Before the United States House of Representatives
Committee on Energy and Commerce
Subcommittee on Energy

Building a 100 Percent Clean Economy: Advanced Nuclear Technology's Role in a Decarbonized Future

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

March 3, 2020

SUMMARY OF TESTIMONY

Decarbonizing America's economy by midcentury is a stiff challenge. We not only need to remake the 80% of America's energy supply (and 60% of electricity) that is powered by uncontrolled fossil fuels; we may need to double total electricity supply by 2050 to help decarbonize industry, transport and buildings.

Fortunately, we have several options to achieve that goal, especially in the electricity sector. We have made strong progress on wind and solar energy, which now supplies 3.5% of America's total annual energy, and 9% of our electricity. We have emerging potential renewable sources such as super hot rock geothermal. We have demonstrated carbon capture and storage that removes carbon from fossil fuel use either before (to make hydrogen) or after combustion, and there many innovative technologies on the horizon that could make those technologies less expensive. And finally, we have America's largest zero carbon source of electricity, nuclear energy, providing 20% of total power consumption.

The question for this hearing is whether nuclear energy can play a significant role in a future zero carbon economy. The evidence suggests it can, but there are many challenges to address, just as there are with all other zero carbon energy sources.

The advantages of nuclear energy are, first, that it is firm or "dispatchable," and not dependent on weather, allowing us to avoid very expensive energy storage to ride through the weeks and months when wind and sun are at low ebb in most regions of the country. Second, nuclear energy plants are very compact, taking up a hundred to a thousand times less space per unit energy produced than an equivalent amount of wind and solar at very high penetrations, and significantly less transmission capacity; high power density may be a valuable attribute in a nation where siting any energy facility is controversial. And because nuclear units produce so much power, we can build them quickly when conditions are right; France eliminated 80% of its grid carbon emissions in two decades through a scale up of nuclear energy. Third, nuclear energy can provide carbon-free heat to displace fossil fuels in industrial processes and buildings, and to efficiently create hydrogen, a zero carbon fuel that can be combusted for electric power without carbon emissions in natural gas turbines and which will be needed for decarbonizing the industrial and transport sectors. While in theory we could provide 100% of our electricity and other fuels with renewable energy, that is a risky bet; more options are likely to increase our chance of success.

At the same time, nuclear energy faces many challenges. Foremost among these are the high cost and delays associated with recent American and European projects. However, high cost and delay are not inevitable, as best construction and project management practices and the building of standardized multiple units have shown elsewhere in the world. In addition, advanced reactor designs using different coolants and other innovations could lower costs even further. We must also address another triad of issues: waste disposal, weapons nonproliferation, and public perception of safety. Some, but not all, of these issues, can be addressed through advanced reactor designs.

To make nuclear a scalable option for future decarbonization, we should:

- Preserve the existing nuclear fleet to lower emissions during the transition and preserve our knowledge and sites
- Create market demand for advanced nuclear through government support, as we did for wind and solar, to achieve scale, and reduce costs through learning-by-doing
- Support R and D for advanced nuclear, particularly focusing on innovative business models, load following, and hydrogen production
- Continue our progress in vigilant but fit-for-purpose regulation that enables advanced reactor innovation, and support international harmonization of nuclear safety regulation
- Resolve key nuclear waste challenges
- Revive a federal research program on low dose radiation health impacts

The Energy and Commerce Committee has an immediate opportunity to promote deployment of advanced nuclear technologies through passage of the power purchase agreement (PPA) provisions of Rep. Luria's Nuclear Energy Leadership Act (NELA) H.R. 3306, which would leverage the purchasing power of the federal government to bring innovative nuclear technologies to market. NELA enjoys strongly bipartisan support of 24 co-sponsors roughly evenly split between Democrats and Republicans. NELA is also supported by a diverse set of stakeholders from the U.S. Chamber of Commerce and National Association of Manufacturers to the International Brotherhood of Electrical Workers and The Nature Conservancy. The recently released CLEAN Future Act recognized this opportunity and included these provisions in its innovation title.

Chairman Rush, Ranking Member Walden, and Distinguished Members of the Subcommittee,

My name is Armond Cohen and I am Executive Director of Clean Air Task Force, an environmental organization dedicated to the protection of Earth's atmosphere, with a strong focus on strategies to commercialize carbon-free energy. I appreciate the opportunity to testify today.

The scale of the climate challenge and the options

Earth's atmosphere has more carbon dioxide than at any time in human experience, most of it added in the last half century. To preserve a natural world anything like we have known, we will likely need to build a 100% carbon-free energy economy by 2050, and then progressively withdraw some of the carbon we've put into the skies already. Achieving climate stabilization targets, as Figure 1 below shows, will require essentially zeroing out energy-related greenhouse emissions from all sectors of the economy around 2050. That means not just the electric sector, but also transportation, industry, buildings and agriculture. And we must accomplish this feat as global demand for energy could as much as double in the coming decades, as developing economies get richer. So, U.S. comprehensive climate legislation with the goal of zero-carbon emissions by midcentury must cover all of these sectors.

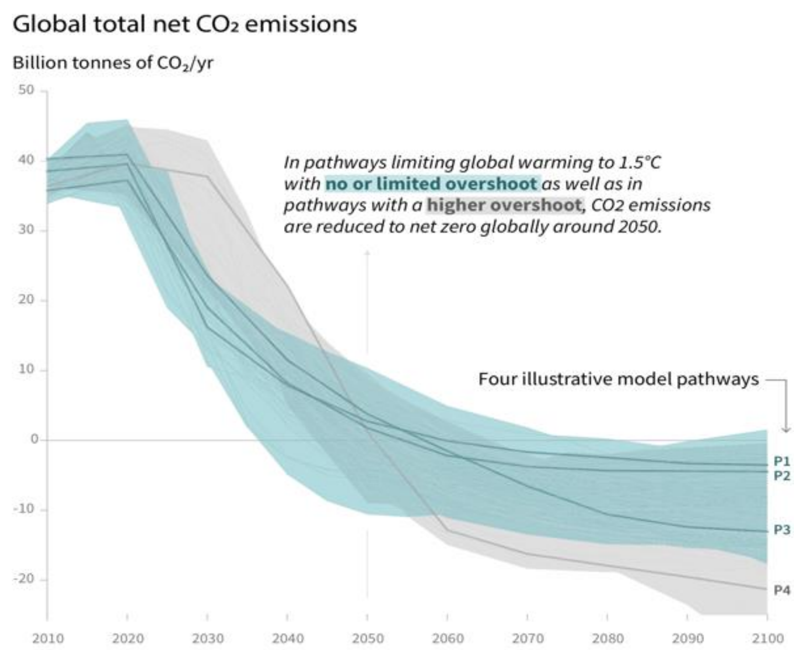

Figure 1: Pathways to limit global temperature to the Paris Agreement target of no more than 1.5 degree warming (Source: IPCC, Special Report: Global warming of 1.5^0 C, 2018)

Although there are significant challenges, the pathway to a carbon-free economy is in concept straightforward: replacing existing greenhouse gas-emitting energy sources with zero-emitting resources and building additional zero-emitting resources to meet future growth. Eventually, we will also likely need to progressively withdraw some of the carbon we have put into the atmosphere already[1].

Decarbonizing America's economy by midcentury is a stiff challenge. We not only need to remake the 80% of America's energy supply (and 63% of electricity) that is powered by uncontrolled fossil fuels; we may need to double total electricity supply by 2050 to help decarbonize industry, transport and buildings.

I was honored in 2018 to be part of a group of authors who published an article in *Science* entitled "Net-zero emissions energy systems" which explored this challenge.[2] The key insight of that article is that it is best to think of a net-zero greenhouse gas emissions energy economy as a ***system*** of complementary and overlapping parts. These parts include zero-carbon electricity, fuels, storage, low-carbon industrial processes, and carbon capture and sequestration from fossil fuel use. A greatly simplified schematic picture of such a system can be seen in Figure 2 below.

---

[1] This testimony addresses creating a carbon-free energy supply. It does not address energy efficiency improvements, carbon in agriculture, which represents roughly 25% of the greenhouse gas emissions problem, or carbon dioxide removal.

[2] Davis, Steven J., et al. "Net-zero emissions energy systems." *Science* 360.6396 (2018): eaas9793.

