NEI Demand Survey and DOE Pathways Report Overview

Presentation to the LINE Committee

John Kotek

Sr. VP, Policy & Public Affairs

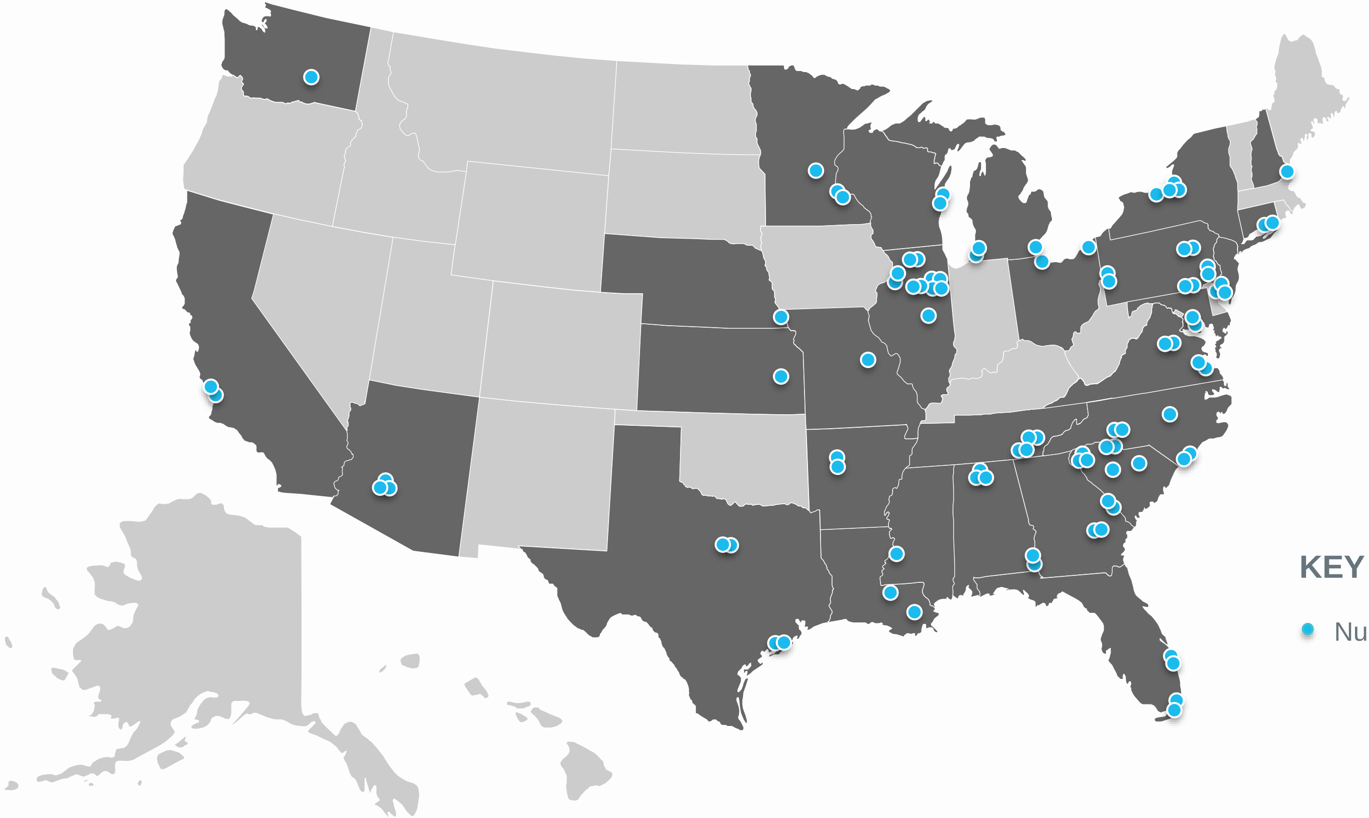
May 2023

NUCLEAR ENERGY INSTITUTE

About NEI

- Washington, D.C., policy and membership organization
- A unified industry voice before U.S. government, international organizations and venues
- A forum to resolve technical and business issues for the commercial industry
- A source of accurate and timely information to members, policymakers, the news media and the public
- 340+ members from 17 countries

Nuclear Provides Nearly 50% of Carbon-Free Electricity



Nuclear generated 18% of electricity in the U.S.

From 92 reactors* at 53 plant sites across the country

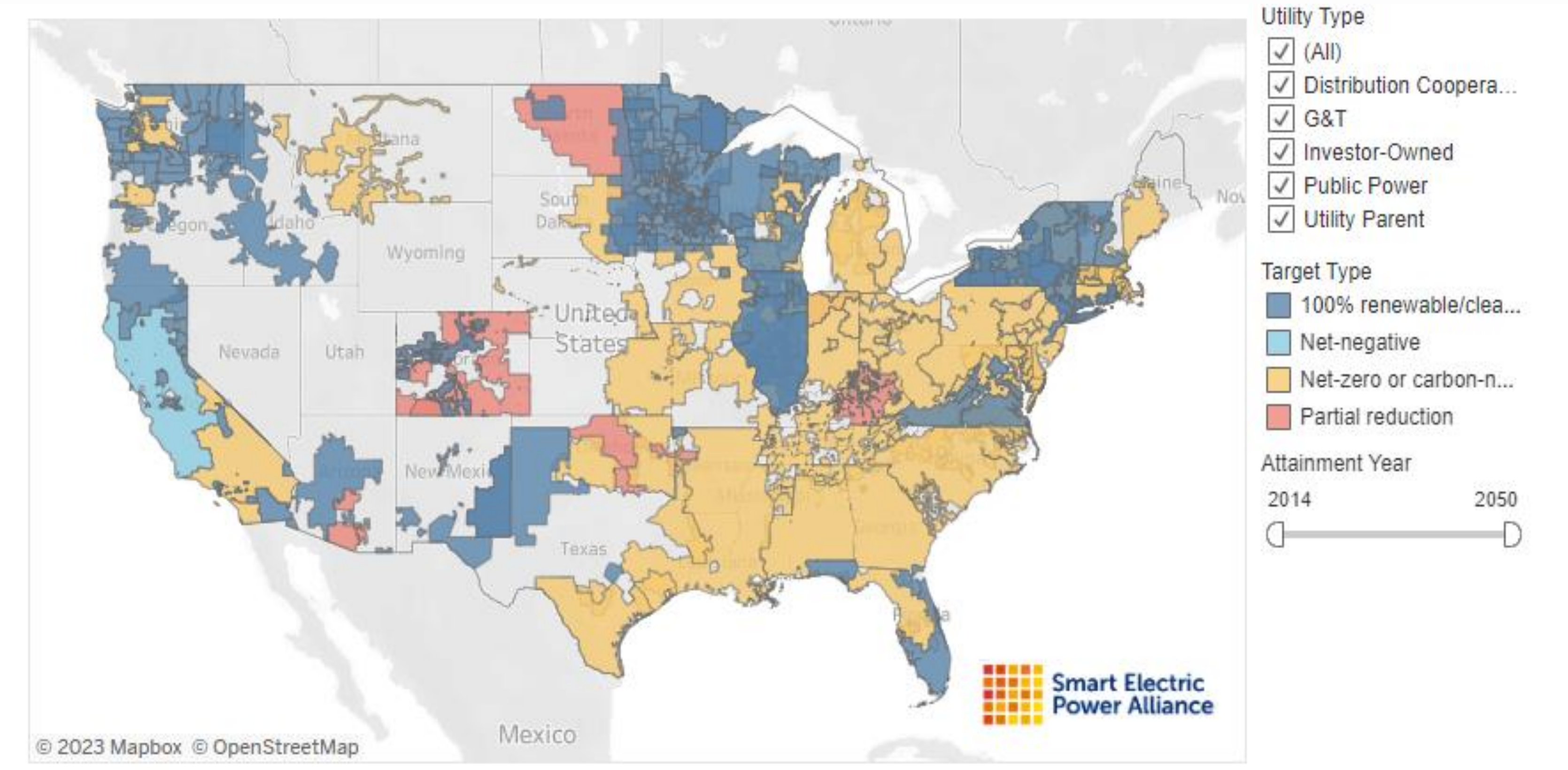
* - soon to be 94!

