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?

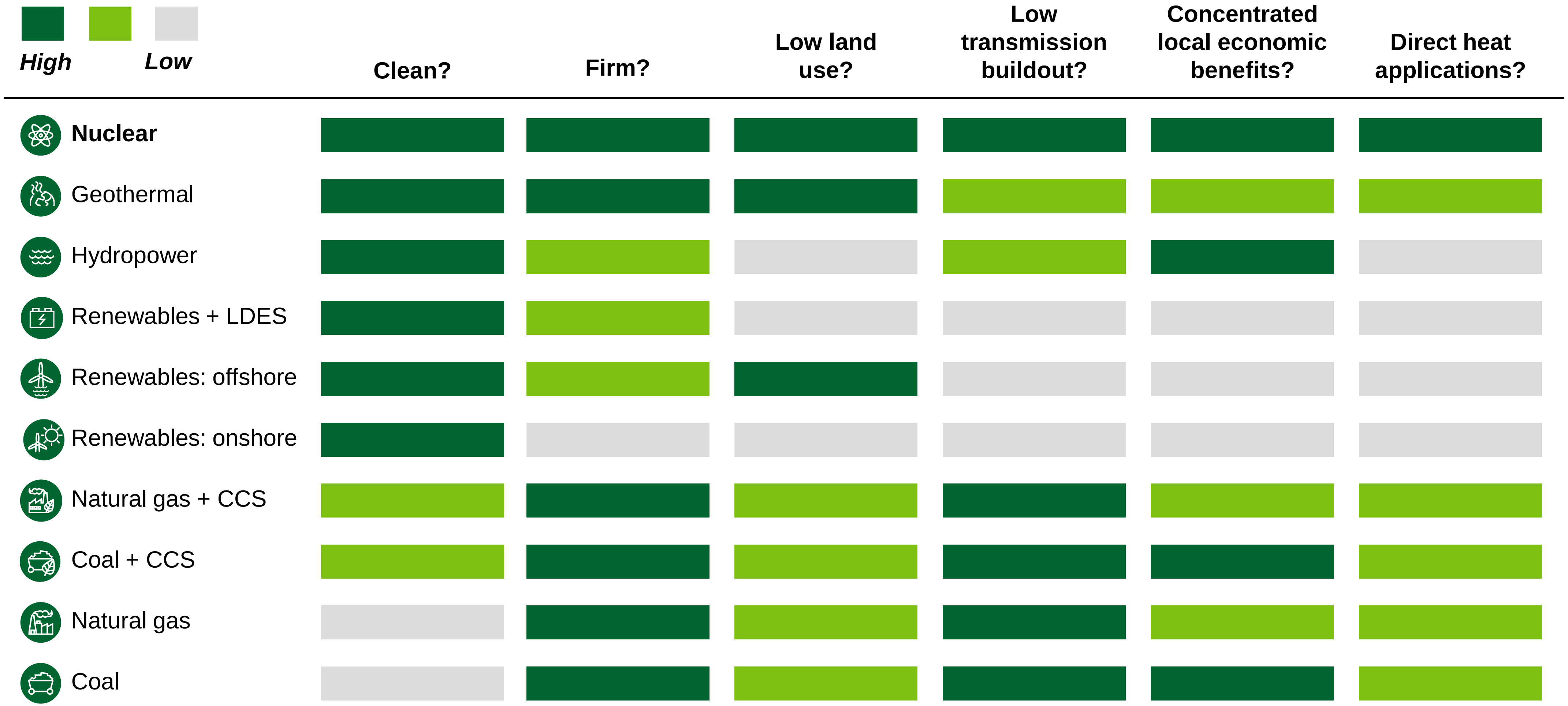
Unprecedented load growth: utilities are now issuing extreme IRP updates for AI, data centers, manufacturing, electrification, etc.

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)

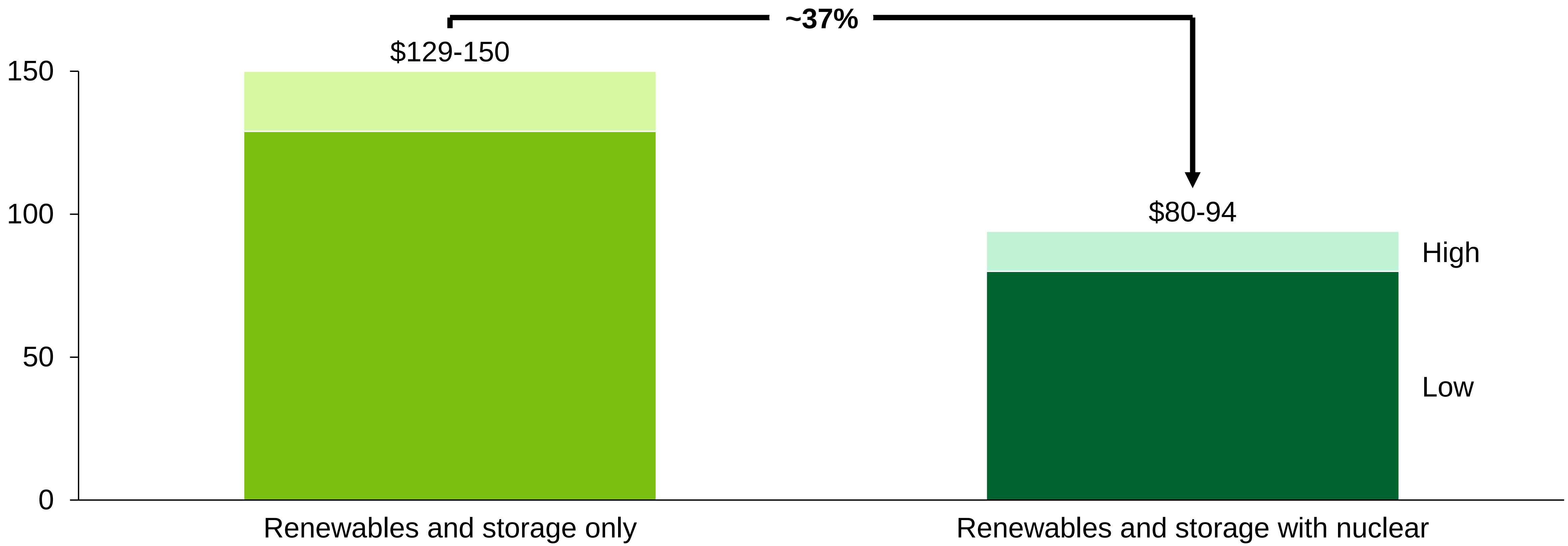
… and more!