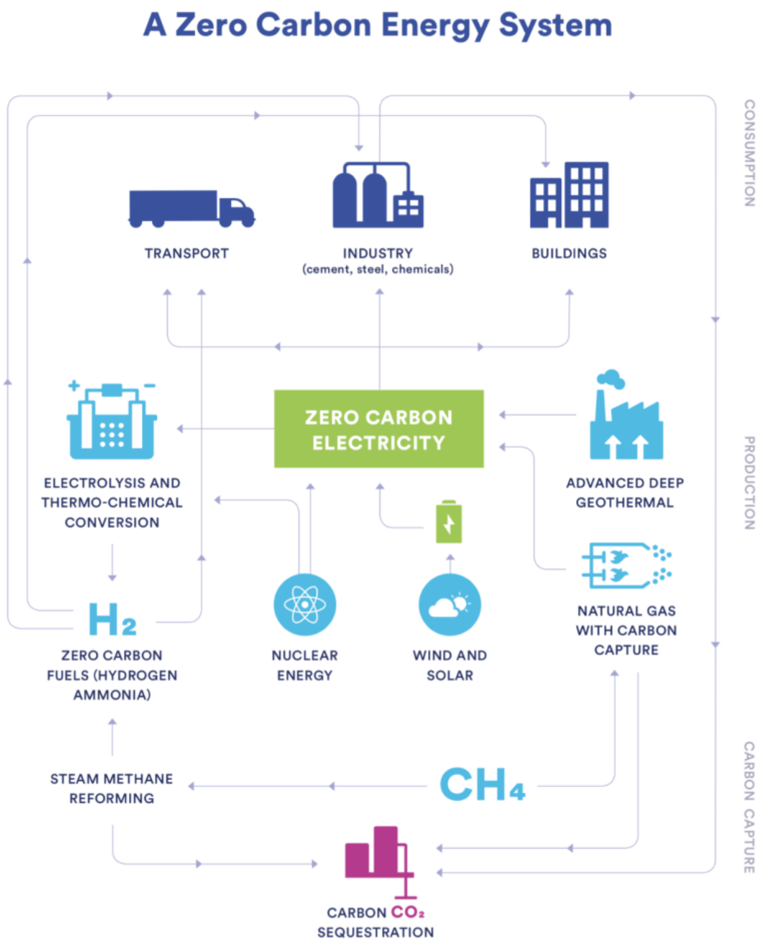

Figure 2: Schematic of a zero-carbon energy system (Source: Clean Air Task Force, 2019)

Building this zero carbon energy system is an enormous lift. Let's just take electricity. Figure 3 below shows the rate at which we will have to scale zero carbon electricity to decarbonize the grid by midcentury, assuming more electrification to decarbonize other sectors. To do so, we would need to build as much as 35 average Gigawatts per year every year from now until 2050. This is ***roughly five to ten times the rate*** at which we have ever deployed zero carbon technology.[3]

[3] And it is roughly three times the rate at which we deployed all generation technologies, predominantly gas, which are much faster and easier to site, in the 28 years from 1990 to 2018. See https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php

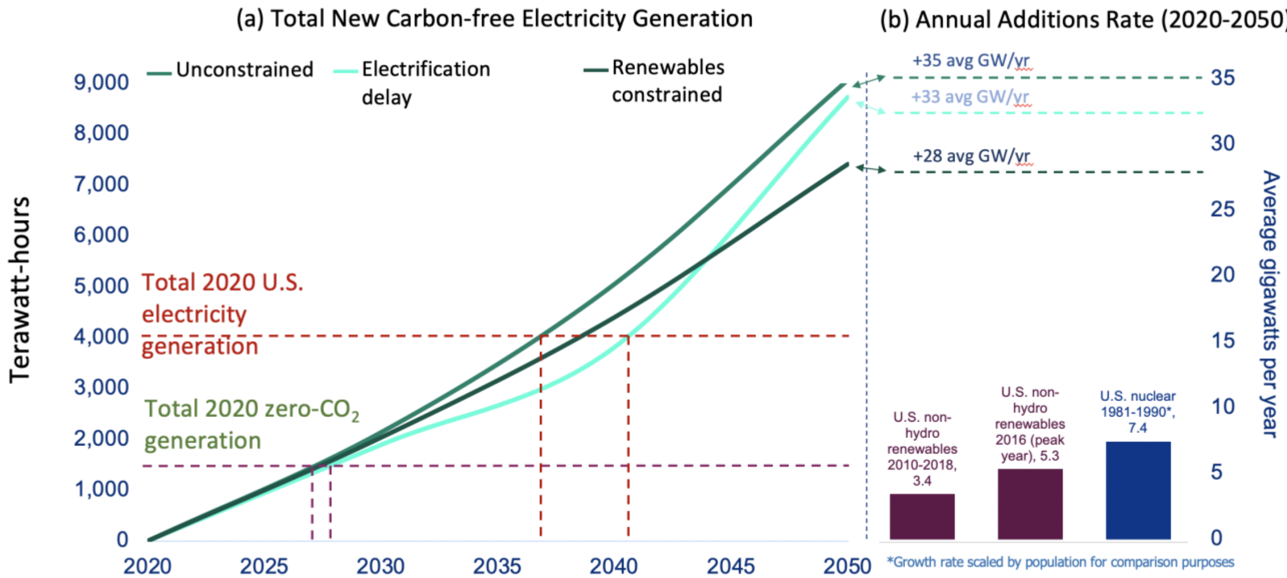

Figure 3: Scaling rates to decarbonize US electricity. Source: J. Jenkins, Princeton University , https://cpree.princeton.edu/sites/cpree2019/files/media/2020-02-010_-_wws_bradford_seminar_-_getting_to_zero.pdf

And that's just electricity, which represents about 40% of total American energy production and 33% of total US carbon dioxide emissions from fossil fuel burning. The other 60% of US energy is derived from oil, gas and coal for transportation, industrial process, and building heat. We need to decarbonize those sectors too. Some we can decarbonize with electricity, but many end uses will be difficult to electrify, especially heavy transport and high temperature heat in industry. For those, and perhaps for parts of the light duty transport and building sector, we'll need a zero carbon fuel, likely hydrogen-based. Today, we produce almost no zero carbon fuels for energy end uses.

Fortunately, we have several options to achieve the zero carbon goal, especially in the electricity sector. We have made strong progress on wind and solar energy, which now supplies 3.5% of America's total annual energy, and 9% of our electricity. We have emerging potential renewable energy sources such as super hot rock geothermal.[4] We have demonstrated carbon capture and storage that removes carbon from fossil fuel use either before (to make hydrogen) or after combustion, and there many innovative technologies on the horizon that will make those technologies less expensive.[5] And finally, we have America's largest zero carbon source of electricity, nuclear energy, providing 20% of total US power consumption.

[4] See https://www.catf.us/resource/catf-eon-geothermal-workshop/

[5] See https://www.globalccsinstitute.com/resources/global-status-report/ and https://www.globalccsinstitute.com/wp-content/uploads/2019/08/Global-CCS-Institute_Response-to-the-National-Hydrogen-Strategy-Issues-Papers_July-2019-002.pdf

The question for this hearing is whether nuclear energy[6] can play a significant role in a future zero carbon economy. The evidence suggests it can, but there are many challenges to address, just as there are with all other zero carbon energy sources.

The potential value of nuclear to decarbonization

But why even bother? With solar and wind costs having fallen so rapidly, why expend effort on nuclear energy?

The value of firm energy

The advantage of firm energy like nuclear power is, first, that it is "dispatchable," and not dependent on weather. This allows us to avoid very expensive energy storage to ride through the weeks and months when wind and sun are at low ebb in most regions of the country.

The value of firm energy can be illustrated in an example using the Western United States. Figure 4 below simulates demand (today) and supply in the 14-state Western Electricity Coordinating Council (WECC) region, assuming the grid receives 100% of its annual energy from wind, solar and battery storage. In this example, wind, solar and battery storage are optimized to supply the lowest cost mix. In particular, wind and solar capacity is built substantially in excess of system peak demand to account for low wind and sun days, and to minimize battery storage use. As can be seen, there are two large periods – one lasting more than two months, and one lasting a month, where average hourly renewable energy supply falls below demand.