KEY

● Nuclear power reactor

Updated: May 2022 for the Year 2021

UTILITIES WITH EMISSIONS REDUCTION TARGETS



Utility Type
- ☑ (All)
- ☑ Distribution Coopera...
- ☑ G&T
- ☑ Investor-Owned
- ☑ Public Power
- ☑ Utility Parent

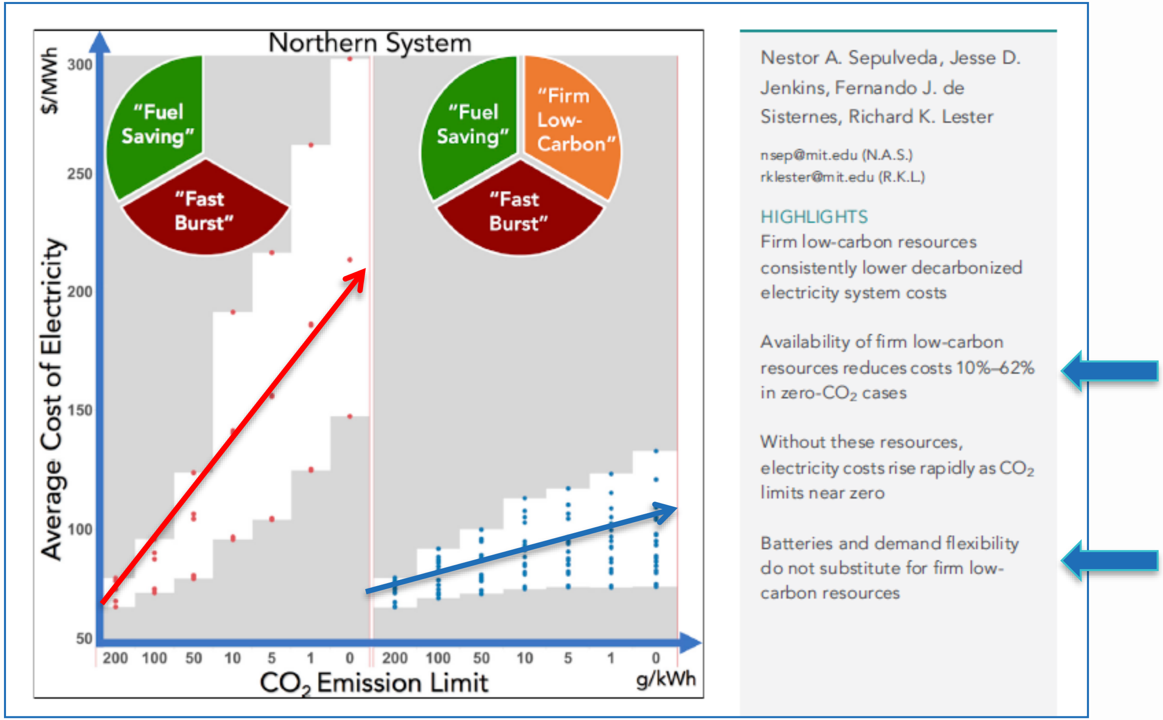
Target Type
- 🟦 100% renewable/clea...
- 🟦 Net-negative
- 🟨 Net-zero or carbon-n...
- 🟥 Partial reduction

Attainment Year

2014 2050

Source: https://sepapower.org/utility-transformation-challenge/utility-carbon-reduction-tracker/

FIRM, LOW-CARBON GENERATION FROM NUCLEAR ENABLES AFFORDABLE DECARBONIZATION AND SYSTEM RESILIENCE



Nestor A. Sepulveda, Jesse D. Jenkins, Fernando J. de Sisternes, Richard K. Lester

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HIGHLIGHTS

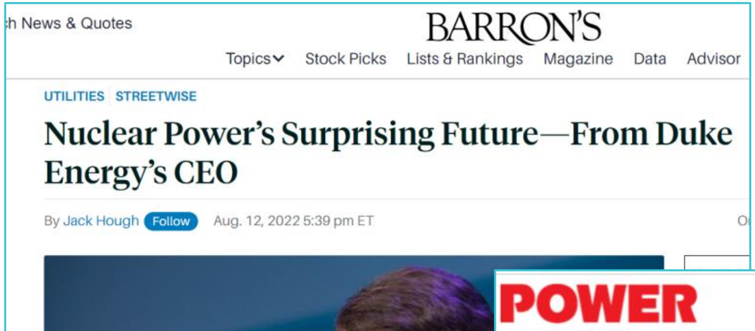
Firm low-carbon resources consistently lower decarbonized electricity system costs

