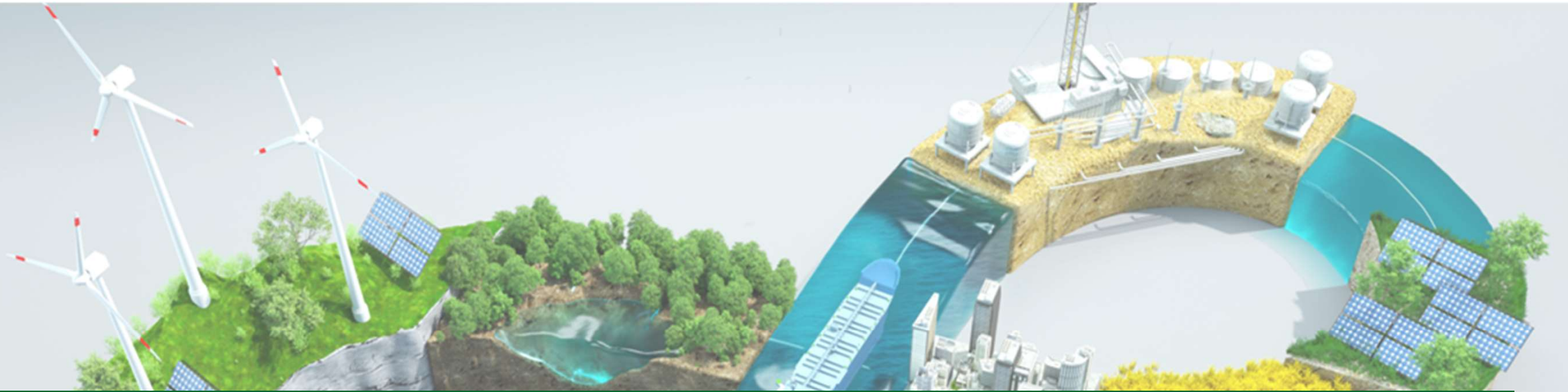




U.S. DEPARTMENT OF
ENERGY



Pathways to Commercial Liftoff

Advanced Nuclear | April 2023

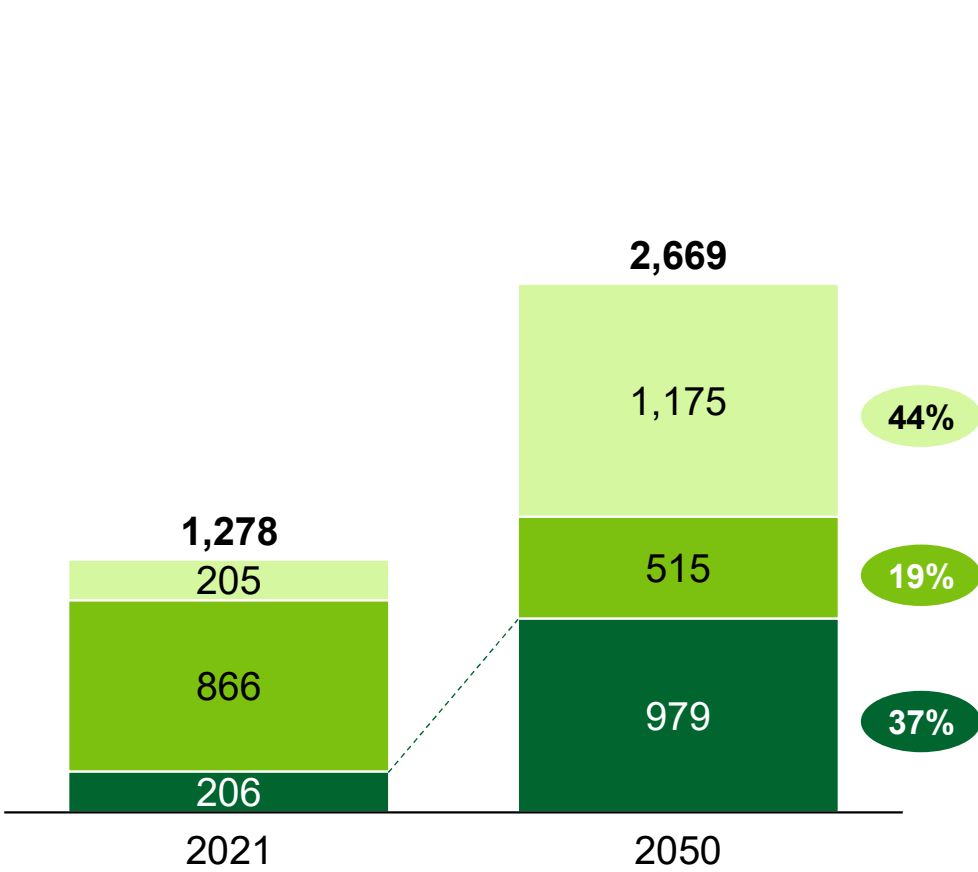


Advanced nuclear includes five major technology types across two generations

	Gen III+		Gen IV		
	Large Light Water	Light Water SMRs	High Temperature Gas Reactors	Metal/Salt Cooled	Micro
Power output	~1+ GW	~70–300 MW	~80–270 MW	~200–800 MW	~1–50 MW
Typical fuel	LEU	LEU	HALEU	HALEU	HALEU
Coolant	Water	Water	Gas, e.g., helium	Metal or salt	Various
Select programs (reactor developer)	LPO loan guarantees for Vogtle Units 3 and 4 (Westinghouse)	Carbon Free Power Project (NuScale)	Advanced Reactor Demo. Program (X-energy)	Advanced Reactor Demo. Program (TerraPower)	DOD Project Pele (BWXT), Eielson Air Force Base RFP (TBD)