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

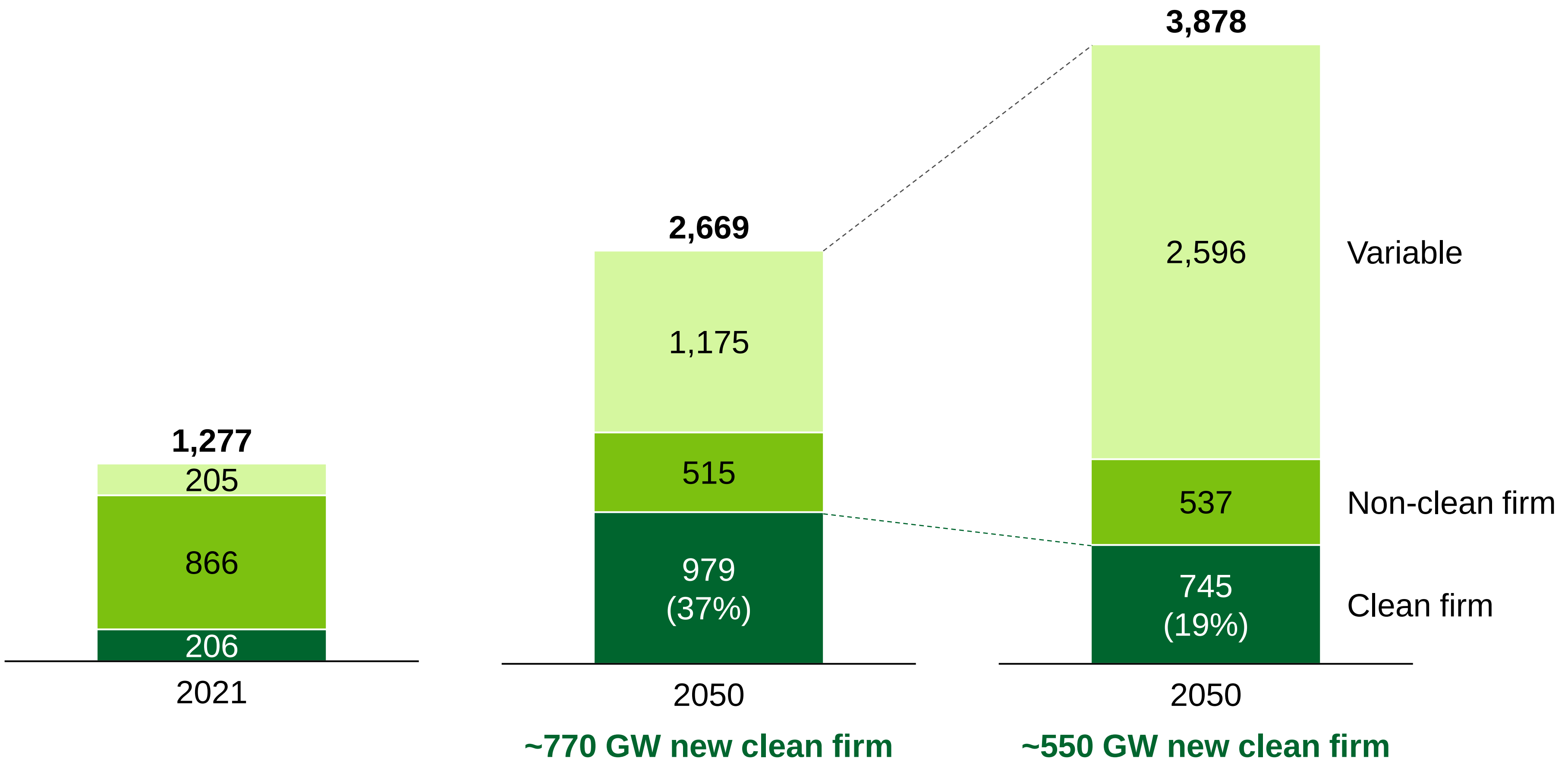


Modeled costs are for California in 2045 across three models; Source: Baik et al. (2021), "What's different about different net-zero carbon electricity systems?"

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



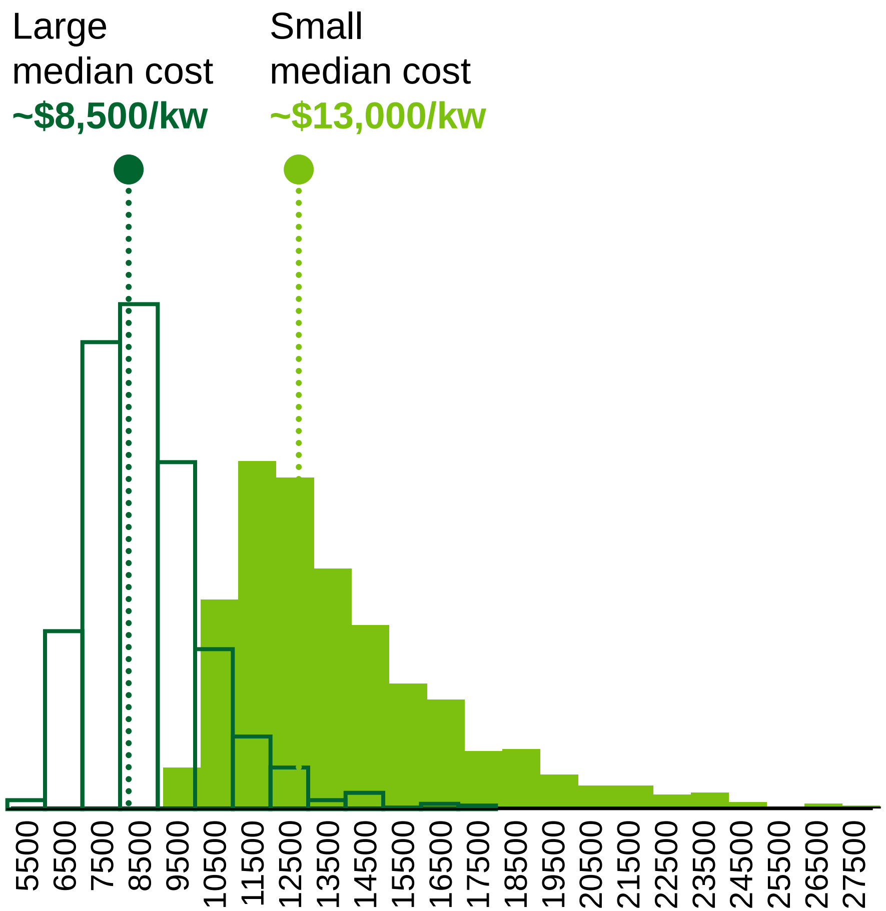
Clean firm power sources included are nuclear, hydropower, geothermal, energy storage (when charged using clean electricity), natural gas with carbon capture, geothermal, BECCs; non-clean firm is fossil generation with emissions otherwise offset