Availability of firm low-carbon resources reduces costs 10%–62% in zero-CO_2 cases

Without these resources, electricity costs rise rapidly as CO_2 limits near zero

Batteries and demand flexibility do not substitute for firm low-carbon carbon resources

Utilities Including New Nuclear in Future Resource Planning



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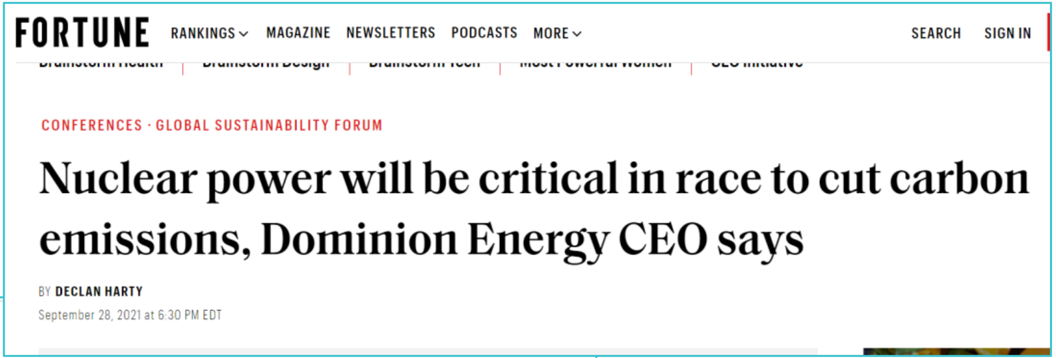
UTILITIES STREETWISE

Nuclear Power's Surprising Future—From Duke Energy's CEO

By Jack Hough Follow Aug. 12, 2022 5:39 pm ET



FORTUNE RANKINGS MAGAZINE NEWSLETTERS PODCASTS MORE SEARCH SIGN IN

CONFERENCES · GLOBAL SUSTAINABILITY FORUM

Nuclear power will be critical in race to cut carbon emissions, Dominion Energy CEO says

BY DECLAN HARTY

September 28, 2021 at 6:30 PM EDT

POWER

Feb 10, 2022
by Sonal Patel

Nuclear

TVA Unveils Major New Nuclear Program, First SMR at Clinch River Site

The Tennessee Valley Authority (TVA) will invest in a major program that will explore the construction of multiple advanced nuclear reactors—starting with a GE-Hitachi BWRX-300 small modular reactor (SMR) at its Clinch River site in Tennessee.

TVA Board members during a meeting on Feb. 10 unanimously approved TVA's "New Nuclear Program," a broad new initiative that the utility describes as a "disciplined, systematic 'roadmap' for TVA's exploration of advanced nuclear technology, both in terms of various reactor designs being proposed and potential locations where such facilities may be needed in the region to support future energy needs."

ALSO IN THIS ISSUE
February 10, 2022

Nuclear | Feb 10, 2022
Fusion Energy Breakthrough: Record Performance Achieved at JET
by Aaron Larson

Commentary | Feb 10, 2022
Renewable Energy Future Includes DERs to Support Decarbonization

Expanded Versatility Meets a Diverse Set of Market Needs

Spectrum of Sizes and Options

Micro
(Few MW)

Mini
(10s of MW)

Small
(100s of MW)

Large (1,000+ MW)

