Current Status of Advanced Nuclear Reactors

NC Energy Policy Council

Marc Nichol
Nuclear Energy Institute

August 18, 2021

NUCLEAR ENERGY INSTITUTE

Agenda

- Technology
- Projects
- Cost/Value Proposition
- Regulatory

Current State

- Over 60 new technologies being actively developed by private sector
- DOE funding 12 different designs, >$5B over 7 years
  - 3 Demonstration Plants
  - 9 Technology Development
- U.S. utilities evaluating nuclear in IRPs
- Growing interest in conversion of coal power sites to nuclear
- Continued strong support in Congress

Technology

Technology Developers*

NUSCALE Power for all humankind

X energy

framatome

ARC ADVANCED REACTOR CONCEPTS, LLC

BWXT BWX Technologies, Inc.

USNC ULTRA•SAFE•NUCLEAR

GENERAL ATOMICS

TERRESTRIAL ENERGY

NuGen

OKLO

Westinghouse

TerraPower

Kairos Power

HolosGen™

ELYSIUM INDUSTRIES

GE HITACHI

ZENO POWER SYSTEMS

Hydromine Nuclear Energy

Alpha Tech Research Corp

HOLTEC INTERNATIONAL

RADIANT

Muons, Inc. Innovation in Research

BSCE ADNA

* = partial list

Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

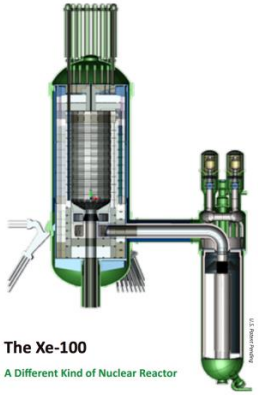
Micro Reactors (< 20MW)

Oklo (shown)
Approximately a dozen in development

LWR SMRs <300MW

NuScale (shown)
GEH X-300
Holtec SMR-160

High Temp Gas Reactors

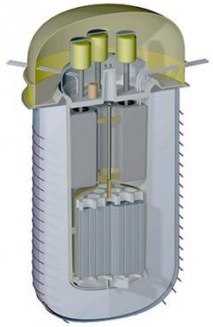


X-energy (shown)
Several in development

Liquid Metal Reactors

TerraPower Natrium (shown)
Several in development

Molten Salt Reactors



Terrestrial (shown)
Several in development

Non-Water Cooled
Most <300MW, some as large as 1,000 MW

Advanced Nuclear Versatility

Spectrum of Sizes/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

Businesses

Vehicles

Rail

Shipping

Steel

Water

Concrete

Factories

Projects

Current State – DOE Demonstrations*

Planned to be online in late 2020s:

Developer	Technology	Utility	Location	Size
NuScale	Integral PWR	UAMPS	Idaho	6 @ 77MW
TerraPower & GE-Hitachi	Liquid Sodium	Pacific Corp.	Wyoming	345 - 500MW w/thermal storage
X-energy	High Temperature Gas	Energy Northwest	Washington	4 @ 80MW

* = does not include non-commercial demonstrations

Current State – Other Demonstrations*

Planned to be online in late 2020s:

Developer	Technology	Utility / Owner	Location	Size
TBD (GEH, X-energy, or Terrestrial)	SMR	OPG	Ontario, Canada	TBD
Oklo	Micro Reactor	Oklo	Idaho	1.5 MW
Ultra Safe Nuclear Corp.	Micro Reactor	Global First (w/ OPG)	Chalk River, Canada	5 MW
TBD (X-energy or BWXT)	Mobile Micro Reactor	Department of Defense	Idaho	TBD
TBD	Micro Reactor	Department of Defense	Alaska	TBD

* = does not include non-commercial demonstrations

Utility and State Interest

State	Legislative Action	Utility Action
Alaska	Bills introduced to repeal voter approval to site	Interest in micros for mining/DoD
Arizona		Utility interest in 25 MWe of UAMPS/NuScale
Idaho	Tax incentives passed	Host of UAMPS/NuScale SMR
Montana	Passed bill to study coal to SMR Repealed voter approval to site	Northwest Energy interested in coal to nuclear
Nebraska	Passed bill on SMR tax incentives	
North Carolina	Passed bill paying for ESP	Duke Energy includes SMRs in IRP
Virginia	Nuclear Energy Strategic Plan Clean energy standard including nuclear	Dominion includes SMRs in IRP
Washington	Clean energy standard including nuclear	Energy Northwest with X-energy demo Grant County PUD MOU with X-energy and NuScale
Wyoming		Rocky Mt. Power siting for Terrapower demo

Coal to Nuclear Transition

- Coal power plant shutdowns can be devastating to local communities
- Transition to a small modular reactor (SMR) can provide carbon-free replacement power while:
  - Capitalizing on existing infrastructure,
  - Saving jobs, and
  - Supporting communities
- Pursuing policy actions to encourage coal to nuclear

Cost/Value Proposition

Current State – Affordability

SIMPLER

- Inherent Safety
- Less Equipment
- Smaller Facility
- Regulatory Efficiency

READILY AVAILABLE EQUIPMENT

- Off-the-shelf Equipment
- Proven Performance

FACTORY-BUILT

- 60-80% of Equipment
- U.S. Supply Chain Growth

FASTER CONSTRUCTION

- Smaller Structures
- Assembly vs. Construction
- Modern Construction Methods

IMPROVED PERFORMANCE

- Higher Thermal Efficiency
- Design and Construction Best Practices
- Operational Excellence