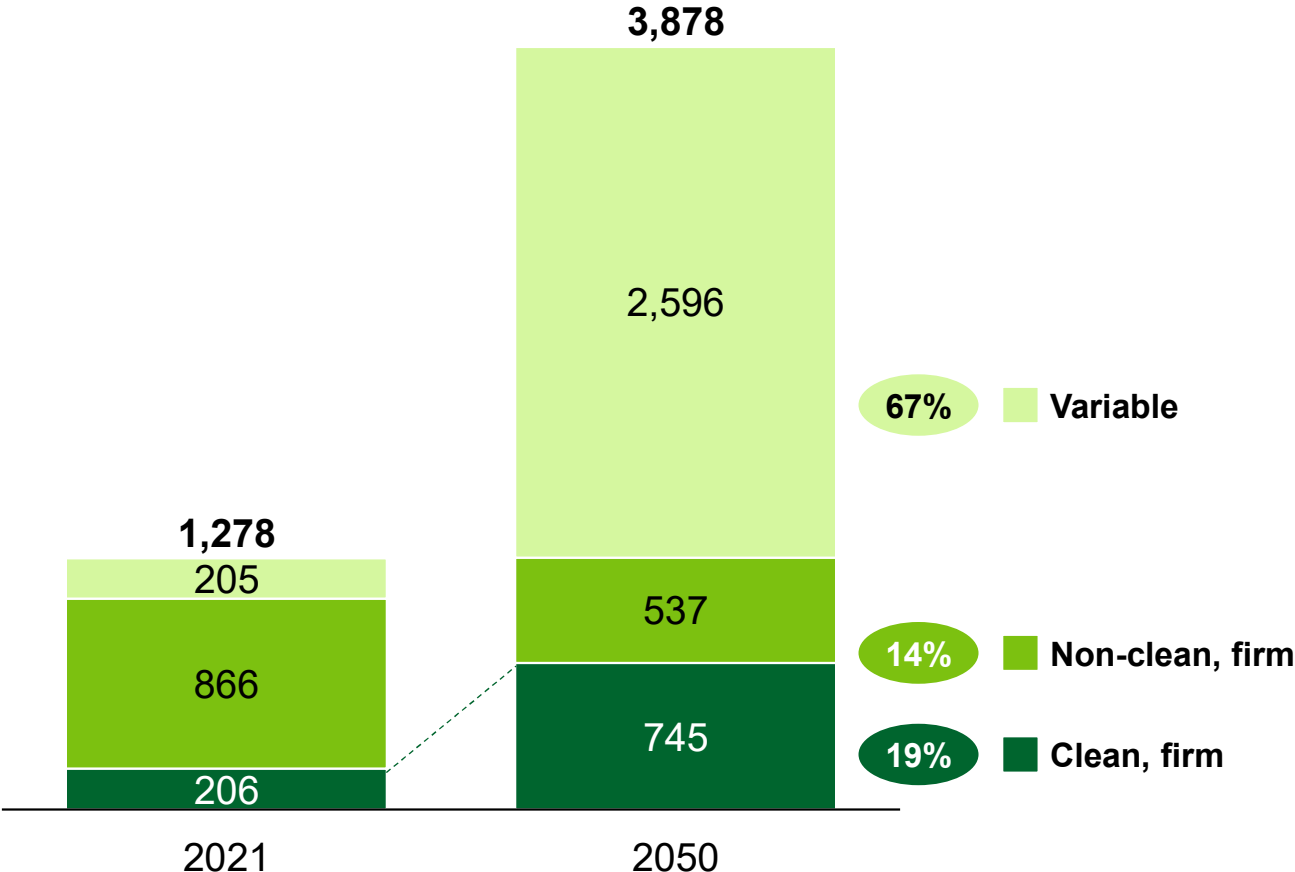
Achieving net-zero in the U.S. by 2050 would require ~550–770 GW of additional clean, firm capacity

Capacity in lower renewables case, GW



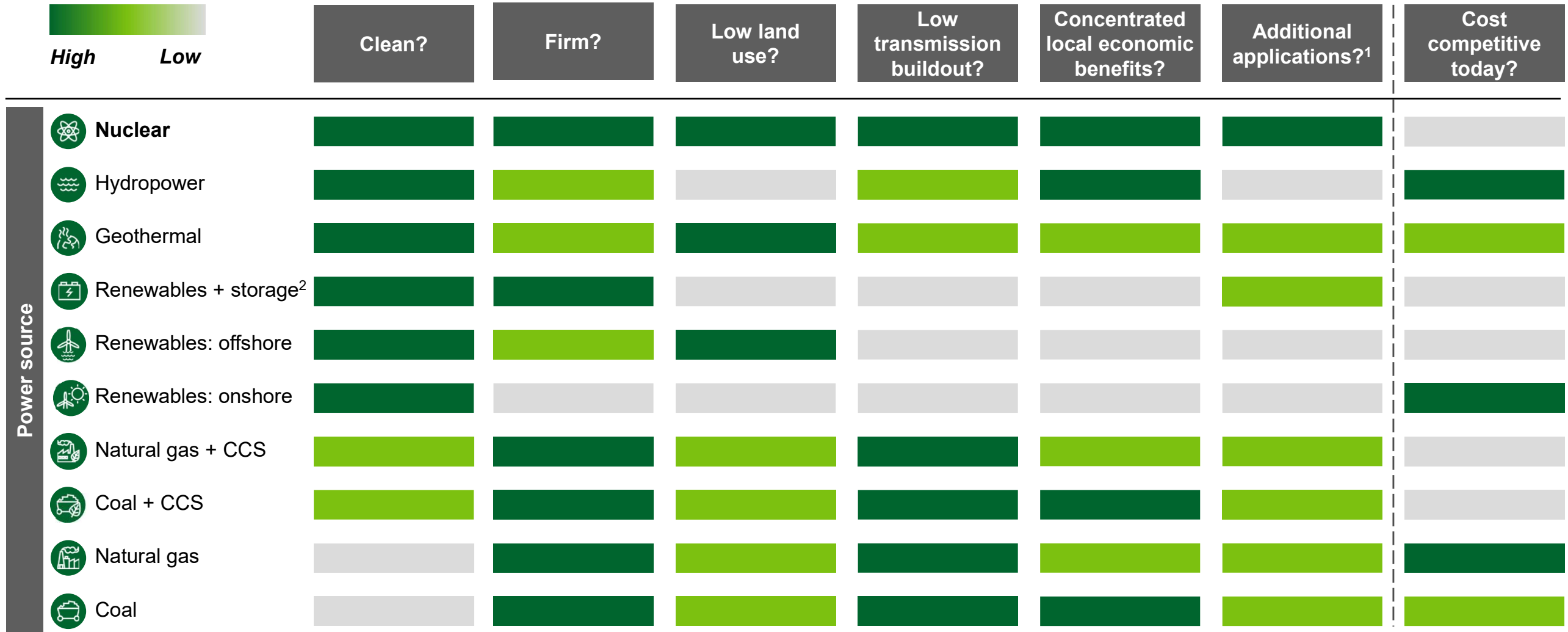
~5x clean, firm (~770 GW)