Variety of Outputs

Electricity

H_2 Hydrogen

Process Heat

Multitude of Uses

Homes

Vehicles

Businesses

Aviation

Rail

Shipping

Concrete

Steel

Factories

Water

Space

Watch the video: https://www.youtube.com/watch?v=7zN_YLg-roo

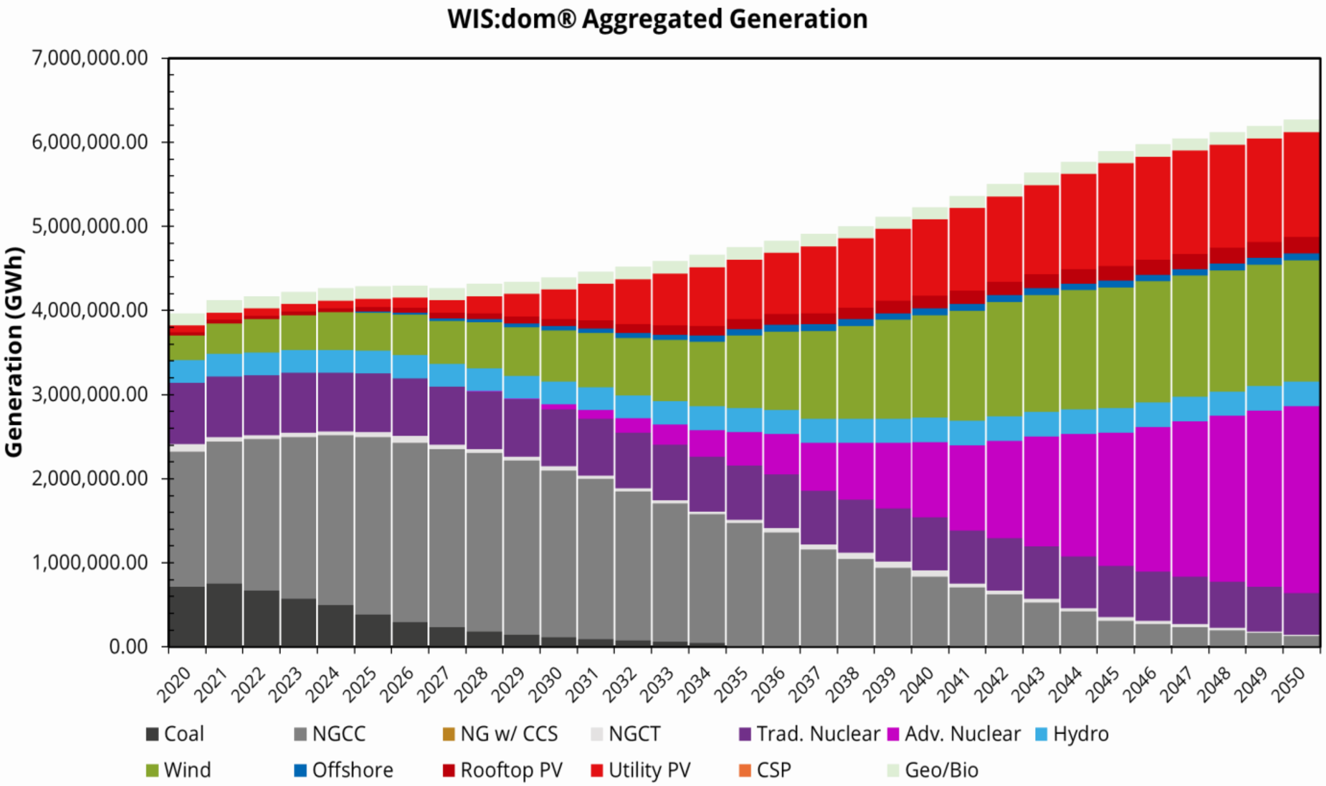
VCE Study - Overview

- Commissioned Vibrant Clean Energy to model electricity system
  - 95% reduction in carbon emissions by 2050
  - Modest load growth, NREL assumptions for renewables, no CCS

- Nominal case
  - $3800/kW overnight cost
  - Non-binding constraint on expansion

- Constrained case
  - $5500/kW overnight cost
  - Conservative capacity to expand

Nominal Case



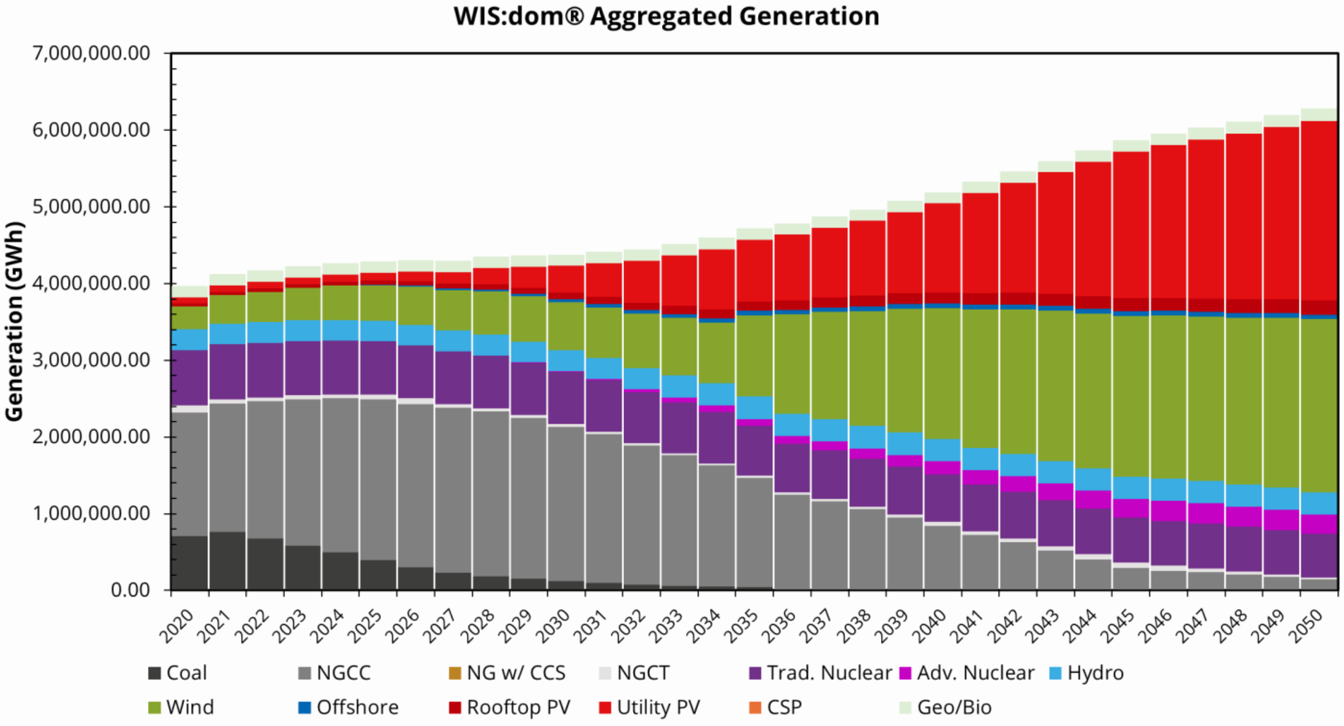
Generation: 2,718 TWh
Legacy: 491 TWh
Advanced: 2,227 TWh

Capacity: 404 GW
Legacy: 67 GW
Advanced: 336 GW

Share: 43%

Converted Fossil: 271

Constrained Case



Generation: 827 TWh
Legacy: 575 TWh
Advanced: 252 TWh

Capacity: 146 GW
Legacy: 85 GW
Advanced: 60 GW

Share: 13%

Converted Fossil: 42

Lowest System Cost Achieved by Enabling Large Scale New Nuclear Deployment

Lowest Cost System

Nuclear is 43% of generation (>300 GW of new nuclear)

Wind and solar are 50%

Energy System with Nuclear Constrained

Wind and Solar are 77% of generation

Nuclear is 13% (>60 GW of new nuclear)

Increased cost to customers of $449 Billion

Both scenarios are successful in reducing electricity grid GHG emissions by over 95% by 2050 and reducing the economy-wide GHG emissions by over 60%

Source: Vibrant Clean Energy: https://www.vibrantcleanenergy.com/media/reports/

Electric Utilities are Planning for New Nuclear

Nuclear power's potential role in meeting their company's decarbonization goals:

SLR >90% of fleet expects to operate to at least 80 years

GW ~100 GW of new nuclear opportunity by 2050s

SMRs Translates to > 300 SMR-scale plants

* - NEI utility member companies produce nearly half of all US electricity

U.S. DEPARTMENT OF ENERGY

Pathways to Commercial Liftoff

Advanced Nuclear | March 2023

Report available at https://liftoff.energy.gov/

Following slides courtesy of Julie Kozeracki, DOE Loan Programs Office

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

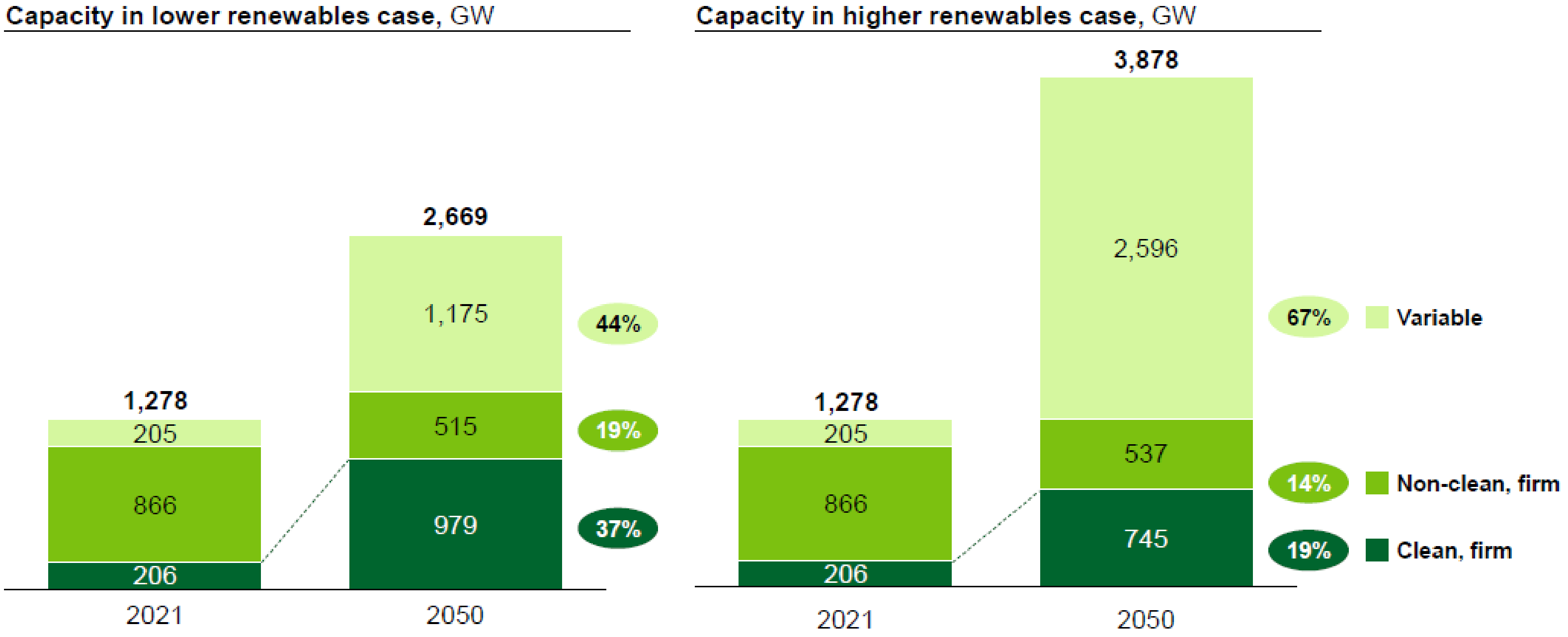
Requirements for scaling to 200GW of new US nuclear by 2050

- 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)

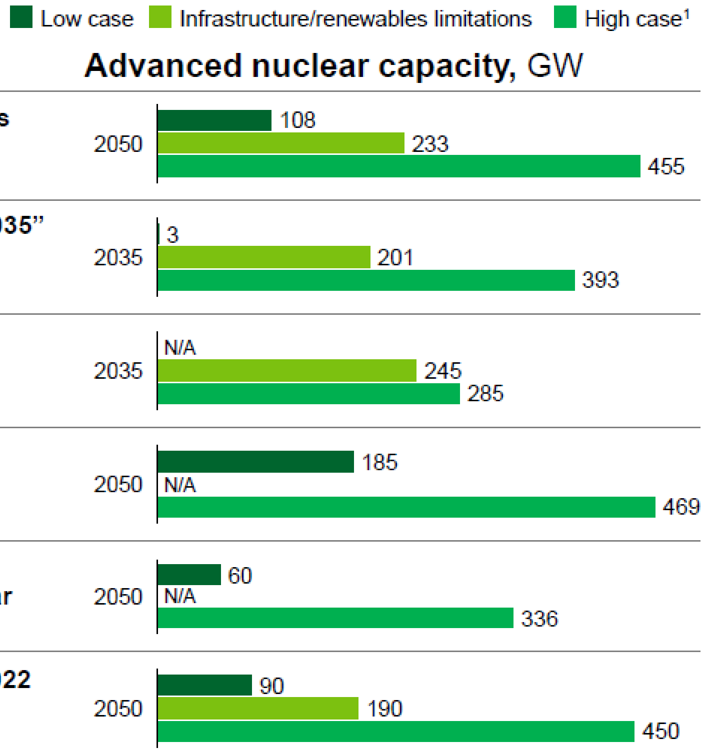
Achieving net-zero in the U.S. by 2050 would require ~550–770 GW of additional clean, firm capacity



~5x clean, firm (~770 GW)

~3.5x clean, firm (~550 GW)

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



Model		Low case	Infrastructure/renewables limitations	High case[1]
Demonstration and Deployment Pathways Modeling (this report)[2]	2050	108	233	455
NREL, 2022 "100% Clean Electricity by 2035"	2035	3	201	393
Princeton University "Net-Zero America: Potential Pathways, Infrastructure, and Impacts"	2035	N/A	245	285
Breakthrough Institute, 2022 "Advancing Nuclear Energy"	2050	185	N/A	469
Vibrant Clean Energy, 2022 "Role of Electricity Produced by Advanced Nuclear Technologies"	2050	60	N/A	336
Pacific Northwest National Laboratory, 2022 "Scenarios of Nuclear Energy Use in the United States in the 21st Century"	2050	90	190	450

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

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)

