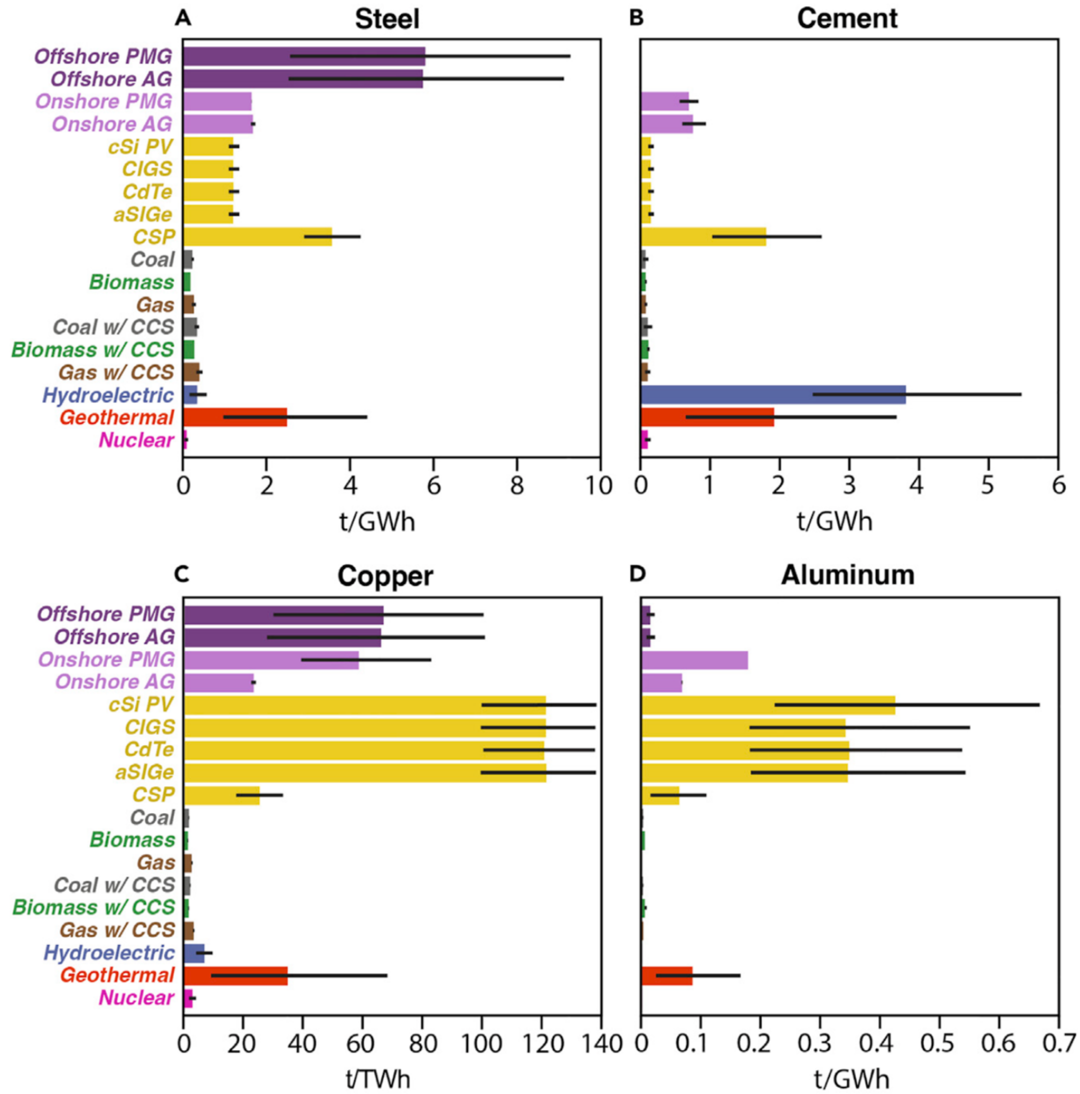

Figure 4. Material intensity of four selected bulk materials

(A–D) (A) Steel, (B) cement, (C) Cu, and (D) Al in each generation technology, expressed in tons per unit of electricity generation (t/GWh or t/TWh). Black whiskers reflect the range of total intensities spanning the 2.5th–97.5th percentiles. PMG, permanent magnet gearbox wind turbine drive; AG, asynchronous gearbox wind turbine drive; cSi PV, crystalline silicon solar photovoltaic; CIGS, copper indium gallium selenide thin-film solar; CdTe, cadmium telluride thin-film solar; aSiGe, amorphous silicon germanium thin-film solar; CSP, concentrating solar power.

Figure 17: Material intensity of four selected bulk materials.[42]

[42] Seaver Wang et al., *Future demand for electricity generation materials under different climate mitigation scenarios*, 7 Joule 309 (2023), https://www.sciencedirect.com/science/article/abs/pii/S2542435123000016.

The same advantage holds true for critical minerals, as shown in Figure 18 below. This is a significant factor, as the availability and geopolitics of critical mineral mining and processing is an emerging issue in the energy transition, and one not readily solved in the next couple of decades.

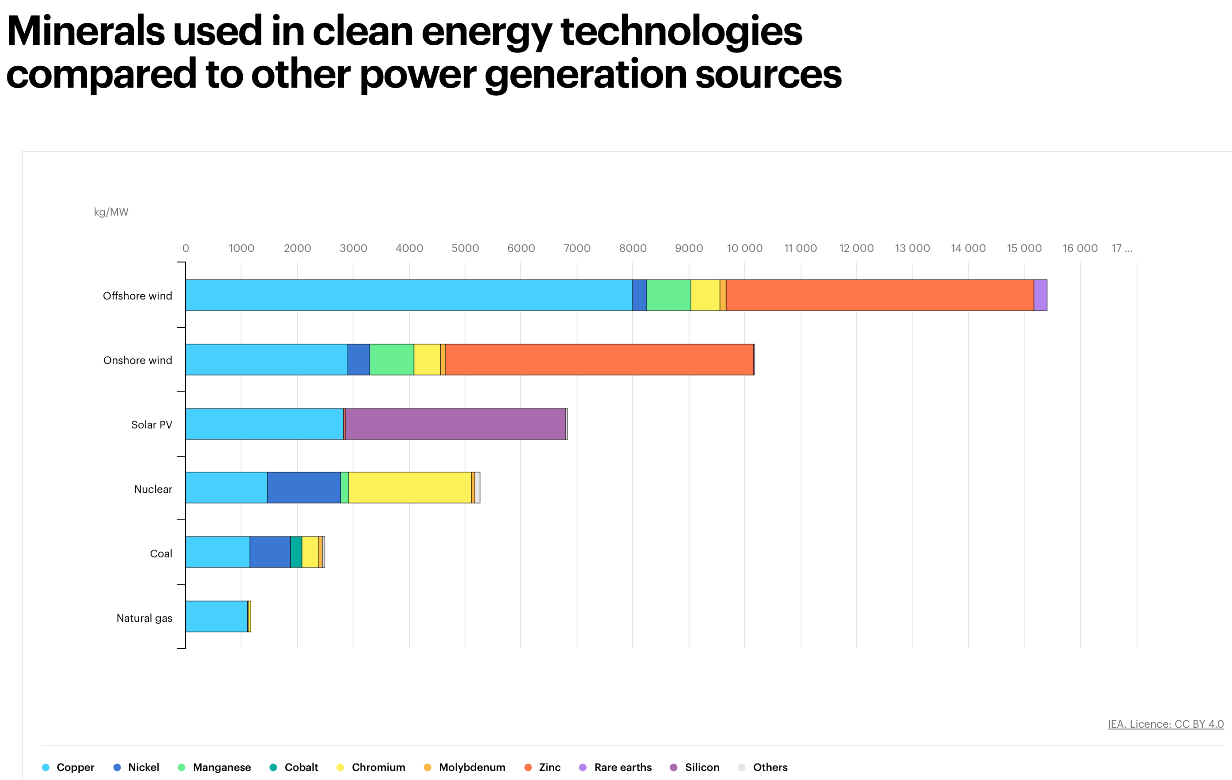

Figure 18[43]: Note that the metric in this Figure is kg/MW rather than kg/MWH. Since nuclear energy generation typically has a capacity factor three times or more that of wind or solar, the disparity displayed would be even greater if measured in materials per unit of energy output terms.

[43] IEA, *The Role of Critical Minerals in Clean Energy Transitions* (2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

II. <u>Nuclear energy is not being deployed at the scale and pace needed, and recent Western builds have been very high cost.</u>

Despite these advantages, nuclear energy has stagnated globally, and recent large light water reactor projects such as the Vogtle units 3 and 4 in Georgia, a half decade late and two times over budget, have rightly led critics to question whether nuclear energy is a viable pathway; only China and Russia are building nuclear reactors at a significant rate, and even their efforts are short of climate scale and speed.

As Figure 19 below shows, total net global nuclear capacity rose rapidly between 1970 and 1990 and has been essentially level since then, with a post-Fukushima dip which is now only slowly rebounding:

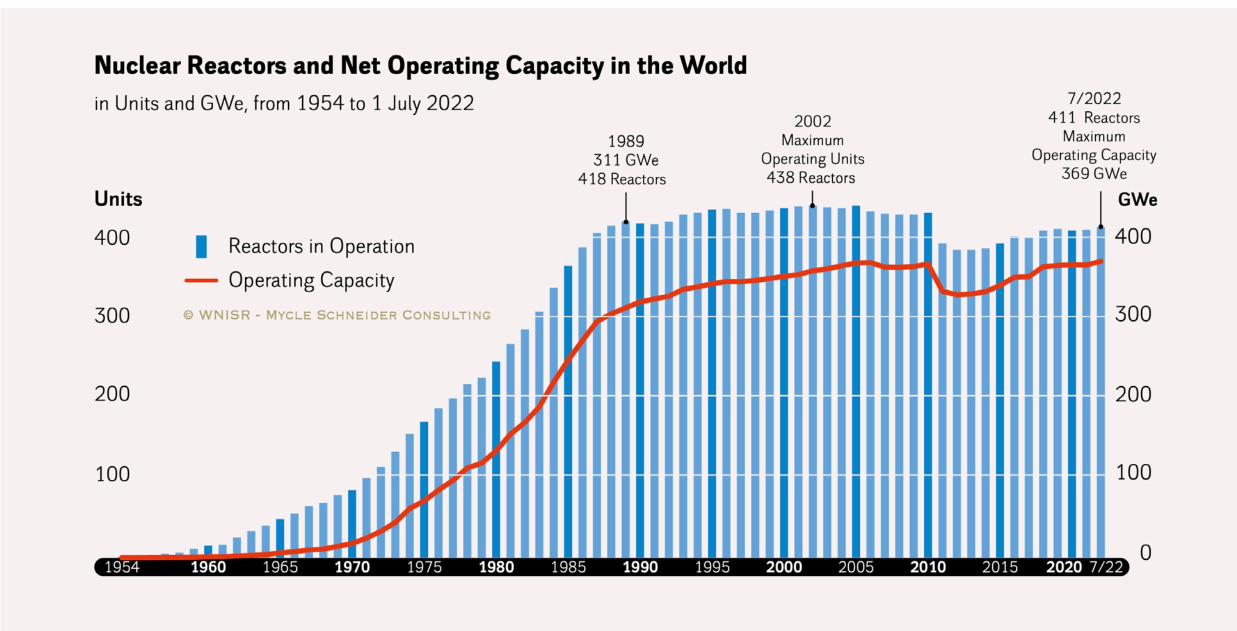

Figure 19[44]

A closer look in the figure 20 below reveals that the post-Fukushima gain is due almost entirely to China's new build, which raises geopolitical concerns:

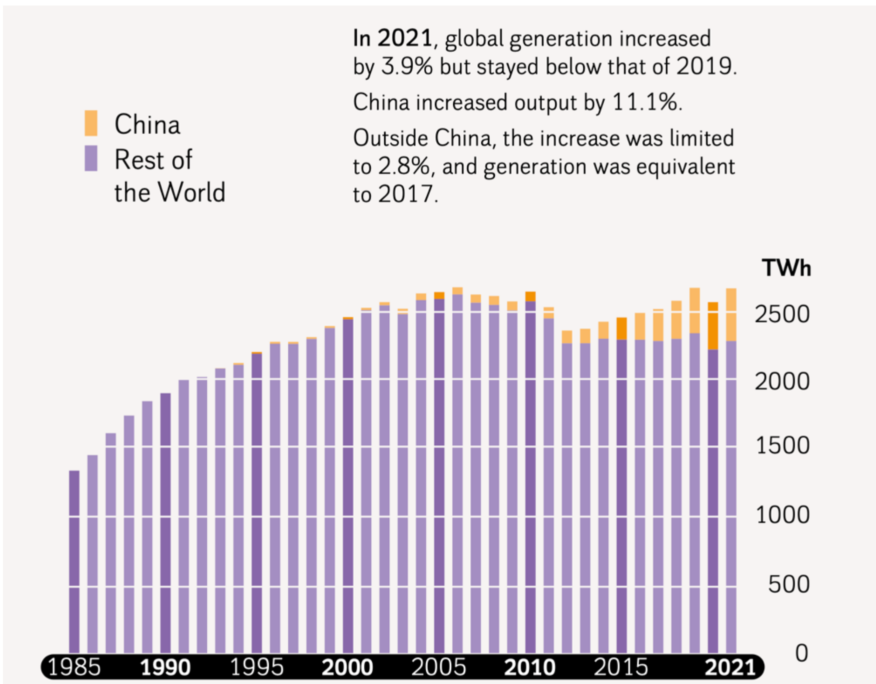

Figure 20: Nuclear energy generation, with China broken out.[45]

Not only have Western additions been slow to build; they have all come in at relatively high cost. For example, the construction on Vogtle 3 and 4 in Georgia began in 2013 and was initially projected to be completed by 2017 and 2018, respectively, at an estimated total cost of $14 Billion. Instead, the project has taken a decade to complete, and experienced numerous delays

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[44] Mycle Schneider et al., The World Nuclear Industry Status Report 2022, at 45 (2023), https://www.worldnuclearreport.org/IMG/pdf/wnisr2022-v3-lr.pdf

[45] *Id.* at 40.

and cost overruns, with the estimated cost doubling to more than $28 billion. Similar cost overruns and delays have been experienced with other large light water reactors in the UK (Hinkley B), France (Flamanville), and Finland (Olkiluoto).

It is worth noting that costs have been much lower outside the U.S. and Europe, as Figure 21 below shows:

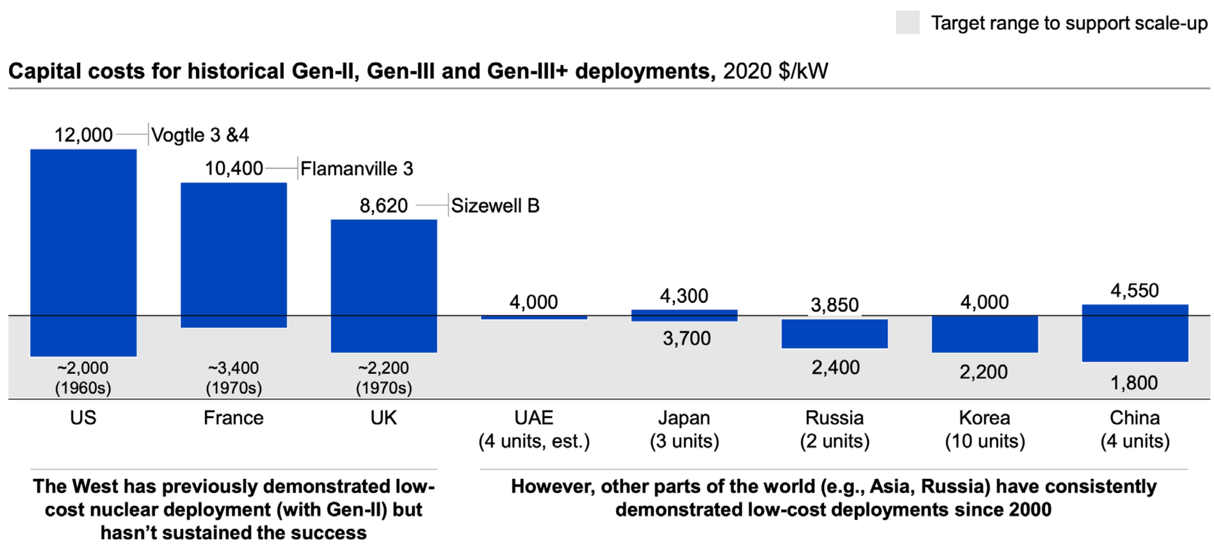

Figure 21[46]

However, high cost and delay is not inevitable, as best construction and project management practices and the building of standardized multiple units have shown elsewhere. A recent study for the UK-based Energy Technologies Institute analyzed the costs associated with more than

[46] CATF, based on Energy Tech. Inst., *Nuclear Cost Drivers Project: Full Technical Report* (2020), https://www.lucidcatalyst.com/_files/ugd/2fed7a_917857d4f3544323a84f163e5e904c23.pdf [hereinafter ETI, *Full Technical Report*]; Jessica Lovering et al., *Historical Construction Costs of Global Nuclear Power Reactors*, 91 Energy Policy 371 (2016), https://www.sciencedirect.com/science/article/pii/S0301421516300106.

two dozen large light water nuclear plants built over the last few decades.[47] The report, while showing Asian costs to be lower than OECD costs, decomposed cost drivers through a detailed scorecard method and found that the difference in unit costs was not primarily driven by the stringency of safety regulation ***per se*** or unit labor costs in Asia, but rather by the efficiency of project management, ***responsive*** regulation, and other best practices. Specifically, top factors that led to lower costs included:

- Having a completed design before construction;[48]
- Building multiple units at single site, and repeated build of the same design;
- A regulator that was willing to work with developers to focus on fundamental safety performance rather than box-ticking;
- Incentives aligned for cost management, and having a conscious cost control program; and
- Unified project management, rather than having decision-making and responsibility split between vendors, constructors and off-takers.

Simply applying best project and construction management practices to the U.S. context, and multiple builds, and little else, the report concluded that conventional large scale water-cooled U.S. nuclear plant construction costs could be reduced by at least a third.

However, reducing the cost of a reactor from $12,000/kw to $8,000/kw will not solve the problem, nor necessarily speed up delivery times. More aggressive action is needed.

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[47] *See* Energy Tech. Inst., *The ETI Nuclear Cost Drivers Project: Summary Report* (2018), https://d2umxnkyjne36n.cloudfront.net/documents/D7.3-ETI-Nuclear-Cost-Drivers-Summary-Report_April-20.pdf.
[48] Vogtle 3 and 4 were only partially designed before construction began, necessitating costly re-dos of key project segments.

The poor cost performance and high project delivery risk is certainly one of the reasons why current nuclear investment globally is so low compared to other low carbon energy sources, as shown in Figure 22 below.

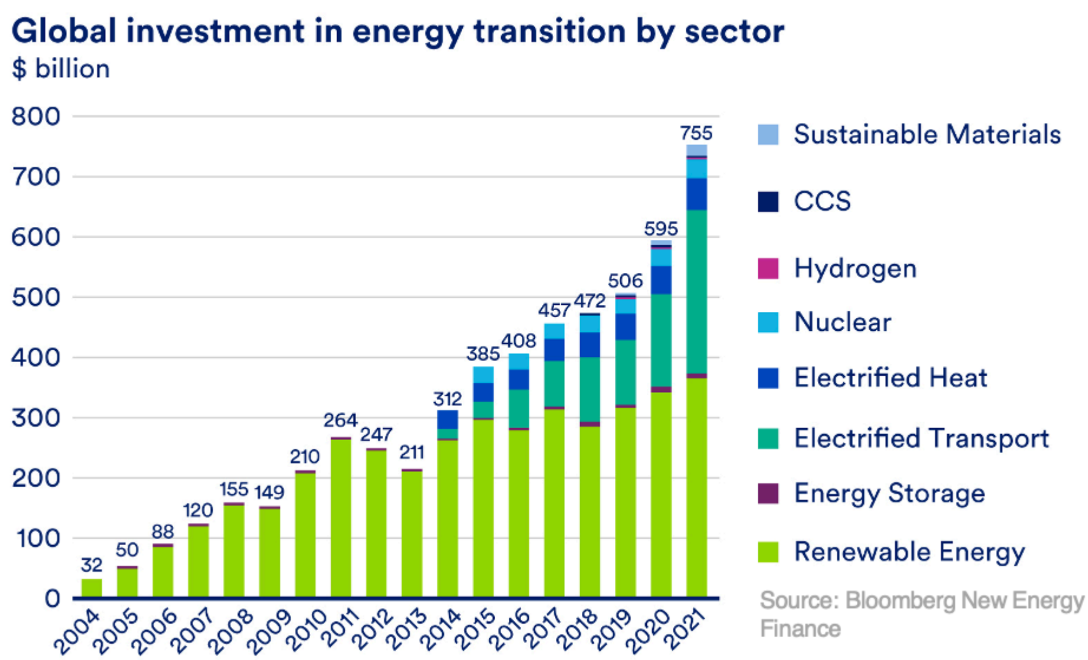


Figure 22[49]

And it is obvious that the current global nuclear spend is far lower than would be required in a nuclear scale up of 100+ GWs per year:

[49] BloombergNEF, *Energy Transition Investment Trends 2022: Executive Summary,* at 1 (2022), https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends-Exec-Summary-2022.pdf.

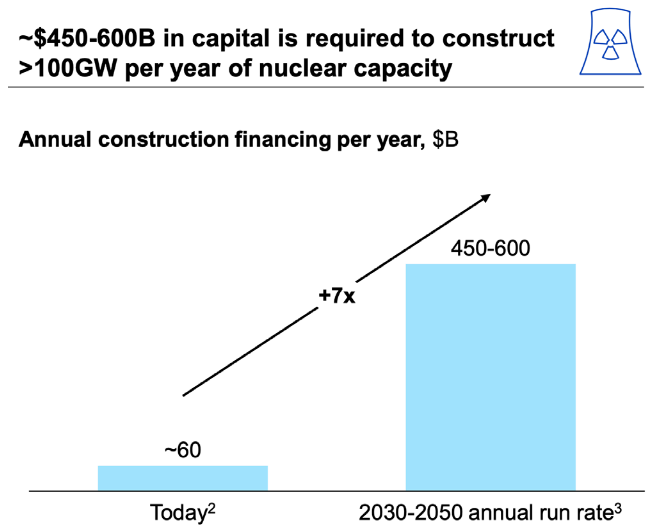


Figure 23[50]