Capacity in higher renewables case, GW



~3.5x clean, firm (~550 GW)

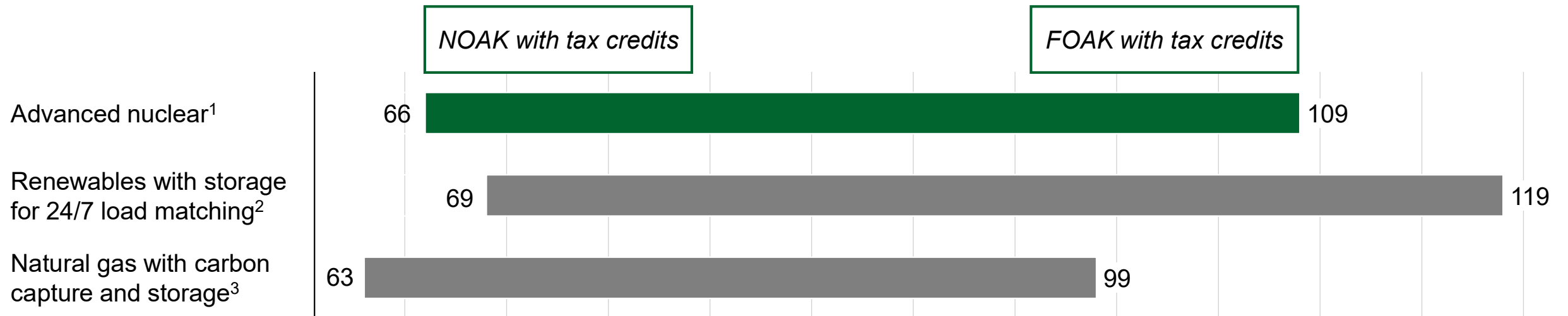
Nuclear has a unique value proposition for the net-zero grid



1. Additional applications include clean hydrogen generation, industrial process heat, desalination of water, district heating, off-grid power, and craft propulsion and power
 2. Renewables + storage includes renewables coupled with long duration energy storage or renewables coupled with hydrogen storage

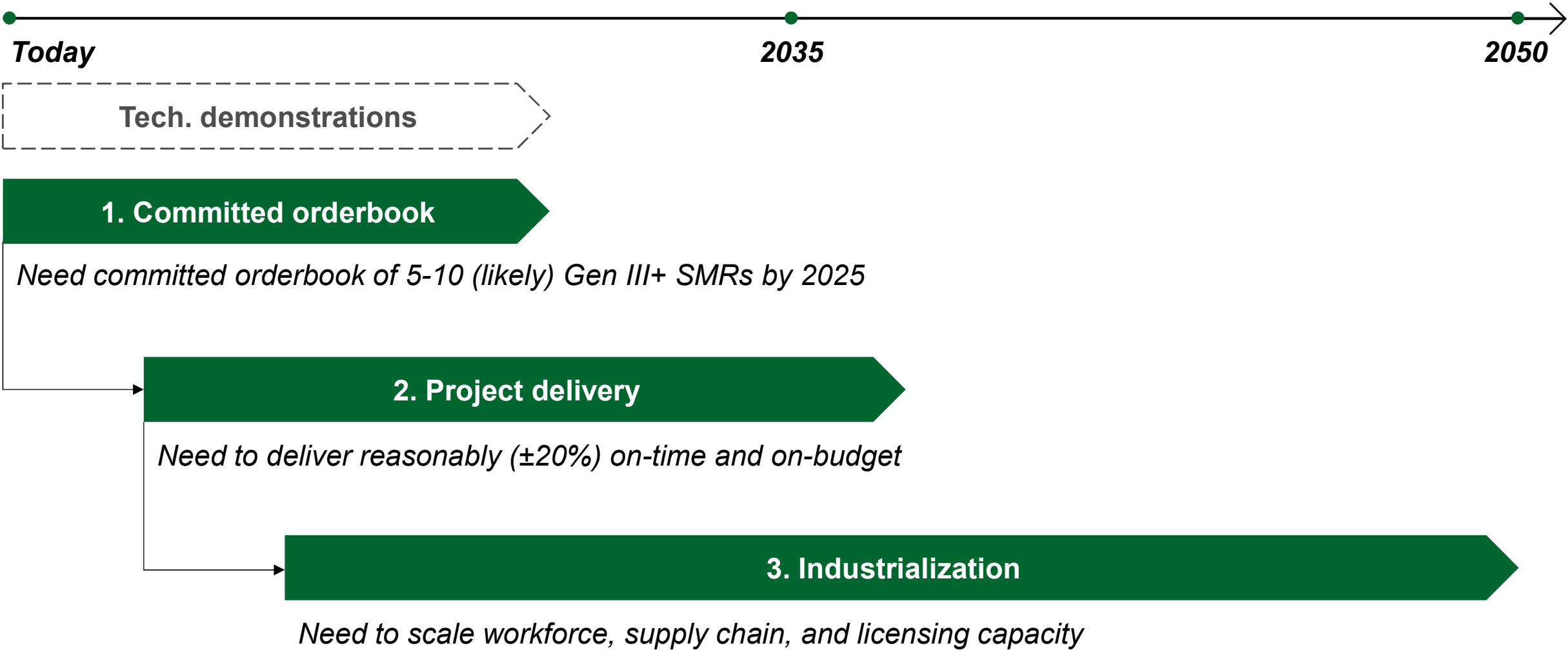
Nuclear is expected to be cost competitive with other clean firm resources