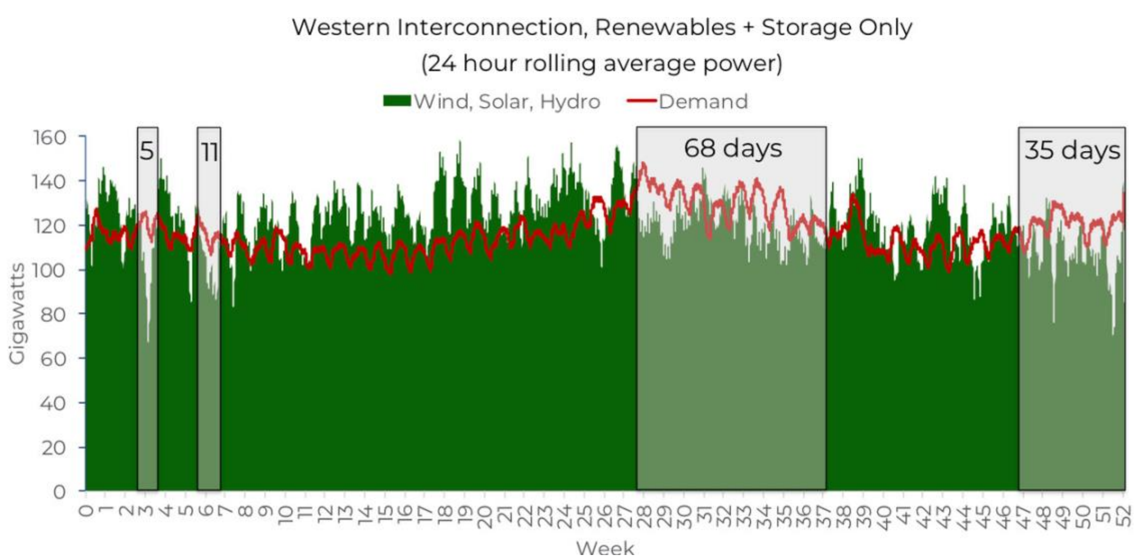

Figure 4: Western state demand and supply at 100% renewables plus batteries. Source: J. Jenkins, Princeton University, preliminary modeling.

[6] In this testimony, I address only nuclear fission, and do not address fusion energy.

Why not just fill these gaps with more storage? Figure 5 and 6 show why this would be a risky approach. To balance demand and supply, figure 5 shows that the Western states would need to build roughly 33 TWH or 3.3 Terawatts of generation equivalent storage, assuming ten hour batteries (today's grid scale-batteries typically only store 4-8 hours worth of energy). That is roughly ***three times the amount of all generating capacity existing today in the United States*** (see Figure 6). Today, the region has only a little over 4 GW of storage, in the form of pumped hydroelectric reservoirs; this amount of storage capacity would need to be increased by 825 times to meet the requirement. Even with battery costs of $50 per kwh, about 75% lower than today's costs, the capital cost of such a battery pack would be $1.65 Trillion, or about ***twenty times*** the total annual amount paid by customers for electricity in the Western states.

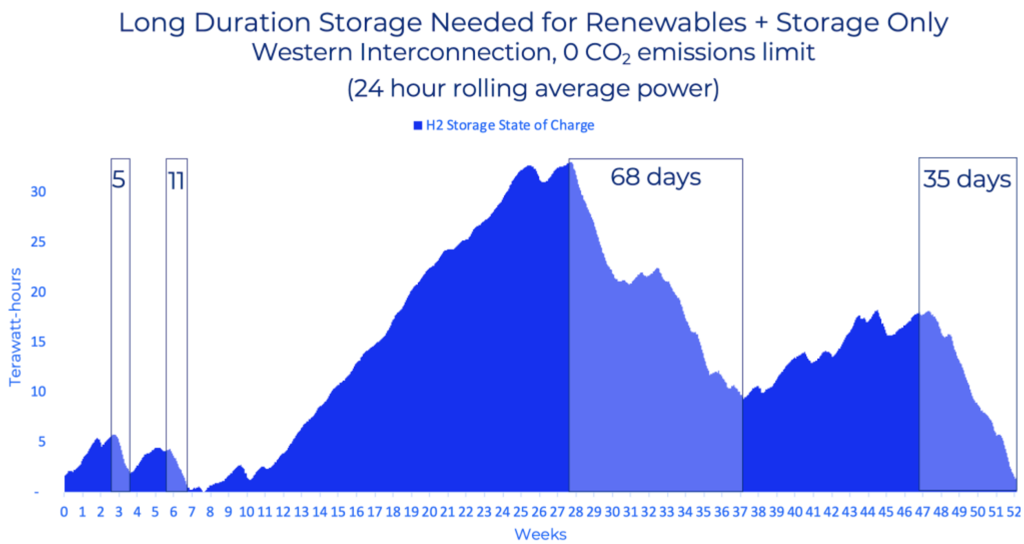

Figure 5: Battery storage required for a Western grid with 100% wind and solar. Source: J. Jenkins, Princeton University, preliminary modeling.

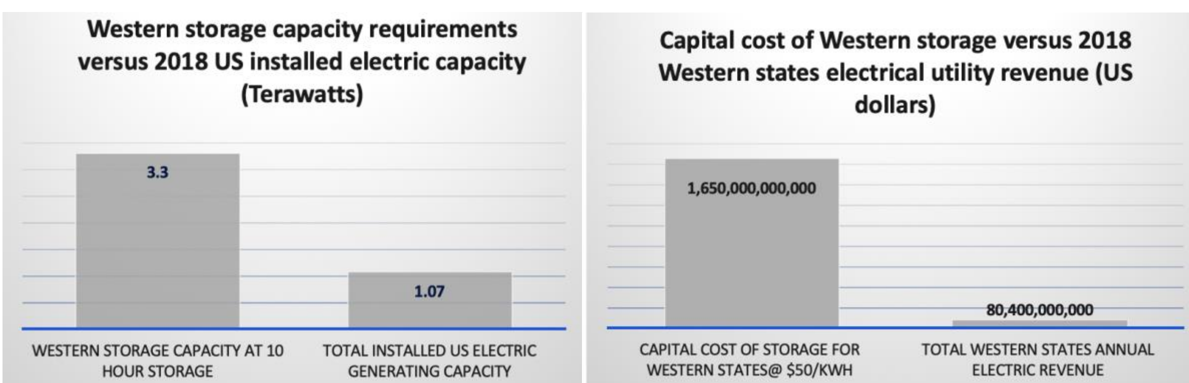

Figure 6: Capacity and costs of batteries necessary to support a 100% wind and solar Western grid. Source. Clean Air Task Force calculated from data in Figures 3 and 4 on previous slides with capacity and revenue data from US Energy Information Administration (2018).

Numerous studies have shown that, for this reason, ***forcing a zero carbon system to operate without zero carbon firm energy results in substantially higher costs*** than a balanced system with firm energy of some kind, such as nuclear, or fossil with carbon capture.[7] The results of one such study are depicted in Figure 7 below, showing rapidly escalating costs of a wind and solar based system, includes hydroelectric, storage and demand response:

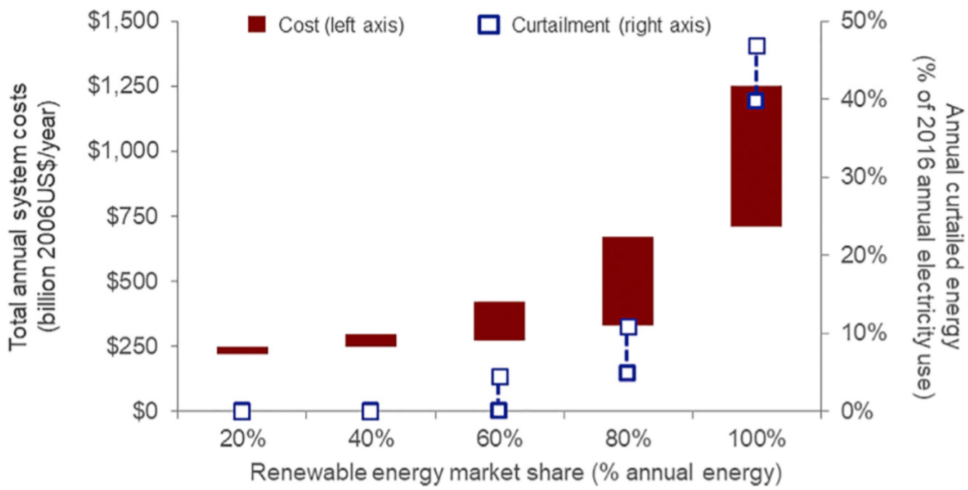

Figure 7: Taken from Jenkins et al., Getting to Zero Carbon Emissions in the Electric Power Sector, Joule (2018), https://doi.org/ 10.1016/j.joule.2018.11.013, adapted from Frew, Bethany A., Jacobson, M. et al. "Flexibility mechanisms and pathways to a highly renewable US electricity future." *Energy* 101 (2016): 65-78.