Advanced nuclear includes reactor types of all sizes across two generations

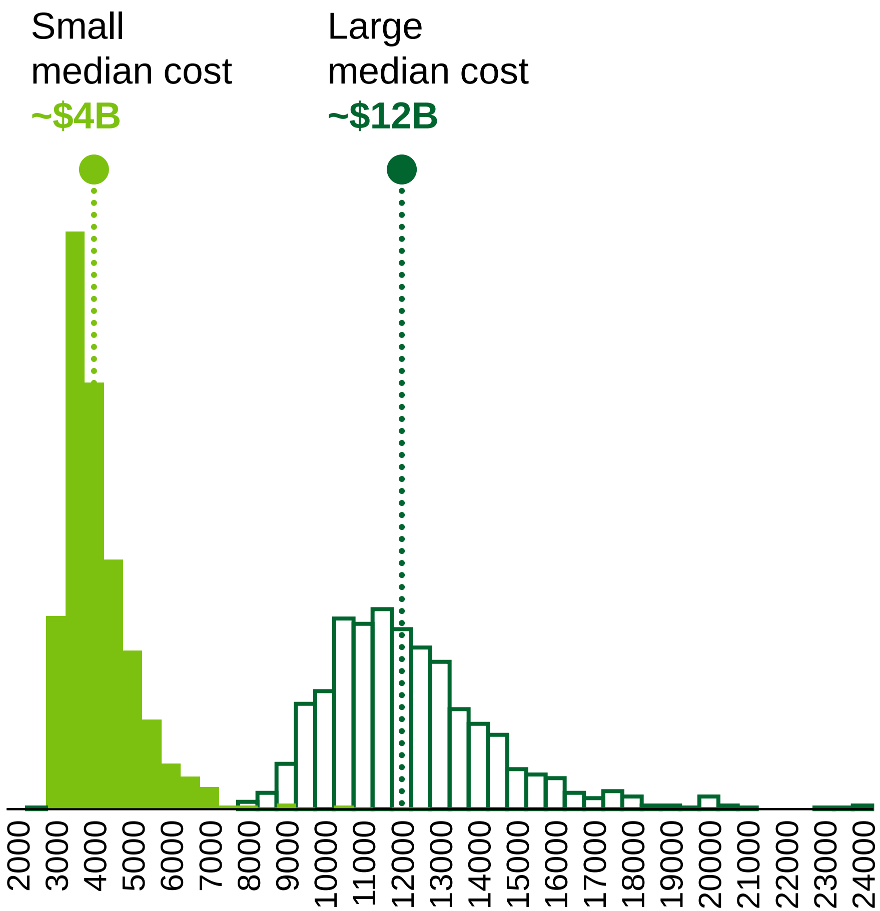
	Gen III+	Gen IV		
Coolant	Light water	Gas	Liquid metal	Molten salt
Examples	• Pressurized water reactor • Boiling water reactor	• High temperature gas reactor • Gas fast reactor	• Sodium fast reactor • Lead fast reactor	• Fluoride high temperature reactor • Molten chloride fast reactor
Typical fuel	LEU, 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	• GE Hitachi • Holtec • NuScale • Westinghouse	• BWXT • General Atomics • Radiant • X-energy	• ARC • TerraPower • Oklo	• 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
	(outlined bar)	(solid green bar)
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

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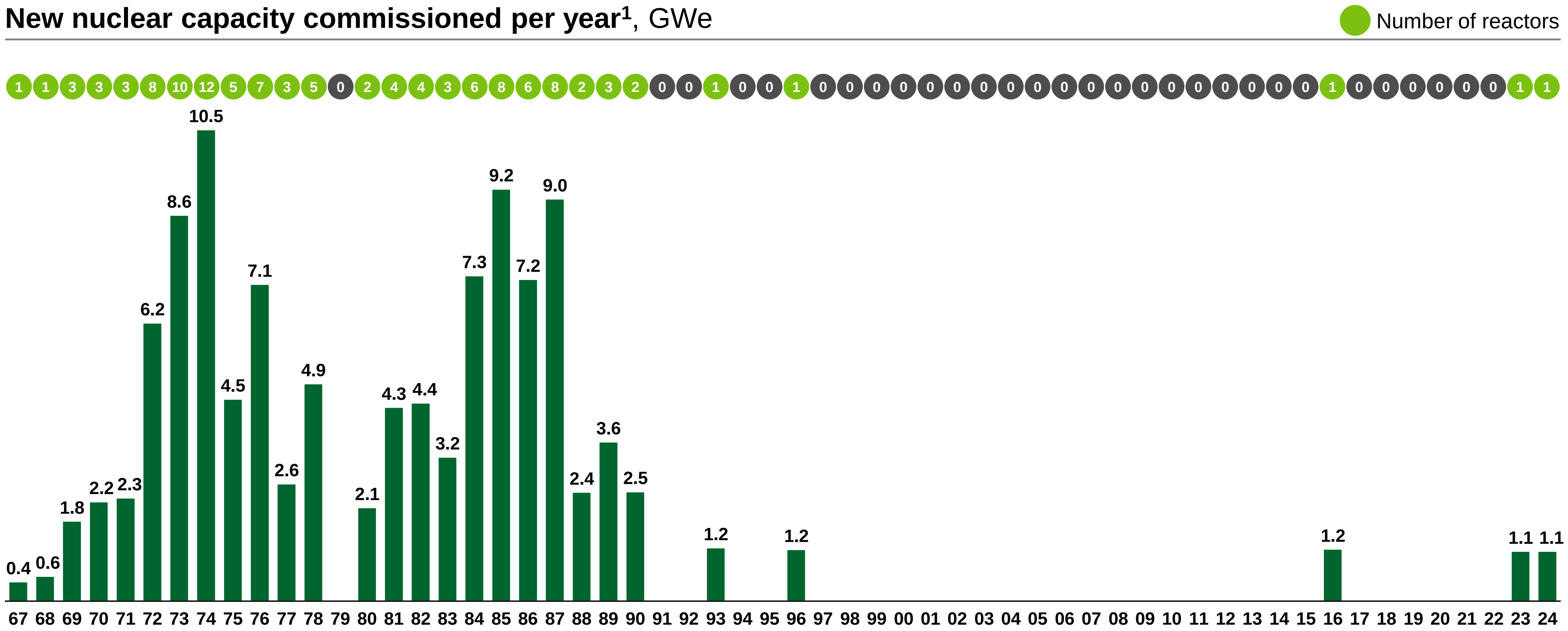
Most of the US fleet was built 1970-1980s; in 1974, 12 reactors came online