Estimated LCOE of clean firm energy resources, \$/MWh



1. Advanced nuclear estimated LCOE from \$3,600/kW (NOAK) and \$9,000/kW (FOAK) overnight capital cost and includes 30% 48E ITC (without either 10% adder) 2. Renewables with storage for 24/7 load matching from LDES Council's "A path towards full grid decarbonization with 24/7 clean Power Purchase Agreements" and the LCOE is calculated as (annualized cost of renewable generation + storage capacity) / clean energy delivered to the off-taker excluding additional costs or revenues that would impact final PPA price and includes the ITC under section 48 for the full investment cost of the facility 3. Natural gas with carbon capture and storage numbers from the McKinsey Power Model and include the 45Q tax credit

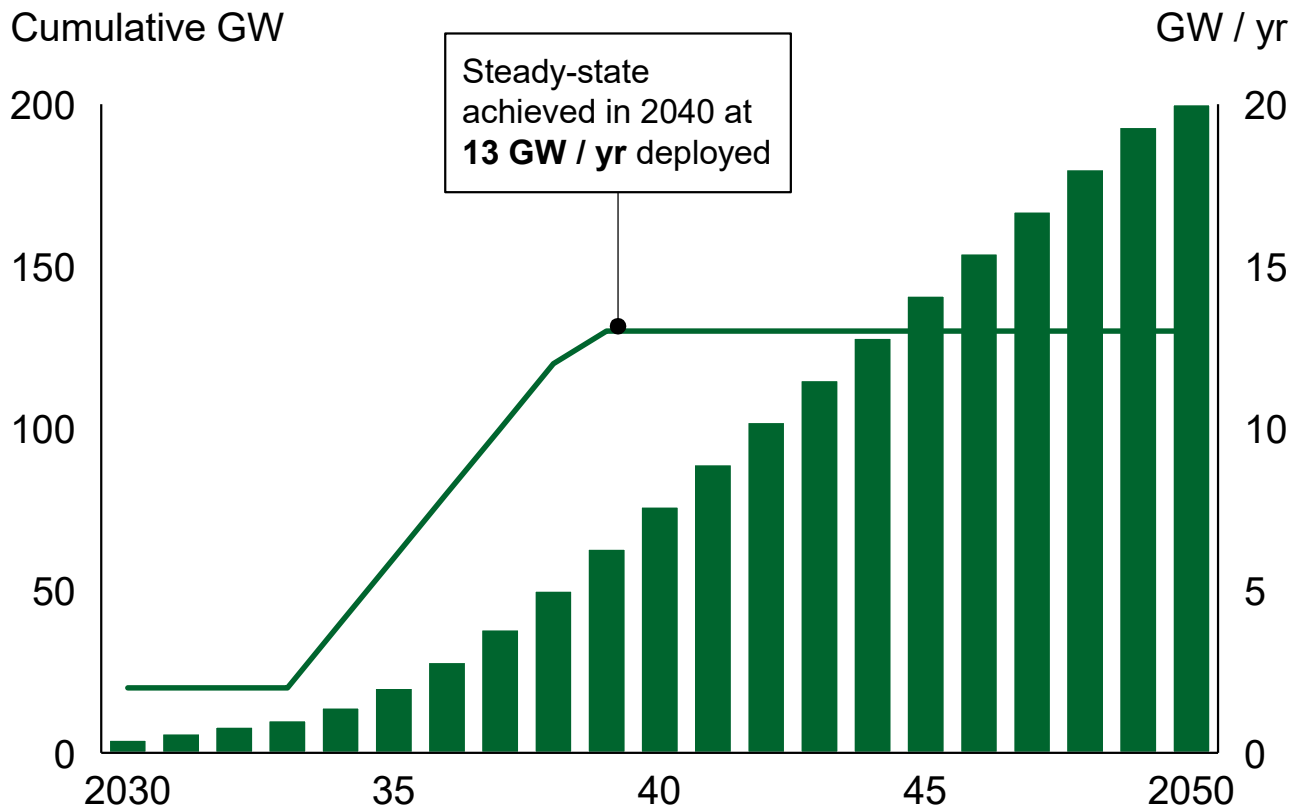
Three key stages inform path to deploying advanced nuclear at scale



Waiting until mid-2030s to deploy at scale could lead to missing decarbonization targets or overbuilding supply chain