It is always possible that extremely cheap long-duration storage that is 95-98% lower than today's battery costs will be developed to solve this problem. But it would be unwise to count on this as a solution, which envisions a far more aggressive cost target than has been contemplated to date; some doubt whether this kind of efficiency gain is physically possible. But that's just one risk of an all-renewables approach. Others are discussed below.

Land use and power density

Second, nuclear energy plants are very compact, taking one hundred to a thousand times less space per unit energy produced compared to wind and solar (see Figure 8 below). And this comparison ignores the additional renewable capacity required to help meet peak demand at times of low wind and sun as a greater percentage of total electricity is provided by renewables.

[7] A good summary of this literature can be found in Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. "Getting to Zero-carbon Emissions in the Electric Power Sector." *Joule* 2.12 (2018): 2498-2510.

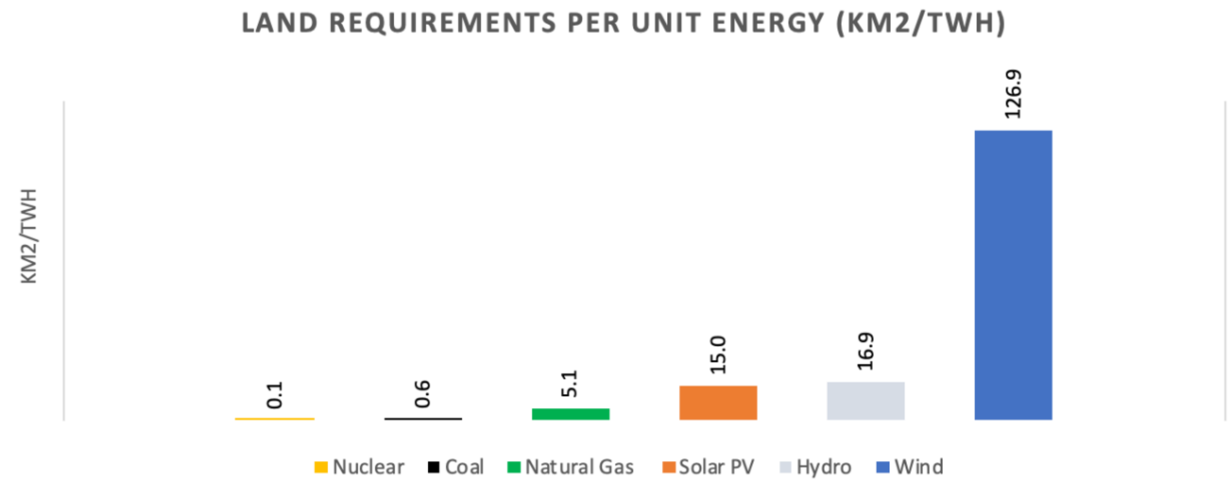

Figure 8: Power produced per square meter of power plant by technology. Chart source: Clean Air Task Force, from Trainor, Anne M., Robert I. McDonald, and Joseph Fargione. "Energy sprawl is the largest driver of land use change in United States." *PloS one* 11.9 (2016).

Very high wind and solar driven power systems also require significantly more transmission capacity to tie remote production to central sources, and to take advantage of variations in wind and sun across large areas, as Figure 9 below shows:

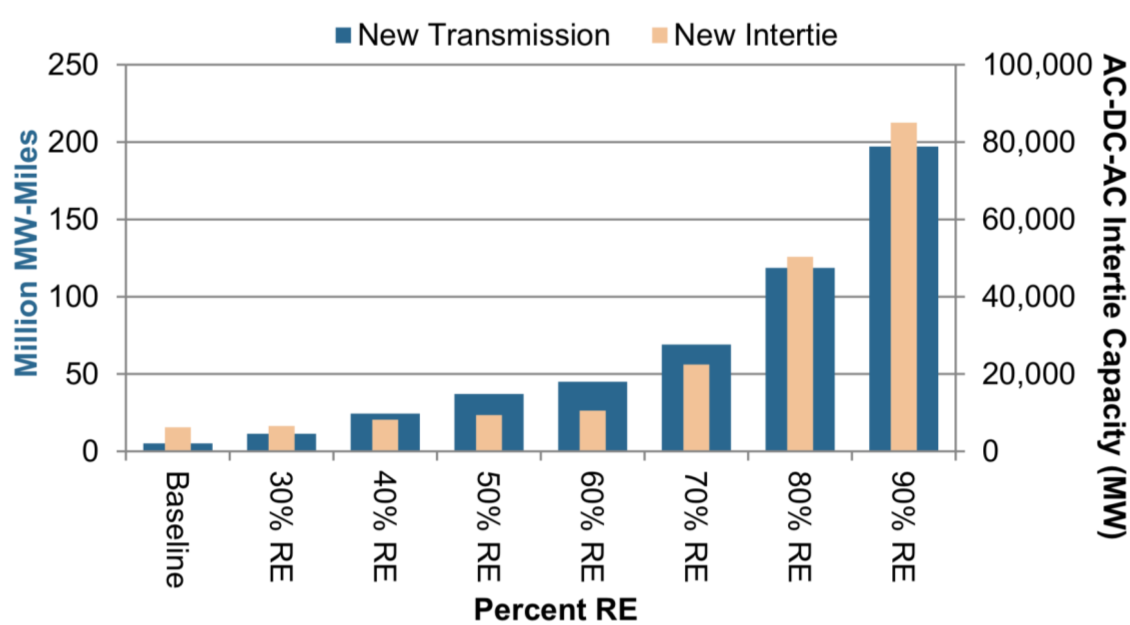

Figure 9: Transmission required for various levels of renewable energy deployment. Source: National Renewable Energy Laboratory, “Renewable Electricity Futures Study,” Executive Summary, p. 26.

To provide some idea of the footprint of an all-renewable system, CATF recently created a preliminary visualization of an all-wind and -solar energy system for Virginia necessary to serve current electrical load, depicted in Figure 10 below. While this map is notional – it does not reflect exactly where wind farms or solar farms ***would*** be placed but shows their relative footprint to Virginia land area – it does provide a sense of order of magnitude of the space required: roughly two million acres (3,100 square miles) onshore, and 400,000 acres (625 square miles) offshore.

