



ADVANCE NUCLEAR STATE COLLABORATIVE

***UPDATED* PATHWAYS TO COMMERCIAL**

LIFTOFF: ADVANCED NUCLEAR

OCTOBER 28, 2024

4:00 – 5:00 PM ET

Housekeeping

- Use the Q&A box on the zoom toolbar to ask questions at any time
- Audience questions will be asked after all presentation
- The webinar recording and slides will be emailed to registrants after today's webinar



Updated Pathways to Commercial Liftoff: Advanced Nuclear

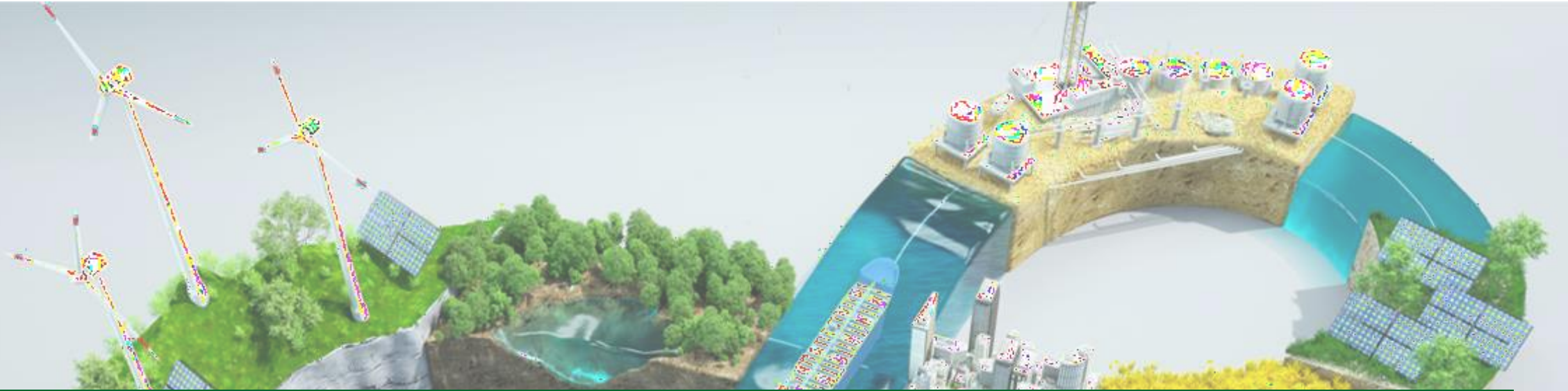


Moderator: Hon. Michael Carrigan, Illinois Commerce Commission

Julie Kozeracki, Director of Strategy, DOE Loan Programs Office



U.S. DEPARTMENT OF
ENERGY



Advanced Nuclear Pathways to Commercial Liftoff

Report Update Summary Presentation

September 2024



Why did we write and update the Nuclear Liftoff Report?

Why did we write the Liftoff Report?

What is advanced nuclear and its value proposition? Report covers Gen III+ and IV across large reactors, SMRs, and microreactors

Do we need new nuclear for net zero when renewables are so cheap? Yes, likely 200 GW of new nuclear in the US by 2050, tripling current capacity, especially given renewables buildout!

Report was a collaboration between LPO, OCED, OTT, NE, INL, and ANL

Why did we update it for 2024?

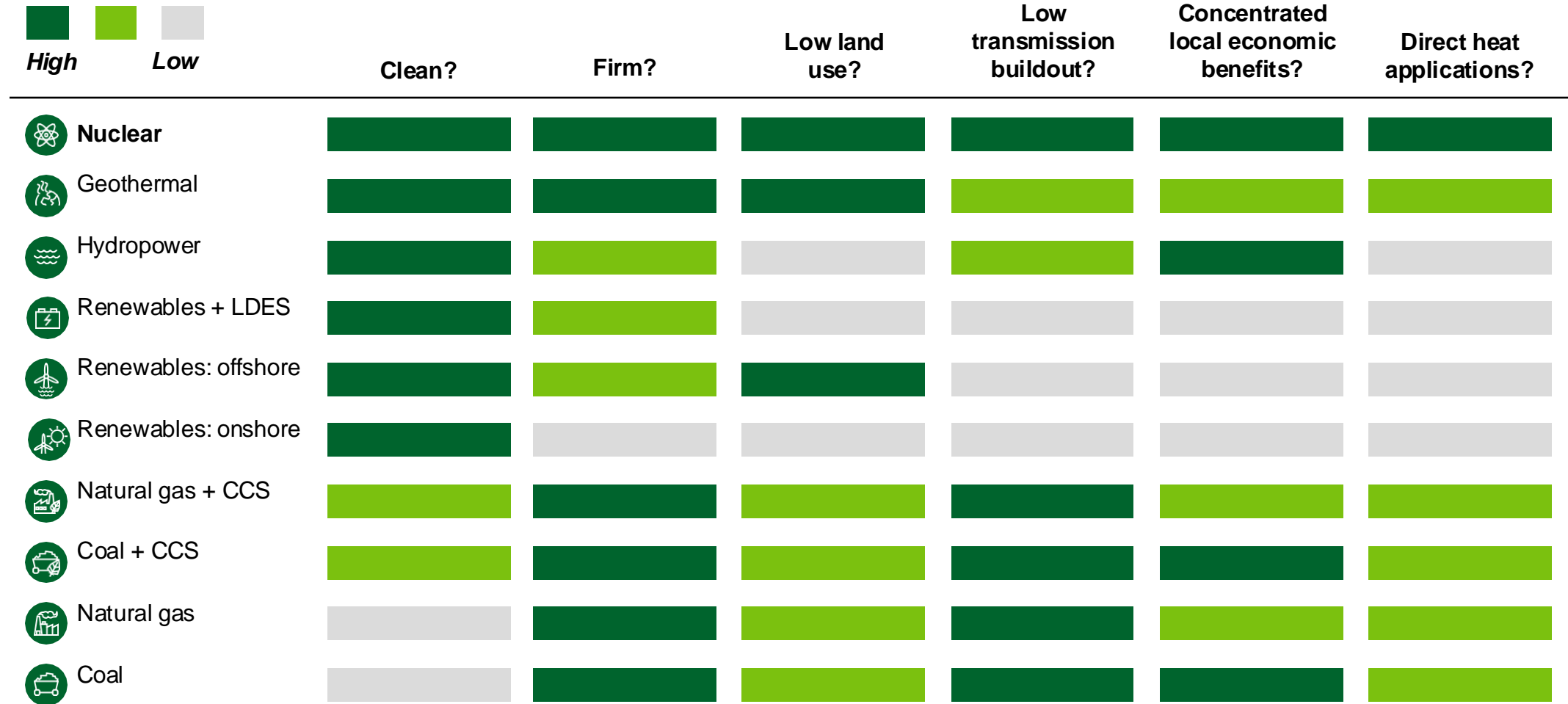
Unprecedented load growth: utilities are now issuing extreme IRP updates for AI, data centers, manufacturing, electrification, etc.

Renewed interest in AP1000s: utilities now saying they value having a constructed design, a supply chain, and a workforce

Value of the existing fleet: in 2022, reactors were being shut down; in 2024, there are plans to restart closed reactors; most sites have room for more reactors (~60-95 GW worth)