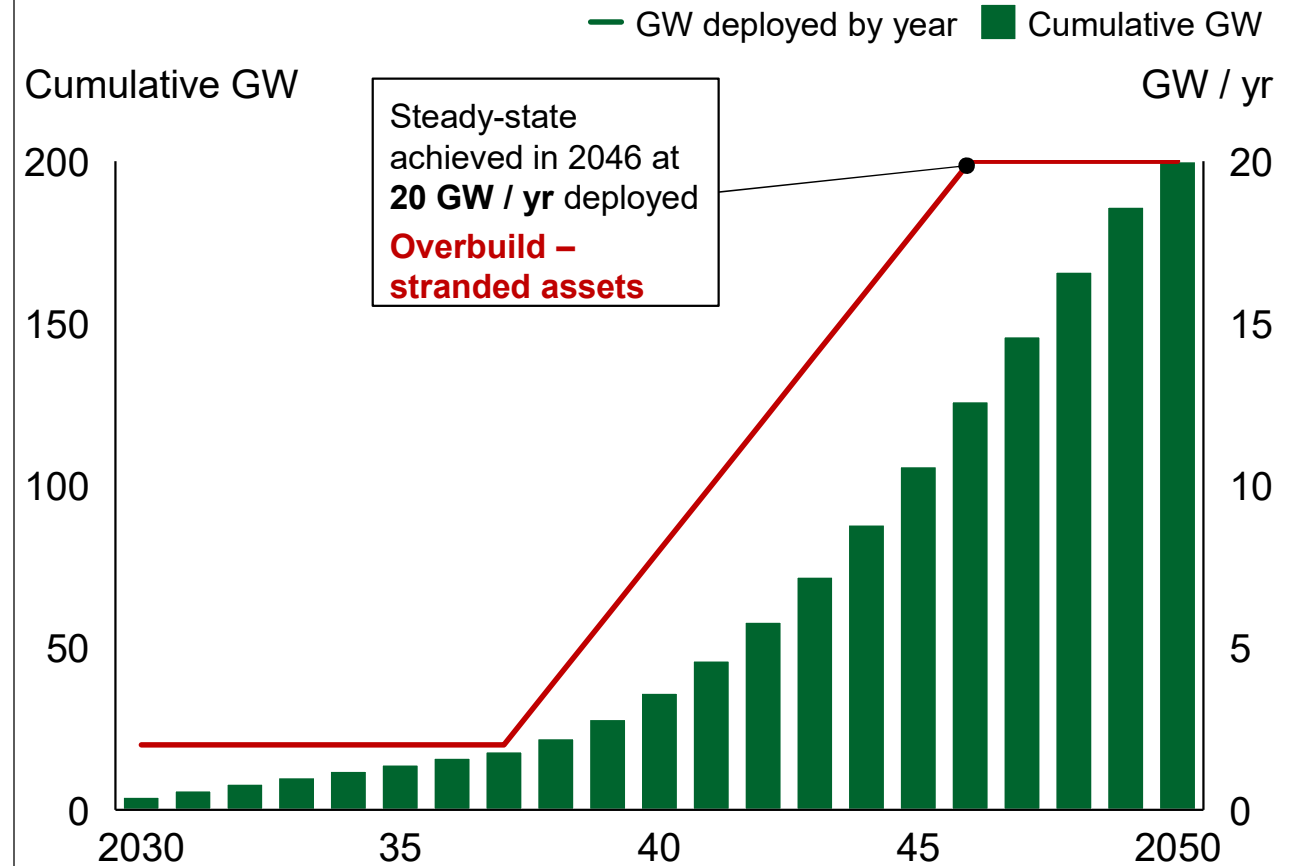
New nuclear deployment starting in 2030

Annual deployment (GW / yr) built and Cumulative GW online



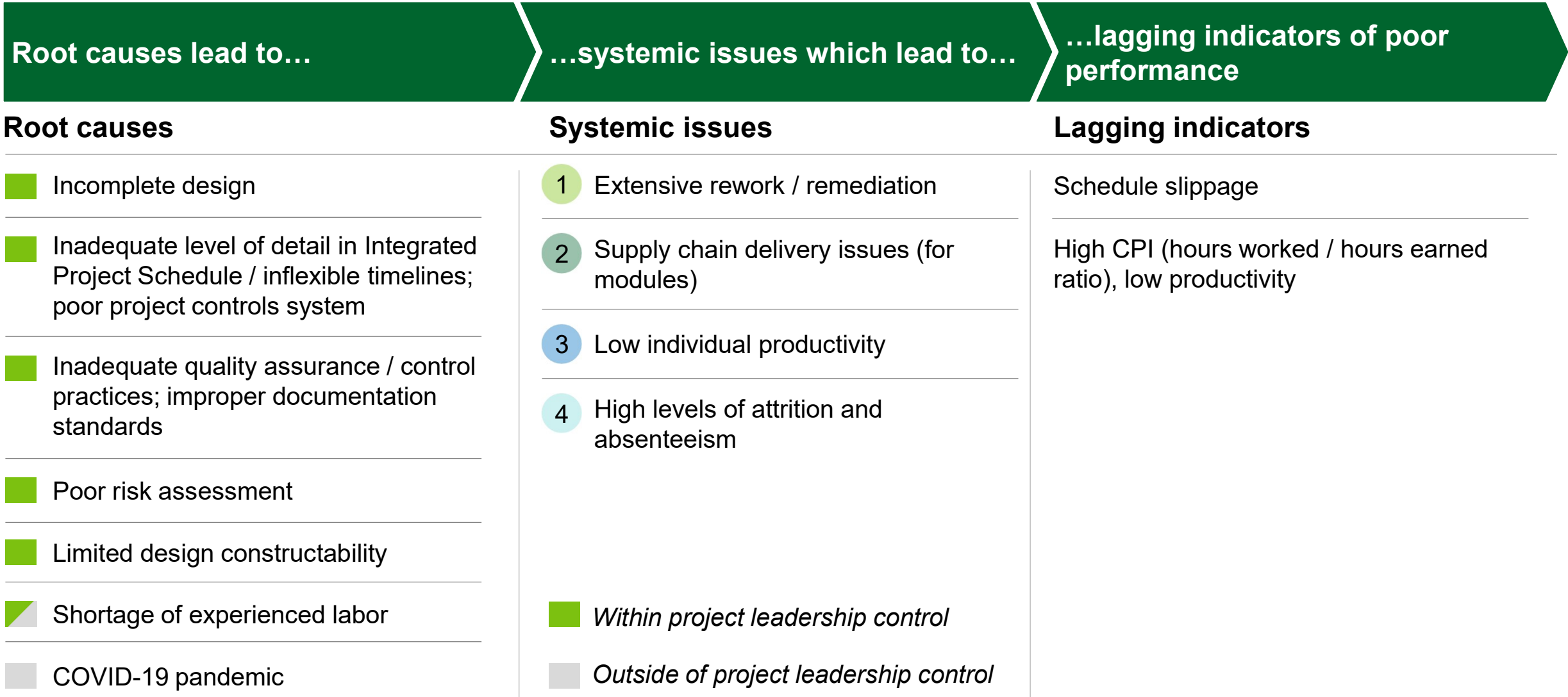
New nuclear deployment starting in 2035

Annual deployment (GW / yr) built and Cumulative GW online



1. Construction and manufacturing | Assumptions: 2-year licensing timeline concurrent with early site prep; Manufacturing (1 yr) followed by construction (3 yrs) occurs post-licensing and site prep