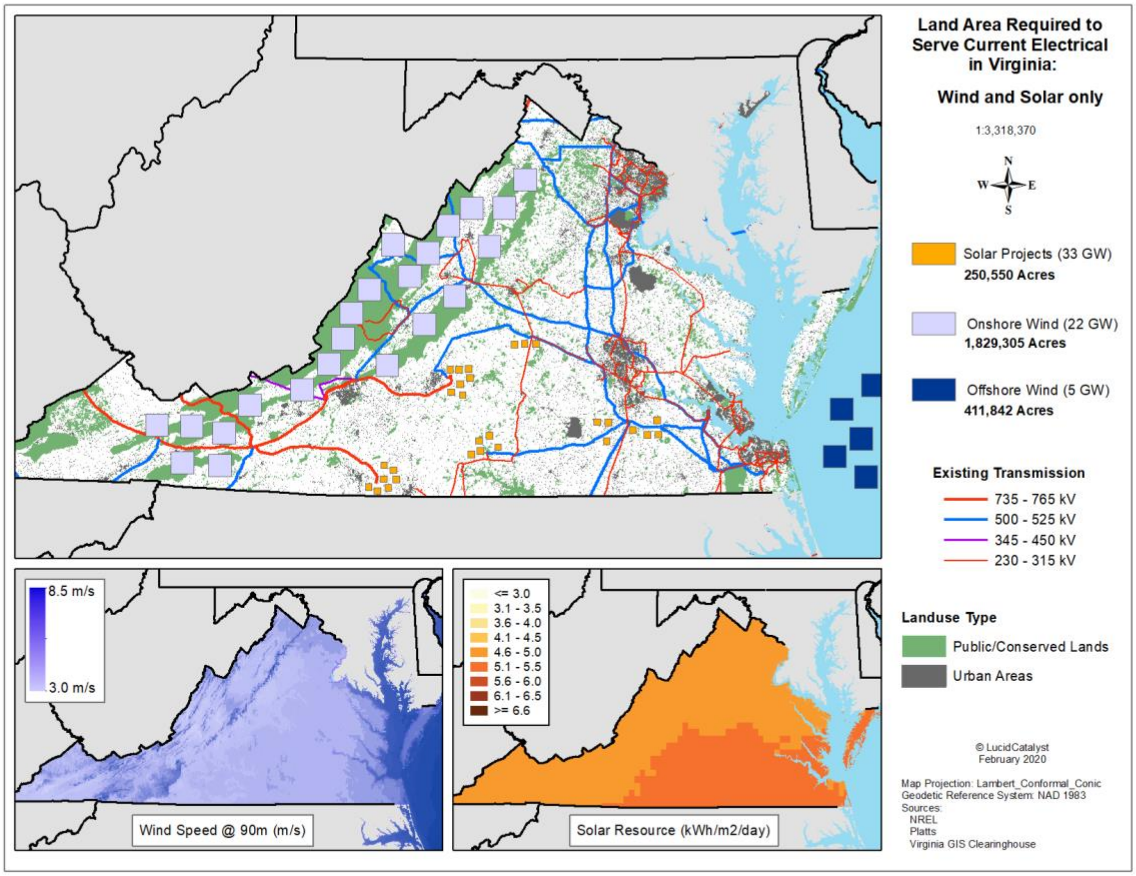

Figure 10: Land and ocean footprint of a notional 100% wind-and-solar electric system in Virginia, with 5 GW of offshore wind. This picture likely understates the total footprint, as it assumes no excess capacity is built above annual needs to allow for adequate supply during low wind and sun periods, and curtailment during high wind and sun periods. Source: Clean Air Task Force, from National Renewable Energy Laboratory data.

Siting battles of renewable energy infrastructure have proven intense in many areas of the country.[8] They are likely to escalate as renewable energy proposals increase. While these hurdles may be overcome, they do introduce a significant additional risk factor in decarbonization.

---

[8] See S. Gross, “Renewables, Land Use and Local Opposition in the United States” (Brookings Institution 2020) and sources cited therein.

Scaling rates

Partly because of the the enormous amount of energy that a nuclear power plant can provide per unit space, and the fact that nuclear energy plugs into existing grids quite easily without extensive modification, history has shown that nuclear energy can scale rapidly when policy is aligned to do so and there is a standard product available that can be built repeatedly. Figure 11 illustrates that nuclear energy has scaled quite rapidly in several countries, at multiple rates compared to renewable energy.

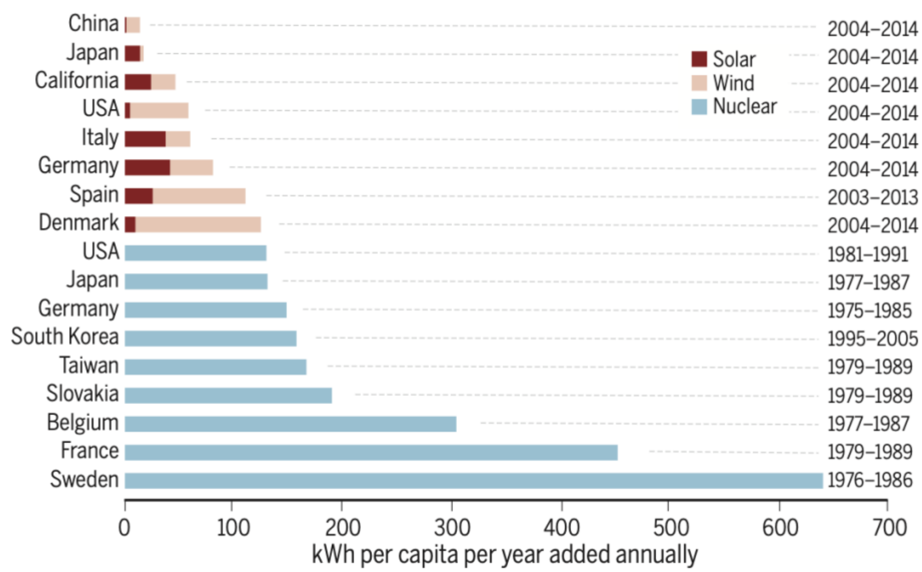

Figure 11: Average annual increase of carbon-free electricity per capita during decade of peak scale-up. Source: Cao, J., Cohen, A., Hansen, J., Lester, R., Peterson, P., & Xu, H. (2016). China-US cooperation to advance nuclear power. *Science*, *353*(6299), 547-548.

The most dramatic example of scaling is France, which nearly completely decarbonized its electric grid in 15 years through the deployment of nuclear energy, shown in Figure 12 below:

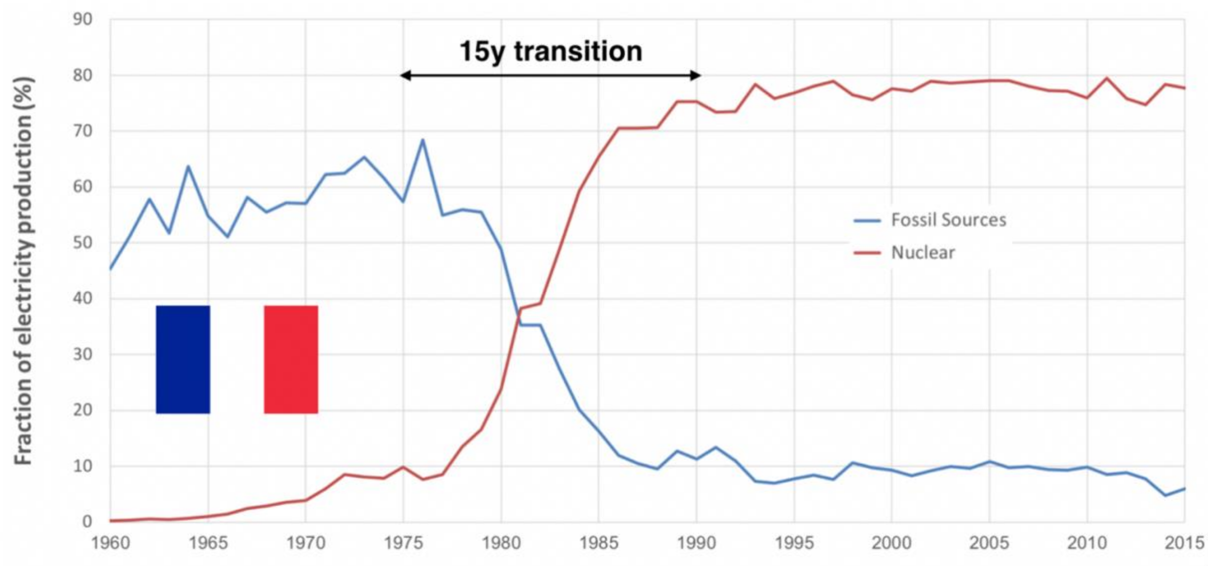

Figure 12: French electricity sources 1960-2015. Source: CATF based on World Bank Development Indicators

As discussed later, to achieve nuclear scaling rates like these again, we will need to improve nuclear business models and supporting policies. But it can be done.

Capability to produce zero carbon fuels

As noted at the outset, electricity represents only 40% of America's energy production and 33% of the US energy/CO2 problem (see Figure 13 below):

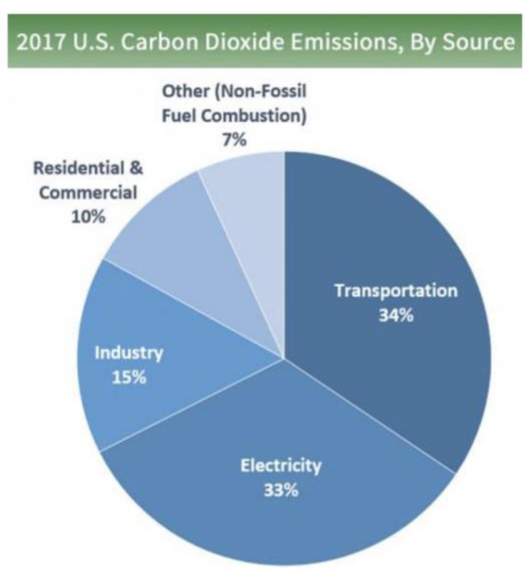

Figure 13: Sources of US carbon dioxide emissions. Source: US Energy Information Administration.