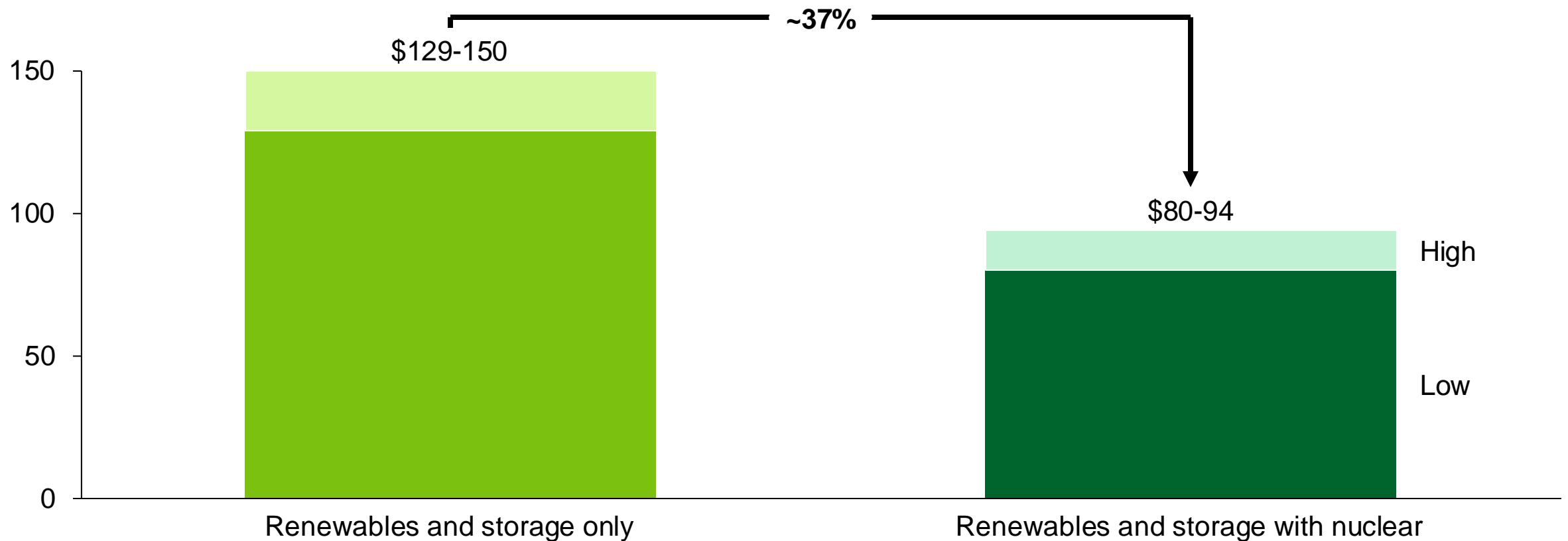
... and more!

Nuclear offers a unique value proposition for a net zero grid



Including nuclear (and other clean firm resources) with renewables and storage decreases the cost of decarbonization

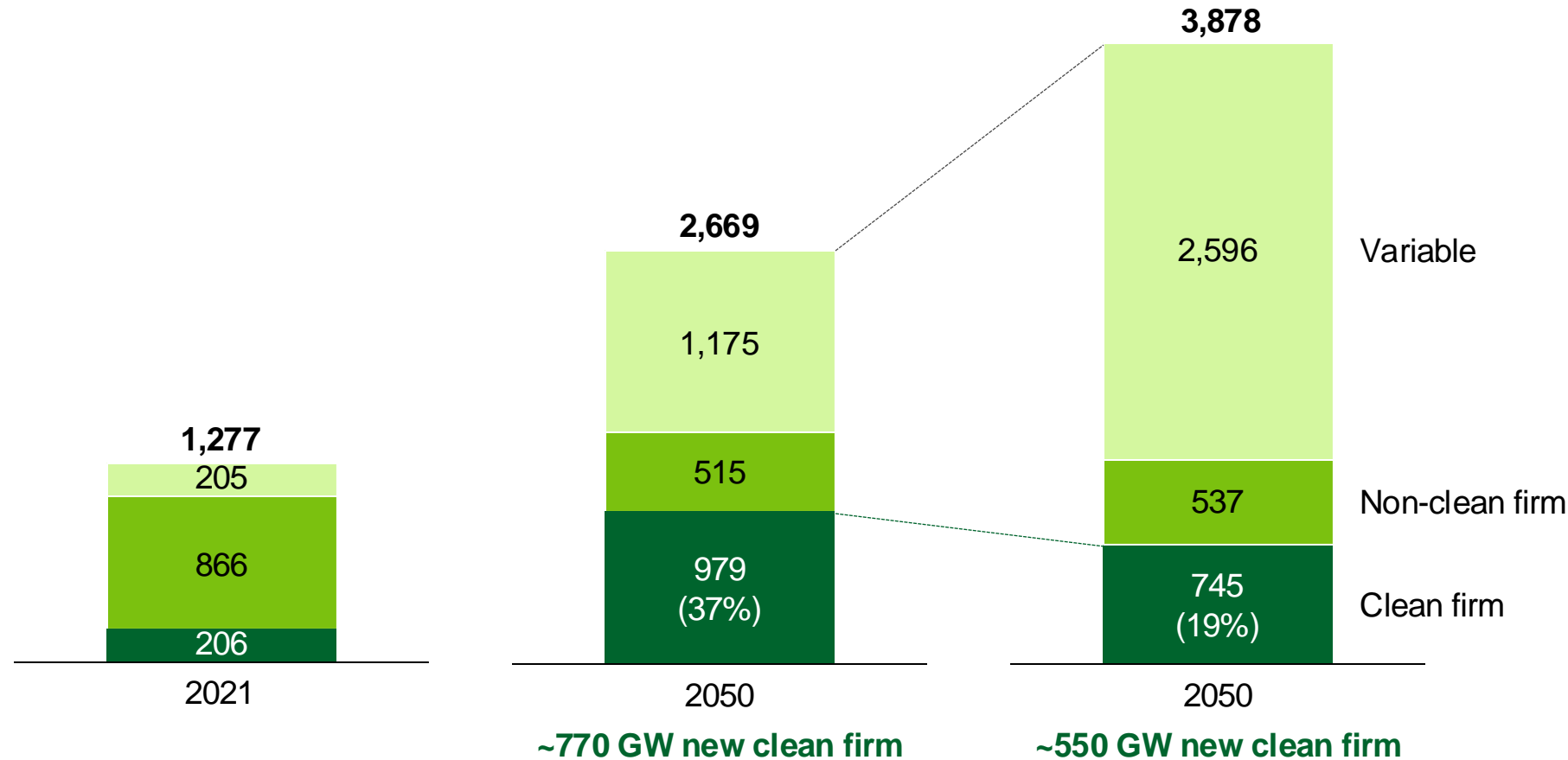
Generation and transmission system costs with and without nuclear, \$/MWh



Modeled costs are for California in 2045 across three models; Source: Baik et al. (2021), "What's different about different net-zero carbon electricity systems?"
Renewables and storage only costs were \$129, \$133, and \$150; renewables and storage with nuclear costs were \$80, \$84, and \$94 per MWh

Clean firm reduces need for building additional generation capacity (as well as storage and transmission)

Installed capacity with varying levels of new clean firm generation, GW



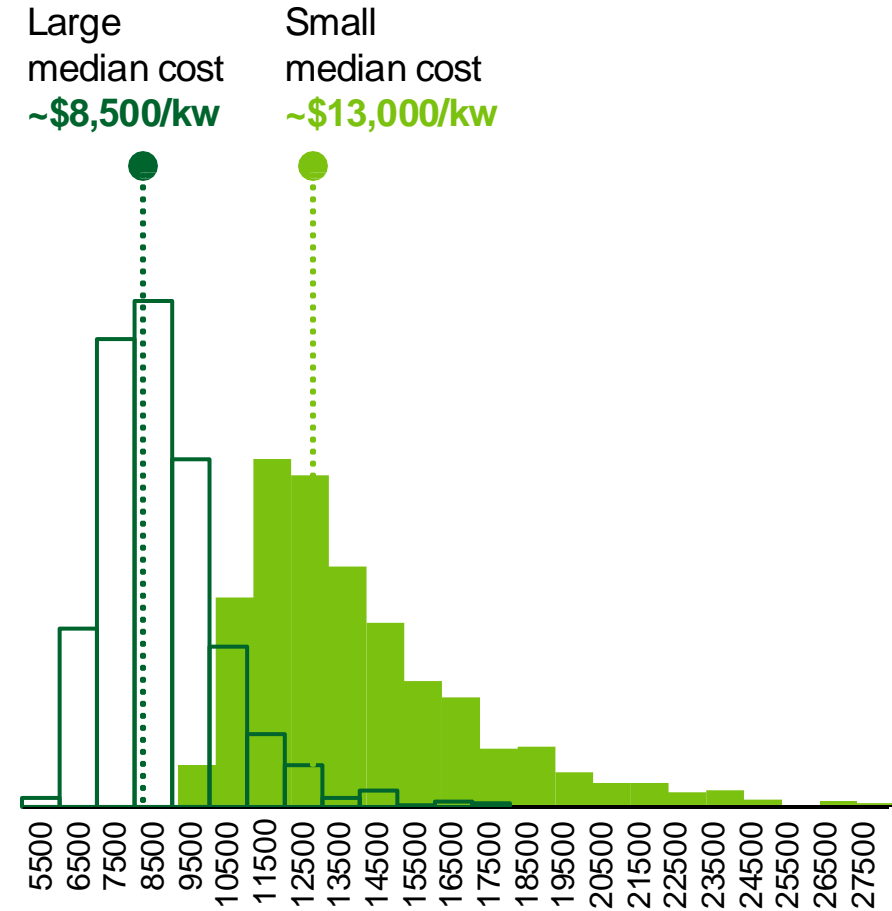
Clean firm power sources included are nuclear, hydropower, geothermal, energy storage (when charged using clean electricity), natural gas with carbon capture, geothermal, BECCs; non-clean firm is fossil generation with emissions otherwise offset