Clean, Reliable and Affordable Electricity Portfolios

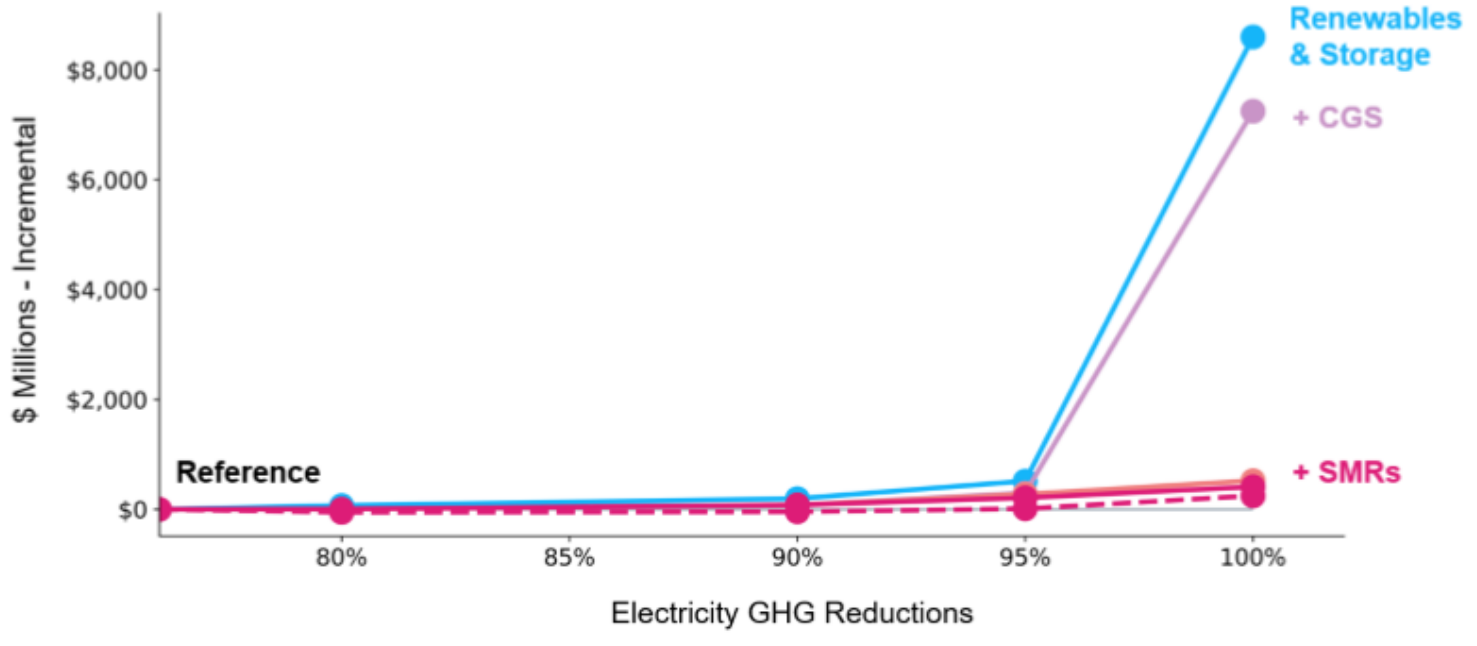
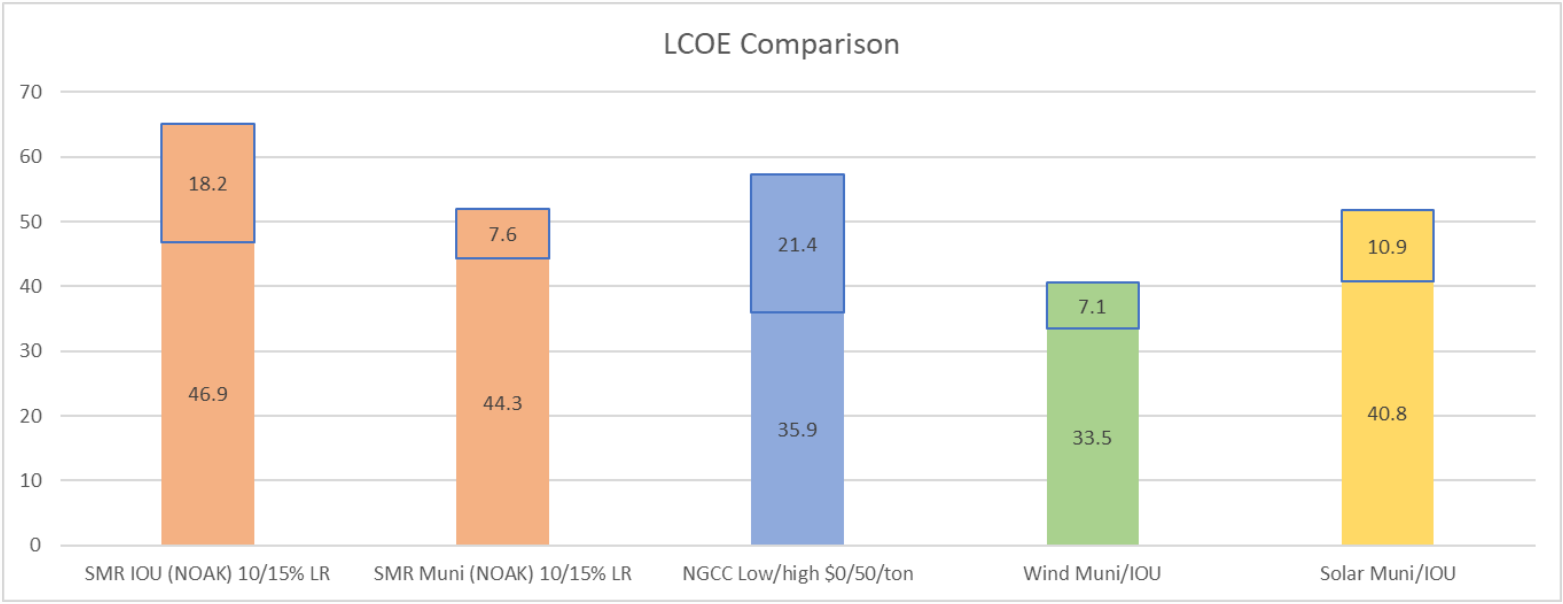


Figure 4: GHG abatement costs. The y-axis represents the incremental cost of each scenario compared to a Reference case that does not apply an emissions constraint.

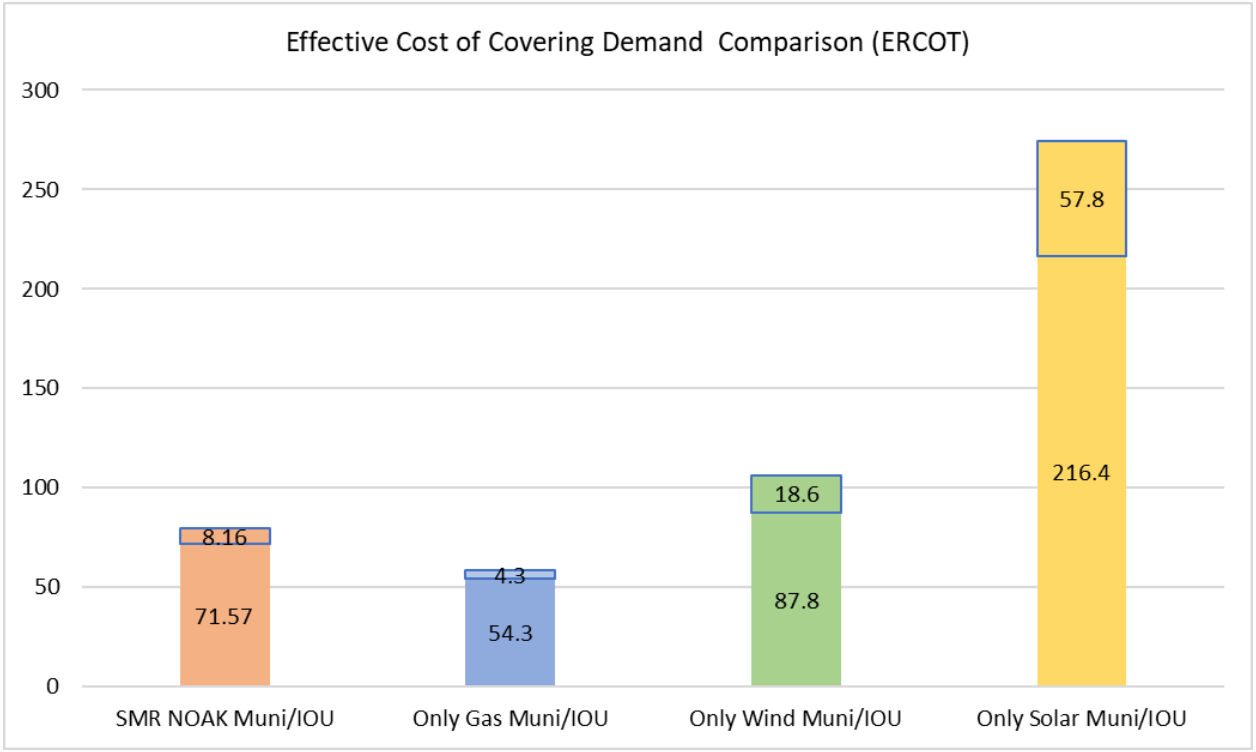
https://www.energy-northwest.com/Documents/E3%20Study%20Executive%20Summary%20final.pdf