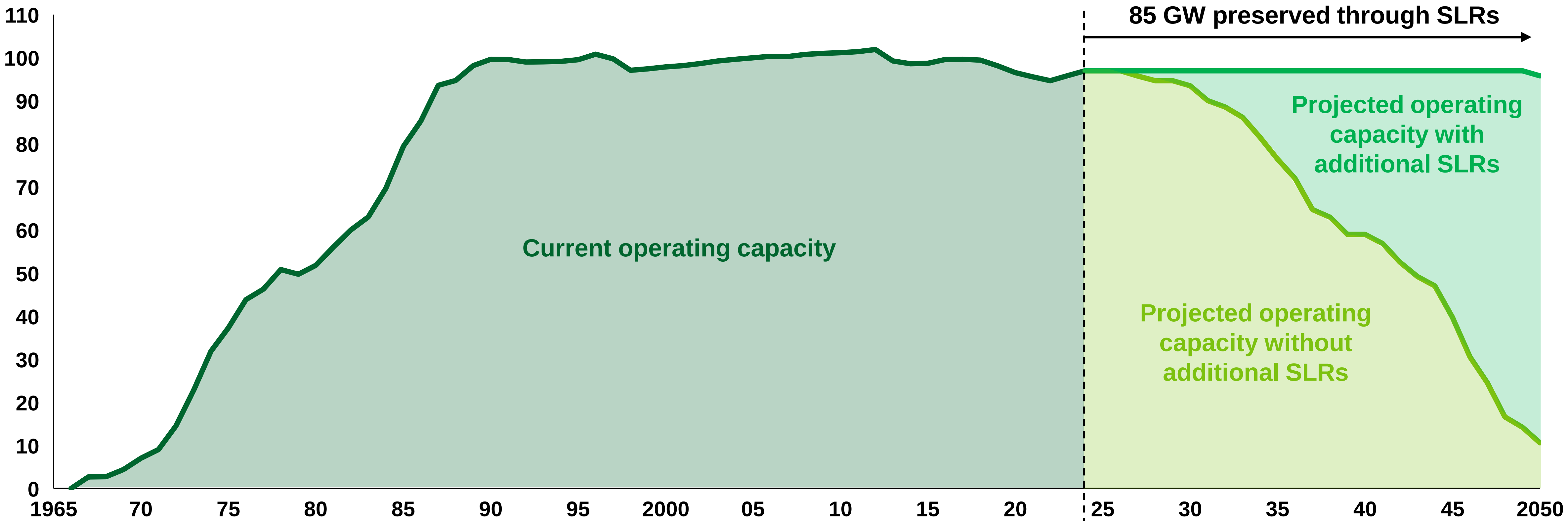
New nuclear capacity commissioned per year[1], GWe



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

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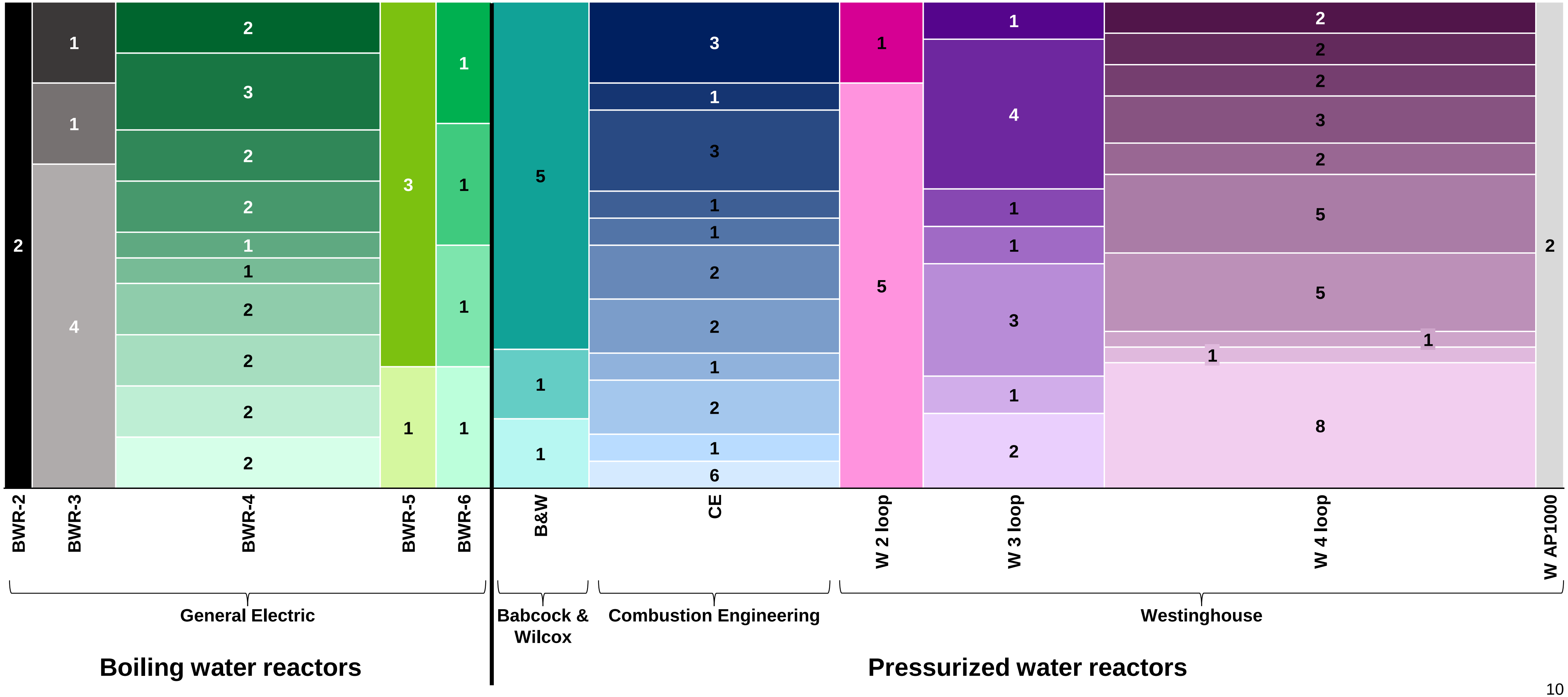
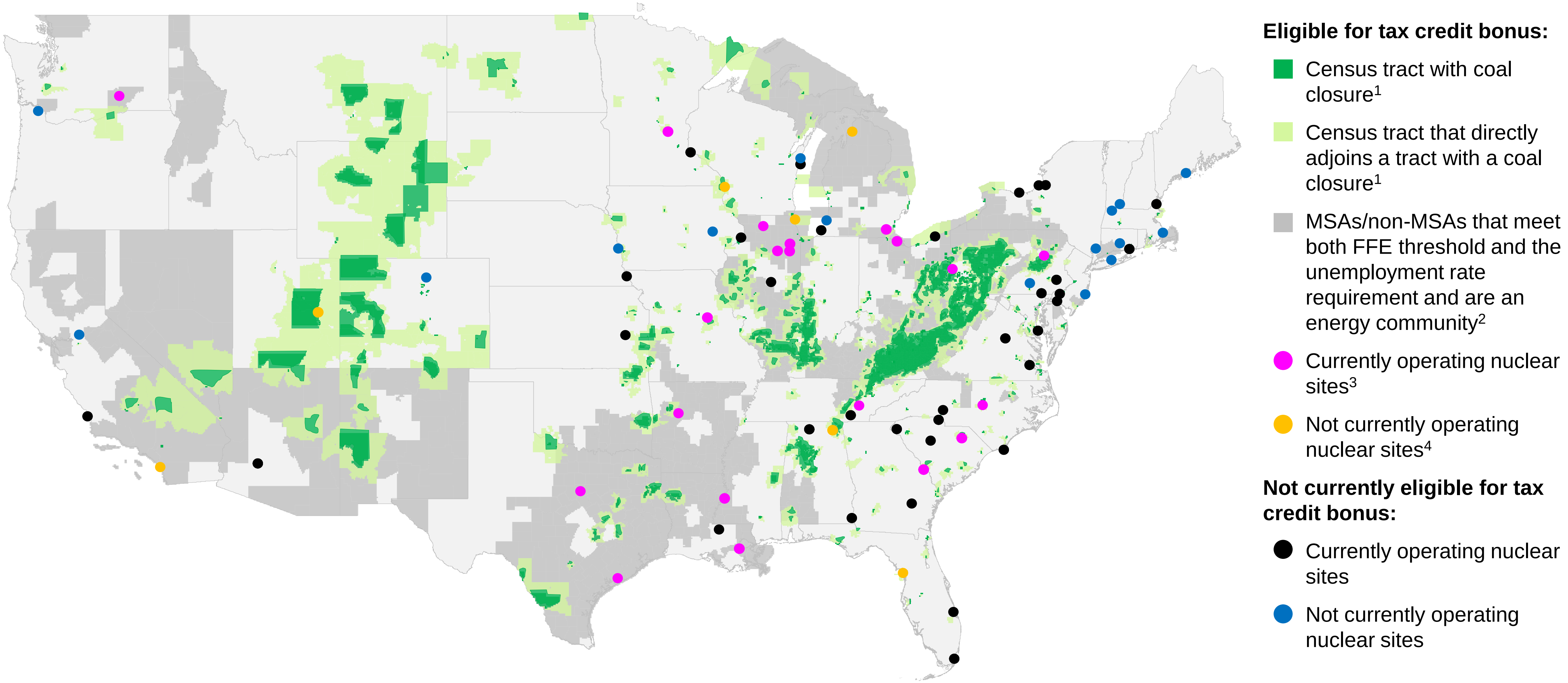
The lack of learning effects in the US may in part be explained by the construction of over 50 unique reactor designs