Advanced nuclear includes reactor types of all sizes across two generations

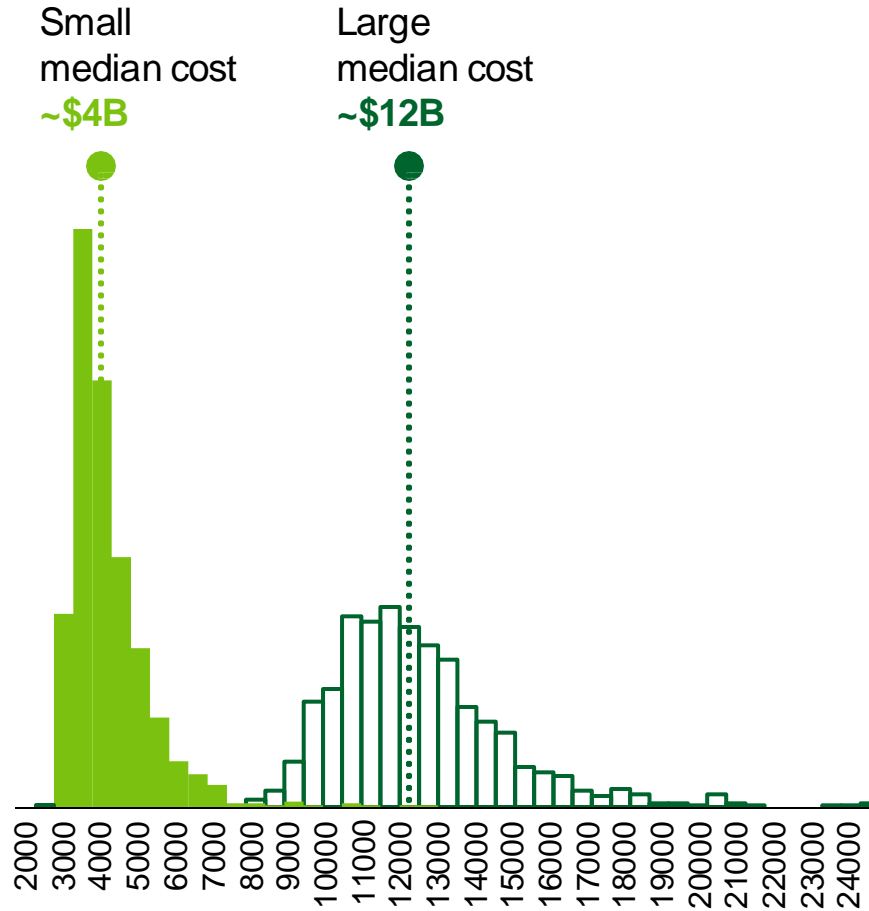
	Gen III+	Gen IV		
Coolant	Light water	Gas	Liquid metal	Molten salt
Examples	<ul style="list-style-type: none"> • Pressurized water reactor • Boiling water reactor 	<ul style="list-style-type: none"> • High temperature gas reactor • Gas fast reactor 	<ul style="list-style-type: none"> • Sodium fast reactor • Lead fast reactor 	<ul style="list-style-type: none"> • Fluoride high temperature reactor • Molten chloride fast reactor
Typical fuel	LEU, LEU+	HALEU	HALEU	HALEU
Outlet temperature	~300°C	~750°C	~550°C	~750°C
Power output	Large, small	Small, micro	Small, micro	Small
Example reactor designers	<ul style="list-style-type: none"> • GE Hitachi • Holtec • NuScale • Westinghouse 	<ul style="list-style-type: none"> • BWXT • General Atomics • Radiant • X-energy 	<ul style="list-style-type: none"> • ARC • TerraPower • Oklo 	<ul style="list-style-type: none"> • Kairos • Terrestrial

Large reactors are cheaper \$/kw with narrower cost distributions while SMRs may offer smaller overall project costs

Cost per kw



Total reactor cost



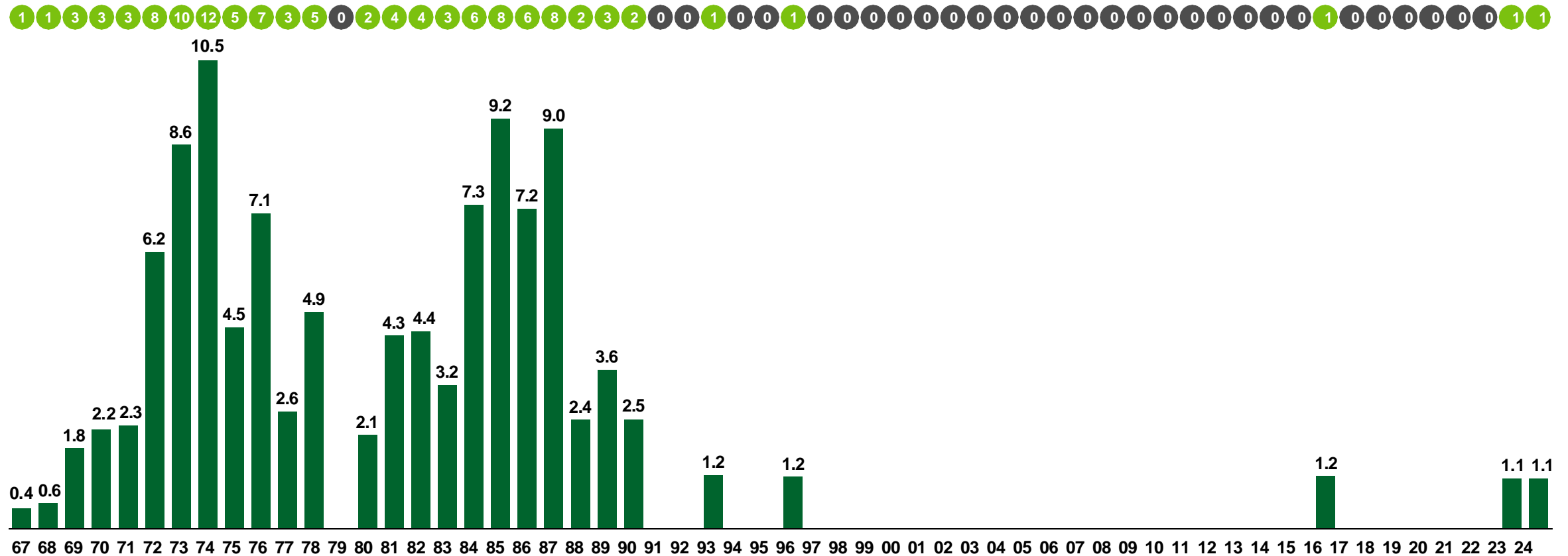
	Large	Small
MW	1400	300
StDv/Mean	0.19	0.26
Skew	1.46	2.64

Note: these are modeled costs for large and small boiling water reactors; specific designs will have their own cost profiles that will vary