Advanced Reactor Cost Competitiveness in Electric Markets



From SMR Start Report on SMR Economics: http://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf

Considering system reliability needs makes nuclear even more affordable



Government Deployment Support

- Valuing all carbon-free sources of energy
- State Programs
  - Tax incentives (e.g., property)
  - Advanced cost recovery
  - Infrastructure
- Federal Programs
  - Cost-share
  - Tax Credits (e.g., Production)
  - Loan Guarantees
  - Federal Power Purchase Agreements

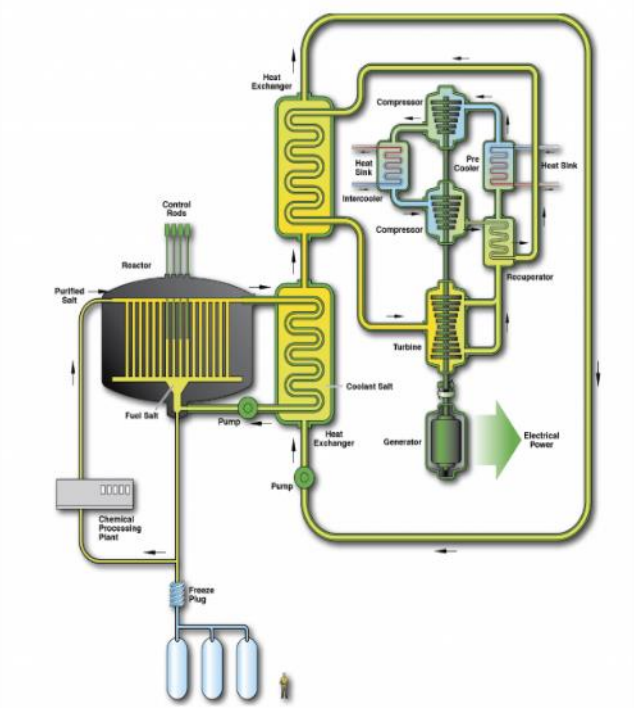
http://smrstart.org/wp-content/uploads/2017/07/SMR-Start-State-Options-for-New-Nuclear-Approved-2017-06-26.pdf

http://smrstart.org/policy-statement/

Regulatory

NRC Applications and Pre-Application

- NuScale – Light-water SMR
- Oklo Aurora – micro-reactor
- GEH BWRX-300 – Light-water SMR
- General Atomics EM2 – gas cooled fast reactor
- Holtec SMR-160 – Light-water SMR
- Kairos Power – salt cooled with TRISO fuel
- Terrestrial Energy – molten salt reactor
- TerraPower – Natrium
- TerraPower – molten chloride fast reactor
- Westinghouse – micro-reactor
- X-energy XE-100 – high-temperature gas reactor



Information above from NRC as of Aug 16, 2021

Advanced Reactor Safety

Building upon a strong safety record

- Operating fleet: one of the safest industrial working environments
  - Strong-Independent Regulator, Built tough, Operational Performance
- Enhancing safety for advanced reactors*

Inherent Safety Features	Reduce Risks	Emergency Response

• Rely on physics
  • Natural circulation
  • Gravity
• Below grade
• Higher melting points
• Atmospheric pressure
	• Smaller source terms
	• Minimize potential for accidents
	• Mitigate consequences
		• Maintain safety without the need for
		  • Power
		  • Additional coolant
		  • Human actions
		• Emergency planning

*Features vary by design

Regulatory Priorities

- Streamlining the regulatory process
  - Timely and efficient NRC safety reviews
  - Environmental reviews
- Resolving key technical and policy issues
  - Emergency planning zones
  - Physical security
  - Population criteria for siting
- Modern and efficient regulatory framework
  - Risk-informed licensing approaches
  - Technology-inclusive rulemaking

Top-Line Summary

- Tangible movement to multiple initial demonstrations in 2020s
- Federal and state policies evolving in right direction
- Regulatory and licensing activities are progressing
- Increasing customer interest in deployments around 2030