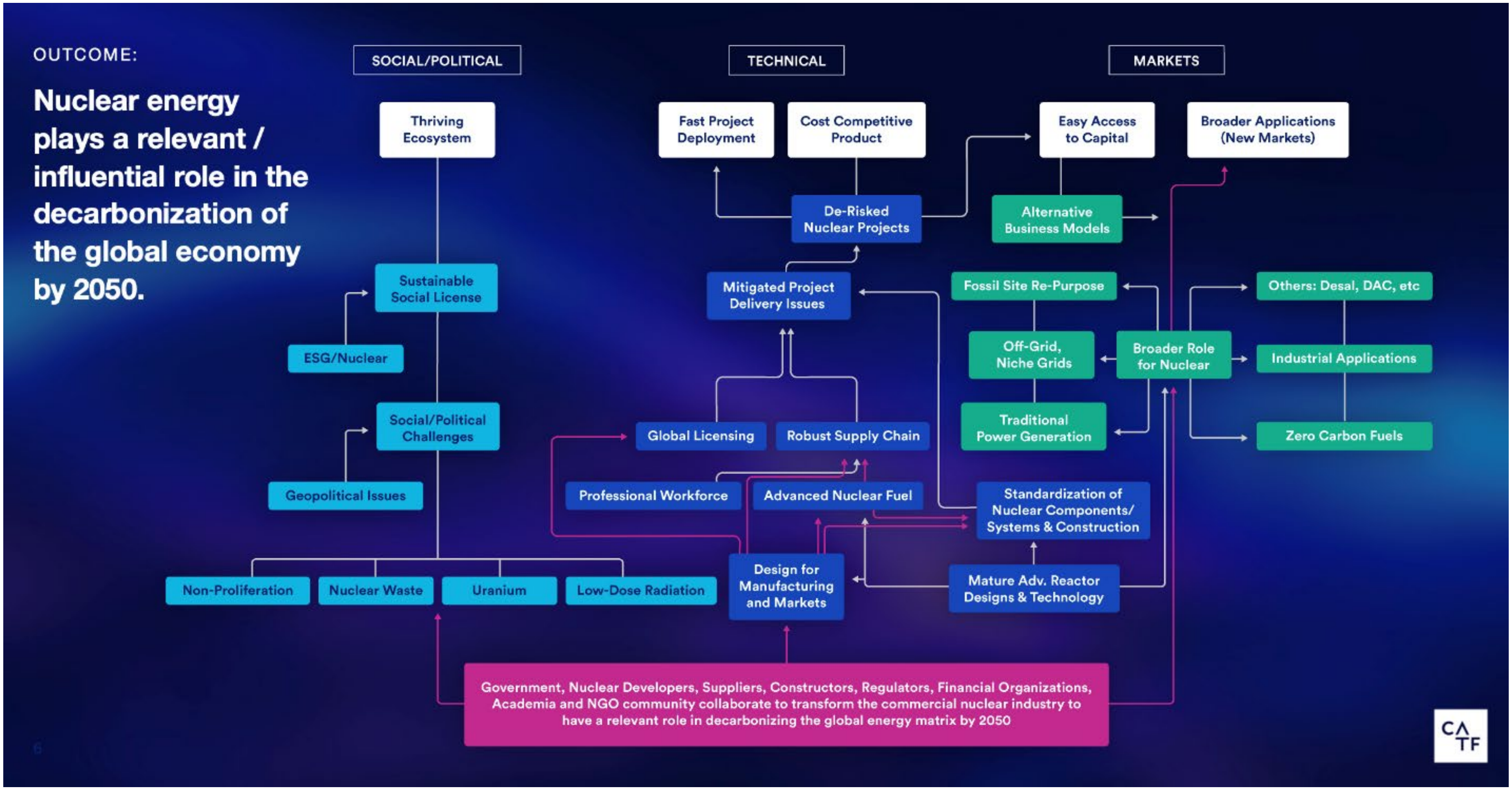
While there is no doubt ideological opposition to nuclear energy in some parts of the world, the dysfunctions of the current nuclear delivery, business and regulatory model for this technology also bear much of the blame. Remedying these dysfunctions becomes even more critical as we think about the need to rapidly expand nuclear energy across multiple regions of the world.

III. How do we fix the problem?

CATF's analysis of the nuclear scale up challenge, and recent work by McKinsey and Company,[51] has identified that the problem lies in the existence of a complex techno-economic-

[50] CATF. "Today" assumes 63.6 GW under construction, 7-year average construction time, and overnight construction costs of $6,500/kW on average. 2030-50 scenario assumes 130 GW per year of new nuclear build with a mix of large and small reactors.
[51] *See* Cramer et al., *supra* note 30.

political ecosystem with multiple barriers to scale up. The multiple problems that need solving are reflected in the schematic on the next page.



Above: What needs to happen for nuclear energy to be relevant to decarbonizing the global energy matrix by 2050. Source: CATF analysis.

For today's purposes, I will focus on a few of the most important attributes of a global nuclear energy enterprise that would make a difference to climate, energy security, and cost management.

A. A globalized commoditized, standardized and highly manufacturable and rapidly scalable "product" rather than large bespoke and complicated construction "projects."

The key to cost reduction and rapid scale-up of energy technologies historically has lay in the ability to standardize, repeat, and scale to volume.[52] When nuclear has scaled rapidly, it has done so based on the repeat build of standard designs, for example in the case of South Korea:

[52] *See generally* Abhishek Malhotra & Tobias S. Schmidt, *Accelerating low-carbon innovation*, 4 Joule 2259 (2020), https://www.cell.com/joule/pdf/S2542-4351(20)30440-2.pdf.

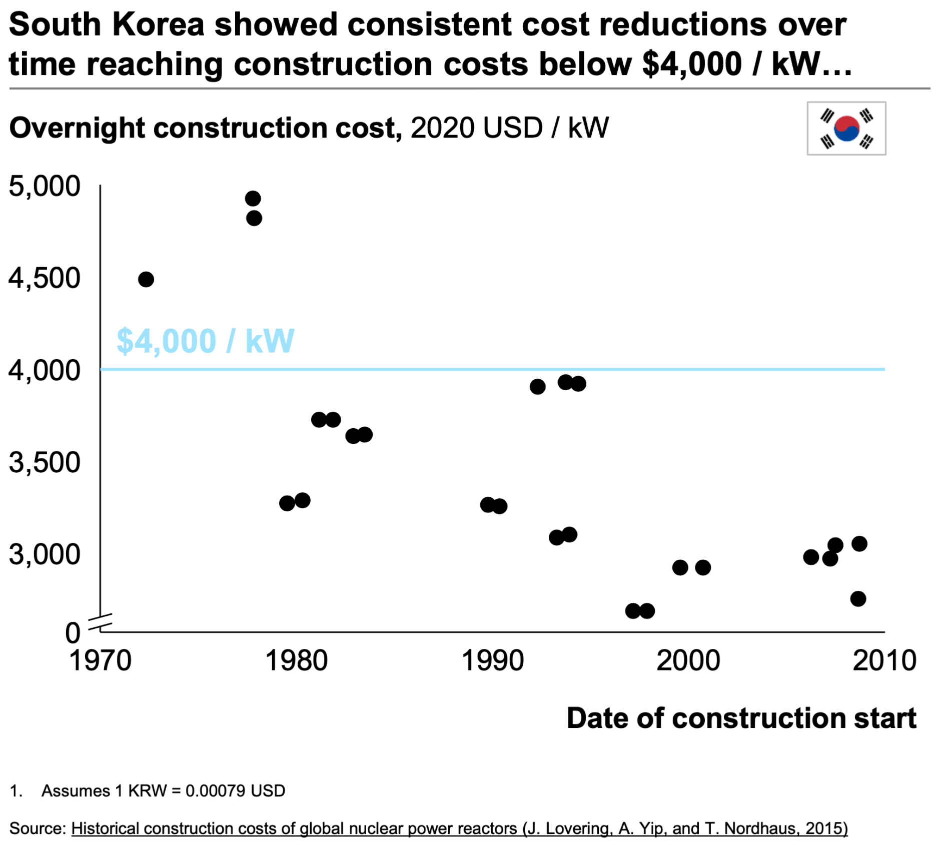
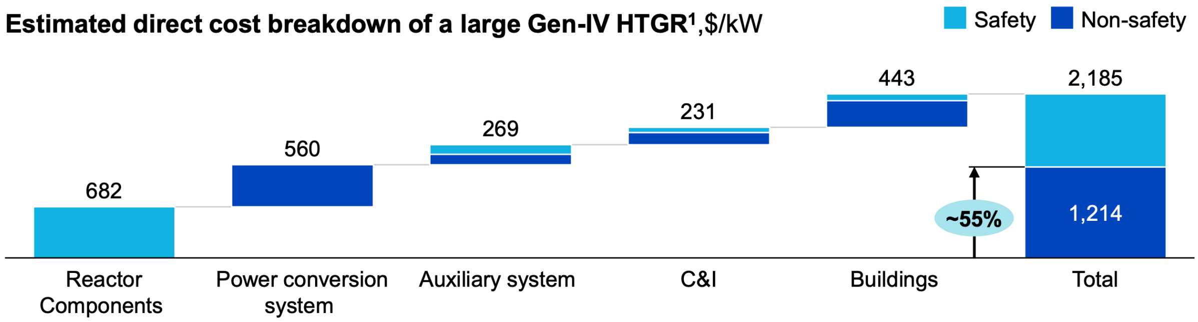


Figure 24[53]

CATF analysis suggests that, in addition to repeat of standardized ***designs***, standardized ***manufacture*** of non-safety related components, which represent 55% of total unit costs, could markedly reduce overall plant costs:

[53] CATF, based on Lovering et al., *supra* note 46).



Included components

Safety		Non-Safety		
Shutdown cooling system	Reactor pressure vessel	Generator	Most buildings	Heat exchanger
Vessel cooling system	Fuel handling, treatment, and storage	Power conversion vessel	Heat exchanger vessel	Turbine
Radiation management system	Controls and instrumentation	Hot piping	Electric system	Compressor
Core components	Coolant purification system	Ventilation and AC system	Cooling water system	Other systems

1. Note that this breakdown is based on JAEA's high-temperature gas reactor pilot, which falls into Gen-IV archetype 5; generalized learnings can still be applied to other archetypes

Source: ETI "Nuclear Cost Drivers Project" (2020), expert interviews, analogue industries

Figure 25[54]

Modular manufacture of key components overall also offers substantial labor cost savings:

[54] CATF, based on ETI, *Full Technical Report*, *supra* note 46.

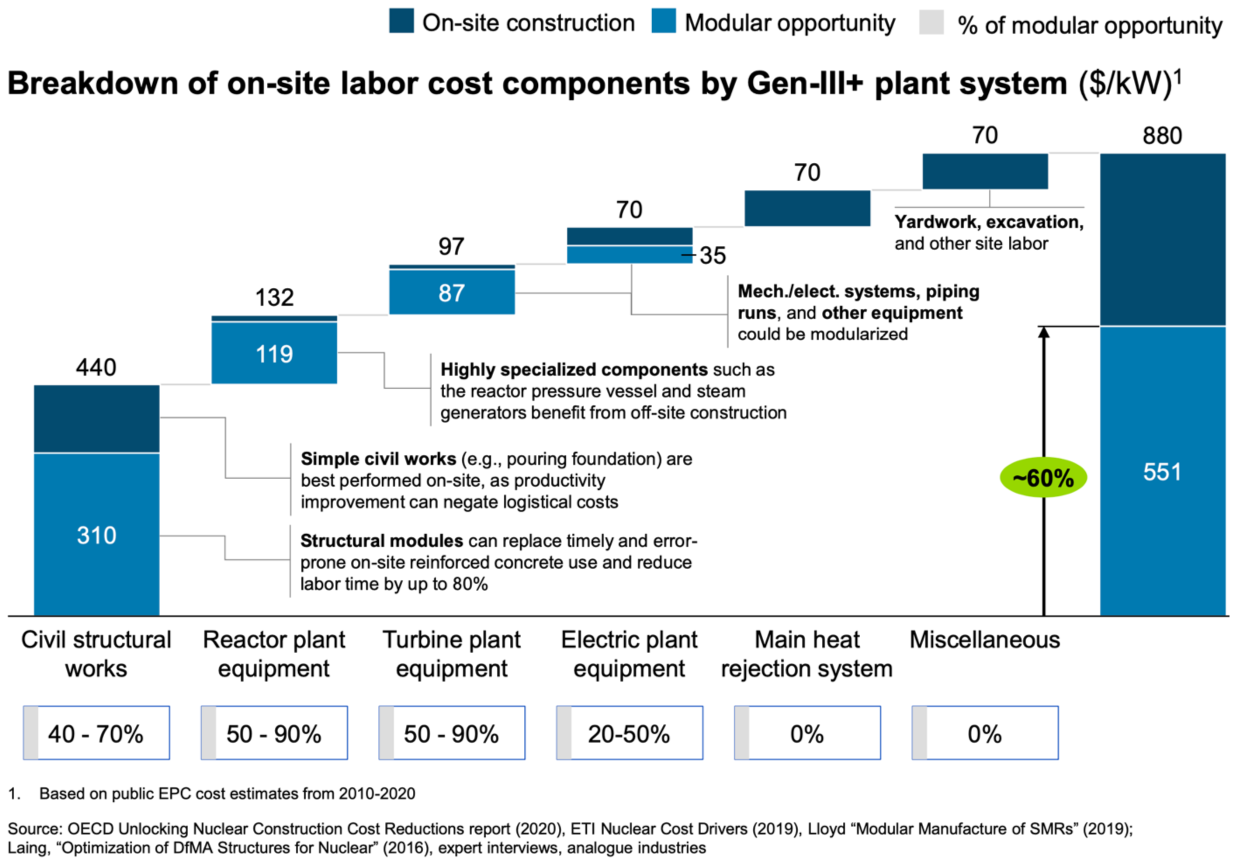


Figure 26. Source: CATF, from sources cited in figure.