US commercial nuclear reactors by design

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

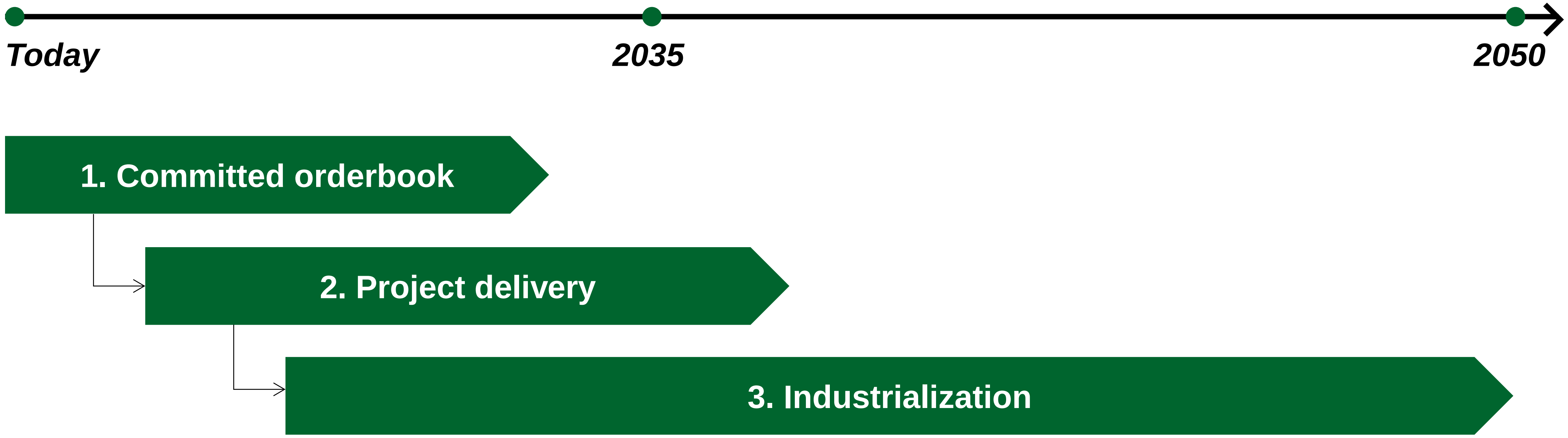


20 operating nuclear sites and 5 formerly operating sites are in communities eligible for energy community tax credit bonuses