Spectrum of technologies available for deployment in 2030s

DISCUSSION

By Third Way, GENSLER

CLEARPATH

NC Energy Policy Council: Advanced Nuclear

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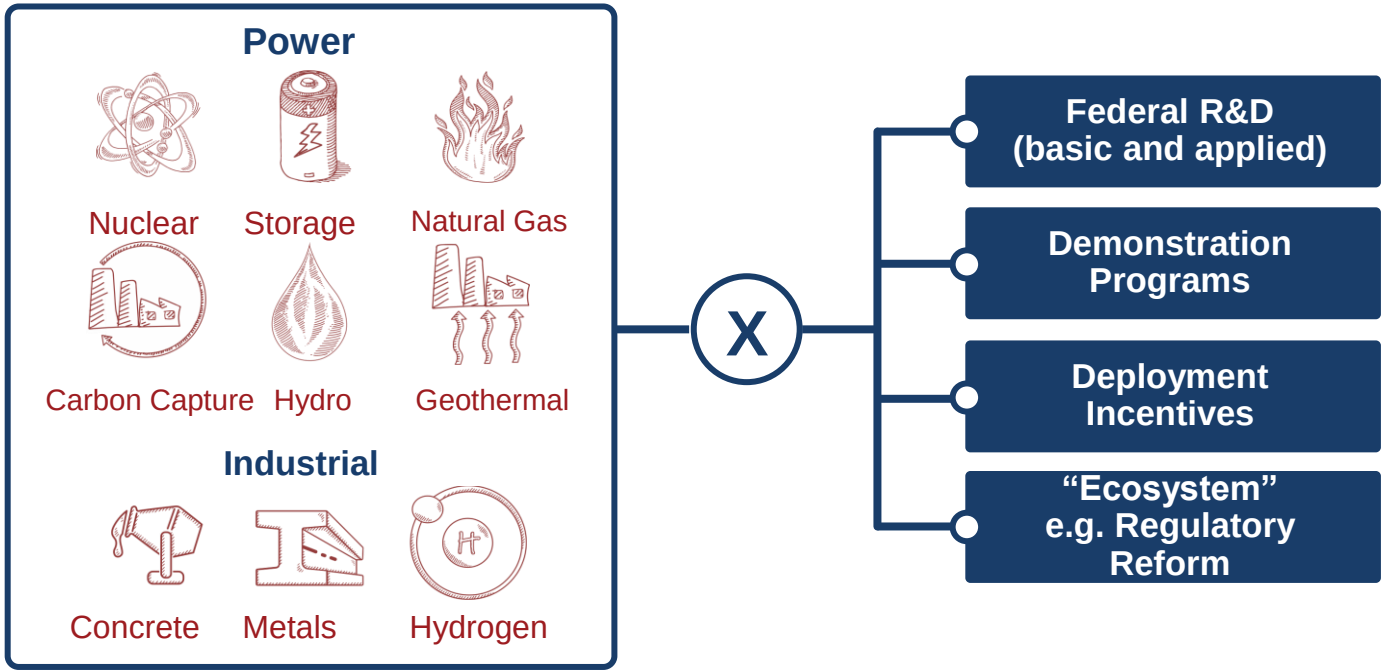
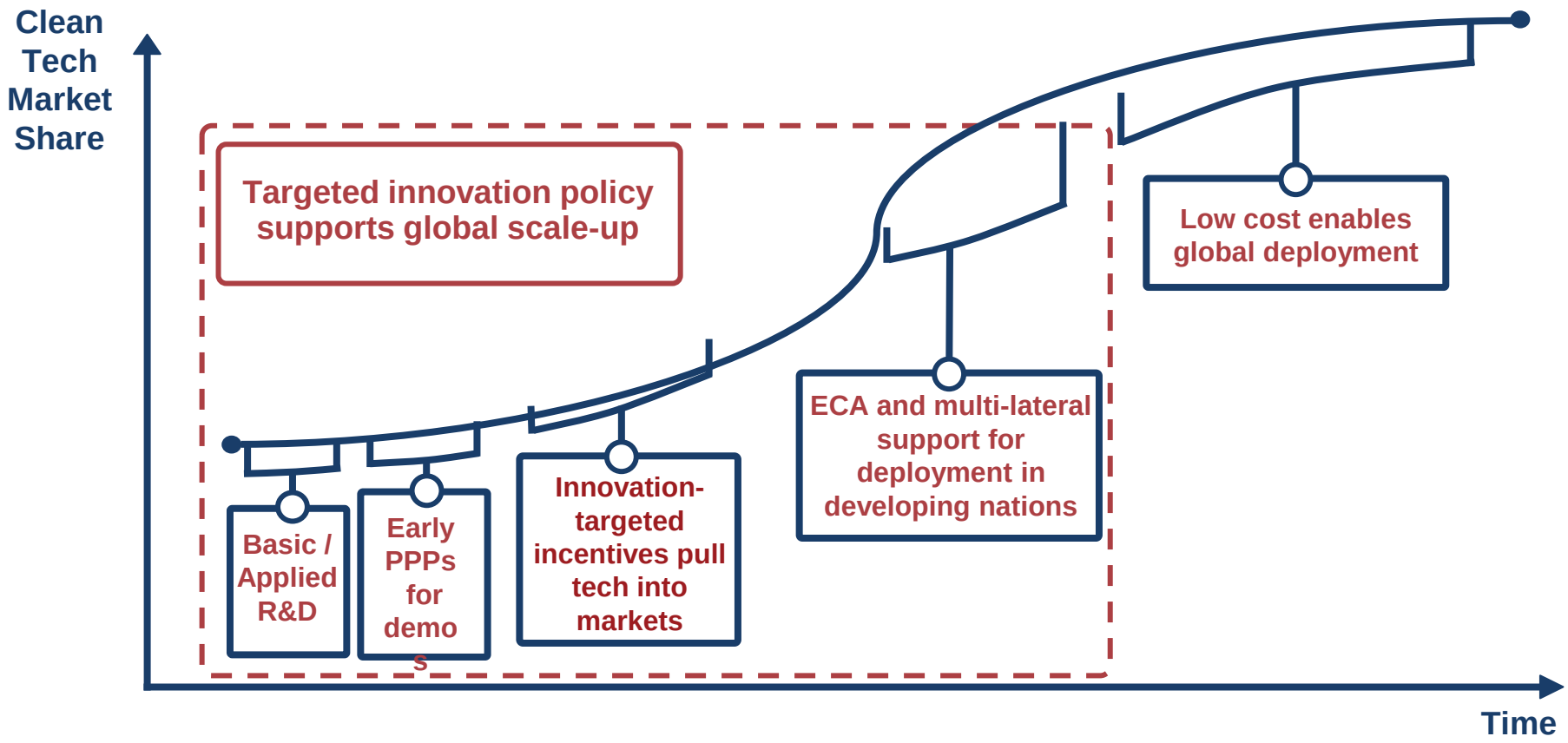
August 18, 2021

CLEARPATH

Key technologies and policy areas



From gas to solar, cheap clean technology has received public policy support to move it up the the global “S curve”



U.S. Nuclear Landscape

Current Projects

- What was in the Energy Act of 2020
- Ongoing nuclear projects and timelines
- The Advanced Reactor Demonstration Program (ARDP)
- Civil Nuclear Credit Program

Role of Existing Nuclear to Reduce Emissions

- Why the NRC needs to modernize its regulatory requirements
- The development of 10 CFR Part 53
- Other ongoing regulatory efforts

Future Projects and Momentum

- Hydrogen demonstrations
- Nuclear legislative initiatives
- What more is needed

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Biggest Climate Policy Success in Over a Decade

The Energy Act of 2020

20+ Large-Scale Clean Energy Demonstrations

- Advanced Nuclear
- Carbon Capture, Utilization, Storage
- Enhanced Geothermal Systems
- Grid-scale Energy Storage
- Industrial Decarbonization Technologies