Vogtle root causes and systemic issues



Catalyzing the orderbook may require interventions to help manage completion risk

Nuclear industry is in a stalemate

The nuclear industry is stuck in a stalemate where utilities and other potential owners recognize an increasing need for nuclear power, but are **too afraid of uncontrolled overrun and project abandonment** risk to place committed orders

Developing a committed orderbook could be facilitated by **pooling demand, e.g., with a consortium of utilities**

Participation in such a model could be **accelerated with financial support** (either public or private) to help de-risk the first 5-10 projects

Possible accelerants for generating orders

Cost overrun insurance	A percentage of construction costs over and above a certain amount are covered by the government or private insurer
Tiered grant	Large grant amount per kW, ramping down over each successive deployment, e.g., second reactor receives less than the first
Government as the owner	Government commits to build and/or operate reactors to provide pooled demand
Government as the off-taker	Government signs offtake contract for some or all of generation from an orderbook

Appendix

Advanced Nuclear Pathways to Commercial Liftoff: Executive Summary

Report aims to create a shared fact base for answering key investor and stakeholder questions

- ***What is advanced nuclear and its value proposition?*** Report covers Gen III+ and IV across large reactors, SMRs, and microreactors; nuclear is clean, is firm, uses land efficiently, requires less transmission buildout, provides regional economic benefits, and has additional use cases and benefits beyond traditional electricity generation
- ***Do we need new nuclear for net zero?*** Likely 100-200GW in the US by 2050, especially given renewables buildout
- ***Why will it be different than recent over-budget builds?*** SMRs may avoid historical cost and constructability challenges; Vogtle provides lessons on the importance of rigorous pre-construction planning

Requirements for scaling to 200GW of new US nuclear by 2050

- Waiting until mid-2030s to deploy at scale would lead to missing targets and/or significant supply chain overbuild
- Need committed orderbook of (likely) Gen III+ SMRs by 2025, 5-10 of one design; one design is necessary, but not sufficient and Gen III+ is likely for nearest-term deployment given utility risk tolerance
- 200GW cumulative deployment will require developing a workforce of ~375K and scaling and adapting component supply chains that are sub-scale today; reduced, predictable licensing timelines also key
- Need to identify incentive and location(s) for long-term spent fuel storage implications

Potential solutions

- Utilities are afraid of uncontrolled overrun and project abandonment risk; catalyzing the orderbook will require intervening to manage completion risk, e.g., overrun insurance, tiered grants, government ownership/offtake
- Project delivery for first reactors needs to actively incorporate Vogtle lessons, with potential EPC partnerships
- Industrialization will require large-scale financing (e.g., low-cost debt) and programs (e.g., labor recruiting, training)

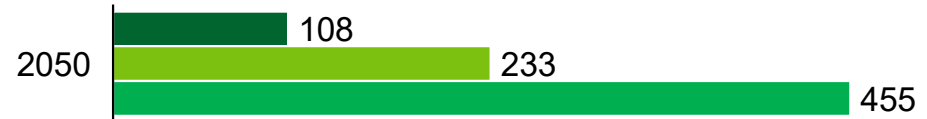
Modeling results show demand for 200+GW of new nuclear capacity

■ Low case ■ Infrastructure/renewables limitations ■ High case¹

Model

Advanced nuclear capacity, GW

Demonstration and Deployment Pathways Modeling (this report)²



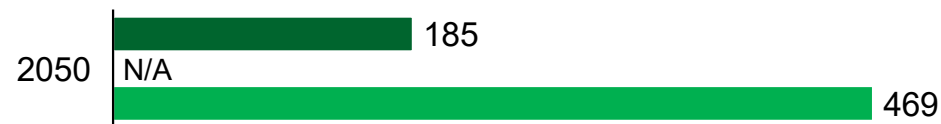
NREL, 2022 “100% Clean Electricity by 2035”



Princeton University “Net-Zero America: Potential Pathways, Infrastructure, and Impacts”



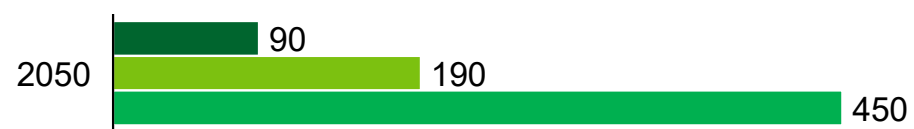
Breakthrough Institute, 2022 “Advancing Nuclear Energy”



Vibrant Clean Energy, 2022 “Role of Electricity Produced by Advanced Nuclear Technologies”



Pacific Northwest National Laboratory, 2022 “Scenarios of Nuclear Energy Use in the United States in the 21st Century”