While we may be able to electrify substantial portions of the US economy and power them with a zero carbon electricity grid, there are likely to be substantial remaining demands for nonelectric fuels for heavy transport, industrial processes like cement and steel, and building heat. Nuclear energy can provide carbon-free heat to displace fossil fuels in industrial processes and buildings, and to efficiently create hydrogen, a zero carbon fuel.

Additionally, existing nuclear power plants (and those future plants without sufficiently high temperatures) can utilize low-cost electricity to power electrolysis facilities and provide hydrogen for use in a zero carbon fuel system. High temperature reactors are currently on the horizon and poised to make a large impact on hydrogen production at greater efficiency. We don't need to wait for a complete hydrogen economy to start using this zero carbon fuel. Blending nuclear-produced hydrogen into existing natural gas pipelines can have a measurable impact on overall emissions without much infrastructure improvements. Currently, Hawaii blends 12% hydrogen into its natural gas pipelines in some areas[9], reducing overall emissions -- and additional pilot programs are underway in nations like the UK[10].

Nations like the United States, where some nuclear power plants are economically challenged, are looking at hydrogen production very seriously as a way to improve the economics of existing units. In September 2019, the U.S. DOE announced that it had partnered the Idaho National Lab with three utilities (FirstEnergy, Xcel Energy, and Arizona Public Service) to pioneer nuclear electrolysis technology and future forms of hydrogen production.[11] Prior to that, Exelon and Nel Hydrogen began a DOE sponsored project to scale up existing proton exchange membrane electrolyzer technology for use with a nuclear power plant, and that effort is still ongoing.[12] The UK is engaged in a project with EDF to develop a nuclear hydrogen production facility on the Heysham site this year.[13] Additionally, a 2013 IAEA report[14] discusses nuclear hydrogen production R&D (mostly theoretical and some government sponsored) in Canada, China, the EU, France, India, Japan, Russia, South Africa, South Korea, and the United States.

In short, nuclear-produced heat and hydrogen could be a very powerful tool in the decarbonization toolkit, even if nuclear power ultimately proves not to be needed to decarbonize electric grids.

---

[9] https://www.hawaiigas.com/clean-energy/hydrogen/

[10] https://www.theguardian.com/environment/2020/jan/24/hydrogen-uk-gas-grid-keele-university

[11] https://apnews.com/bd2475e2fc604c9c8b85b60360fd7f4c

[12] https://www.theengineer.co.uk/nuclear-norwegian-hydrogen/

[13] https://www.politicshome.com/news/uk/energy/nuclear-power/opinion/edf-energy/106242/hydrogen-nuclear-power-could-be-new-source, https://www.gov.uk/government/news/hydrogen-powered-distillery-to-produce-sustainable-gin

[14] Hydrogen Production using Nuclear Energy, IAEA, 2013, https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1577_web.pdf

Risk management

Given the size of the climate problem and related energy system transformation task, and the consequences of failure to decarbonize in time, we face a very large risk management challenge. Every zero carbon energy technology has its challenges at large scale.[15] We have briefly discussed above the challenges of an all renewable system in size, cost and build rate. As discussed below, nuclear faces its own significant challenges. The same is true for the use of fossil energy with carbon capture.

Portfolio theory and common sense suggests that reliance on any one pathway creates a higher risk of failure. This is illustrated through the simple generic example in Figure 14, where even an 80% chance of success in meeting each condition of deployment of a technology can result in a 50% probability of failure, which are very poor odds for climate mitigation. Creating more options for zero carbon electricity, transport fuel, heat and industry will increase our chances of success.

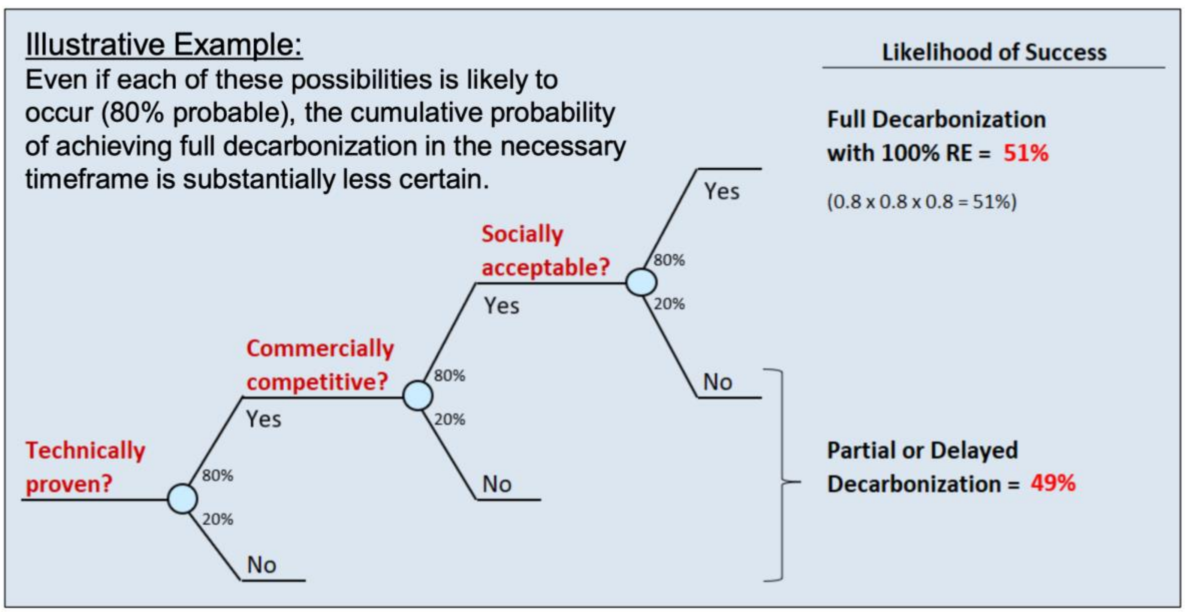

Figure 14: Risk of reliance on a single technology pathway to decarbonize. Illustration courtesy of Bruce Phillips, The Northbridge Group.

While in theory we could provide 100% of our electricity with renewable energy, that is a risky bet; more options are likely to increase our chance of success.

[15] See Loftus, Peter J., et al. "A critical review of global decarbonization scenarios: what do they tell us about feasibility?" *Wiley Interdisciplinary Reviews: Climate Change* 6.1 (2015): 93-112.

The challenges of nuclear power

At the same time, nuclear energy faces many challenges:

Cost and delay

Foremost among these are the high cost and delays associated with recent American and European projects. The two are related, as delays result in additional interest costs during construction.

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[16] for the UK-based Energy Technologies Institute analyzed the costs associated with more than two dozen large light water nuclear plants built over the last few decades. The first observation from the study is that nuclear costs have varied widely, by a factor of six, as shown in Figure 15 below:

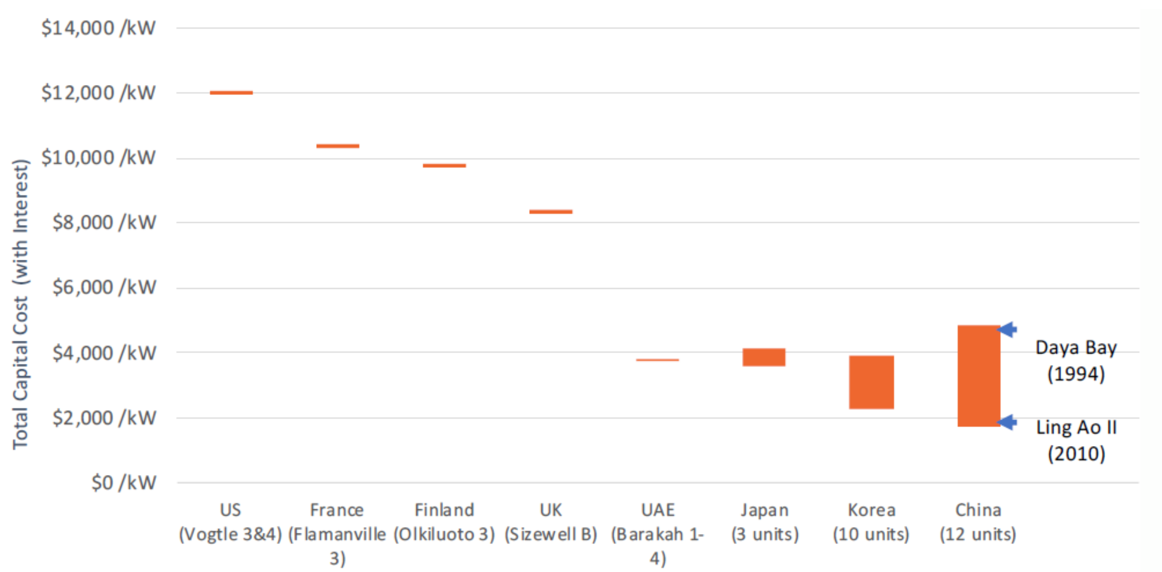

Figure 15: Variations in recent nuclear power plant costs. Source: see footnote 16.