Early to Mid-2020s

Advanced Nuclear Fuel Availability Program

Integrated Energy Systems and Hydrogen Demos

Enhancements to Loan Guarantee program

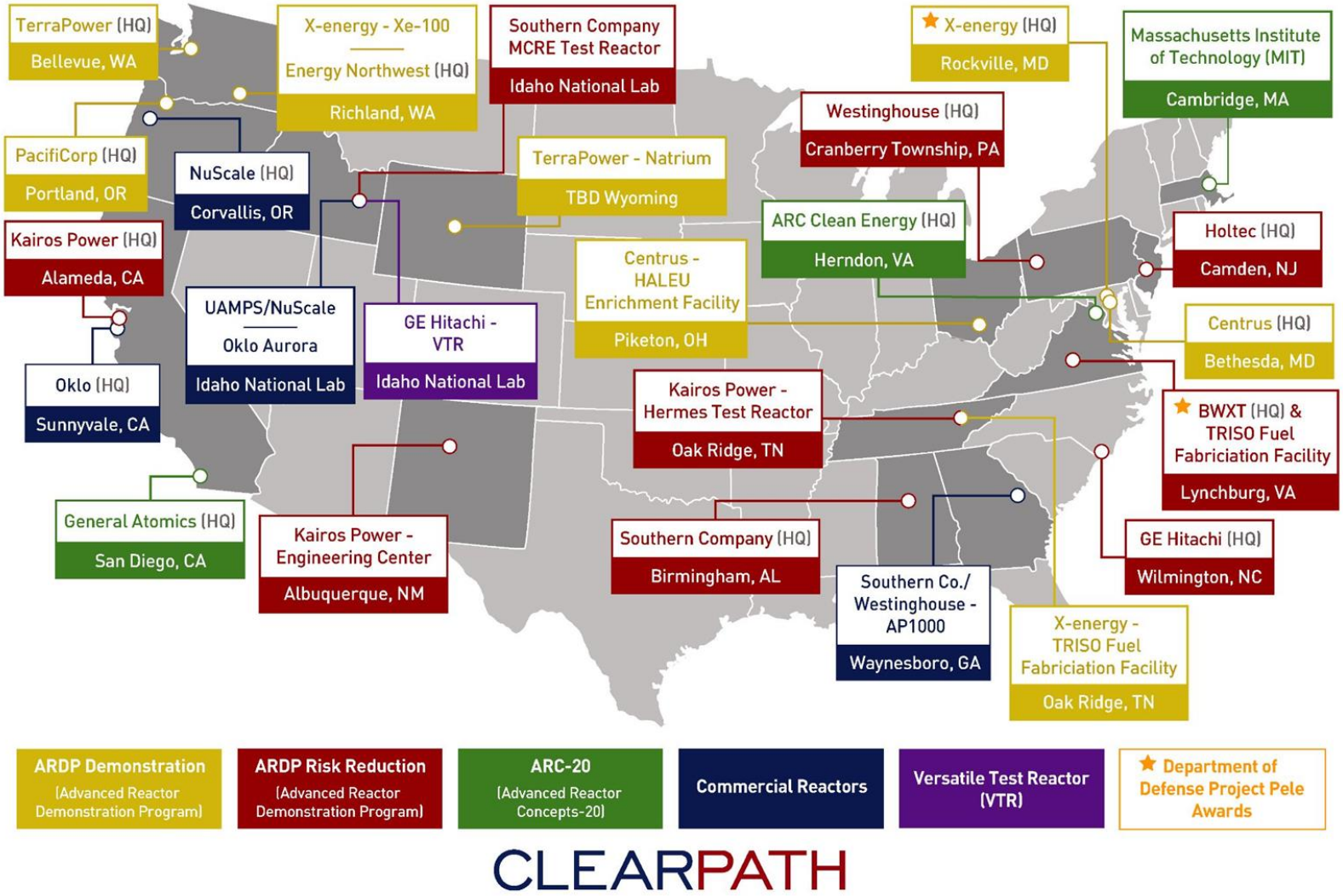
- No fees until financial closing
- Ability to reduce fees, provide a credit subsidy
- Project eligibility expansion, more transparency

Research, development, demonstration, and technical assistance for industrial energy

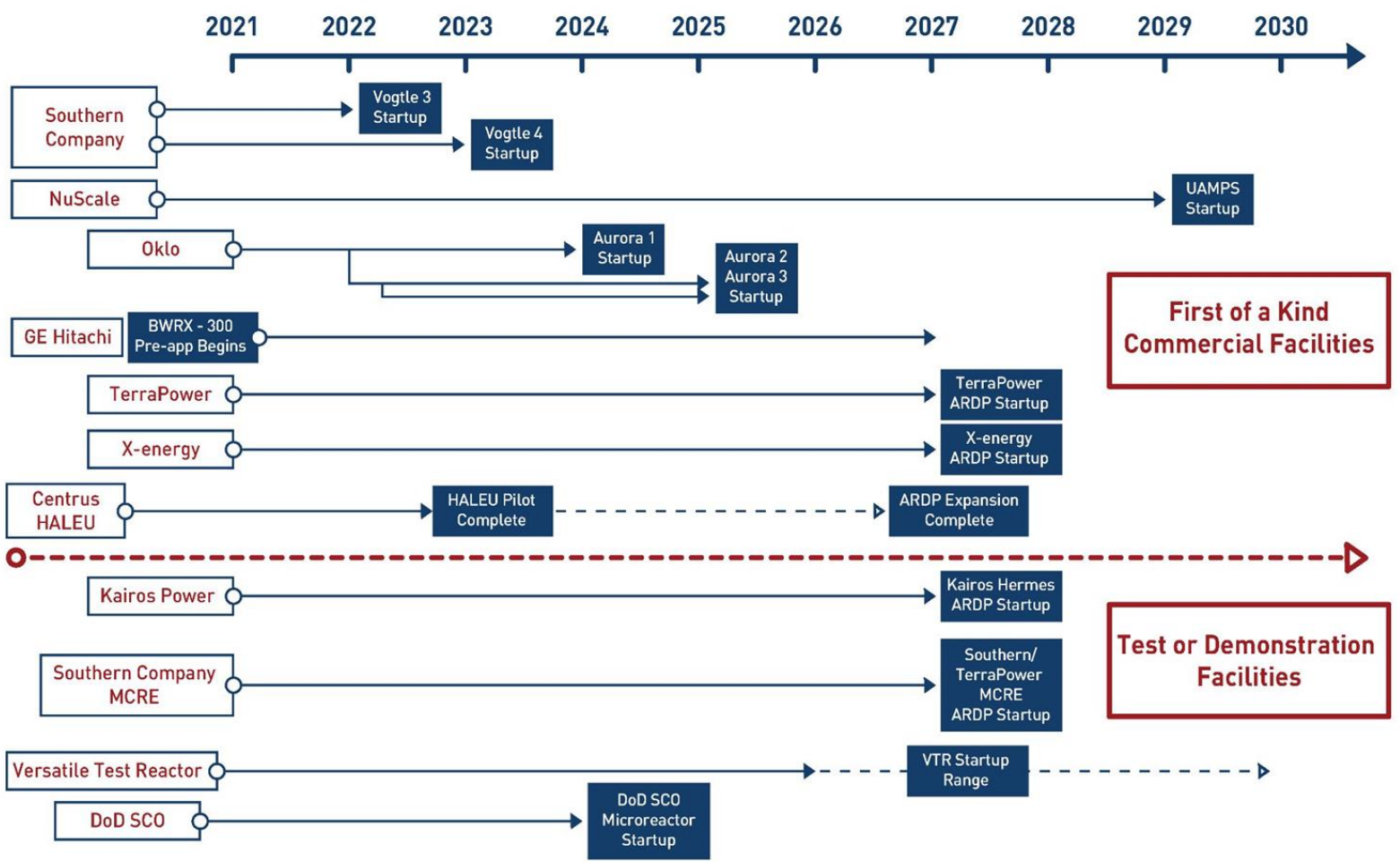
- Plan to develop and deploy smart manufacturing technologies