Most of the US fleet was built 1970-1980s; in 1974, 12 reactors came online

New nuclear capacity commissioned per year¹, GWe

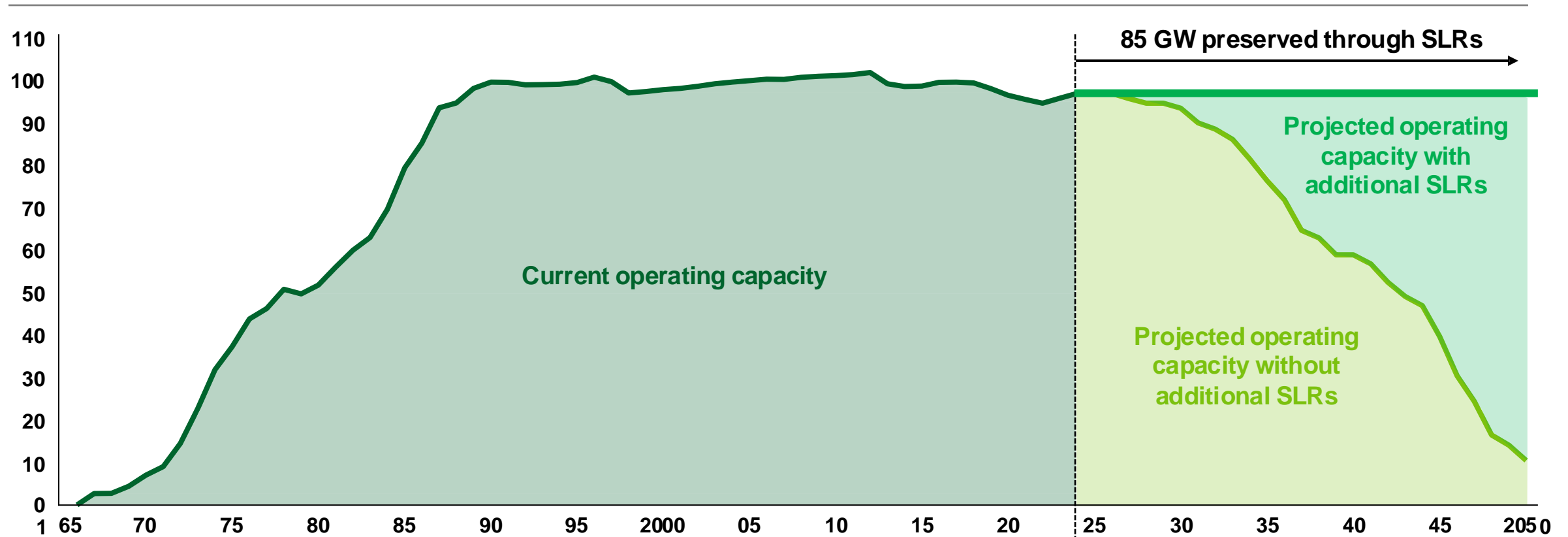
● Number of reactors



1. Excludes test and prototype reactors; Note: Watts Bar 1 & 2 construction originally began in 1973 and halted in 1985; construction resumed on Unit 1 in 1992 and Unit 2 in 2007

Of the 94 operating nuclear reactors in the US, 84 require subsequent license renewal to operate until 2050

Nuclear historic and projected operating capacity by current license status,^{1,2} GW

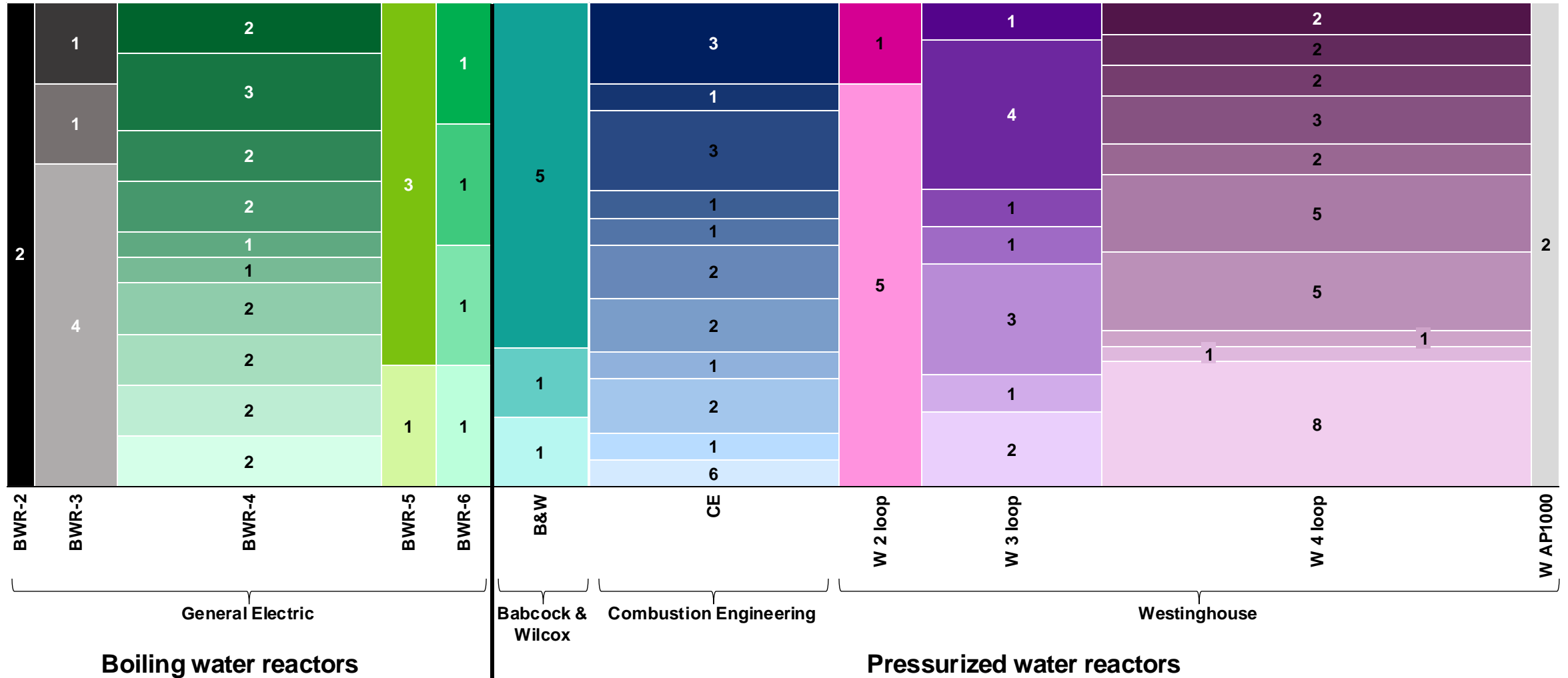


1. Excludes test and prototype reactors; does not include potential restarts 2. Current licensing status includes all confirmed initial and subsequent license renewals only

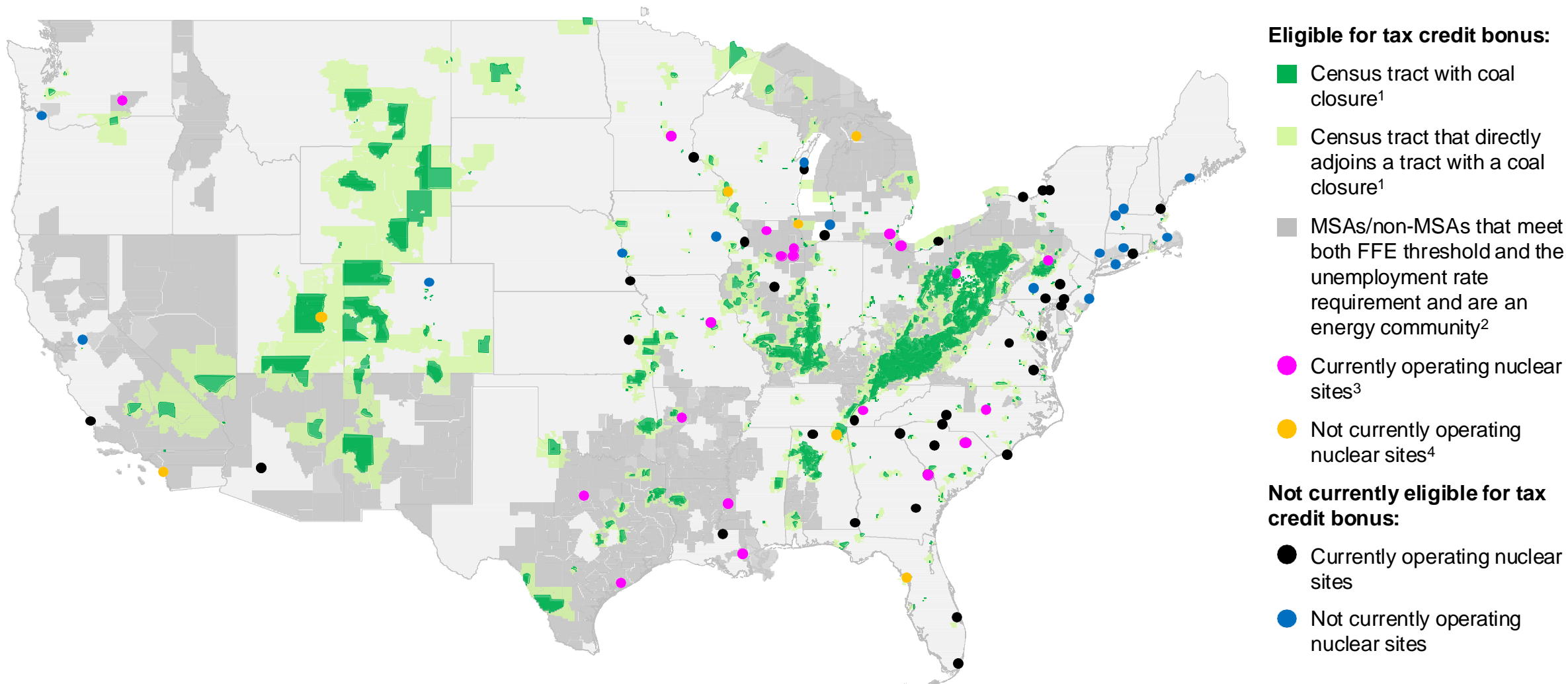
The lack of learning effects in the US may in part be explained by the construction of over 50 unique reactor designs