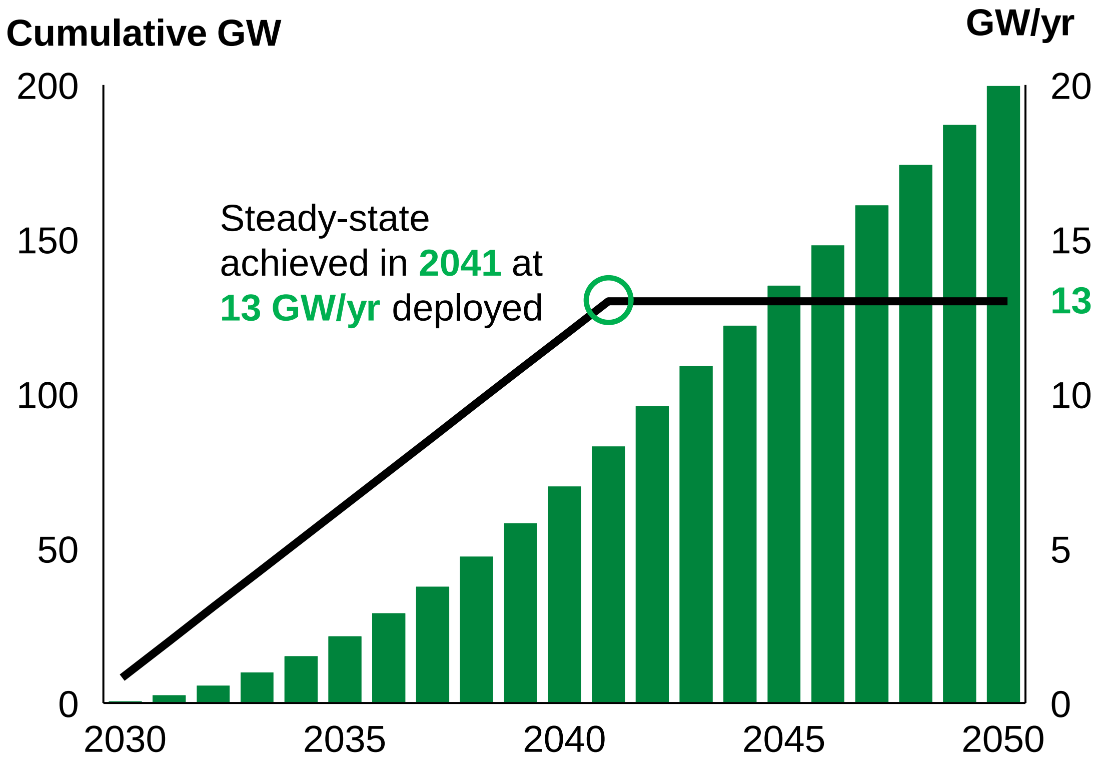
1. Census tract with a coal closure or directly adjoining a census tract with a coal closure 2. MSAs/non-MSAs that meet both the Fossil Fuel Employment threshold and the unemployment rate requirement 3. Arkansas Nuclear One, Beaver Valley, Braidwood, Byron, Callaway, Columbia, Comanche Peak, Davis-Besse, 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