Elevate the DOE Office of Technology Transitions

- Empowers office to better support American entrepreneurship


TerraPower (HQ)
Bellevue, WA
X-energy - Xe-100
Energy Northwest (HQ)
Richland, WA
Southern Company
MCRE Test Reactor
Idaho National Lab
★ X-energy (HQ)
Rockville, MD
Massachusetts Institute of Technology (MIT)
Cambridge, MA
Westinghouse (HQ)
Cranberry Township, PA
PacifiCorp (HQ)
Portland, OR
NuScale (HQ)
Corvallis, OR
TerraPower - Natrium
TBD Wyoming
ARC Clean Energy (HQ)
Herndon, VA
Holtec (HQ)
Camden, NJ
Kairos Power (HQ)
Alameda, CA
Centrus - HALEU Enrichment Facility
Piketon, OH
UAMPS/NuScale
Oklo Aurora
Idaho National Lab
GE Hitachi - VTR
Idaho National Lab
Centrus (HQ)
Bethesda, MD
Oklo (HQ)
Sunnyvale, CA
Kairos Power - Hermes Test Reactor
Oak Ridge, TN
★ BWXT (HQ) & TRISO Fuel Fabriciation Facility
Lynchburg, VA
General Atomics (HQ)
San Diego, CA
Kairos Power - Engineering Center
Albuquerque, NM
Southern Company (HQ)
Birmingham, AL
GE Hitachi (HQ)
Wilmington, NC
Southern Co./ Westinghouse - AP1000
Waynesboro, GA
X-energy - TRISO Fuel Fabriciation Facility
Oak Ridge, TN
ARDP Demonstration
(Advanced Reactor Demonstration Program)
ARDP Risk Reduction
(Advanced Reactor Demonstration Program)
ARC-20
(Advanced Reactor Concepts-20)
Commercial Reactors
Versatile Test Reactor (VTR)
★ Department of Defense Project Pele Awards

CLEARPATH


2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Southern Company
Vogtle 3 Startup
Vogtle 4 Startup
NuScale
UAMPS Startup
Oklo
Aurora 1 Startup
Aurora 2 Aurora 3 Startup
First of a Kind Commercial Facilities
GE Hitachi
BWRX - 300 Pre-app Begins
TerraPower
TerraPower ARDP Startup
X-energy
X-energy ARDP Startup
Centrus HALEU
HALEU Pilot Complete
ARDP Expansion Complete
Kairos Power
Kairos Hermes ARDP Startup
Test or Demonstration Facilities
Southern Company MCRE
Southern/ TerraPower MCRE ARDP Startup
Versatile Test Reactor
VTR Startup Range
DoD SCO
DoD SCO Microreactor Startup

CLEARPATH

What is the ARDP?

Historical development

- Senators Lamar Alexander (R-TN) and Lisa Murkowski (R-AK), working with ClearPath and the National Labs, came up with the idea in 2016
- Concept was included in multiple bipartisan bills
- Kicked off in FY20 appropriations and authorized in the Energy Act of 2020

Clear goals and timelines

- Build 2 commercial reactors in 7 years: TerraPower in WY + X-energy in WA
- Also supports 5 longer-term designs, e.g., Kairos research reactor Hermes
- **<u>This moonshot goal mobilized the entire industry</u>**

Requirements for application

- Goal required robust teams of reactor developers, utilities, private capital, and manufacturers to meet these timelines and cost share requirements
- Need to actually submit an NRC license application for review and approval
- Need a plan to procure fuel

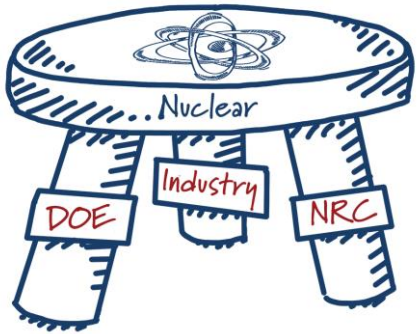
The Benefits of Setting a Goal

Align Industry → Concrete goal aligned private industry resources in order to meet the aggressive timeline

Bipartisan Support → Congressional support - from authorization to appropriations - will keep program on track and provide oversight

Regulatory → Funding for NRC modernization has enabled them to review advanced reactors

DOE Resources → Companies leveraging historical DOE and National Lab research, e.g., X-energy and Kairos using TRISO fuel tested at ORNL