US commercial nuclear reactors by design

Columns show design families, colors show >50 MW differences, box area sized by number of reactors

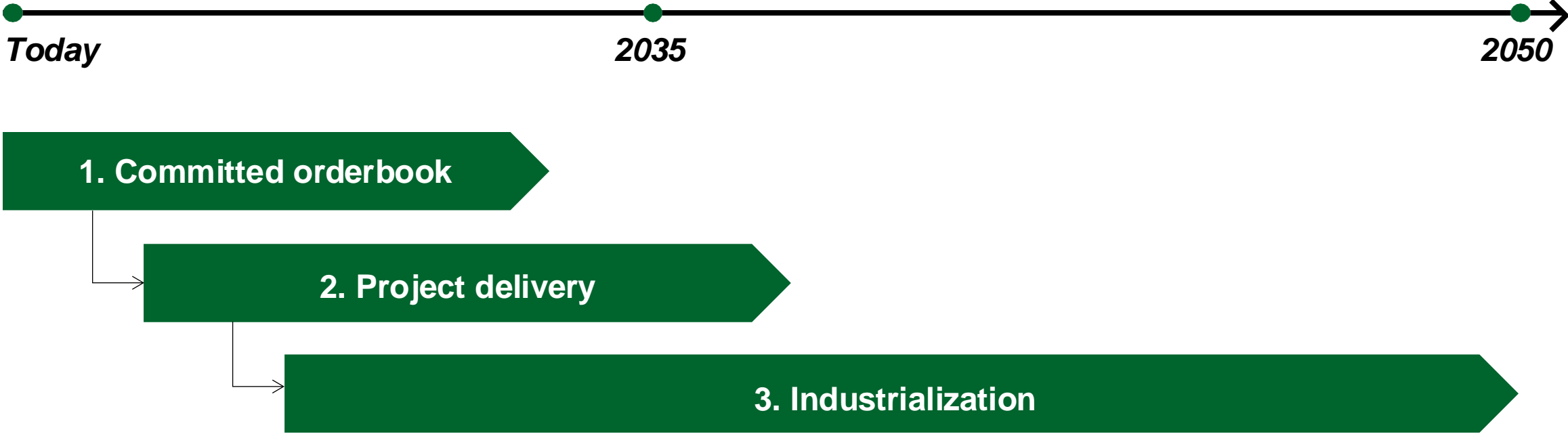


20 operating nuclear sites and 5 formerly operating sites are in communities eligible for energy community tax credit bonuses



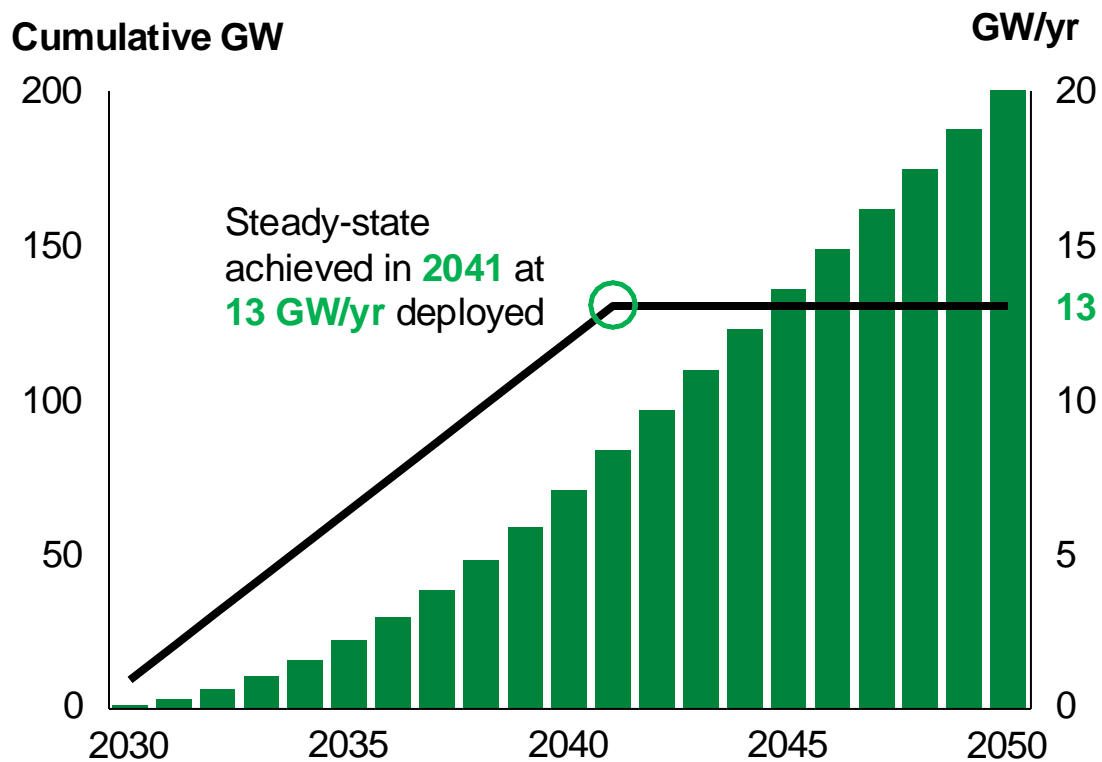
1. Census tract with a coal closure or directly adjoining a census tract with a coal closure 2. MSAs/non-MSAs that meet both the Fossil Fuel Employment threshold and the unemployment rate requirement 3. Arkansas Nuclear One, Beaver Valley, Braidwood, Byron, Callaway, Columbia, Comanche Peak, Davis-Besse, Dresden, Fermi, Grand Gulf, H.B. Robinson, LaSalle, Monticello, Shearon Harris, South Texas, Susquehanna, Vogtle, Waterford, Watts Bar 4. Bellefonte (unfinished), Big Rock Point (retired), Blue Castle (proposed), Crystal River (retired), La Crosse (retired), San Onofre (retired), Zion (retired)