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%

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

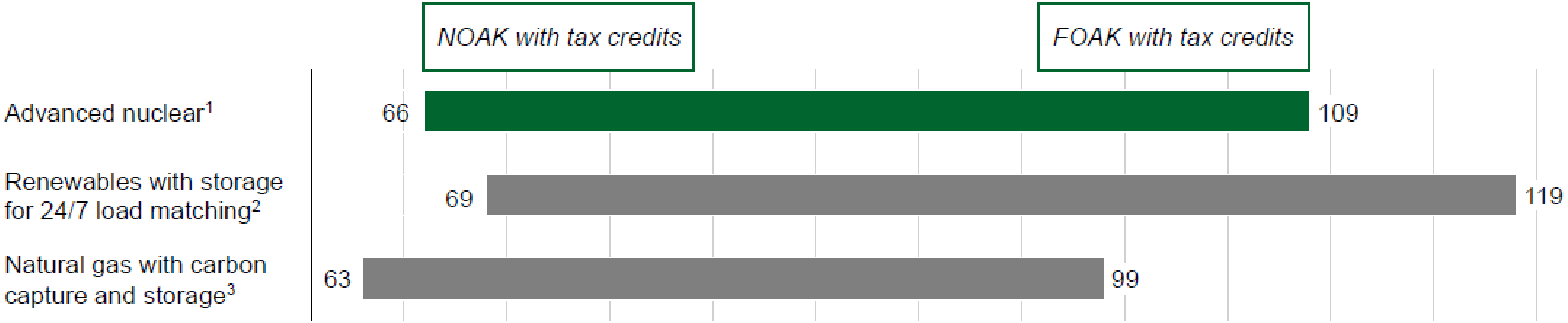
High ■ ▣ □ *Low*

Power source	Clean?	Firm?	Low land use?	Low transmission buildout?	Concentrated local economic benefits?	Additional applications?[1]	Cost competitive today?
Nuclear	■	■	■	■	■	■	□
Hydropower	■	▣	□	▣	■	□	■
Geothermal	■	▣	■	▣	▣	▣	▣
Renewables + storage[2]	■	■	□	□	□	▣	□
Renewables: offshore	■	▣	■	□	□	□	□
Renewables: onshore	■	□	□	□	□	□	■
Natural gas + CCS	▣	■	▣	■	▣	▣	□
Coal + CCS	▣	■	▣	■	■	▣	□
Natural gas	□	■	▣	■	▣	▣	■
Coal	□	■	▣	■	■	▣	▣

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

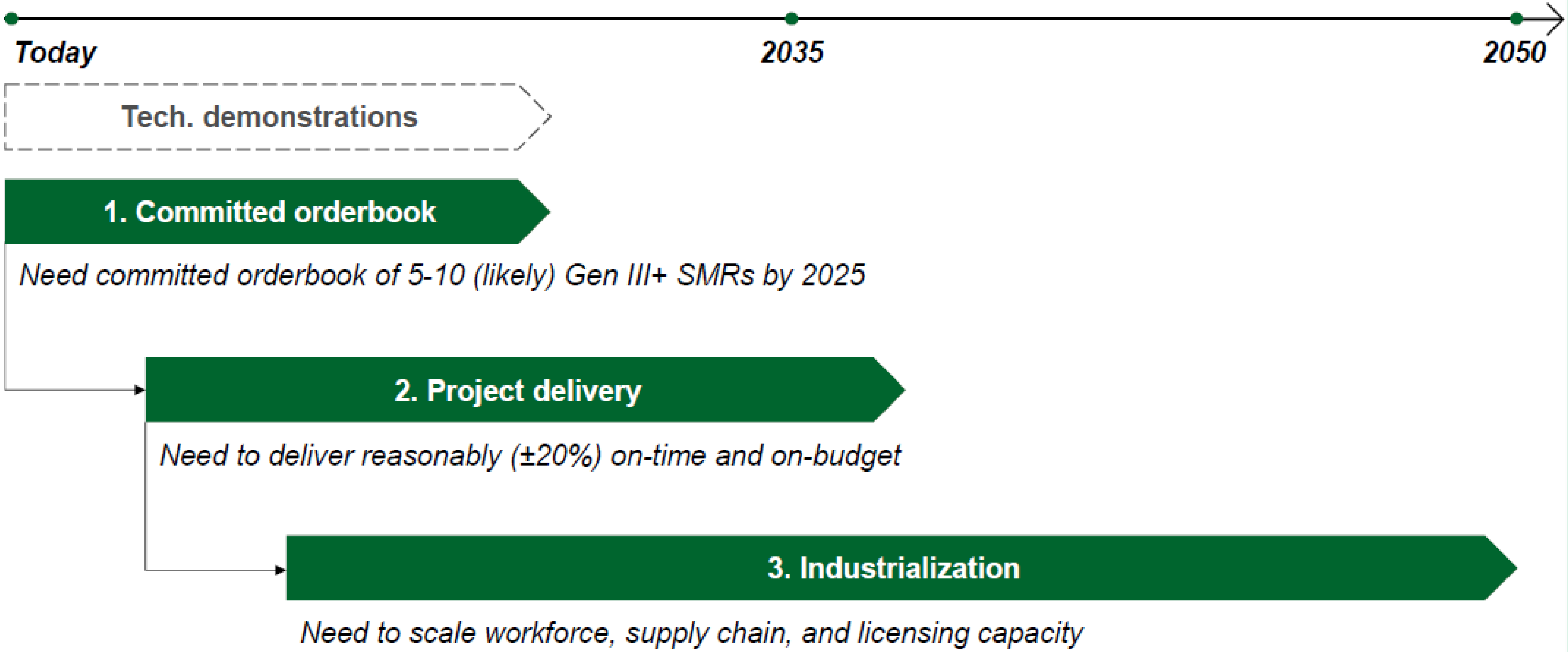
Nuclear is expected to be cost competitive with other clean firm resources