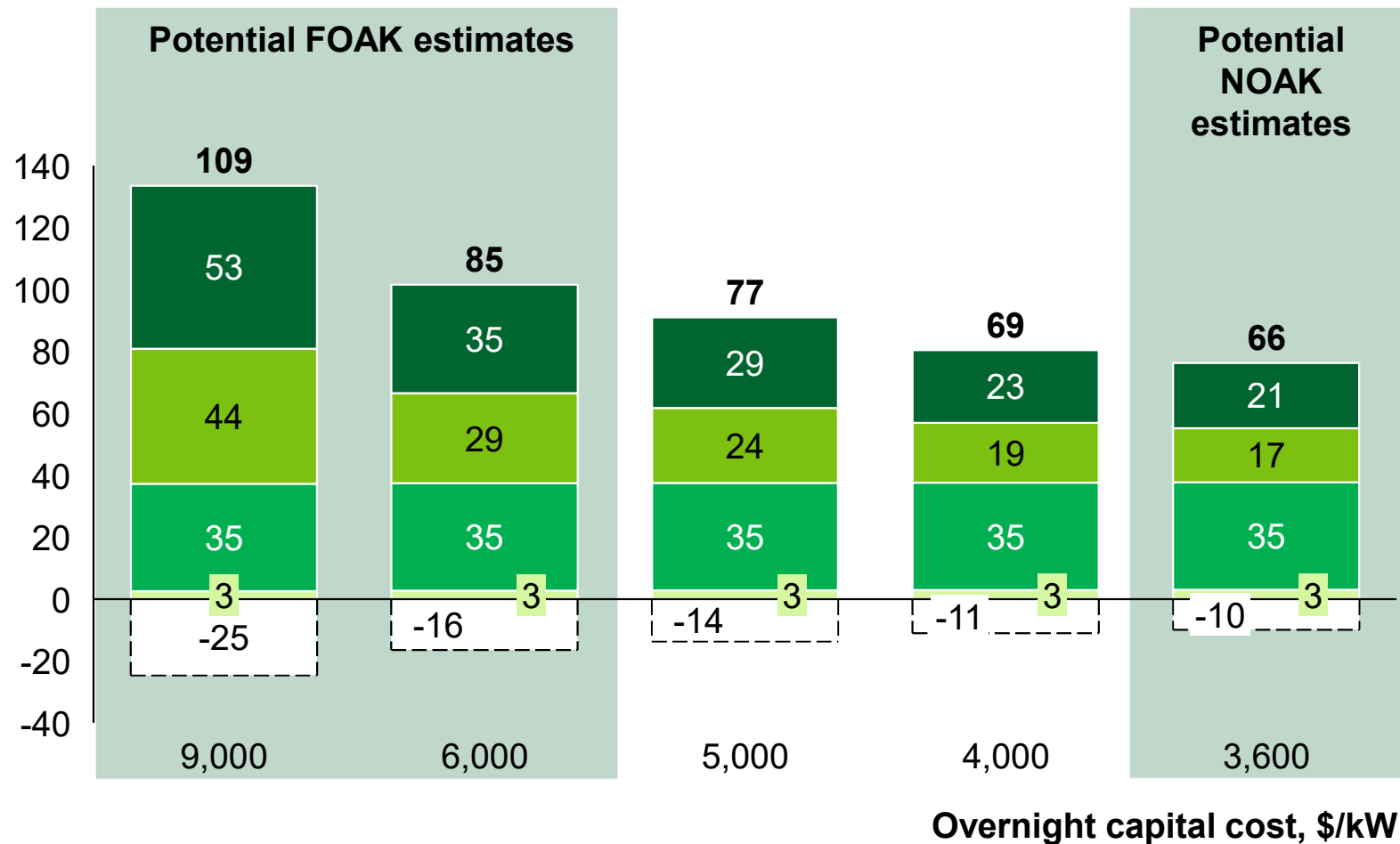


1. “Low” and “high” refer to the level of nuclear build out; methodology for “low” and “high” nuclear build-out cases differ report to report; 2. NZD Low-RES case sensitivities shown

LCOE expected to achieve sub \$60/MWh if capex costs reach <\$5000k/kW

LCOE of advanced nuclear given varying overnight capital costs, \$/MWh

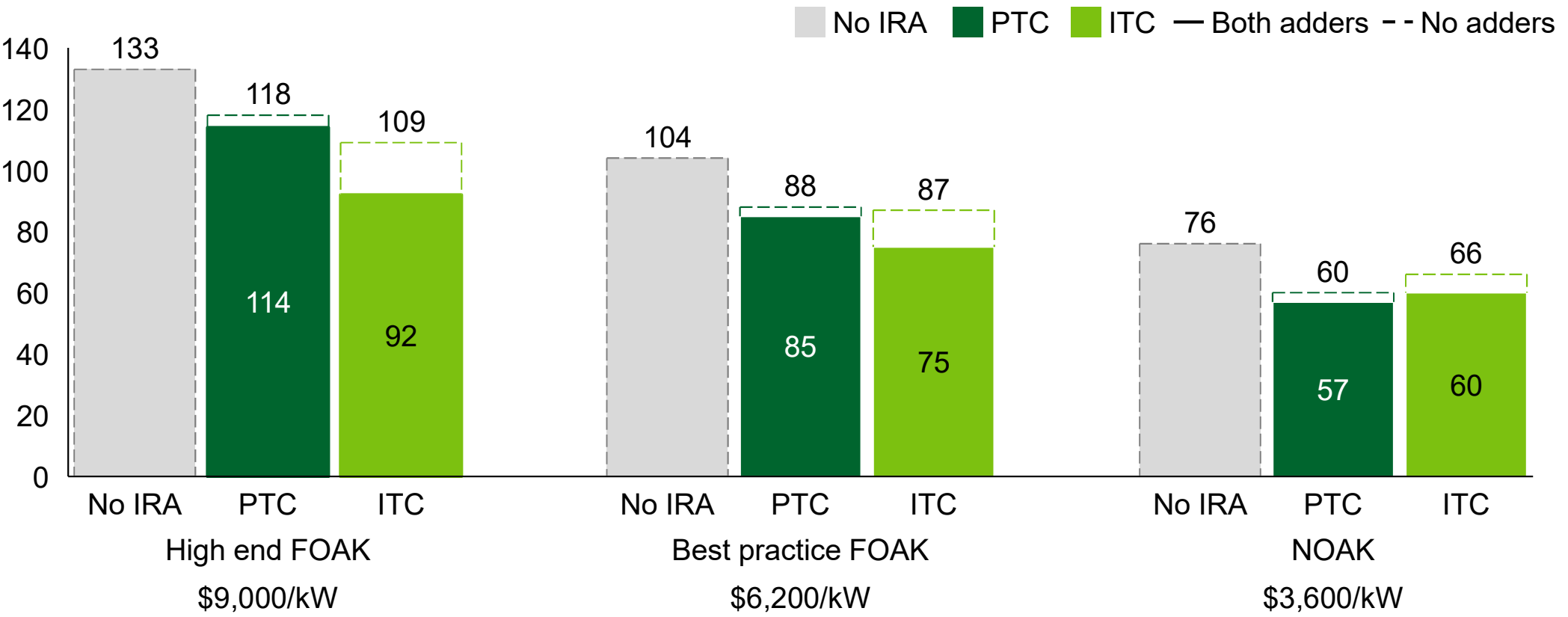
■ Overnight capital cost
 ■ Financing
 ■ Opex, fuel, and sustaining capital
 ■ Tax
 Tax credit (ITC)