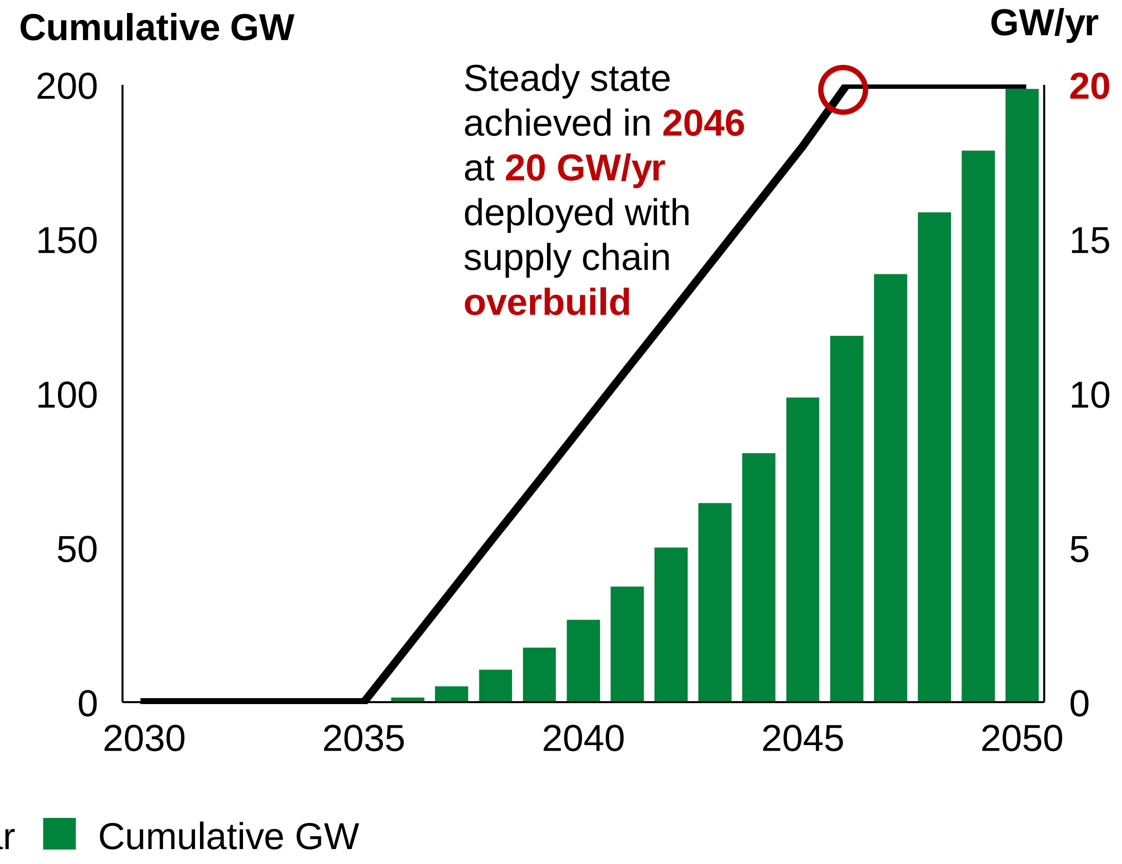


Delaying new nuclear deployment could increase the cost of decarbonization

New nuclear capacity starting in 2030



New nuclear capacity starting in 2035



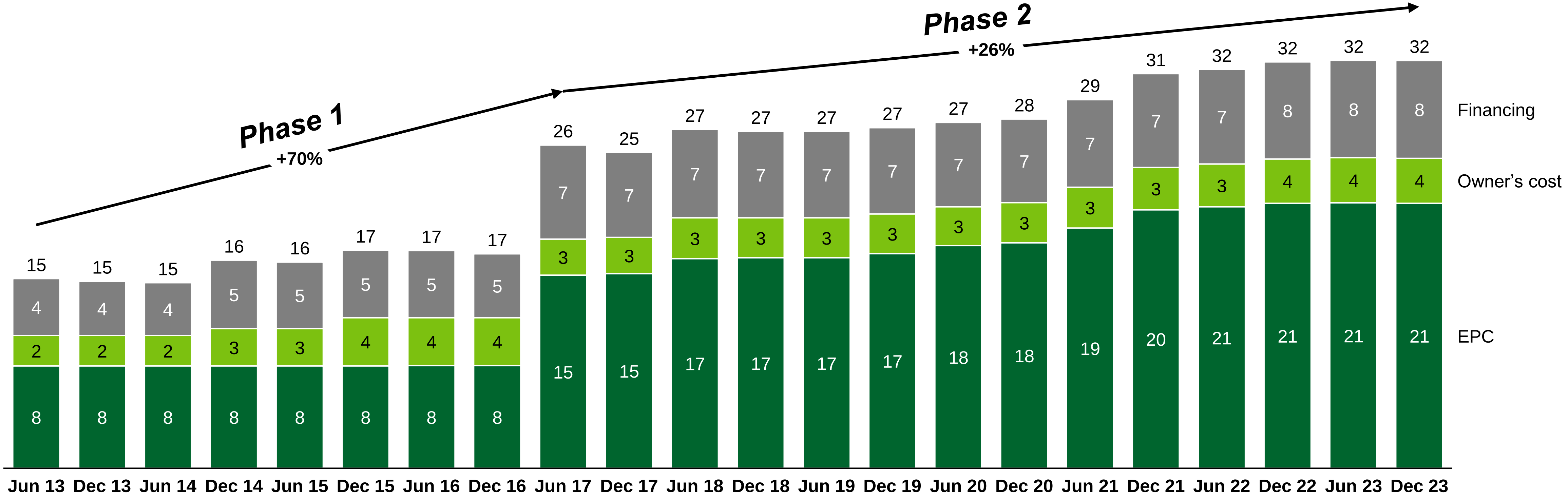
Any nuclear project requires many different roles to be filled; consortium approaches can help aggregate demand and share costs

	Reactor design	Project management: Licensing and site dev	Project management: Project management	Project management: Construction	Project management: Multi-project integration	Own (and/or invest equity)	Operate	Offtake
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



First nuclear concrete — **Westinghouse bankruptcy and project restructuring** — **Beginning of COVID-19 pandemic**

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)

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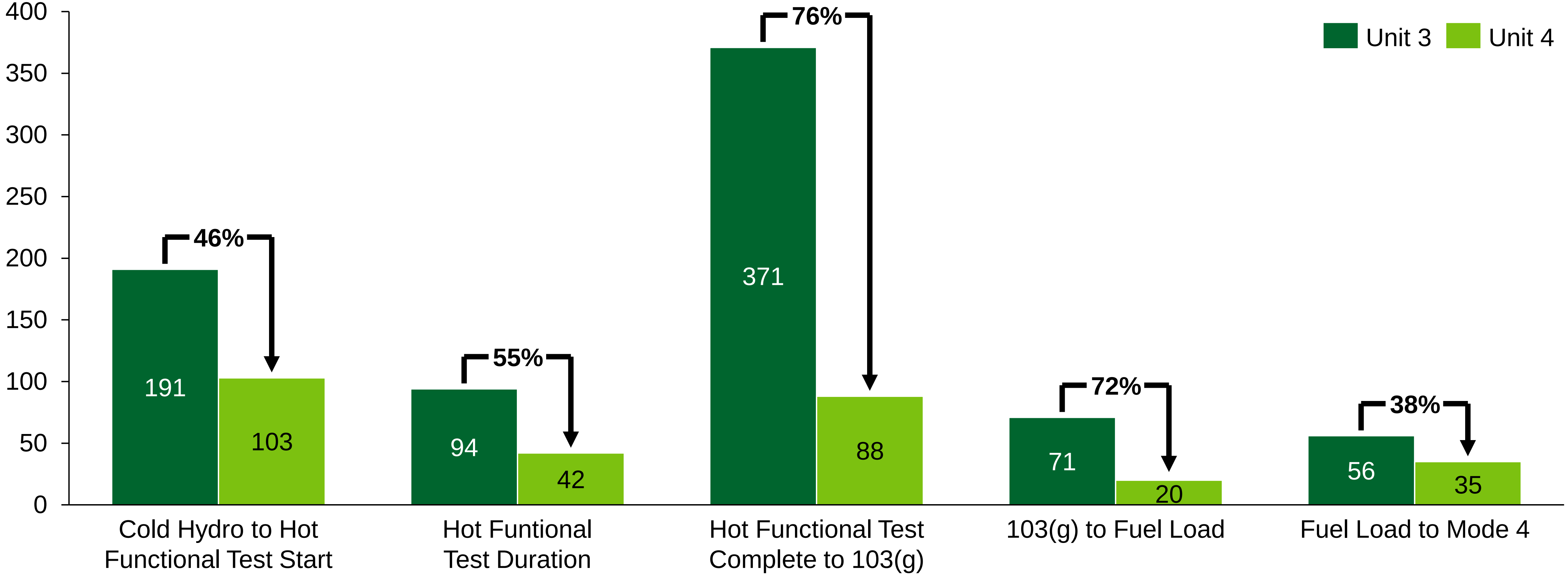
Improvement between Vogtle Units 3 and 4

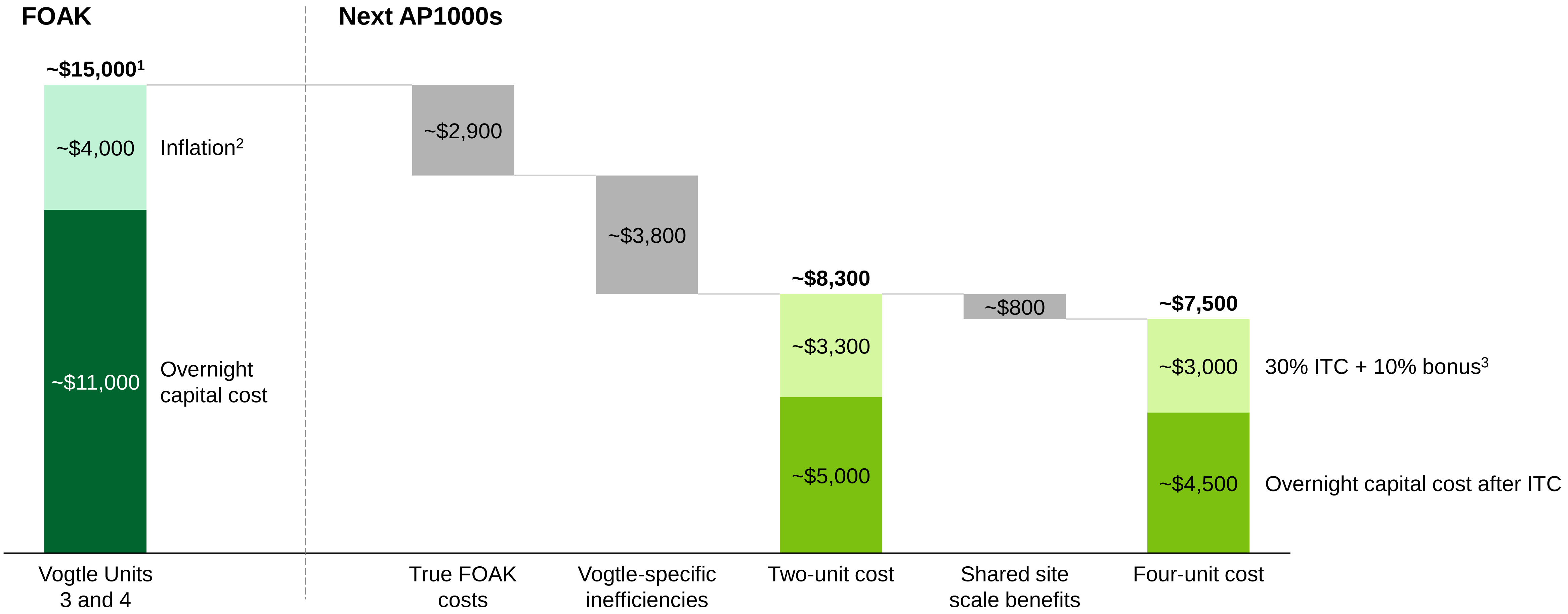
Days between major milestones for Vogtle Units 3 and 4, days