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



Today **2035** **2050**

Tech. demonstrations

1. Committed orderbook

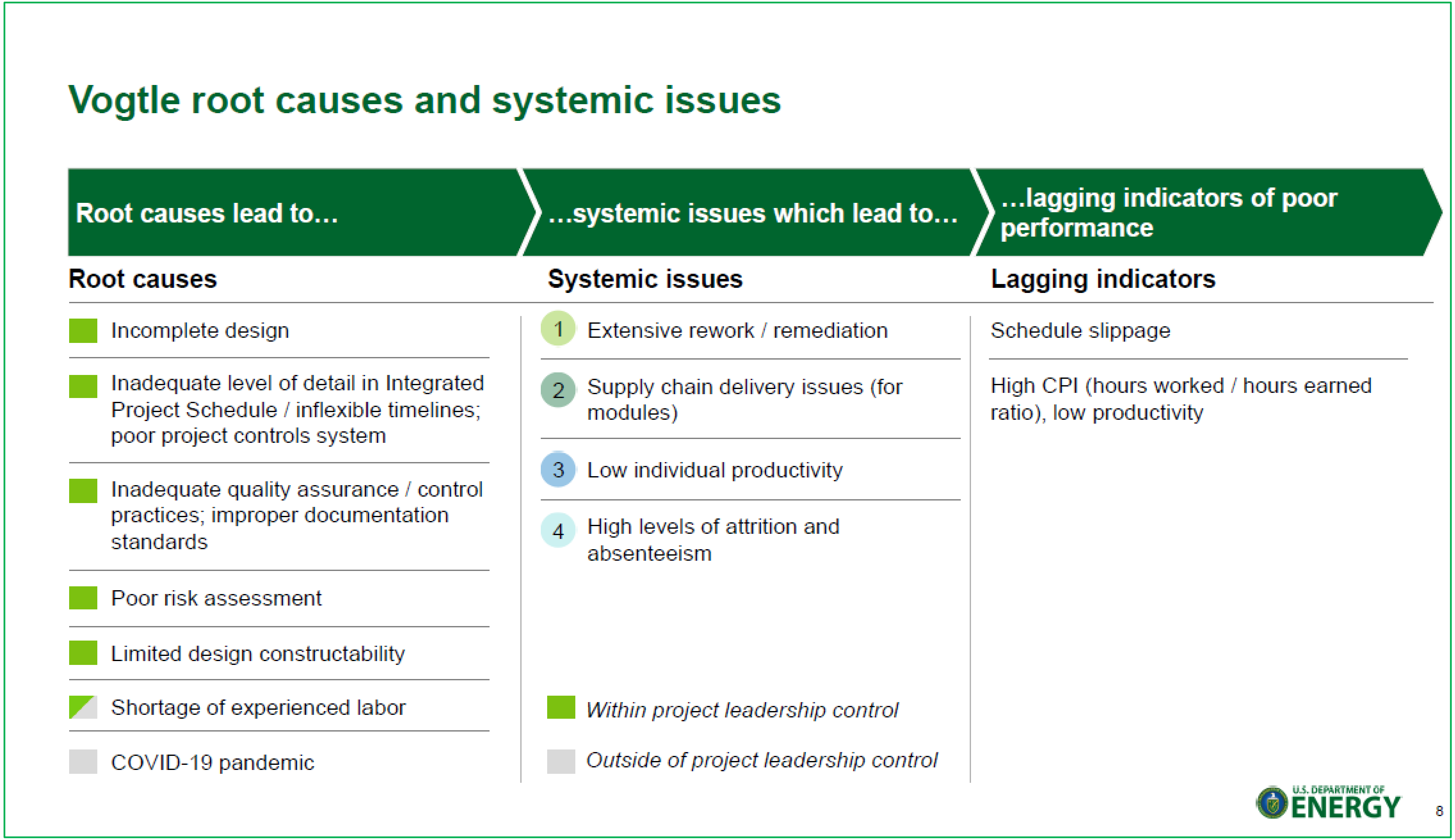
Need committed orderbook of 5-10 (likely) Gen III+ SMRs by 2025

2. Project delivery

Need to deliver reasonably (±20%) on-time and on-budget

3. Industrialization

Need to scale workforce, supply chain, and licensing capacity



Vogtle root causes and systemic issues

Root causes lead to… **…systemic issues which lead to…** **…lagging indicators of poor performance**

Root causes

- 🟩 Incomplete design
- 🟩 Inadequate level of detail in Integrated Project Schedule / inflexible timelines; poor project controls system
- 🟩 Inadequate quality assurance / control practices; improper documentation standards
- 🟩 Poor risk assessment
- 🟩 Limited design constructability
- ◪ Shortage of experienced labor
- ⬜ COVID-19 pandemic

Systemic issues

1. Extensive rework / remediation
2. Supply chain delivery issues (for modules)
3. Low individual productivity
4. High levels of attrition and absenteeism

🟩 *Within project leadership control*

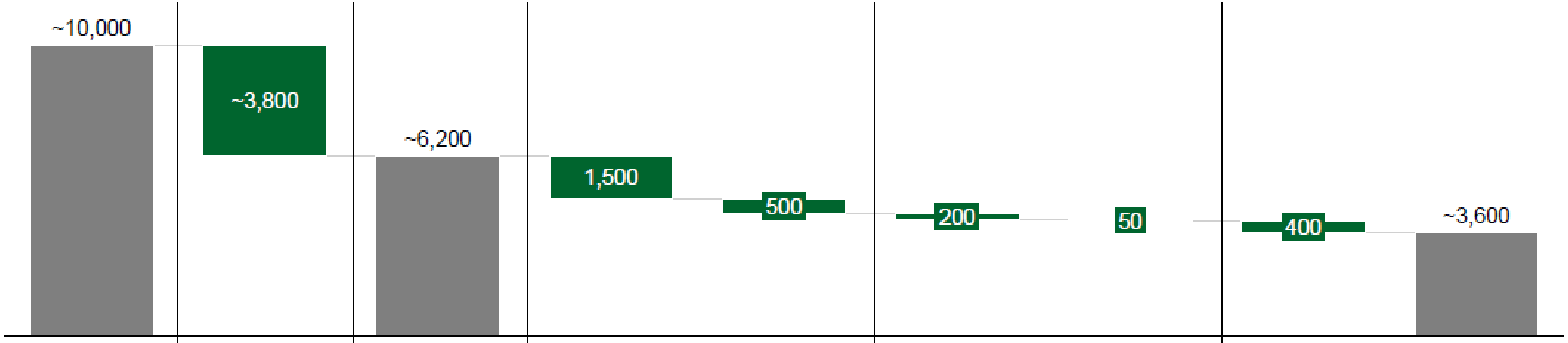
⬜ *Outside of project leadership control*

Lagging indicators

- Schedule slippage
- High CPI (hours worked / hours earned ratio), low productivity

Why will new projects be different than recent over-budget builds?