Three phases for the nuclear industry to achieve liftoff

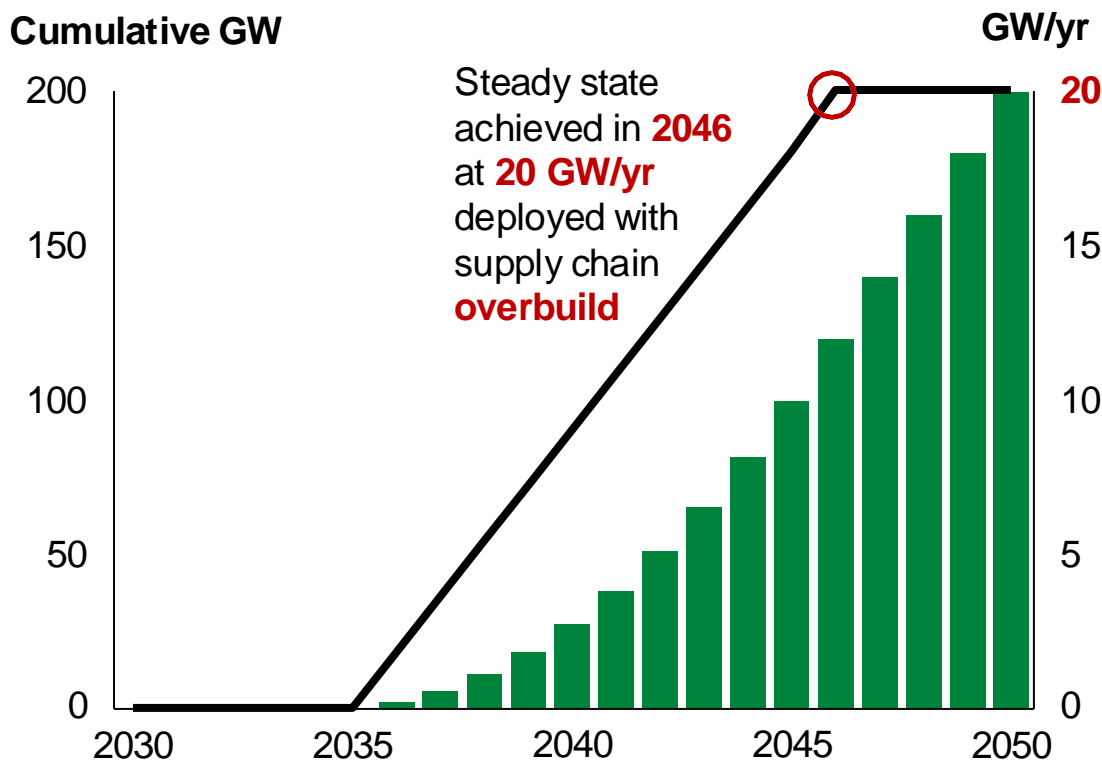


Delaying new nuclear deployment could increase the cost of decarbonization

New nuclear capacity starting in 2030



New nuclear capacity starting in 2035



— GW deployed by year ■ Cumulative GW

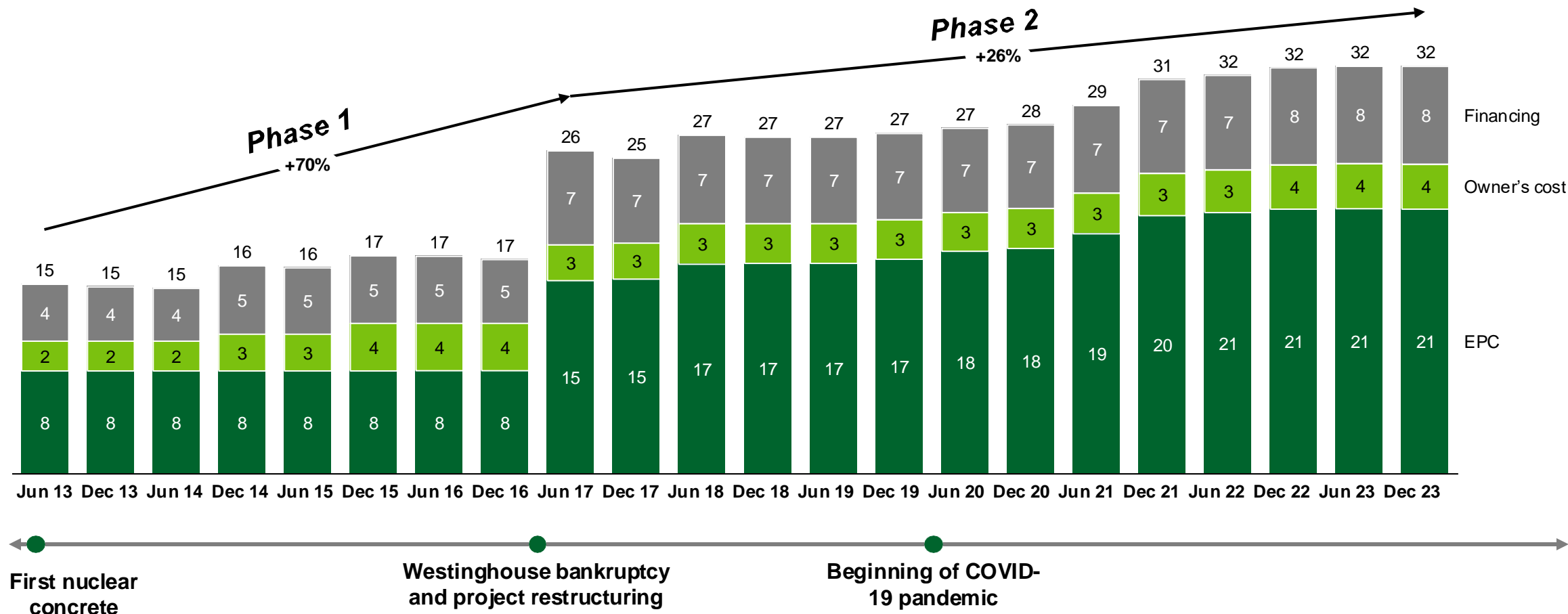
Any nuclear project requires many different roles to be filled; consortium approaches can help aggregate demand and share costs

	Reactor design	Project management			Own (and/or invest equity)	Operate	Offtake	
		Licensing and site dev	Project management	Construction	Multi-project integration			
Multi-utility	Reactor designer	Utility	Utility	Constructor	Potential for new role	Utility	Utility	Utility ratepayers, large offtaker
Aggregated tech offtake	Reactor designer	Utility	Utility	Constructor		Utility or tech offtaker	Utility	Tech offtaker
Developer model	Reactor designer	Developer	Developer	Constructor		Utility or infrastructure fund	Utility	Utility ratepayers, large offtaker
Industrial offtaker	Reactor designer	Industrial offtaker	Industrial offtaker	Constructor		Utility or industrial offtaker	Utility	Industrial offtaker

□ Roles that differ from multi-utility

When Southern took over project management role, reset budget closer to final cost, especially accounting for Covid impacts

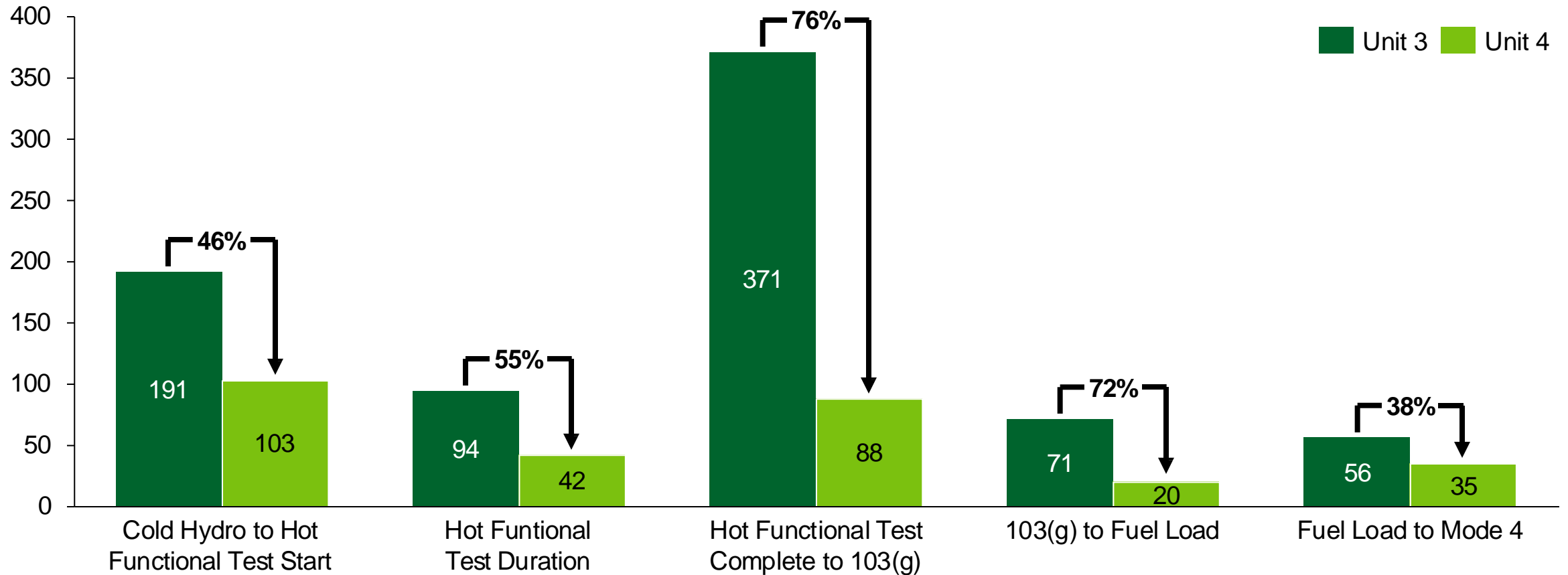
Projected total cost during construction of Vogtle Units 3 and 4,¹ \$B