The goal should be to build Boeings, not cathedrals; Corollas, not Lamborghinis; Timexes, not handmade Swiss watches.

B. Cost competitiveness

Multiple models discussed above suggest that nuclear energy delivered in the cost range of $4,000-5,000/kw would experience wide uptake in many markets.

C. Fast delivery times

A key risk associated with nuclear adoption in the West has been decade-plus delivery times exemplified by projects in Europe and the US. Other resources such as wind and solar projects (although not associated transmission) can be delivered in 1-3 years from order. For nuclear to scale, we must normalize 3-5 year delivery times, as has been achieved in Asia. Commoditization, standardization, and highly manufactured content can help.

D. Low risk to buy

Cost overruns and behind-schedule delivery make nuclear risky for off-takers. The reforms discussed here can reduce that risk.

E. Easy to license across national borders

The majority of global CO_2 emissions and energy use is already located in the developing world, and this percentage will increase in the coming decades. The U.S. represents only 15% of global energy consumption and 14% of global CO_2 emissions.

That means we could fix U.S. nuclear licensing barriers but this would not address the global climate, energy and nuclear licensing challenge, which today could entail serial reviews of the same technology by dozens of countries seeking to build it, many of which do not have the human resources to perform such reviews. Recent analysis commissioned by CATF suggests that multiple national licensing regimes can add as much as 30% to the cost of a nuclear plant:

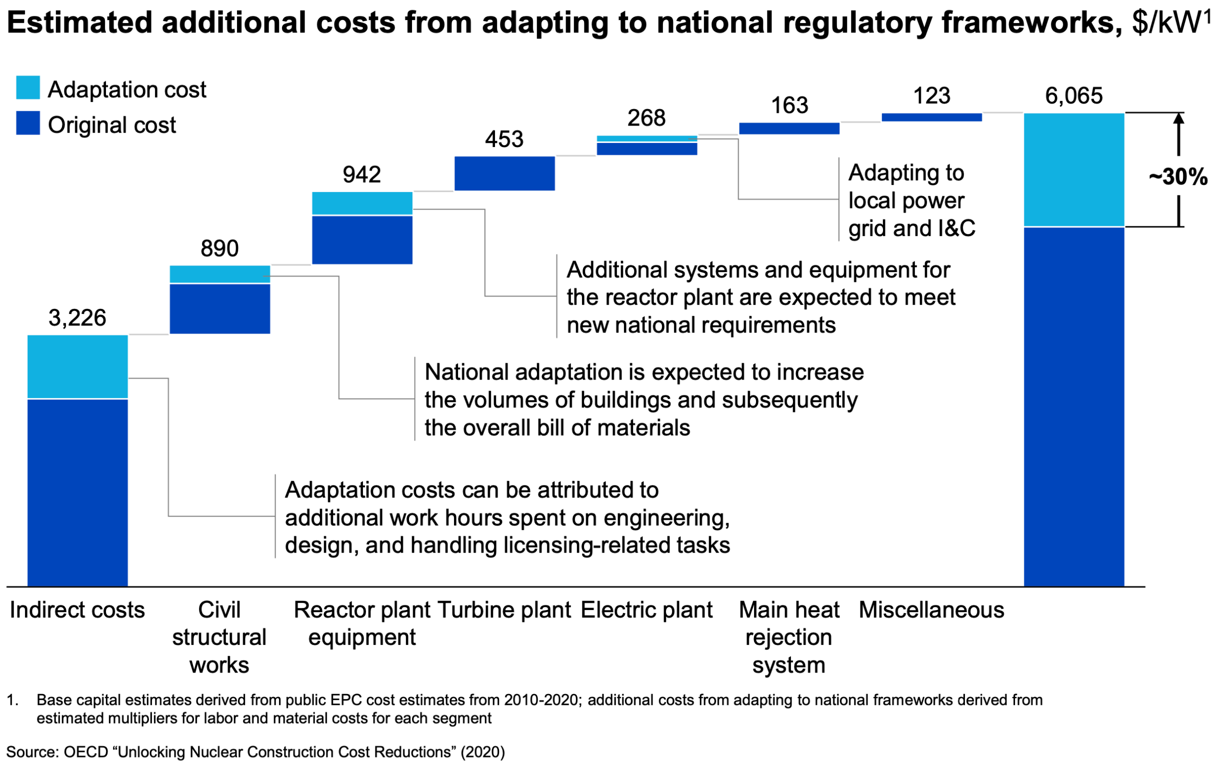


Figure 27: CATF, from sources cited in figure.

Experience in other sectors suggests that mechanisms that credit cross-border licensing to the extent possible can aid rapid scale up, as exemplified in the case of aviation:

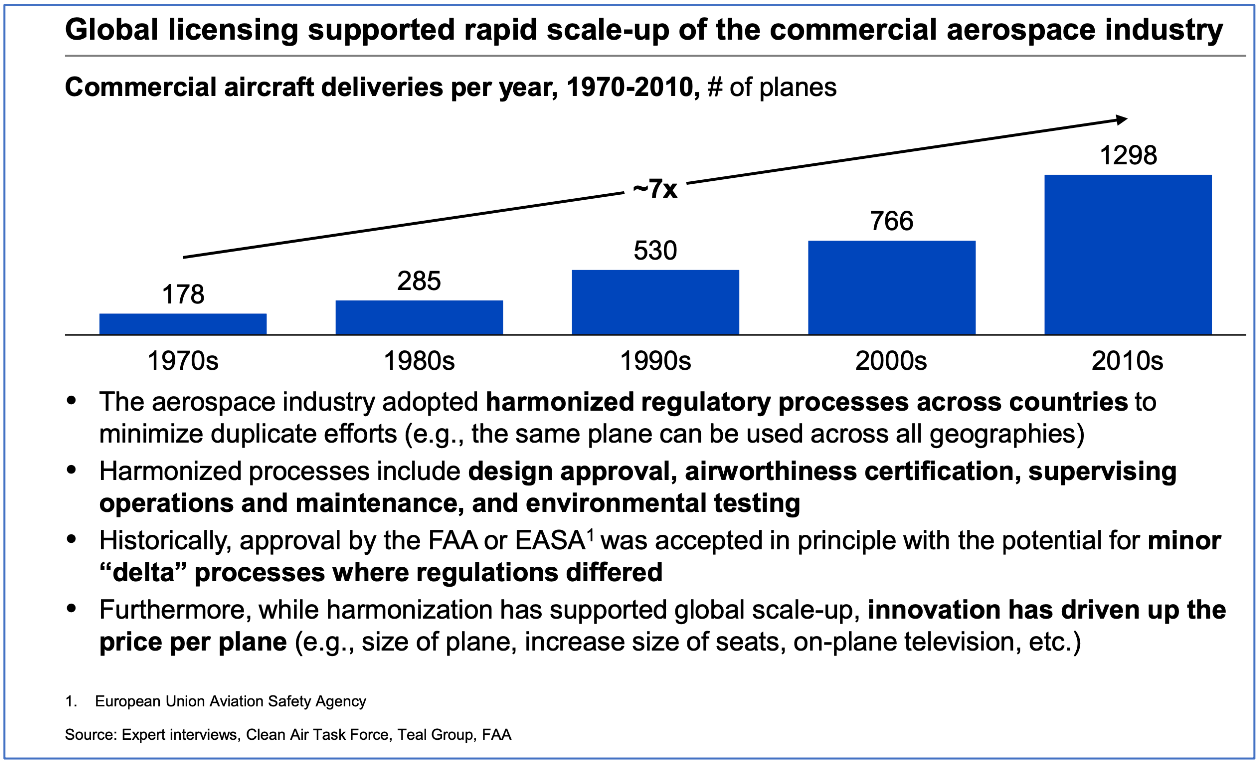


Figure 28[55]

A recent McKinsey and Company analysis suggests a general direction to be taken:

> Industry leaders, regulators, and policy makers could set up an industry consortium (or empower an existing one) to define global licensing requirements and proactively work with governments to lay out a road map for scaling up. In the natural gas industry, for example, the International Group of Liquefied Natural Gas Importers (GIIGNL)—often in cooperation with other organizations, such as the American Petroleum Institute—defines common technical standards for liquefied natural gas across the globe and works with governments to see those standards codified.[56]

F. Build enabled in nuclear newcomer countries

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[55] CATF, based on expert interviews with Teal Group and the Fed. Aviation Admin.
[56] Cramer et al., *supra* note 30.

Nuclear energy is deployed in only 30 countries today, mostly the OECD, which is not where most future energy demand or emissions risk lies. Yet licensing and oversight capability takes decades to build. A way must be found to fast forward newcomer countries to adopt and oversee new build.

G. Financeable on near-normal commercial terms

The cost of financing represents a very large percentage of nuclear construction costs, given the problems outlined above. Even as those problems are increasingly addressed, given the unique nature of nuclear technologies, it will take a very long time for nuclear power plants to be financed using commercial market mechanisms such as gas or LNG plants are today. Just as wind and solar projects required, and continue to require, mechanisms to de-risk large scale deployment, mechanisms will likely be required to de-risk large scale nuclear build.

H. Capable of decarbonizing sectors such as fuels and industrial heat as well as electricity.

Electricity represents only 20% of final energy demand today, with liquid, solid and gaseous fuels supplying the rest. Even with massive electrification, there is likely to be significant residual demand for molecules in a decarbonized world for industry and transport. Nuclear can play a substantial role in producing that zero carbon fuel through existing electrolysis technology and advanced high-temperature electrolysis.[57] Likewise, nuclear can supply large quantities of both low and high temperature heat for industrial processes and even commercial and residential

[57] *See generally* Nuclear Hydrogen Initiative, *Hydrogen Production From Carbon-Free Nuclear Energy* (2022), https://cdn.nuclear-hydrogen.org/wp-content/uploads/2022/07/25201728/NHI_NHProduction_Report_07.25.22.pdf.

end uses.[58] While electricity is likely to be the first market in which a scaled-up nuclear industry is focused, completing the decarbonization journey in molecule-dominated sectors could also be a role for nuclear.

Rolling up the multiple reforms listed above, it is CATF's position that there can be significant cost reductions for new nuclear build, even before we get to additional cost savings from Gen IV technologies:

Overnight construction cost (OCC) reduction levers from FOAK reactor to NOAK, %

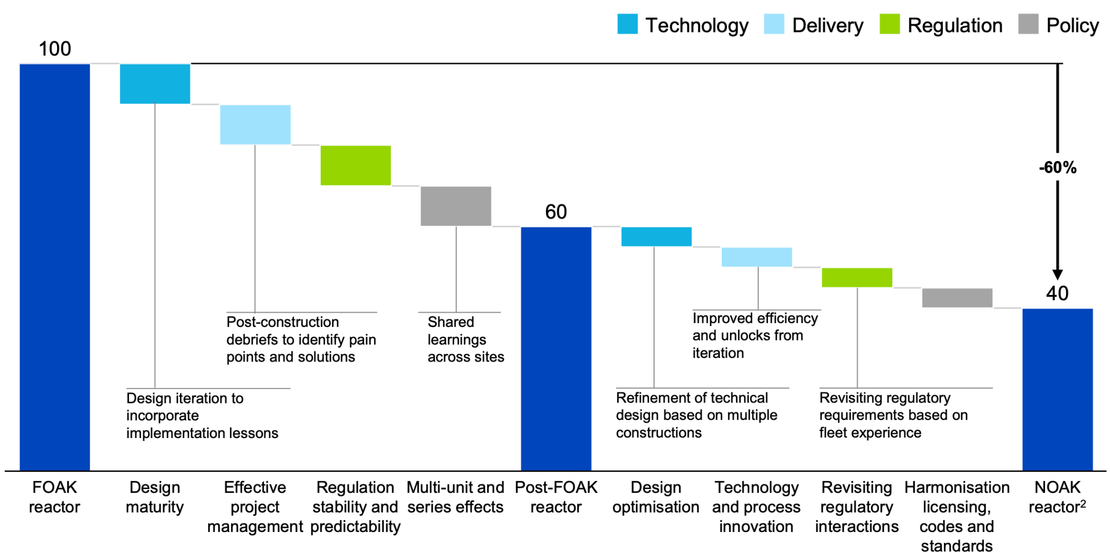

Figure 29

[58] IAEA, *Industrial Applications of Nuclear Energy* 10 (2017), https://www-pub.iaea.org/MTCD/Publications/PDF/P1772_web.pdf.