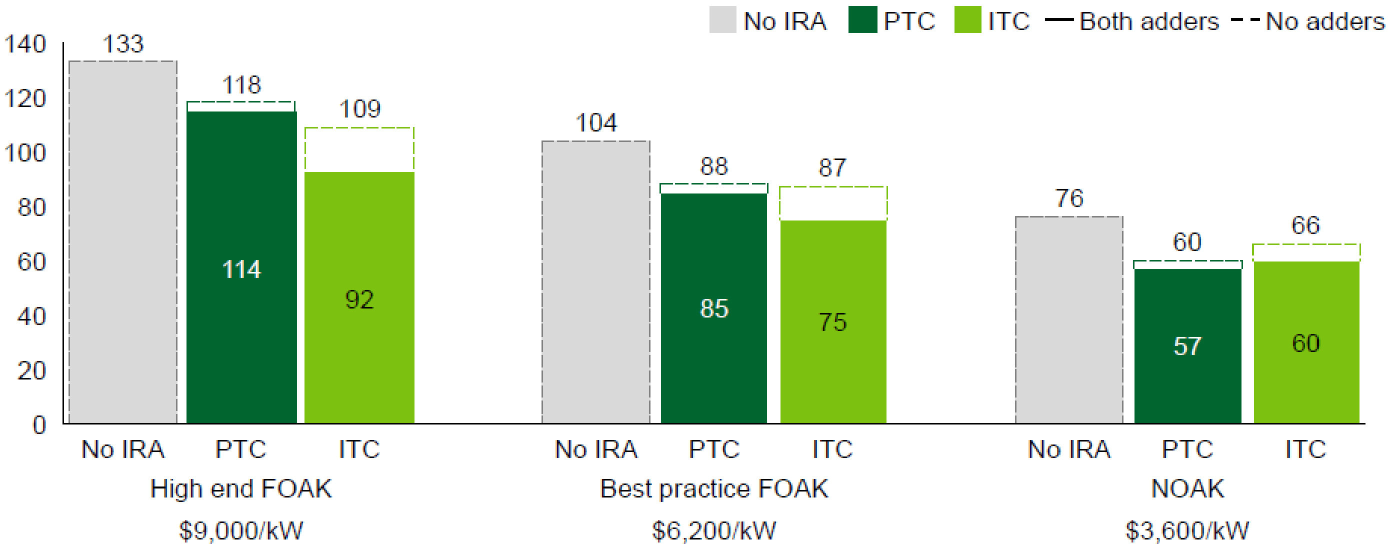
Potential advanced nuclear FOAK to NOAK overnight capital costs, $/kW



	Recent FOAK projects	Cost reductions driven by best practices	Best practices FOAK	Yard/cooling/ installation	EPC	Nuclear island equipment	Turbine island equipment	Owner's costs	NOAK
Cost reductions by individual cost category		30-40%		40-50%	40-50%	20-30%	10-20%	30-40%	**~40%** Total cost reduction
Key drivers of cost reduction		**Best practice project delivery, esp. pre-planning**		**Learning by doing** **Standardization** **Build time reduction**		**Supply chain development** **Modularization**		**Driven by reductions in other cost categories**	

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

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

QUESTIONS?

By Third Way, GENSLER

Key Federal Policy Developments

Bipartisan Infrastructure Bill

Civil Nuclear Credit Program
$6B to support financially challenged plants

ARDP Funding
$2.5B funding for two projects

Nuclear Hydrogen Hub
$8B total in the bill

Inflation Reduction Act

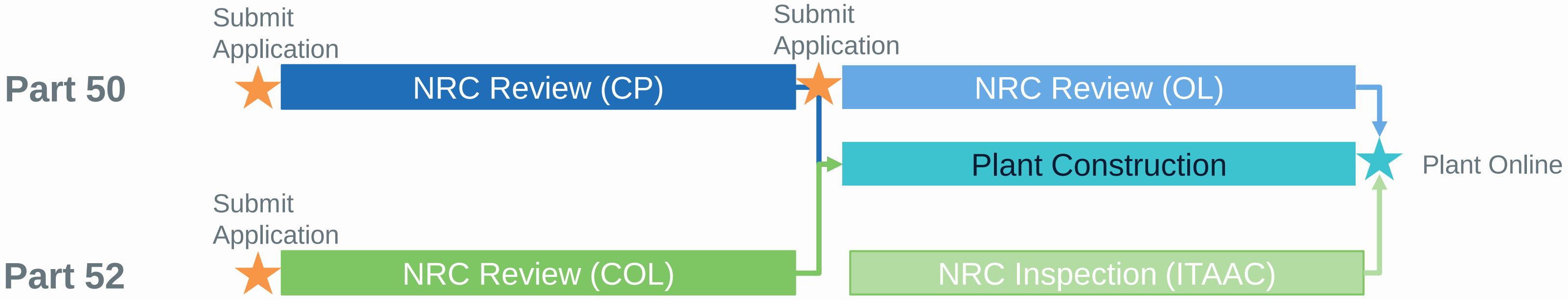
Production Tax Credit (PTC) for Operating Plants
Up to $15 per MWh

Technology-Inclusive PTC for Clean Electricity
$30 per MWh

Technology-Inclusive Investment Tax Credit (ITC) for Clean Electricity
30% + 10% in energy communities + 10% using U.S. components

Clean Hydrogen Credit
$3 per kilogram

NRC Licensing Processes



U.S. Licensing Durations and Costs

Type[1]	Duration[2]	Cost[3]
DC	3 to 4 years (4 to 9)	\$45M to \$68M
COL	2.5 to 3.5 years (4)	\$28M to \$30M
ESP	2 years (3 to 6)	\$6M to \$19M
OL	3 to 3.5 years (8)	\$42M

1) DC = Design Certification, COL = Combined Operating License, ESP = Early Site Permit, OL = Operating License
2) NRC Generic Schedules: https://www.nrc.gov/about-nrc/generic-schedules.html; “()” reflects historical performance which has exceeded generic schedules, in some cases by more than double; these generic and historical schedules do not include pre-application, acceptance, commission approval and hearings/rulemakings which adds 1 to 3 years to the actual schedule
3) NRC Letter to Senator Inhofe April 7, 2015 (ML1508A361), costs of more recent reviews are even higher on an inflation adjusted basis

Advanced Reactor Licensing Progress

Approved

1. NuScale Power

Under Review

1. Abiline Christian University
2. Kairos Power*
3. NuScale (power uprate)

Pre-Application

1. GEH BWR X-300
2. General Atomics
3. Holtec SMR-160
4. Kairos Power
5. Oklo
6. TerraPower Natrium
7. TerraPower MCFR
8. Terrestrial
9. Univ. of Illinois U-C
10. X-energy
11. Westinghouse

*Non-commercial reactors