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

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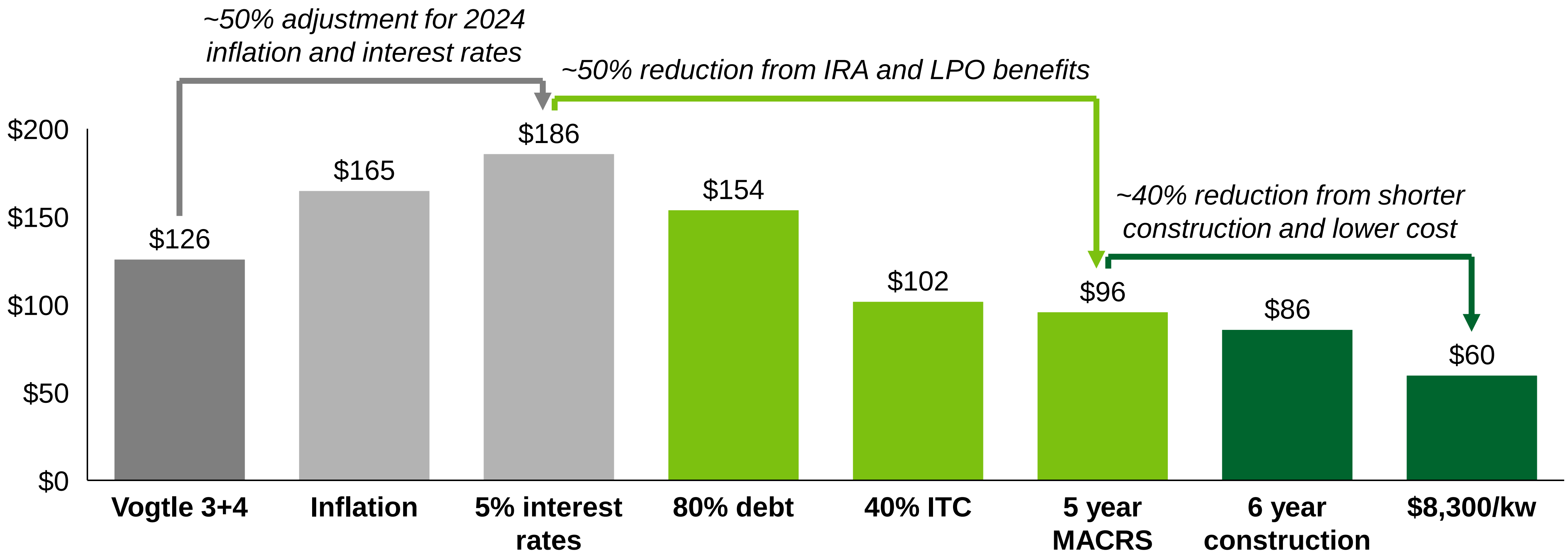
Even assuming Vogtle costs inflated to 2024, next AP1000 could be <$100/MWh with IRA benefits and closer to ~$60/MWh with cost reductions

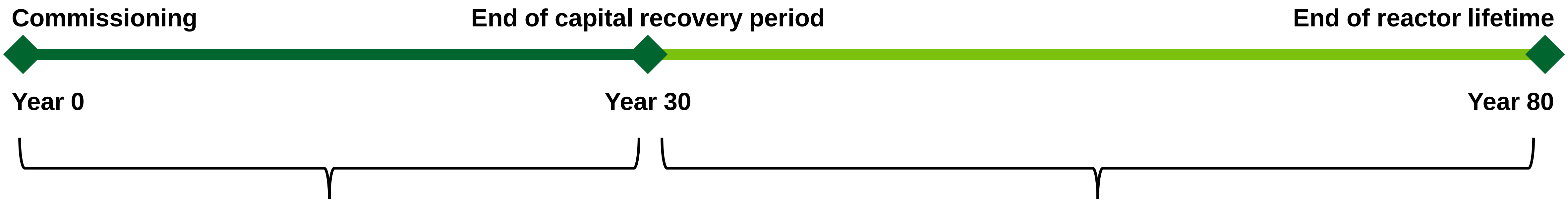
Estimated LCOE, 2024 $/MWh



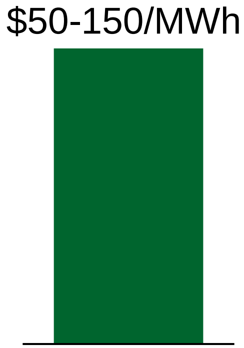
	Vogtle 3+4	Inflation	5% interest rates	80% debt	40% ITC	5 year MACRS	6 year construction	$8,300/kw
Overnight capital cost	$11,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$8,300
Construction time	11 years	11 years	11 years	11 years	11 years	11 years	6 years	6 years
Interest rate on debt	3.5%	3.5%	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

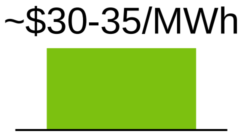


LCOE during capital recovery period (~30 years)



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)



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

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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	• Consortium committing to 5-10 (or more) reactors • Financial assistance, e.g., grants • Government build and ownership	• Completion or debt guarantees • Contingent equity • Contingent debt • Flexible PPA prices	• Mature cost estimates • Construction best practices incorporating lessons from Vogtle • FOAK to NOAK cost levers

- Investment tax credit or overrun insurance (*both sharing and insuring*)
- Government-enabled offtake certainty (*both sharing and insuring*)

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