IV. What should U.S. policymakers do?

The U.S. can be at the center of this transformative effort. And America has recently taken some useful steps forward with the Energy Act of 2020, Infrastructure Investment and Jobs Act, CHIPS and Science Act, and Inflation Reduction Act to bolster nuclear energy by providing incentives for preserving the existing U.S. nuclear fleet and programs and tax credits for the commercial demonstration and deployment of advanced nuclear reactors.[59] But more ambitious action is needed at home, and on the global stage, to create a global nuclear ecosystem that can deliver hundreds of Gigawatts per year, roughly ten times the current global build rate.

Elements of a transformative strategy include:

A. A public-private collaboration to enable a commoditized product ecosystem, with maximum standardization, manufacturability and recategorization of nuclear and non-nuclear grade components

As established above, nuclear energy simply will not scale at sufficient pace if we continue to build large bespoke, customized construction "projects." We need to re-invent the nuclear delivery model to deliver something in the range of 100 Gigawatts of new nuclear build per year, comprised of perhaps 400-500 units (many if not most on multi-unit sites), the same order of magnitude in units as gas fired plants at their peak or Boeing aircraft.

[59] *See generally* Boston Consulting Group, *Impact of IRA, IIJA, CHIPS, and Energy Act of 2020 on Clean Technologies* (2023), https://breakthroughenergy.org/wp-content/uploads/2023/04/Nuclear-Cleantech-Policy-Impact-Assessment.pdf.

This is a complex task that will require strategic collaboration of the nuclear industry, the investment community and government. It will also require unprecedented cooperation across the supply chain. Future U.S. government support should focus on development of the manufacturing infrastructure, and, in support for new build, explicitly favor, or even exclusively support, nuclear products that emerge from these standardized platforms.

B. Public policies that drive large orders that enable repeat deployment of standardized designs

The history of the nuclear industry discussed above demonstrates that we have only achieved cost reduction and scale through repeat builds of standardized designs. We can no longer continue to build one-off "first of a kind" plants that end up being "last of a kind" due to the inevitable high costs of learning being loaded into a single plant or two.

Next -generation U.S. nuclear financial support for new build should explicitly favor (or even limit itself to support), whether through investment tax credits, production tax credits, or contracts for differences, multi-unit "batches" of single designs rather than individual unique designs.

C. A strategic shot program to drive nuclear CapEx costs below $4,000/kw

The U.S. nuclear program supports plenty of technical innovation, but has never had a comprehensive strategic initiative to reduce the cost of delivered nuclear energy plants analogous to the Sunshot program for solar and the Earthshot program for hydrogen. It needs one.

A good example to follow would be the United Kingdom's Office of Renewable Energy ("ORE") Catapult program, which has helped spur a dramatic transformation of the offshore wind industry. The ORE's initial goal was to reduce the levelized cost of electricity for offshore wind projects reaching their Final Investment Decision to below £100/MWh by 2020. As shown in the figure below, this goal was actually achieved four years ahead of target.

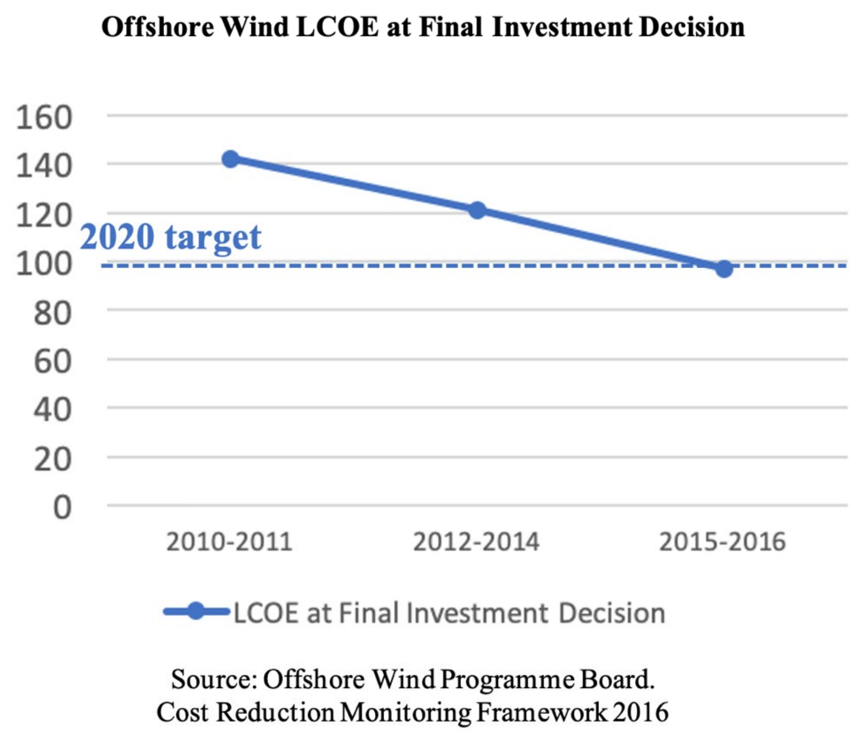

Figure 30: Source: U.K. ORE.

The ORE developed a highly detailed, measurable approach to track cost reduction progress, which ensured that it was, together with industry, prioritizing the highest value areas to direct their resources. This approach was called the Cost Reduction Monitoring Framework ("CRMF").

The CRMF was one of the ORE's most successful initiatives. It was established in 2014 by the Offshore Wind Program Board (a consortium of senior, private sector, NGO, and government representatives) and takes a "structured approach to assess the progress of cost reduction in UK offshore wind project against key milestones."[60] Progress is measured against technology innovation, supply chain, and financing milestones, each reflecting evidence from offshore wind developments in other areas of the EU as well as all over the world. Every 1-2 years, qualitative assessments (questionnaires and interviews) and quantitative assessments (project field data) are used to measure movement toward milestones. The qualitative assessment measures 70 cost reduction indicators against the 2020 milestones set for each indicator. As shown in the figure below, the 70 indicators are grouped into 14, higher level groups and weighted by cost reduction potential. By identifying and demonstrating cost reduction across key areas including

[60] Catapult Offshore Renewable Energy, Offshore Wind Program Board, *Cost Reduction Monitoring Framework 2016*, at 5 (2016), http://crmfreport.com/wp-content/uploads/2017/01/crmf-report-2016.pdf.

foundations, high voltage cables, electrical systems, access in high seas and wind measurement, the sector has transformed its overall performance on cost and delivery.

While there are obvious differences between nuclear energy and the offshore wind sector – mainly the size and complexity of nuclear, as against smaller financial and physical footprint of offshore wind turbines, many of the same program design principles could apply: isolating the key cost centers and undertaking a relentless cost reduction focus.

D. An innovation program targeted at nuclear energy applications for zero carbon fuel production and industrial heat

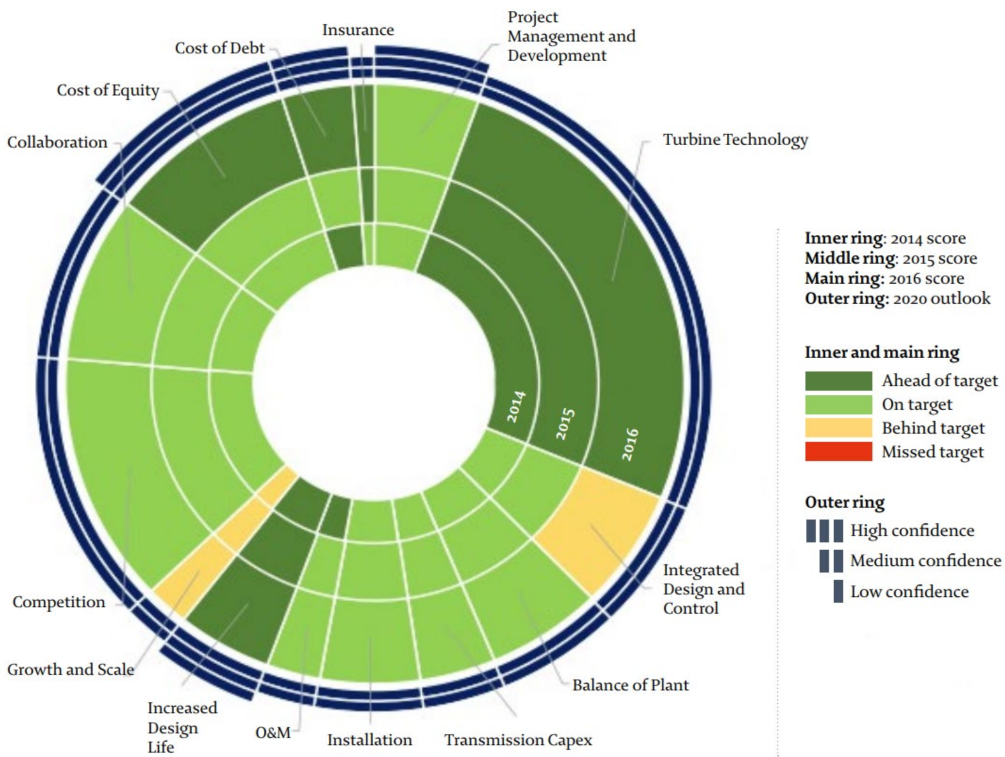

Figure 31[61]

[61] *Id.* at 8.

Nuclear energy has unique attributes that make it ideal for non-electric applications – it is energy dense, available 24 hours a day/7days a week, and produces not just electricity but also heat. (See Figure 32.) As such, it is an ideal source of energy to decarbonize the hard-to-abate sectors, both by producing zero carbon fuels like hydrogen and ammonia, as well as providing the electricity and heat for chemical and other industrial uses.[62] Programs are needed, however, to support the scaling of nuclear technologies for these applications. The DOE's H2 Hubs program already allocates funding for at least one hydrogen hub based on nuclear energy, but a broader, integrated inter-agency program aimed at scaling advanced nuclear as an industry decarbonization catalyst is needed to achieve transformative results.

[62] *See generally* IAEA, *supra* note 58.