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 differences in regulation or unit labor costs in Asia***, but rather by the

[16] Energy Technologies Institute, "The ETI Nuclear Cost Drivers Project," Energy Technologies Institute (2018), https://d2umxnkyjne36n.cloudfront.net/documents/D7.3-ETI-Nuclear-Cost-Drivers-Summary-Report_April-20.pdf

efficiency of project management and other best practices. Specifically, top factors that led to lower costs included:

- Having a completed design before construction
- Building multiple units at single site, and repeated build of the same design (see China data point in Figure 15)
- Incentives aligned for cost management
- Unified project management
- Having a conscious cost control program

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

Many have suggested that further reduction in cost could be achieved by large conventional water-cooled nuclear plants through changing the fundamental industry business and delivery model. Such fundamental changes might include:

- Higher levels of standardization to enable multiple builds of the same design[17]
- Aggregated demand for dozens of units of the same design, rather than singles and doubles
- Higher fraction of manufactured versus built-on-site content, resulting in less role for costly environment/procurement/construction firms
- Industry-wide open architecture, allowing for standardization and commoditization of the non-nuclear parts of the plant (which represent the vast majority of plant costs) to increase competition and drive down costs
- Mass-manufacturing in aircraft- and shipyard-like production lines
- International harmonization of safety licensing, as exists for aviation, to speed global diffusion of reactor designs and increase scale

These are the cost reduction opportunities for conventional water-cooled reactors. Further cost reductions may be achievable through more advanced designs, mainly using coolants other than water.

Examples of such advanced nuclear plants[18] being developed in North America and around the world include but are not limited to those in the table below:

---

[17] Lovering, Jessica R., Arthur Yip, and Ted Nordhaus. "Historical construction costs of global nuclear power reactors." *Energy Policy* 91 (2016): 371-382.

[18] https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf?fbclid=IwAR09CR2mjhsZq6uh9cy2N0PDGSvbUUmy9zbaOp79mt_6OKfbcJMPeGRdYjU

Coolant	Thermal Neutron Spectrum	Fast Neutron Spectrum
Water	Small Modular Reactor (SMR)	
Helium	High Temperature Gas-Cooled Reactor (HTGR) and Very High Temperature Reactor (VHTR)	Gas-Cooled Fast Reactor (GFR)
Liquid Metal	—	Sodium Fast Reactor (SFR), Lead-Cooled Fast Reactor (LFR)
Molten Salt	Fluoride-Cooled High Temperature Reactor (FHR), Molten Salt Reactor–Fluoride (MSR-fluoride)	Molten Salt Reactor–Chloride (MSR-chloride)

Advanced nuclear plant types Source: see footnote 18.

Some advantages of these reactors:

- Thermal reactors differ from fast reactors in that they use more energetic (faster) neutrons to propel the reaction. "Reactors of this type have a higher fuel utilization rate and, with a fast neutron spectrum, used nuclear fuel from light water reactors can be used as a fuel source, after some processing.[19]"
- Reactors operating with liquid metal coolant operate at high power density, therefore reducing overall radioactive material and size, due to the thermochemical properties of the coolant.
- Molten Salt has a high boiling point similar to liquid metal but allows for fuel to be mixed in solution with coolant, in some designs, reducing overall volume.
- Gas cooled reactors can leverage existing gas technology, and some utilize more robust fuel designs such as TRISO.

Across the board, these advanced reactor concepts utilize passive safety characteristics, such as reduced pressures or meltable release plugs, that eliminate auxiliary equipment and improve economics while reducing accident probability.

The value proposition of these advanced reactors could be substantial:

- Significantly lower capital and/or operational costs than existing plants
- Reduced material inputs
- Manufacturability or rapid deployment capability
- Passive safety systems and inherent safety strategies
- Ease of operation and maintenance
- Reduced emergency planning zones
- Reduced offsite impact during an accident and increased flexibility/scalability of siting
- Increased proliferation resistant, decreased waste production and/or actinide management capacity, and more efficient use of fuel resources
- Hybrid generation adaptability (e.g. hydrogen production, desalination, etc.) and/or load following

[19] https://www.catf.us/wp-content/uploads/2018/04/Advanced_Nuclear_Energy.pdf

All of these attributes could lead to substantially lower capital, licensing and operating costs. A recent detailed study[20] of cost inputs to eight different advanced reactor offerings concluded that the levelized cost of energy from these designs was likely to average $60/MWH, with some as low as $40/MWH. These costs are well within the range of other firm generating capacity options in North America such as combined cycle gas, and even competitive with wind and solar (sources with much lower firm capacity value) in many parts of the country. The estimated cost spread is shown in Figure 16 below.

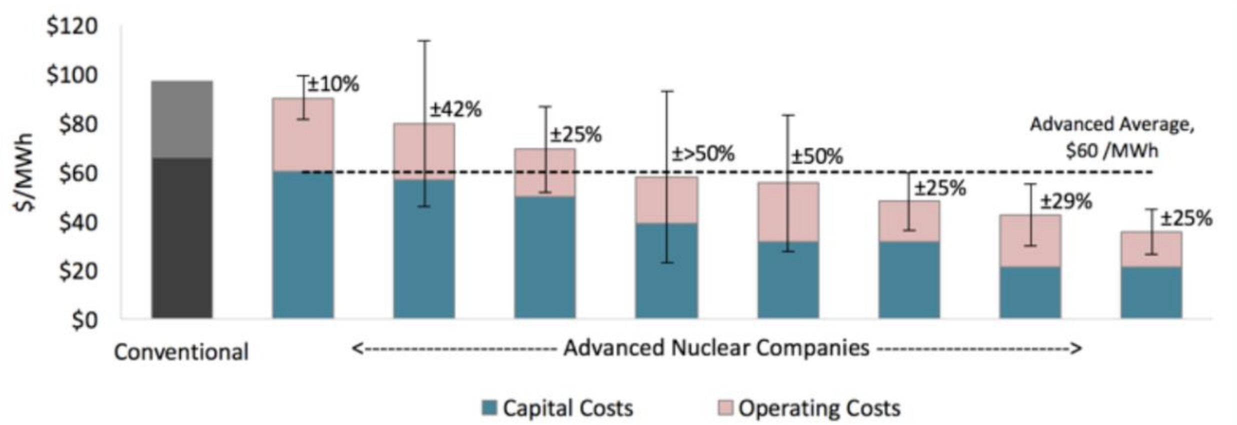

Figure 16: Advanced reactor cost estimates. Source: see footnote 20.

Non-cost challenges

Volumes could be written, and have been, about the other challenges of nuclear energy expansion: impasses in the United States over permanent waste disposal, the risk of weapons proliferation, and the potential for loss of coolant accidents such as happened at Fukushima, Chernobyl and Three Mile island, and associated public fear of radiation releases. These issues are real and must be confronted. Some, but not all, of these issues, can be addressed through advanced reactor designs. Other witnesses today will address those issues, and they can be the subject of future hearings.

Here we make several high-level observations that may provide the basis for further discussion.

- *Waste/unspent fuel.* While permanent waste disposal has proven to be a political thicket, the volumes of waste are very small compared to most other industrial waste streams, and there are many practical avenues forward should we decide as a society that nuclear energy expansion is important for swift decarbonization. The likely way forward involves consent- and incentive-based siting, as was recently implemented in Finland, where a permanent

[20] Energy Innovation Reform project, "*What will advanced nuclear power plants cost?" (2016),*
[*https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf*](https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf)

geologic repository was granted a construction license in 2015[21] and is scheduled to be operational in the mid-2020s.[22] Private sector companies are pursuing options that could achieve disposal goals using new pathways,[23] and advanced reactor concepts could further reduce the already small waste volumes.[24]

- *Safety.* The question of nuclear safety and the risk of potential radiation releases will likely remain highly controversial. A better understanding of the health effects of low dose ionizing radiation could help, along with enhanced safety features of advanced reactors such as reduced operating pressures, smaller sizes, reduced radioactive inventories, reduced reliance on water, and other passive safety features.