1. These figures are an estimate of total project cost based on a scaled-up view of Georgia Power's 45.7% share of the project, this means of estimation is inexact due to the differing Financing and Owner's costs between stakeholders. Project costs that are excluded from the VCM reports include: (i) budgeted cost contingency that has not been allocated; (ii) additional cost contingency budgeted by certain other owners (iii) nuclear fuel costs (and related financing costs); and (iv) certain monitoring costs, some of which are owner-specific. Source: Georgia Public Services Commission's Vogtle Construction Monitoring Reports (VCM)

Improvement between Vogtle Units 3 and 4

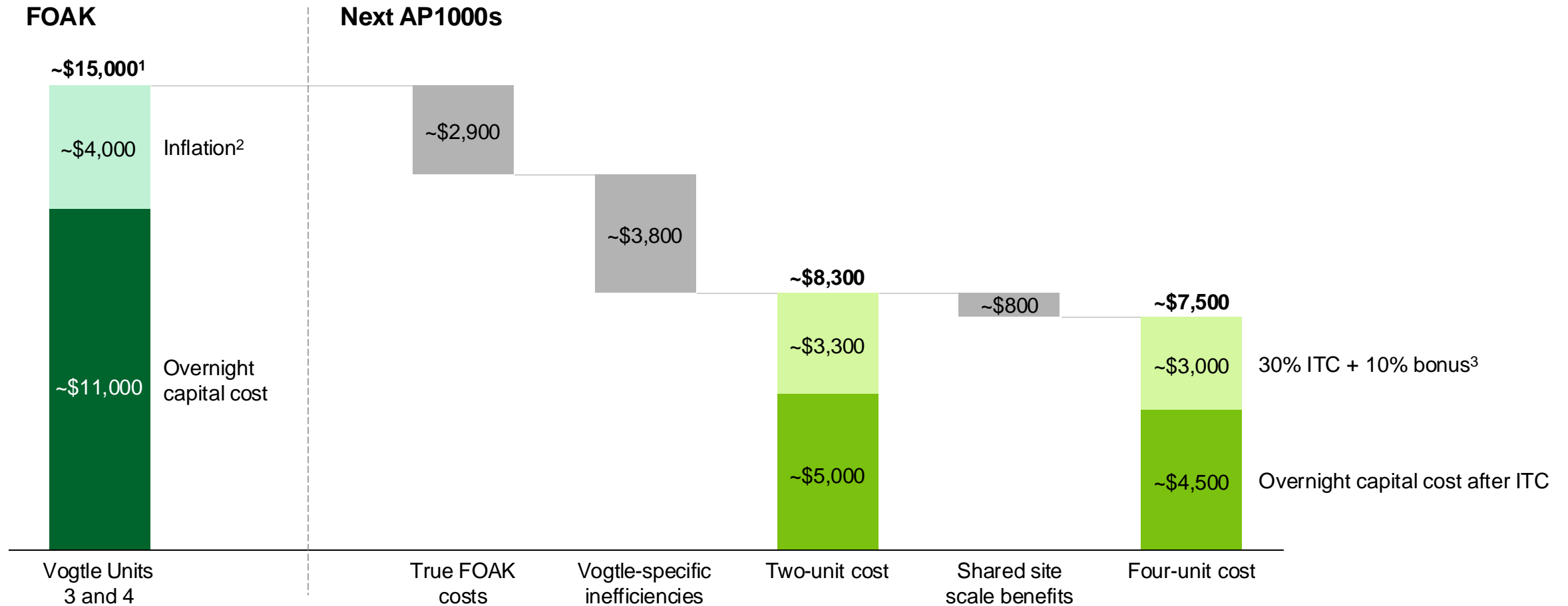
Days between major milestones for Vogtle Units 3 and 4, days



Source: Southern Company

Much of Vogtle's costs were true FOAK costs and the next AP1000 would be eligible for 30-50% ITC paired with LPO loans

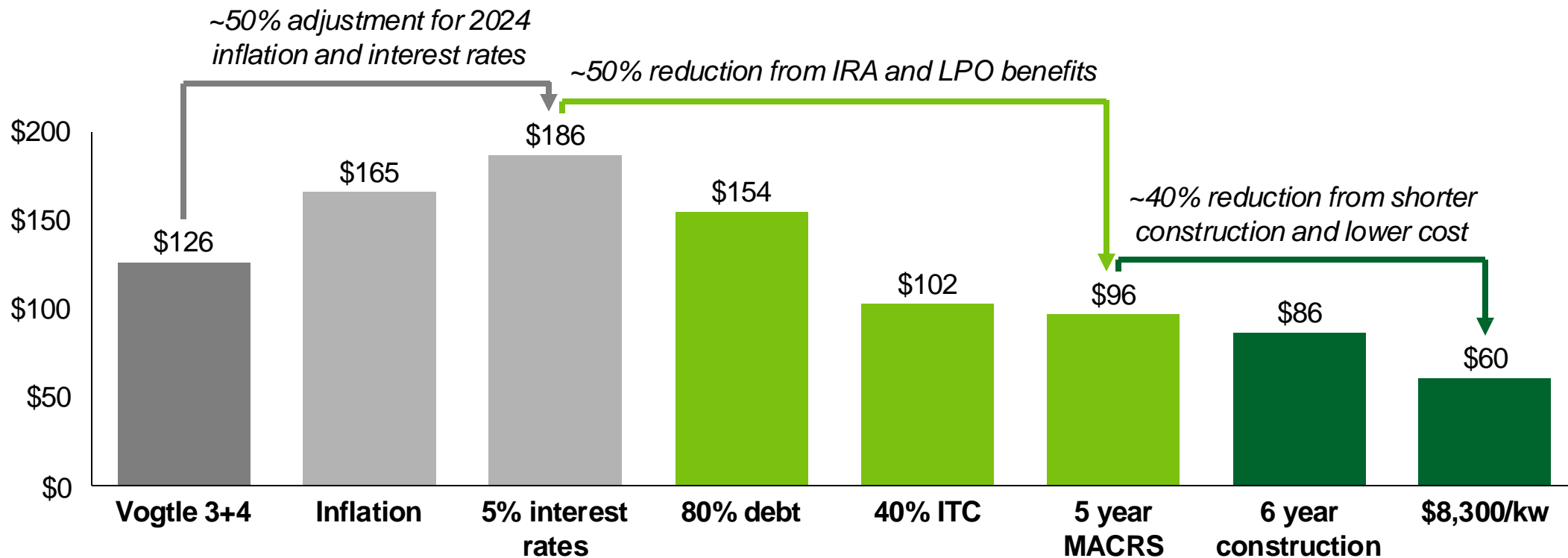
Overnight capital cost evolution from Vogtle to next AP1000s, 2024 \$/kw



1. Vogtle OCC estimation and projections in 2024 USD from K. Shirvan, 2024 Total Cost Projection of Next AP1000; 2. Vogtle OCC calculated from VCM 30 (actual outlays over the course of the project) then adjusted for inflation to 2024 values; 3. ITC and bonuses are applied to "all-in" costs

Even assuming Vogtle costs inflated to 2024, next AP1000 could be <\$100/MWh with IRA benefits and closer to ~\$60/MWh with cost reductions

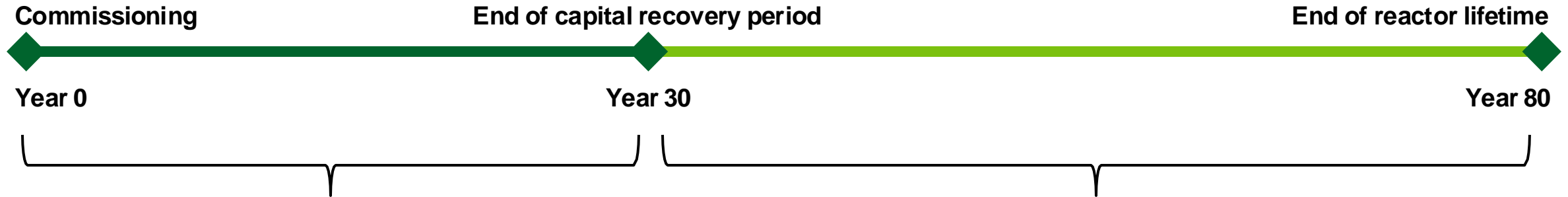
Estimated LCOE, 2024 \$/MWh



Overnight capital cost	\$11,000	\$15,000	\$15,000	\$15,000	\$15,000	\$15,000	\$15,000	\$8,300
Construction time	11 years	11 years	11 years	11 years	11 years	11 years	6 years	6 years
Interest rate on debt	3.5%	3.5%	5%	5%	5%	5%	5%	5%
Debt fraction	60%	60%	60%	80%	80%	80%	80%	80%
Tax credit	PTC (old)	PTC (old)	PTC (old)	PTC (old)	40% ITC	40% ITC	40% ITC	40% ITC
Depreciation	15 years	15 years	15 years	15 years	15 years	5 years	5 years	5 years