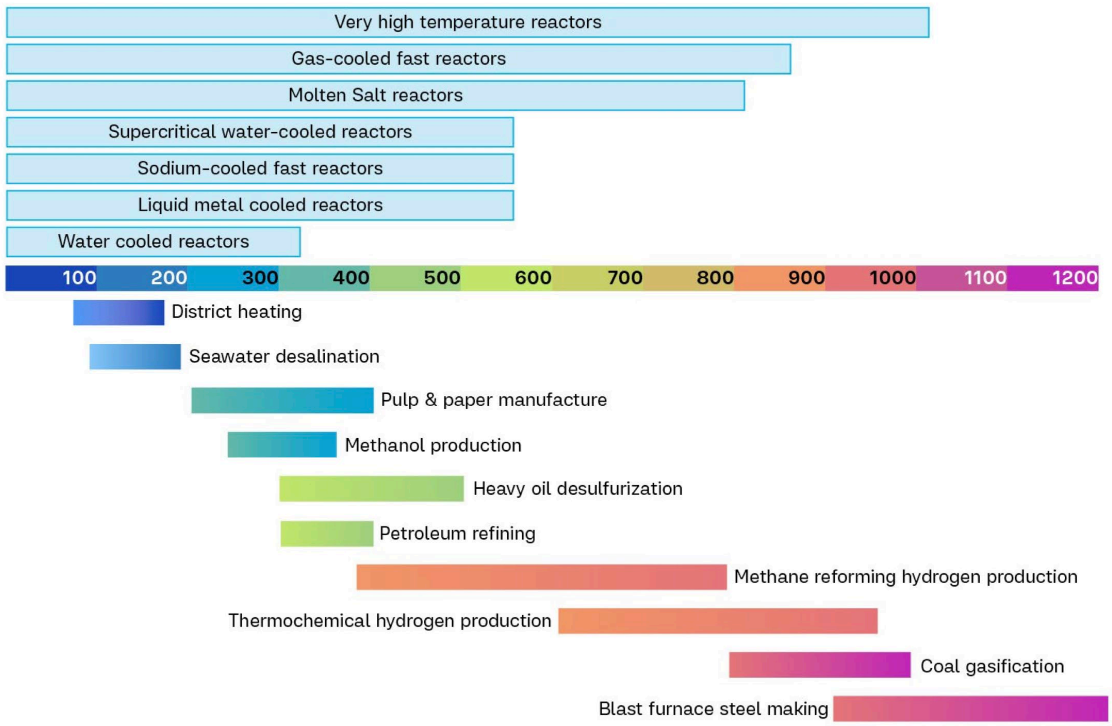

Figure 32: Advanced reactor industrial applications, referenced to Centigrade outlet temperatures.[63]

For hydrogen, such a program might focus on the following objectives:

1. Create a pathway for large-scale commercial hydrogen production from existing reactors within the next three years, starting in 2022;
2. Demonstrate hydrogen production using high-temperature steam electrolysis from advanced reactors by 2028; and
3. Demonstrate pilot thermochemical production of hydrogen within the next five years.

E. New global initiatives to facilitate multi-national design review and licensing; adoption in the developing world; and de-risked financing

[63] Nuclear Hydrogen Initiative, *supra* note 57, at 10.

The U.S. can also catalyze several international efforts that would speed deployment of U.S. nuclear energy technology:

1. Multi-national design review and licensing

In the last two decades, licensing nuclear projects has been a challenge to deployment of nuclear energy even in markets with decades of experience licensing and deploying them. A significant issue for all vendors is the lack of harmonized international nuclear licensing regimes. As a result, vendors need to undergo repetitive licensing processes in each jurisdiction with potentially different laws, requirements, and technical standards. In addition to this, when a new country decides to have a nuclear program, they need to create a nuclear regulator. There are a variety of models to choose from and in some instances, countries are pressured by the sponsoring vender's country to choose their regulatory model, so that the reactor technology does not need to be re-licensed.

This lack of harmonization, the choice of national nuclear regulatory regime and the introduction of advanced reactor technologies has seen existing and new regulators struggling to adapt away from processes designed for large light water reactors. These advanced reactor technologies use helium, liquid metals or molten salts as primary coolant and use fuel forms and types, with which few even developed nuclear regulators have any historical experience.

In addition, licensing a nuclear project in an embarking country is an order of magnitude more challenging, because along with developing the project, that country needs to simultaneously create the government infrastructure, laws and international treaties necessary for nuclear energy, including licensing and regulation of construction and operations.

The concept of a harmonized international licensing effort is not a new concept to the world, e.g., the aviation sector has the International Civil Aviation Organization ("ICAO"). As a possible model for such an institution, ICAO is a special agency of the United Nations, funded and directed by 193 national governments to support their diplomacy and cooperation in air transport as signatory states to the Chicago Convention (1944).

Such an institution would provide civil nuclear reactor technologies with processes to deliver a globally acceptable Design Acceptance Certificate ("DAC"). The DAC processes would be based on the best and most appropriate regulatory processes for the design and safety assessment of advanced nuclear reactor technologies. The vision is that when a nuclear reactor technology has completed and gained a DAC, this will be acceptable to any country that has integrated the GLA-DAC certificate and process into their regulatory regime. Thus, the DAC could offer existing regulators as well as newly created developing and embarking country regulators with a generic assessment of a technology's safety and design, prior to committing to a project. Going forward with a project and application for a license, the DAC would form a basis for the Pre-Construction Safety Report ("PCSR") with appropriate site-specific technical information and environmental impact assessments.

CATF recognizes that the licensing process for a nuclear technology is an in-country process, designed and specified by a country's nuclear regulator in accordance with their licensing model. However, we see the DAC providing a substantial savings in the global diffusion timeline.

2. **Speeding nuclear adoption in newcomer countries through an International Technical Support Organization ("ITSO")**

There are more than 30 countries considering, planning or starting nuclear power programs, ranging from sophisticated economies to developing nations. One of the biggest barriers to these programs is the lack of human resource capacity to license nuclear projects – such capacity can take decades to develop. The ITSO would pool resources of existing technical support organizations globally to provide licensing and oversight assistance to regulators in these newcomer countries, thus catalyzing their ability to develop and license new nuclear projects. A discussion of this concept can be found on CATF's website.[64]

3. **De-risked financing**

Nuclear energy could greatly benefit from a multilateral financing mechanism to financially de-risk nuclear deployment. At present multilateral banks and international financing institutions such as the World Bank will not finance this sector for a host of reasons. Yet, these institutions have a proven track record of catalyzing commercial investment at a 50x rate. Several experts have a proposed an International Bank for Nuclear Infrastructure – a dedicated international financial institution that would finance nuclear infrastructure (not just reactors, but also supply

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[64] CATF, *Establishing the Framework to Facilitate Licensing of New Nuclear Projects in Embarking Countries* (Apr. 14, 2023), https://www.catf.us/resource/establishing-framework-facilitate-licensing-new-nuclear-projects-embarking-countries/.

chain and sectors like LEU and HALEU production) in the United States and globally,[65] and the U.S. should play a leading role in standing up such an organization.

F. Provision of a "sandbox" environment for demonstration and testing of new designs

A "sandbox environment" is a regulatory approach that allows live, time-bound testing of innovations under a regulator's oversight. It allows for evidence-based decision-making and adaptive deployment of advanced technologies under a controlled safe environment while allowing institutions and regulators to experiment with innovative concepts at the edge or even outside the existing policy or regulatory framework.[66] In recent years, the relatively new approaches of sandboxes and experiments have emerged among some countries and have proven to be effective in creating a more conducive and contained space where governments, in partnerships with the private sector and other relevant stakeholders, are able to test technologies in a controlled space with a small sample group before launching them at scale, allowing them to dramatically reduce costs and limit the chances of failure and negative impacts. There are already many examples of sandboxes in the financial community, although there are already a few instances of application to the health, education, energy sectors to mention a few.[67]

In the case of nuclear energy, we offer two possible permutations. One is to designate a portion of some unpopulated federal reserve land as a nuclear prototype testing park, where private

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[65] *See International Bank for Nuclear Infrastructure,* https://nuclearbank-io-sag.org (last visited Apr. 16, 2023).
[66] *See* United Nations Secretary-General's Special Advocate for Inclusive Finance for Development, *Briefing on Regulatory Sandboxes* (2020), https://www.unsgsa.org/sites/default/files/resources-files/2020-09/Fintech_Briefing_Paper_Regulatory_Sandboxes.pdf
[67] *Inside the UK's Regulatory Sandbox: How It Fosters FinTech Innovation, Drives Multisector Growth*, PYMNTS (Jul. 20, 2022), https://www.pymnts.com/news/regulation/2022/inside-the-uks-regulatory-sandbox-how-it-fosters-fintech-innovation-drives-multisector-growth/.

industry could test or demonstrate designs in a demonstration-appropriate environment while preserving safety. Statutory change would likely be necessary for this option. Another option is to incorporate the various innovative elements of a sandbox into one or more physical areas in one or more countries to demonstrate and deploy advanced reactors designs. Microreactors – with their small size, manufacturability, and transportability – are probably best suited for such an approach.

G. Reform of U.S. NRC licensing practices for new advanced designs, to focus on performance in order to realize the promises of previous acts of Congress.

1. Components of Good Regulation

The U.S. NRC will need to be ready to license large numbers of new advanced reactors by 2030 if nuclear energy is going to play a significant role in reaching U.S. energy and climate goals. And effective domestic licensing for these technologies also can help advance their adoption globally, adding the significant climate benefit they promise. The current efforts underway at the NRC therefore are critical to the successful commercialization of advanced nuclear energy, and they need to be done right, to advance innovations while keeping to NRC's core mission to provide safe and cost-effective domestic nuclear energy.

The NRC values independence, openness, efficiency, clarity, and reliability as "Principles of Good Regulation."[68]

[68] Nuclear Regulatory Cmm'n ("NRC"), *NRC: An Independent Regulatory Agency*, at 2, https://www.nrc.gov/docs/ML2028/ML20282A656.pdf (last visited Apr. 16, 2023); *see also* NRC, *Principles of*

These values, while important, will not alone be sufficient to enable deployment of advanced nuclear energy at the scale and pace essential to meaningfully address climate change. For that to occur requires a different approach to regulation that retains concerns with safety and public health but focuses on performance standards, not specific design elements, as described further below. With the appropriate direction and support from Congress, the Commission can meet the challenge.

Effective nuclear facility licensing involves processes that are:

- Mission-focused (fulfilling the NRC's stated mission to protect public health and safety, to promote the common defense and security, and to protect the environment);
- Timely (providing licensing decisions on a timeline that facilitates commercial deployment);
- Cost-effective (avoiding excessive staff or applicant costs to resolve application questions);
- Efficient (making best use of staff and applicant time and personnel resources);
- Predictable (meeting established applicant expectations for duration, cost, and requirements for both one-time and repeatable licensing processes); and

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Good Regulation, https://www.nrc.gov/docs/ML1413/ML14135A076.pdf (last visited Apr. 16, 2023) (expounding on the agency's regulatory principles).

- Transparent (ensuring applicant, public understanding of regulatory processes and information).[69]

The most urgent issue facing the NRC today is the creation of a new licensing and regulatory framework for advanced reactors.[70] Because advanced fission reactors incorporate features that are quite different from the those characterizing most fission reactor designs deployed in the U.S. today, the current regulatory scheme is ill-suited for licensing them. In particular, the prescriptive approach of Parts 50 and 52 is aimed at the designs and related safety concerns of the existing fleet, not the varied advanced safety and operational features of the new advanced fission reactors.

This is why Congress passed the 2019 Nuclear Energy Innovation and Modernization Act ("NEIMA"), directing development by 2027, of a "technology-inclusive, risk-informed, performance-based regulatory framework" ("TI-RIPB") for advanced reactors, which is "flexible and practicable for application to a variety of reactor technologies."[71] This kind of regulatory approach would apply to all advanced fission reactor designs and technologies (technology-inclusive), using information from risk assessments to define safety performance standards based on safety analyses focused on the most important issues (therefore, be risk-informed), and regulate plants based on how they perform against these standards (be performance-based), not based only on the elements and requirements for their physical designs. If developed and

[69] Patrick White & Judi Greenwald, Nuclear Innovation Alliance, *2023 Nuclear Reform Recommendations (Discussion Draft)* 1 (2023), https://nuclearinnovationalliance.org/sites/default/files/2023-02/Discussion%20Draft%202023%20NRC%20Reform%20Recommendations%20%282_13_23%29_0.pdf.

[70] This testimony focuses on advanced fission reactors. While NEIMA included both fission and fusion energy in its definition of "advanced nuclear reactors," NEIMA, 115 Pub. L. 439, § 3(1), 132 Stat. 5565 (2019), it is CATF's position that fusion energy technologies are significantly different from advanced fission reactors, and further from market readiness, and therefore must be regulated differently and separately from advanced fission reactors and on a later time scale than the current Part 53 rulemaking being undertaken by the NRC.