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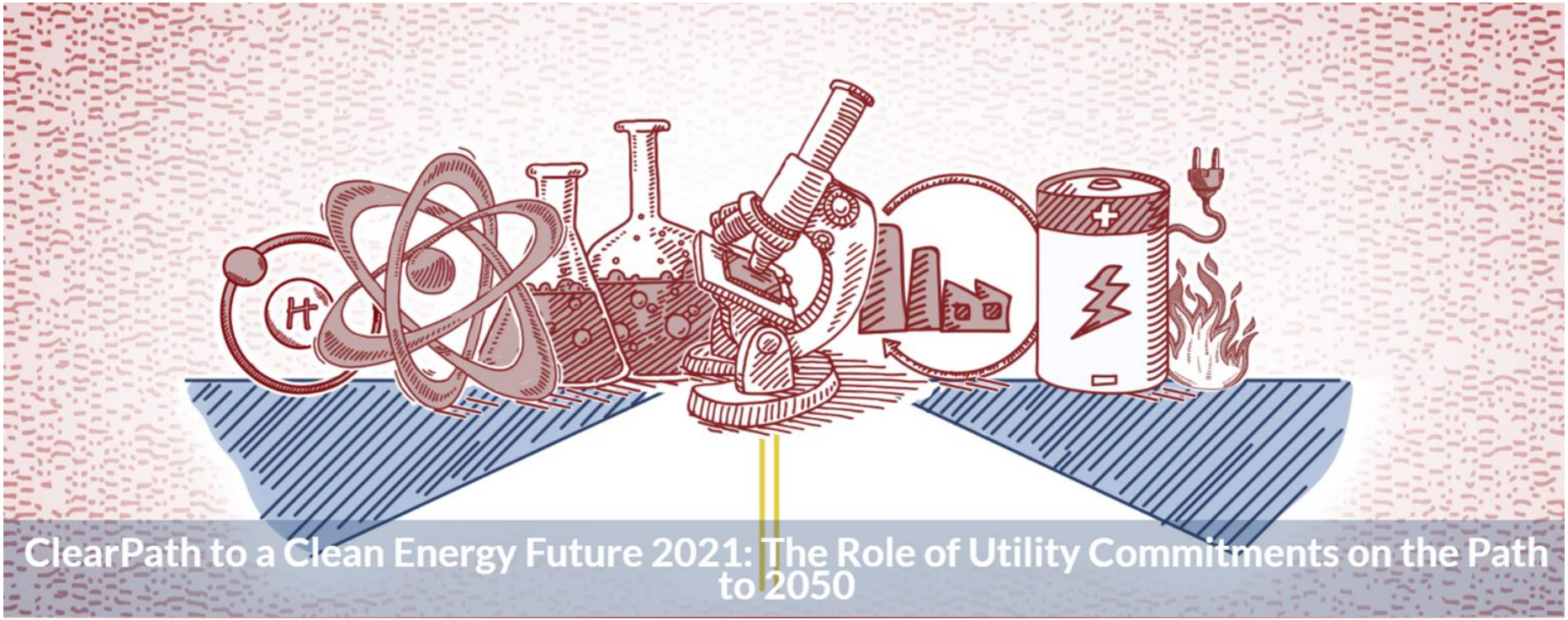
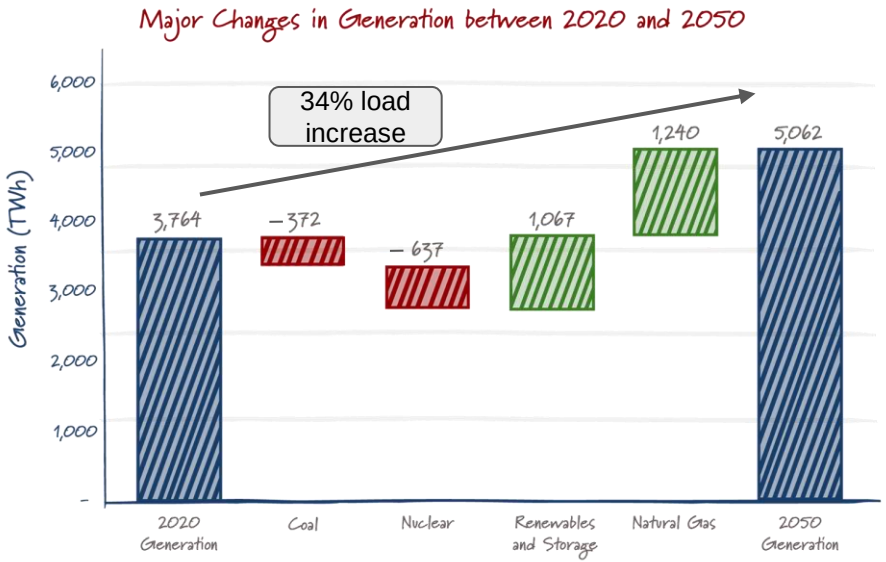
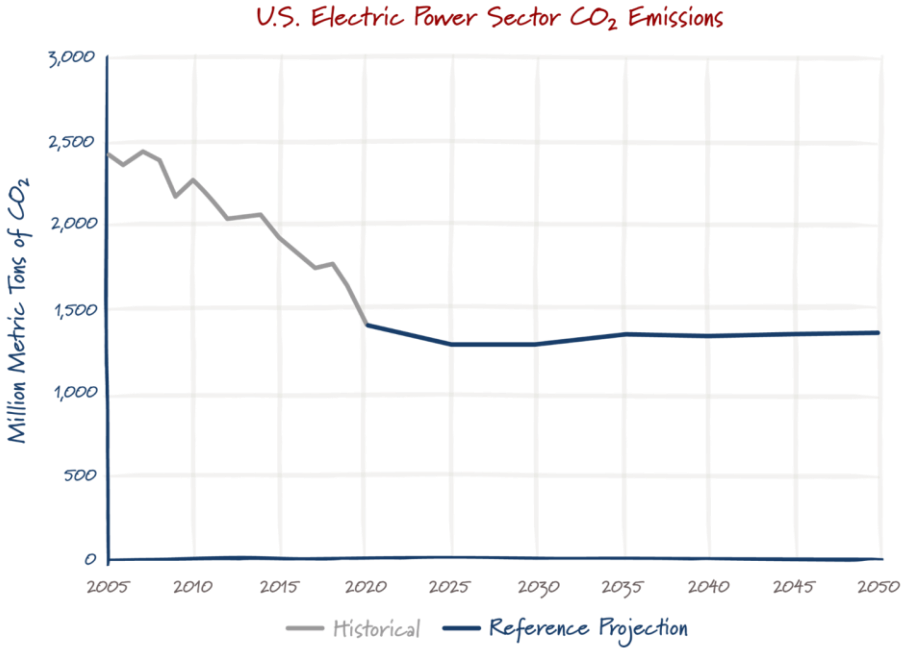


ClearPath to a Clean Energy Future 2021: The Role of Utility Commitments on the Path to 2050

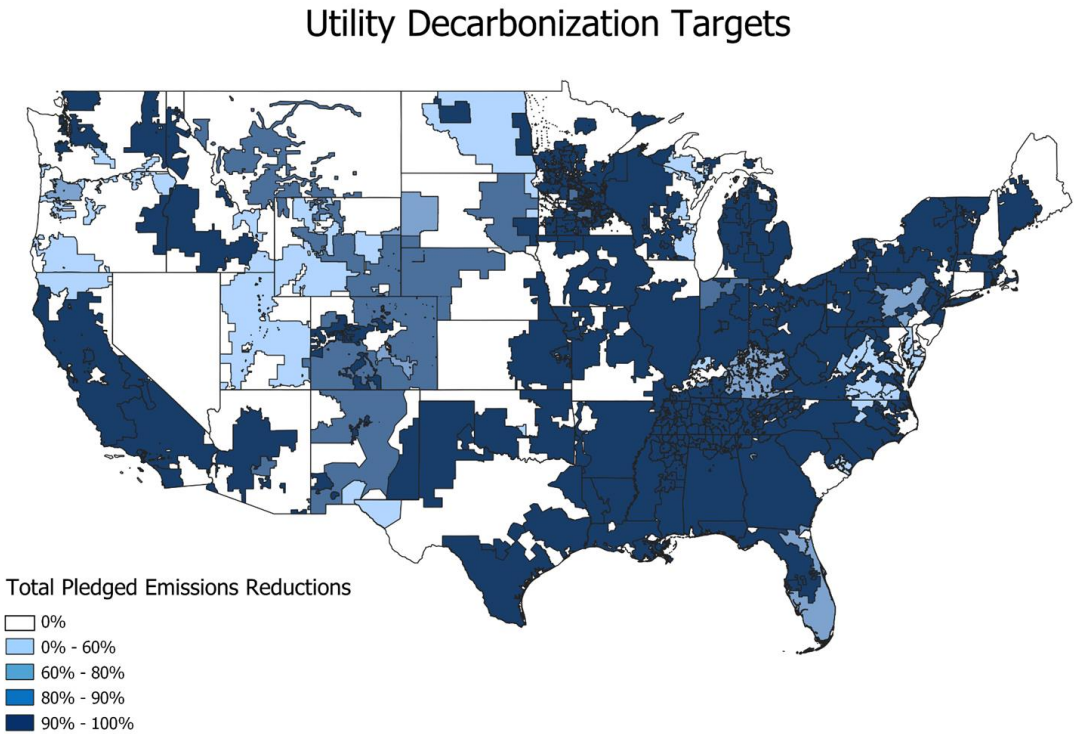
Power Sector Emissions Could Flatline After 2025