Source: NREL "Examining Supply Side Options to Achieve 100% Clean Electricity by 2035", Inflation Reduction Act, EIA Annual Energy Outlook 2022

The IRA provides a powerful boost to nuclear power economics, but may not be sufficient to accelerate commitments for deployment at scale

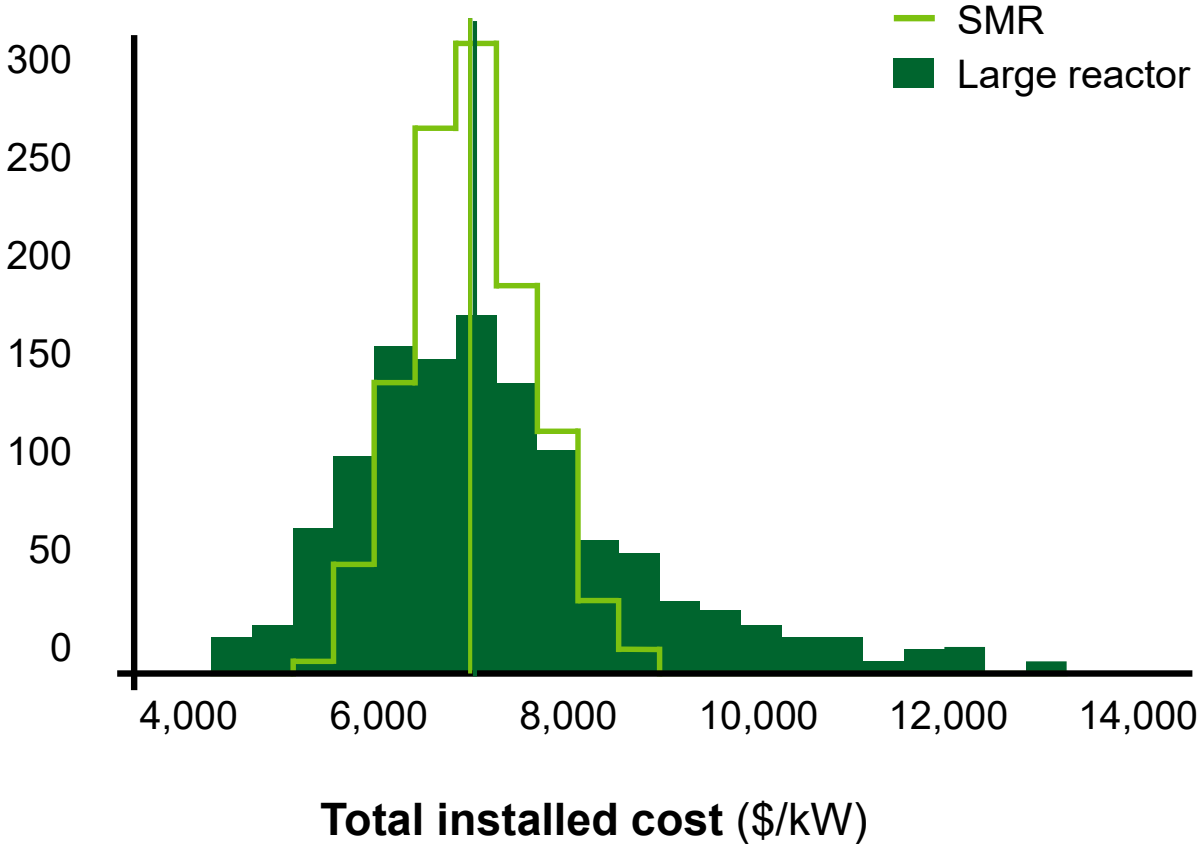
Advanced nuclear FOAK LCOE before and after IRA impact, \$/MWh



1. "Both adders" represents the ITC / PTC with the addition of both 10% adders for energy communities and domestic content

Small modular reactors can provide more certainty of hitting a predicted cost target

Probability distribution of cost of advanced nuclear



Demonstration programs are underway to demonstrate the technological viability of novel nuclear technologies

Program	Reactor developer	Reactor type	Years of award	Awardee cost-share	DOE cost-share	DOE cost-share (%)
Advanced Reactor Demonstration Program (ARDP)	TerraPower	Sodium fast reactor	2021-2028	\$2.0B	\$2.0B	50%
ARDP	X-energy	High temperature gas reactor	2021-2027	\$1.2B	\$1.2B	50%
Carbon Free Power Project (CFPP)	NuScale	Light water reactor	2020-2030	\$3.6B	\$1.4B	28%