[71] *Id.* § 3(14).

implemented correctly, a TI-RIPB regulatory framework could readily facilitate the effective and efficient licensing of the many designs that make up advanced nuclear energy reactors.[72]

The Commission, correctly recognizing how important it is to move a new regulatory framework forward in a timely way, in October 2020 pressed staff to develop a regulatory framework for advanced reactors by 2024, rather than the NEIMA-directed 2027.[73] And after many public meetings, the NRC staff has now submitted to the Commission on March 1, 2023 a proposed advanced reactor regulatory framework (10 CFR Part 53). Unfortunately, the current draft of the proposal still does not meet the promise underlying a truly TI-RIPB rule, but instead incorporates some of the same flawed structure and prescriptive analytic and programmatic requirements that make more conventional nuclear reactor licensing challenging today. At this point, the Commission should direct NRC staff to pull the proposed rule package back and modify it before releasing it for public comment.[74]

a. Shortcomings of the Current Proposed Part 53 Rules

It is certainly the case that some of the issues with the NRC's proposed regulatory package are due, in part, to the challenges of preparing a novel rule subject to complex constraints in a relatively short period of time. The proposal submitted to the Commission, however, also

[72] Patrick White, Nuclear Innovation Alliance, *Bridging the Gap on 10 CFR Part 53*, at 2 (2023), https://nuclearinnovationalliance.org/nia-brief-bridging-gap-part-53-rule-development.
[73] NRC, Secretary Memorandum SRM-SECY-20-0032, *Rulemaking Plan on "Risk-Informed, Technology-Inclusive Regulatory Framework For Advanced Reactors (Rin-3150-Ak31; Nrc-2019-0062)"* (2020), https://adamswebsearch2.nrc.gov/webSearch2/view?AccessionNumber=ML20276A293.
[74] An alternative approach would be for the Commission to issue a supplemental rule package making changes to the proposal, for a second public comment period. That approach is less efficient than simply pulling back the current package for modification before initial publication in the Federal Register and the opening of a public comment period.

reflects an imperfect approach to balancing regulatory predictability and flexibility in a new licensing rule, with the likely result that advanced reactor developers may choose not to rely on this optional new regulatory approach at all.

As the Nuclear Innovation Alliance points out:

> When the NRC staff began development of Part 53, they leveraged guidance developed as part of the Licensing Modernization Project (a multi-year partnership between NRC and industry to develop new regulatory guidance for non-light water reactors) and replaced technology-specific design requirements with additional safety analysis requirements and operational program requirements. This process enabled applicability to any reactor technology (increasing flexibility) but still preserved the predictability of the existing regulatory frameworks. This initial framework is now characterized as "Framework A" within Part 53. NRC staff's strategy, however, ran into challenges as stakeholders expressed concern that the new safety analysis requirements (e.g., probabilistic risk assessment) and operational program requirements (e.g., Facility Safety Program) would not be applicable and effective for some advanced reactor applicants.
>
> The NRC staff attempted to further increase flexibility by creating alternative deterministic safety analysis requirements ("Framework B"), but stakeholders still expressed concern that the process was not sufficiently flexible. The challenge of balancing predictability and flexibility using a combination of design requirements, safety analysis requirements, and operational program requirements is the basis for many differences between NRC staff and external stakeholders on Part 53.[75]

It is CATF's position that it is possible to realize NEIMA's vision of a TI-RIPB regulatory framework and resolve the differences between NRC staff and external stakeholders, without throwing out the extensive work the NRC staff has already done. Instead, aspects of the NRC Part 53 proposal could be retained, while rethinking how to balance regulatory predictability and flexibility in a more performance-based approach.

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[75] White, *supra* note 72, at 3-4.

b. How we move from where we are to where we need to be on advanced reactor licensing

Rather than a rule focused on specific design elements and safety features and operational program requirements, a reimagined Part 53 rule would be focused on performance against safety and public health standards. For example, "requirements for on-site and off-site radiation doses for normal and accident conditions, chronic and acute radioactive effluent releases, and cumulative risk metrics will apply to all advanced reactor technologies."[76] In other words, while advanced reactor designs can be widely varying, the standards for their performance would be the same across all technology types and designs. This is a new idea for the Commission. It requires the NRC to shift from ensuring compliance with design and program operational standards to become a regulator that assesses satisfactory compliance with performance standards. It is admittedly true that this will be a new way for the NRC and its staff to operate. And while it will reduce the regulatory predictability inherent in prescriptive design and other requirements, it will also support and create incentives for more innovation.

While some portions ("Subparts") of the proposed Part 53 rules should be retained, each Subpart should be revised in accordance with the following characteristics:

- An emphasis on performance criteria across the elements of safe, environmentally protective, waste reduction, thermal efficiency, and proliferation resistance set out on NEIMA;[77]

[76] *Id.* at 5.
[77] NEIMA, 115 Pub. L. 439, § 3(1), 132 Stat. 5565 (2019).

- Any technical design criteria or requirements specified should be high-level and technology-neutral;
- Any Subpart that specifies technical criteria or requirements should also specifically and clearly set forth, potentially using staged or iterative licensing approaches, for licensees to adopt alternative technical criteria or requirements. Upon NRC approval, such alternative technical criteria or requirements should be regularly incorporated into the rule, through incorporation by reference, direct final rulemaking, or an alternative efficient rulemaking process (such as a yearly rulemaking update);
- Any Subpart that specifies *how* to meet the technical criteria or requirements (i.e., methods) should specifically and clearly set forth pathways, potentially using staged or iterative licensing approaches, for licensees to adopt alternative methods. Upon NRC approval, alternative methods should be regularly incorporated into the rule, through incorporation by reference, direct final rulemaking, or an alternative efficient rulemaking process;
- All methods incorporated into Part 53 should be presented as options, with language permitting prospective licensees to submit a request to use alternatives to comply. In sum, Part 53 should provide licensees with the flexibility to choose to submit their own methods during the licensing process; and
- For Subparts that contain requirements that may conflict with designs undergoing licensing today, in addition to allowing for alternatives, the NRC Staff should wait to promulgate the rule until closer to 2027 when there is additional information on the approaches taken by the current set of advanced reactor applicants.

Congress should provide direction to the Commission about how to approach the finalization of the Part 53 rulemaking process, in order to properly incorporate the TI-RIPB framework envisioned in NEIMA. The proposed Part 53 rule does not need to be thrown out completely, but it does need a significant reworking, and should be pulled back before publication. Those existing features of the rule that are overly prescriptive and modeled on the current part 50 and 52 approach to conventional light water reactors, because they are design- or method-focused could be removed to an accompanying guidance document, or non-mandatory appendices, rather than regulatory text. New design characteristics and options that later achieve approval could be added to those appendices, to make later licensing of those designs more efficient. And the rule itself should be revised to incorporate a more flexible performance-based approach, focused on meeting safety and operational standards rather than specific designs. In this way the Commission can leverage the work staff already has done, while advancing a more flexible method for licensing that is technology neutral while preserving safety, environmental, and operational standards. We need such a flexible and comprehensive advanced reactor regulatory framework within five years.

In summary, we ask Congress to spur the Commission into action by informing the Commission that the current Part 53 proposal does not conform with the mandate of NEIMA. A number of stakeholder submissions are available that can shed light on what a workable draft rule could look like.[78] With the right Commission direction, and Congressional financial support the

[78] *See, e.g.*, Nuclear Innovation Alliance Comments on Preliminary Proposed Rule Language, "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors," Docket No. NRC-2019-0062-0249 (Aug. 31, 2022); Joint NGO [American Nuclear Society & Breakthrough Institute] Concerns Regarding the NRC's Regulatory Engagement in Developing a "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors," Docket No. NRC-2019-0062-0222 (June 15, 2022); Comments of Clean Air Task Force in Response to

capable NRC staff can create a Part 53 that provides both flexibility and predictability for advanced reactors and enables the timely commercialization and deployment of advanced nuclear energy.

2. Broader NRC Reform

The Nuclear Innovation Alliance ("NIA"), on whose Board of Directors I serve, sought input from stakeholders in the Part 53 process, and more generally, to explore the actual and perceived barriers to the effective licensing and regulation of advanced reactors, beyond the characteristics of the existing regulatory framework. Based on that work, NIA has developed draft policy reform recommendations to address these barriers, specifically identifying Commission-specific actions that could be taken by NRC management, NRC Commissioners, and Congress to increase the effectiveness of advanced reactor licensing. The following material is taken directly from an NIA summary Draft Report summarizing its work and some resulting NRC Reform Recommendations:[79]

the U.S. Nuclear Regulatory Commission's Proposed Rule on a "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors," 85 Fed. Reg. 71,002 (Nov. 6, 2020), Docket No. NRC-2019-0062-0183 (Jan. 7, 2022); Nuclear Innovation Alliance Comments on Preliminary Proposed Rule Language, Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors, Docket No. NRC-2019-0062-0168 (Nov. 5, 2021); Joint NGO Comments on Preliminary Proposed Rule Language, "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors," Docket No. NRC-2019-0062-0120 (July 23, 2021); and American Nuclear Society (ANS) Comments on the Nuclear Regulatory Commission (NRC) Rulemaking for a Risk-Informed, Performance-Based, and Technology-Inclusive Regulatory Framework for Advanced Reactors (10 CFR Part 53), Docket No. NRC-2019-0062-0058 (Mar. 3, 2021) (all describing concerns with the NRC's approach and offering ideas for alternative approaches to the rule).

[79] White & Greenwald, *supra* note 69, 2-5; *see also id.* at Appendix "Detailed NRC Licensing Barriers and Potential Policy Solutions" (describing NIA's study effort and results).

Four barriers were identified as cross-cutting challenges to the efficient and effective licensing of advanced reactors by the NRC:

- Challenges to hiring, training, and retaining qualified staff and management with technical and project management expertise necessary to lead licensing reviews of advanced reactors;
- Insufficient accountability for NRC staff in terms of schedule, breadth of scope, depth of review, or regulatory basis for technical and environmental reviews of advanced reactors;
- Inadequate support and prioritization of innovative practices or processes for reviews, licensing, communication, and management; and
- Inconsistent stakeholder understanding and trust in the regulatory process.

Potential policy solutions for each of these cross-cutting barriers are described below based on the roles that NRC management, NRC Commissioners, and Congress can play in making advanced reactor licensing more effective. Table 1 summarizes highest-priority reform recommendations for NRC management, NRC Commissioners, and Congress for the three cross-cutting licensing barriers. This table provides a summary of the set of policy solutions that could have the greatest impact on the effective licensing of advanced nuclear reactors by the NRC.

Table 1. Cross-cutting NRC barriers and policy recommendations for effective licensing of advanced reactors

Barrier	*NRC Management Solutions*	*NRC Commission Solutions*	*Congressional Solutions*
Challenges to hiring, training, and retaining staff and management with technical and project management expertise necessary to lead licensing reviews of advanced reactors	1. Review and improve hiring and retention practices to both ensure adequate workforce but also promote staff development 2. Review and improve succession/knowledge management planning for projects, branches, and other critical activities 3. Take advantage of existing hiring flexibility to recruit top-tier technical staff and management	Engage third party expert or organization to: 1. Assess impacts of current corporate support caps on hiring and retention capabilities 2. Assess and improve hiring process to accelerate hiring of experienced external technical staff 3. Assess middle and upper management to determine effectiveness and effects on staff retention, and improve management training and practices accordingly	1. Increase or modify corporate support caps for NRC to enable more effective hiring, retention, and staffing 2. Establish Blue Ribbon Committee to conduct a one-year review and audit of NRC effectiveness - heavily weighted with former NRC staff, management, and senior leadership. 3. Provide NRC with more flexible hiring and compensation authority for technical positions within agency (like the Security and Exchange Commission)

Barrier	*NRC Management Solutions*	*NRC Commission Solutions*	*Congressional Solutions*
Insufficient accountability for staff regulatory reviews in terms of schedule, breadth of scope, depth of review, or regulatory basis for licensing review decisions	1. Senior management to hold middle management and staff accountable for completing reviews and reaching conclusions on safety 2. Refocus and improve staff project management and oversight to help create more effective regulatory reviews 3. Provide resources for skilled project managers to receive technical input from other NRC staff experts to reduce reliance on project managers as technical experts for licensing questions 4. Improve middle-managers' project-management skills to increase technical staff focus on regulatory reviews 5. Re-introduce servant leader training as earlier implemented at NRC	1. Prioritize project management training and peer learning for NRC staff and development of technical support for Project Managers and senior leadership 2. Prioritize staff and management accountability on licensing activities 3. Prioritize staff and management focus on implementing development or adoption of project management tools	1. Increase or modify corporate support cap for NRC to provide adequate resources for management 2. Increase or modify NRC off-fee funding to enable greater project management training for NRC staff and management