LCOE fails to capture the full benefit of 80-year clean firm operating assets

Costs over nuclear plant lifetime



LCOE during capital recovery period (~30 years)

\$50-150/MWh



During a nuclear plant's first ~30 years of operations, paying back debt and equity investments is reflected in a **higher initial LCOE**

Generating costs after capital repayment (~50 years)

~\$30-35/MWh



However, once nuclear plants are paid off, they generate power for the remainder of their lifetime with **low and predictable operating costs**

Barriers to liftoff and potential solutions

Barriers to liftoff

Potential solutions

Market power prices do not consistently compensate nuclear for the value it provides

- **System modeling** efforts consistently show the cost saving benefits of clean firm sources like nuclear in a low-carbon energy future
- Innovative power purchasing is a key tool for **large offtakers** to catalyze new generation
- **Clean firm standards** could help drive nuclear deployment
- A **standard value for clean firm** power could help decision makers account for nuclear's decarbonization and reliability benefits
- Broader **electricity market reforms** could incentivize investment in new clean firm assets

Many potential customers cite cost or cost overrun risk as the primary barrier to committing to new nuclear projects

- **Sharing costs to lower barriers to entry**, either among private sector companies or with the government
- Sharing and insuring costs to provide **resiliency for project completion**
- Insuring resiliency through different cost scenarios with **credit tools**
- Ensuring on-budget delivery by **better estimating costs** and implementing best practices

The US lacks nuclear and megaproject delivery infrastructure

- The **integrated project delivery (IPD) model** aligns incentives between owners and contractors to deliver projects on-time and on-budget
- Funding **constructability research** could target the drivers of cost overruns and improve project delivery

Nuclear projects have a variety of tools to share and reduce costs and risks



Sharing costs across projects and participants



Insuring resiliency through cost scenarios

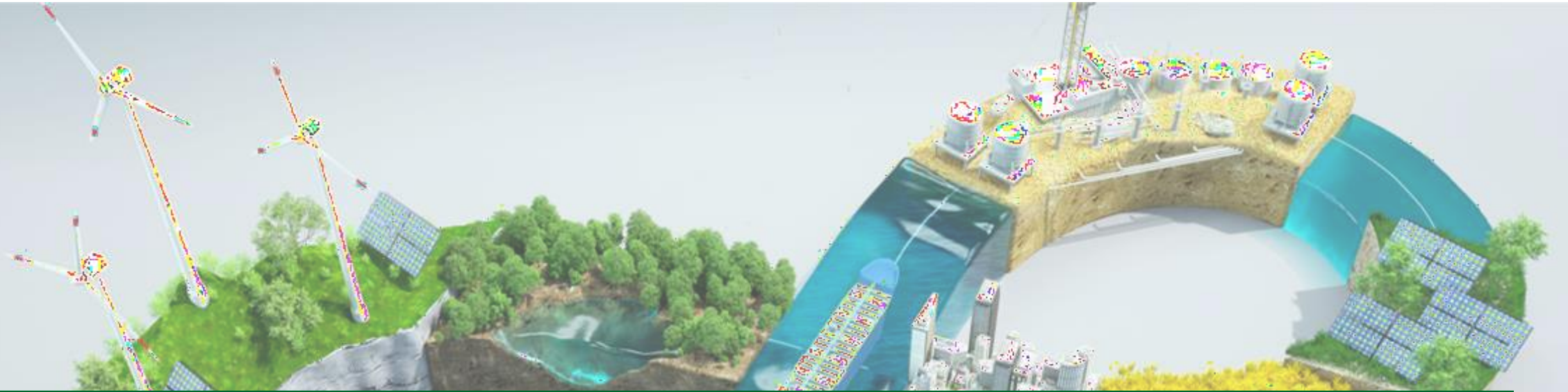


Ensuring project management best practices

Function	Lowers barrier to entry and facilitates critical mass of orders	Defines cost distributions for project resiliency	Promotes on time and on budget delivery
Cost impact	Shares expected costs	Shares unexpected costs	Reduces unexpected costs
Examples	<ul style="list-style-type: none"> • Consortium committing to 5-10 (or more) reactors • Financial assistance, e.g., grants • Government build and ownership 	<ul style="list-style-type: none"> • Completion or debt guarantees • Contingent equity • Contingent debt • Flexible PPA prices 	<ul style="list-style-type: none"> • Mature cost estimates • Construction best practices incorporating lessons from Vogtle • FOAK to NOAK cost levers
	<ul style="list-style-type: none"> • Investment tax credit or overrun insurance (<i>both sharing and insuring</i>) • Government-enabled offtake certainty (<i>both sharing and insuring</i>) 		



U.S. DEPARTMENT OF
ENERGY



Find more resources at liftoff.energy.gov/advanced-nuclear



Questions



Updated Pathways to Commercial Liftoff: Advanced Nuclear



Moderator: Hon. Michael Carrigan, Illinois Commerce Commission

Julie Kozeracki, Director of Strategy, DOE Loan Programs Office

For more information about the Advanced Nuclear State Collaborative



Advanced Nuclear State Collaborative

The National Association of Regulatory Utility Commissioners and the National Association of State Energy Officials formed the Advanced Nuclear State Collaborative (ANSC) with support from the U.S. Department of Energy in 2023. The ANSC convenes state utility regulators and State Energy Officials to enhance collective understanding of the unique regulatory and policy questions surrounding the consideration and deployment of new nuclear generation and support peer learning.

The ANSC is an initiative of the Nuclear Energy Partnership, a multi-year cooperative established in January 2021 between DOE's Office of Nuclear Energy and NARUC.

NARUC and NASEO members can join the ANSC at any time by submitting an expression of interest to NARUC staff describing their state's interest in advanced nuclear generation and act to consider or deploy new nuclear.

For non-NARUC or NASEO members interested in learning more about the ANSC or attending events open to the public, please contact NARUC staff to be placed on an email distribution list.

Visit www.naruc.org

Resources

Activities

Partners

More Information

Resources

- [Coal to Nuclear Repowering: Considerations for State Energy Offices and Public Utility Commissions, April 2024](#)
This report highlights some of the benefits and challenges associated with the coal to nuclear repowering process, with a particular focus on the policy, programmatic, and regulatory considerations of relevance to State Energy Offices and Public Utility Commissions.
 - [Download the report](#)
 - [Read the press release](#)
- [NARUC and NASEO Release Advanced Nuclear State Action Tracker to Highlight State Activities Surrounding Advanced Nuclear, March 2024](#)
[Explore the tracker here.](#)
- [New NARUC-NASEO Advanced Nuclear State Collaborative Helps Better Inform State Approaches to New Nuclear Generation, April 2023](#)
This press release announces the ANSC initiative and lists all participating utility commissions and State Energy Officials as of April 10. [Read to learn more about the ANSC.](#)

Upcoming



NARUC Annual Meeting, Nov. 10-13th in Anaheim, CA
Registration open on NARUC website

ANSC Available Resources



Energy and Industrial Use Cases for Advanced Nuclear Reactors, Oct. 2024.
Available [here](#).

Coal to Nuclear Repowering: Considerations for State Energy Offices and Public Utility Commissions, April 2024. Available [here](#).

Developing State Advanced Nuclear Frameworks *peer sharing call (December 12, 2023)*. Materials available to ANSC members upon request. [WY Energy Authority Nuclear Energy Strategic Framework and Roadmap](#).

[Evaluating Nuclear Waste and Safety Considerations for Advanced Nuclear Deployment](#) (September 27, 2023). Slides available [here](#). Recording available [here](#).

[Facilitating Equitable Community Engagement to Support the Deployment of Advanced Nuclear](#) (August 17, 2023). Slides available [here](#). Recording available [here](#).

[Nuclear Energy Partnership Briefing on Pathways to Commercial Liftoff: Advanced Nuclear](#) with Julie Kozeracki, Senior Advisor, DOE LPO (June 22, 2023) slides available [here](#). Recording available [here](#).

[Advanced Nuclear Resource Repository](#) This repository provides links and overviews for a variety of reports on different aspects of advanced nuclear.