- *Non-proliferation*. The debate over the actual and potential link between civilian nuclear energy and nuclear weapons acquisition is a controversial topic, and is unlikely to ever be finally settled. However, it is clear that current international safeguards have generally prevented proliferation of nuclear weapons from civilian nuclear programs, with the vast majority of countries using nuclear power having no nuclear weapons program. That said, there are design and business model and regulatory innovations that could further reduce proliferation risk associated with the next generation of reactors. For example, most advanced reactors would provide limited access to nuclear material due to below-ground siting, high temperatures, inert environments, and smaller footprints which would be easier to protect and safeguard.[25]

Recommended policy directions

To make nuclear energy a real option for US decarbonization, there are several policy imperatives that need attention:

1. *Preserve the existing nuclear fleet to lower emissions during the transition and preserve our knowledge and sites.*

An important strategic principle is: when you are trying to get out of a hole, avoid digging deeper. That is true for climate emissions. Today's nuclear fleet provides 20% of the nation's electricity, and 60% of its carbon free electricity; it is a valuable foundation to build on as we head to zero emissions. Several states have taken action to ensure that otherwise viable nuclear units remain operating despite cheaper natural gas. Federal policy should support,

---

[21] http://www.posiva.fi/en/final_disposal/onkalo#.XllKzshKiUk

[22] https://www.reuters.com/article/us-finland-nuclear-waste/worlds-first-underground-nuclear-waste-storage-moves-forward-in-finland-idUSKCN1TQ1NL

[23]https://www.powermag.com/press-releases/deep-isolation-announces-memorandum-of-agreement-with-bechtel/

[24] https://www.catf.us/wp-content/uploads/2018/04/Advanced_Nuclear_Energy.pdf

[25] https://www.catf.us/wp-content/uploads/2018/04/Advanced_Nuclear_Energy.pdf

rather than frustrate, such state level action to maintain zero carbon resources as the Federal Energy Regulatory Commission has in its recent Minimum Offer Price Rule for the PJM region undercutting state support for existing nuclear power.[26]

2. *Create market demand for advanced nuclear through government support, as we did for wind and solar, to achieve scale, and reduce costs through learning-by-doing*

As discussed above, to make nuclear competitive, as wind and solar have become, market demand pull policies will be critical. Policies that enable and encourage multiple builds of the same designs may be especially helpful in driving down costs. These policies should be designed, to the extent possible, with incentives for cost control and continuous learning.

The Energy and Commerce Committee has an immediate opportunity to promote deployment of advanced nuclear technologies through passage of the power purchase agreement (PPA) provisions of Rep. Luria's Nuclear Energy Leadership Act (NELA) H.R. 3306, which would leverage the purchasing power of the federal government to bring innovative nuclear technologies to market. NELA enjoys strongly bipartisan support of two dozen co-sponsors roughly evenly split between Democrats and Republicans. NELA is also supported by a diverse set of stakeholders from the U.S. Chamber of Commerce and the National Association of Manufacturers to the International Brotherhood of Electrical Workers and The Nature Conservancy.[27] The recently released CLEAN Future Act recognized this opportunity and included these provisions in its innovation title.

3. *Support research, development and demonstration for advanced nuclear, particularly focusing on innovative business models, load following, and hydrogen production*

Here, we have made an important start with the Nuclear Energy Innovation and Modernization Act (NEIMA) and the Nuclear Energy Innovation Capabilities Act (NEICA)[28]. But there are additional frontiers for RD and D, including R and D for business model innovations such as open architecture systems, mass manufacturing, and design-for-cost. A focus on innovation to enable lower cost load-following reactors will also enable nuclear energy to be more economically attractive in zero carbon grids with increasing amounts of variable renewable energy. Finally, and importantly, as noted, zero carbon fuel production can be an important application for nuclear energy in a decarbonized world. RD and D directed at nuclear designs that enable low cost hydrogen production and related systems (such as low cost electrolyzers and novel thermo-chemical hydrogen production systems) should be a high priority.

---

[26] 169 FERC ¶ 61,239 (December 19, 2019).

[27] See attached Letter in Support of Nuclear Energy Leadership Act to Senate and House Leadership from two-dozen organizations (October 15, 2019) available at: https://static.clearpathaction.org/2019/10/NELA-letter-10-15-2019.pdf

[28] Nuclear Energy Innovation and Modernization Act, Public Law 115-439 (January, 14, 2018); Nuclear Energy Innovation Capabilities Act, Public Law 115-248 (September 28, 2018)

4. *Continue our progress in vigilant but fit-for-purpose regulation that enables advanced reactor innovation, and support international harmonization of nuclear safety regulation*

The Nuclear Regulatory Commission, with support from NEIMA, has made strides in creating a viable regulatory runway for advanced reactor technologies; those efforts should continue and accelerate. The United States should also engage with multiple governments that may be interested in nuclear energy to achieve harmonization of standards to enable rapid global diffusion of safe designs.

5. *Resolve key nuclear waste challenges*

The nuclear waste issue looms large in public sentiment around nuclear energy. Pursuit of a transparent, consent-based siting and regulatory oversight process should be a top priority.

6. *Revitalize US research on the health effects of low dose ionizing radiation*

The US research program on low dose radiation health effects ended roughly a decade ago. New genomic, biomedical and computational technologies may provide greater understanding that will inform public policy and allow for a more factually informed public discussion of the risks and tradeoffs associated with nuclear energy. The Congress recently passed, and President Trump signed, legislation that provides a modest amount of funding to restart a research program,[29] and additional legislation has been proposed to fully fund that program.[30] This issue deserves swift attention.

---

[29] House Committee on Appropriations, Committee Print on H.R. 1865, Public Law 116-95, (Legislative Text and Explanatory Statement (January, 2020) House Committee Print 38-679 (116th Cong.) at p. 466 (Directing $5 million toward the Low Dose Radiation Research Program) https://www.govinfo.gov/content/pkg/CPRT-116HPRT38679/pdf/CPRT-116HPRT38679.pdf See also Report No. 116-83, From The Committee on Appropriations to Accompany H.R. 2960 (May 28, 2019) (directing $10 million toward the Low Dose Radiation Research Program), See also, H.R. 589, Department of Energy Research and Development Act, Public Law, 114-246 (Sept. 28, 2018)(Authorizing the Low Dose Radiation Research program at DOE).

[30] H.R. 4733, The Low Dose Radiation Research Act of 2019 (Rep. Bill Posey)(Introduced October 18, 2019)

ORGANIZATIONS SUPPORTING THE NUCLEAR ENERGY LEADERSHIP ACT

October 15, 2019

The Honorable Nancy Pelosi Speaker U.S. House of Representatives Washington, DC 20515	The Honorable Mitch McConnell Majority Leader U.S. Senate Washington, DC 20510
The Honorable Kevin McCarthy Minority Leader U.S. House of Representatives Washington, DC 20515	The Honorable Chuck Schumer Minority Leader U.S. Senate Washington, DC 20510

Dear Speaker Pelosi, Leader McConnell, Leader McCarthy, and Leader Schumer:

We are writing to express our support for the Nuclear Energy Leadership Act (S. 903 and H.R. 3306).

NELA would accelerate the development of advanced nuclear reactor technologies through a range of policies, including expanding the use of federal power purchase agreements, building demonstration projects for a range of nuclear technologies, establishing new federal research facilities, setting new national goals and strategies, and ensuring the availability of advanced reactor fuel.

As the United States faces critical environmental and national security challenges, including climate change and the rapid development of new nuclear energy capabilities in Russia and China, NELA would help reestablish the United States as a global leader in the next generation of emissions-free nuclear energy.

We urge the House and Senate to promptly consider and pass this important bipartisan legislation.

The Bipartisan Policy Center
BWX Technologies, Inc.
Center for Climate and Energy Solutions
Clean Air Task Force
ClearPath Action
Duke Energy
Energy for Humanity
Energy Impact Center
Framatome
GE Hitachi
International Brotherhood of Electrical Workers (IBEW)
National Association of Manufacturers (NAM)
The Nature Conservancy
Nuclear Energy Institute
Nuclear Innovation Alliance
Nuscale
Terrapower
Terrestrial Energy
Third Way
U.S. Nuclear Industry Council
Utah Associated Municipal Power Systems
Virginia Nuclear Energy Consortium
X-Energy
Xcel Energy