Barrier	*NRC Management Solutions*	*NRC Commission Solutions*	*Congressional Solutions*
Inadequate support and prioritization of innovative practices or processes for reviews, licensing, communication, and management	1. Identify barriers to the development of new regulatory processes or approaches 2. Support and incentivize staff development and testing of new regulatory approaches 3. Have Office of Regulatory Research identify long-term regulatory needs/questions important to agency 4. Engage with FAA and FDA to share lessons learned across federal technology licensing processes	1. Foster and create a culture of innovation, including seeking external stakeholder input, to address regulatory challenges and improve staff activities 2. Create a new internal group at NRC focused the development and implementation of regulatory innovation including reporting requirements on steps taken to incorporate innovative approaches into agency licensing 3. Assess and improve the current role and priorities of the Office of Regulatory Research to ensure that proactive research is undertaken and that it is effectively handed off in order to support the development or improvement of the regulatory process.	1. Direction and funding to NRC Commission to develop an Office of Regulatory Innovation 2. Direction to have GAO or NRC assess and draw lessons from regulatory innovation in other sectors (e.g., FDA, FAA) and report on process improvements or changes 3. Increase or modify NRC off-fee funding to enable greater project management training for NRC staff management 4. Provide off-fee funding to expand and accelerate future focused research at the NRC in order to support the development of regulatory processes that can enable industry to utilize new or novel technologies while the NRC can still meet its public health and safety mission

H. Take measures to establish a new model for low dose rate radiation standards to support appropriate safety regulation

Low dose radiation standards underlie public policy on nuclear energy, both for power operations and waste management. But these standards are based on a questionable model called Linear-No-Threshold ("LNT"), which is itself based primarily on nuclear weapons-based data. Despite considerable counterevidence and the existence of competing models, the continued use of LNT has led to "strict radiation safety regulations that have increased the compliance costs for all uses of radiation, including nuclear medicine."[80] Such strict regulations have also contributed to a fear of nuclear energy that may not be fully justified by the actual risk.

There is basic scientific research that needs to be conducted in order to establish the actual risks from low dose rate radiation exposure, instead of using a linear extrapolation from high dose, acute exposures such as the Hiroshima atomic bomb explosion. This research can have significance, not only on nuclear safety and clean-up standards, but also for the use of nuclear medicine, such as CT scans, by ordinary citizens. A multi-disciplinary, multi-year, research effort is necessary in order to reach a more scientifically grounded foundation regarding the actual health risks and effects of low dose rate radiation.

Congress has repeatedly made clear that we need to explore whether the LNT model can be replaced by a modern, scientifically-rigorous model. In 2020, Congress passed the Low Dose Radiation Research Act, authorizing such research and since then has repeatedly directed in

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[80] Mohan Doss, *Are We Approaching the End of the Linear No-Threshold Era?,* 59 J. Nuclear Medicine 1786 (2018),
https://jnm.snmjournals.org/content/59/12/1786.

Appropriations Report language that DOE begin such a program of research, most recently indicating that up to 20 million dollars could be used by DOE for this purpose.

There is little question about what needs to be done. In the Low Dose Radiation Research Act, Congress directed that the National Academy of Science conduct a report outlining such a research program. Pursuant to the law, the National Academy of Sciences completed this Report in 2022 and detailed what a successful low dose radiation research program would look like.[81] Thus far, however, the DOE has failed to implement the NAS recommendations and has almost entirely ignored the Congressional directive to start such a program, using the relevant funds to bolster ongoing, virtual research and computational modeling largely relevant to other issues. This failure to heed the clear congressional directive continues to set back progress in understanding the real risks of low dose rate radiation. DOE must act now to implement this important initiative.

I. Measures to ensure socially and environmentally responsible uranium sourcing

All mining, including uranium mining, carries the potential for significant negative social and environmental impacts. Issues of concern typically include impacts in relation to: biodiversity; communities; decommissioning; greenhouse gas emissions; human rights; Indigenous Peoples' rights; labor rights; noise, emissions and waste management; operational health and safety; water. Issues such as local beneficiation, transparency, stakeholder engagement, *etc.* are also

[81] Nat'l Acads., *Leveraging Advances in Modern Science to Revitalize Low-Dose Radiation Research in the United States* (2022), https://nap.nationalacademies.org/resource/26434/Low-Dose_Radiation_Highlights.pdf.

significant. Set against the potential negative impacts is the potential for direct and indirect employment, skills training, and local and national development.

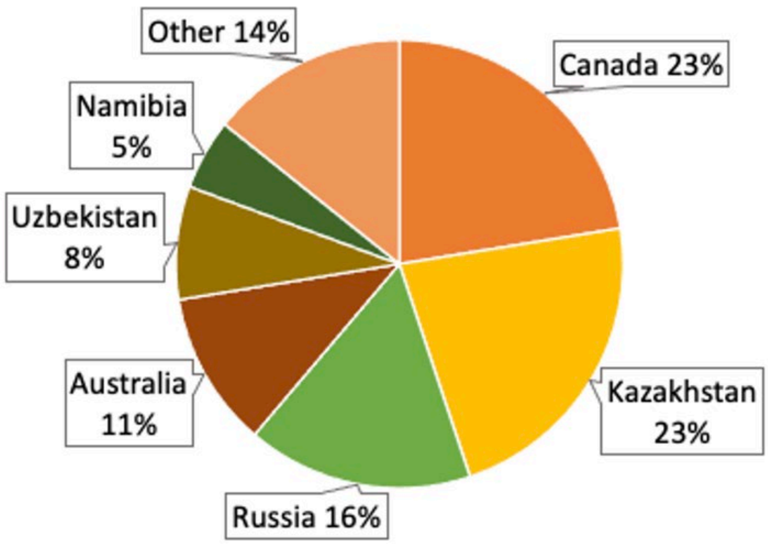

Figure 33: U.S. uranium imports by country (2020). Source: CATF from U.S. EIA[82]

Uranium mining attracts additional attention due to the potential health consequences of radioactivity, and as a consequence of the legacy of uranium mining on Indigenous Peoples' lands. Major deposits of uranium have been located on or near to Indigenous Peoples' lands, including for example in relation to the Ranger Uranium Mine in Australia, Navajo Nation and Lakota Nation lands in the U.S., and lands of first nation communities in Saskatchewan, Canada. In the U.S. in particular the treatment of Navajo men and communities associated with uranium mining in the 1940s and 1950s, their exposure to uranium dust and radon gas and long-term impacts on water sources has left a pernicious legacy.

[82] U.S. EIA, *Nuclear explained: Where our uranium comes from* (Jul. 7, 2022), https://www.eia.gov/energyexplained/nuclear/where-our-uranium-comes-from.php.

If nuclear energy is to be developed at ten times current rate, as we propose, there will be a commensurate increase in uranium mining, much if it sourced globally. Measures to ensure environmental and social responsibility are likely to be essential for the increased volumes to be realized. Setting environmental and social standards for uranium production both domestically and for imports would be an important step for the US.

J. A whole-of-government program to facilitate re-use of retired fossil generation sites for new nuclear build

Numerous reports in the U.S. and overseas have identified the opportunity to re-use existing coal plant sites for new nuclear build, which can offer advantages based on existing transmission, water, and support from local communities.[83] Existing Federal authorities and programs can facilitate the conversion of energy footprint sites. Federal financing will certainly be a key part of the picture. However, financing alone will not be sufficient. There will also be a significant role for the Federal government in providing planning and convening resources. In addition, regulatory innovation will be required – and coordination between the NRC and multiple permitting agencies -- to ensure timely and safe re-use of existing coal sites for new nuclear build.

[83] J. Hansen et al., *Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants* (2022), https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/C2N2022Report.pdf; John Jacobs & Lesley Jantarasami, Bipartisan Policy Center, *Can Advanced Nuclear Repower Coal Country?* (2023), https://bipartisanpolicy.org/report/nuclear-repower-in-coal-country/; Staffan Qvist et al., *Retrofit Decarbonization of Coal Power Plants—A Case Study for Poland*, Energies, Dec. 28, 2020, https://www.mdpi.com/1996-1073/14/1/120.

Conversion of energy footprint suites will require a range of different types of assistance—from site identification, to technical and financial support for site remediation, to financial support for construction of the clean energy resources. Furthermore, it will be important to work closely with local, state, and tribal officials—as well as affected communities. Federal agencies can play an important role as convenors, providers of information on best practices, and developers of worker retraining programs.

There are available models for this kind of comprehensive and site-tailored assistance. For example, DOE—working with the Commerce, Transportation, and Interior Departments—recently packaged together a set of policies to promote the development of offshore wind. This package includes Programmatic Environmental Impact Statements of prime sites, joint research and data-sharing programs with private industry, and financial support from the LPO.[84]

The Biden Administration should create an inter-agency "whole-of-government" task force to lay out and implement a roadmap for mobilizing federal resources on the financial, technical and regulatory front to realize this potential.

K. Measures to ensure availability of high assay low enriched uranium to support advanced technology deployment

High assay low enriched uranium ("HALEU") is critical to establish a commercial advanced nuclear fuel cycle. Not only will HALEU fuel will be required by many advanced reactor designs

[84] The White House, *Fact Sheet: Biden Administration Jumpstarts Offshore Wind Energy Projects to Create Jobs* (Mar. 29, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/.

under development, nine of the ten advanced reactor designs selected for funding under DOE's Advanced Reactor Demonstration Program, including two demonstration reactors to be built within the next seven years, will need HALEU. However, HALEU is not yet commercially available in the U.S., and Russia is the only commercial source of HALEU globally.

The Inflation Reduction Act appropriated $700 million to the Advanced Nuclear Fuel Availability Program to support the domestic production of HALEU, but more is needed to ensure enough HALEU is available to catalyze the industry. That is why CATF signed on to a letter to the House and Senate Energy and Water Appropriations subcommittees in March of 2023 asking for robust funding. Accordingly, CATF is also proposing up to $200 million in FY24 appropriations to support HALEU availability. Congress should do what is necessary to see the availability program to fruition.

L. Establishment of a new national regime for managing nuclear waste

The current regime for storing spent nuclear fuel at power plants, while highly safe, is likely not a long-term solution. The Government Accountability Office estimates the federal government has already paid affected utilities almost $9 billion due to legal liability for not meeting the terms of the Nuclear Waste Policy Act, and that amount continues to rise.[85] It is CATF's position that a new approach is needed that allows for multiple options for managing nuclear waste.

[85] U.S. Gov't Accountability Off., GAO-21-603, Commercial Spent Nuclear Fuel (2021), https://www.gao.gov/assets/gao-21-603.pdf#%5B%7B%22num%22%3A108%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22XYZ%22%7D%2C0%2C99%2Cnull%5D.

First, the federal government should resume progress on a long-term geologic repository under a consent-based siting process, such as has been successful in countries like Sweden and Finland[86]. Laudably, the DOE has already commenced and is gaining experience with such processes for an interim storage facility.[87] Second, private sector innovation should be encouraged in nuclear waste management, to include more efficient fuel utilization, deep borehole technology, and fuel recycling.

Conclusion

Nuclear energy holds great promise to solve the world's trilemma of climate, energy security and cost. But the national and global ecosystem surrounding nuclear energy is profoundly dysfunctional and will not deliver. Incremental change will not do; as detailed in this testimony, we need entirely new business, delivery, financial, and regulatory models to fix the problem. It is time to go big or go home. The U.S. can be a catalyst and provide leadership for the necessary systems change. CATF stands ready to work with our national leaders to make this transformation effort a success.

[86] Cindy Vestergaard et al., *Geological Disposal of Spent Nuclear Fuel*, Stimson (Nov. 22, 2021), https://www.stimson.org/2021/geological-disposal-and-spent-nuclear-fuel/.
[87] U.S. Dep't of Energy, Office of Nuclear Energy, *Consent-Based Siting*, https://www.energy.gov/ne/consent-based-siting (last visited Apr. 16, 2023).