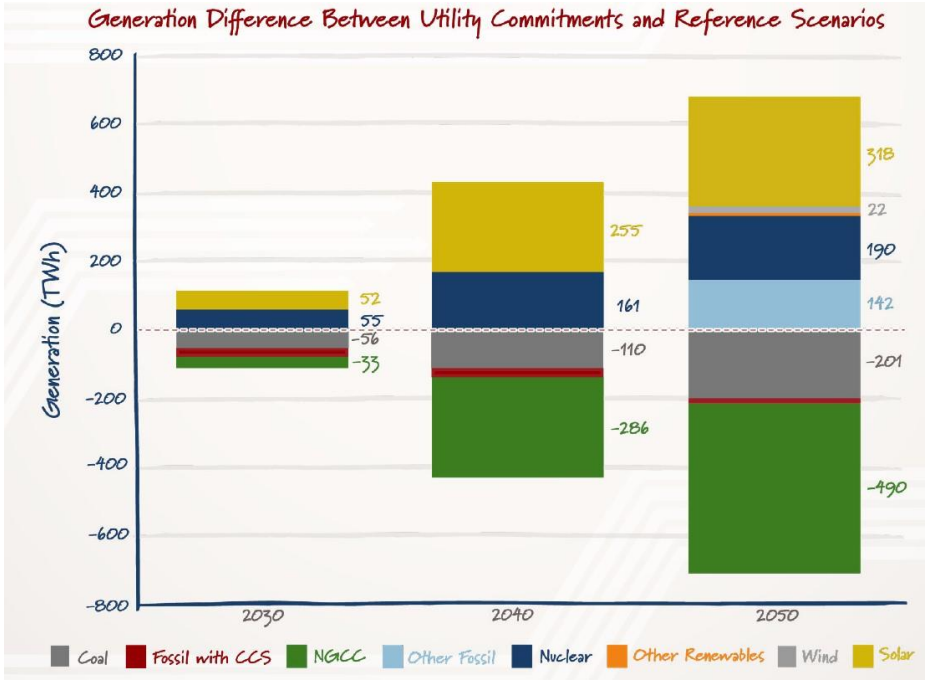
Source: Clear Path to a Clean Energy Future

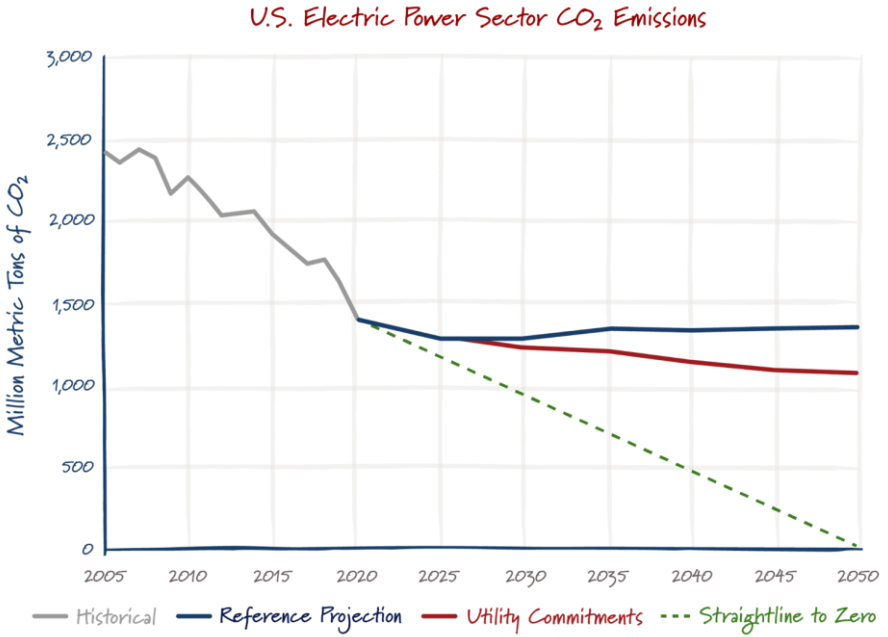
Electric Utility Targets Cover Over 70% of Electric Customers



Source: Smart Electric Power Alliance Utility Decarbonization Tracker

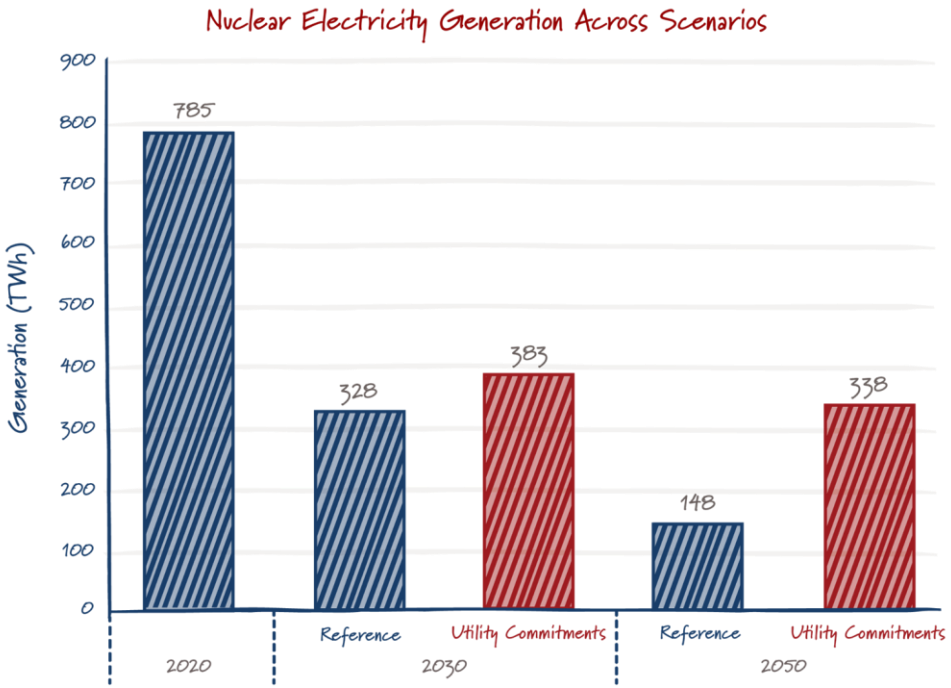
Utility Commitments Narrow the Gap to Net-Zero





Source: Clear Path to a Clean Energy Future

Nuclear is an affordable way to reach commitments



- Maintaining existing nuclear reactors is one of the cheapest ways to help meet utility commitments and reduce carbon emissions
- Utility commitments scenario:
  - Preserved 22 GW of nuclear that closed in reference scenario
  - Leads to 228% more electricity generated from nuclear reactors in 2050 than in reference scenario
  - Still included significant nuclear retirements

Source: Clear Path to a Clean Energy Future

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Hydrogen (H2) and Nuclear

Positives

- H2 is a potential revenue stream
- High electrical capacity factor means a lower cost
- Potential for higher efficiency HTSE

Negatives

- Demand market is not big enough yet for dedicated production

Exelon - Location TBA, Midwest

Fully contracted

- 2019 H2@Scale award funded by EERE+NE
- 1-3 MW PEM LT electrolysis
- Used on site and sold to nearby users
- Operations in Q1 ‘22

Energy Harbor - Davis Besse, OH

In negotiations

- NE FOA with EERE
- Needs an award increase for switchyard upgrades
- 1-3 MW LT electrolysis
- Not official, sold to Columbus bus system and Cleveland Cliffs DRI steel plant
- Operations in ‘22

Xcel Energy - Location TBA, MN

Not yet awarded

- NE FOA with EERE
- 250 kWe HTSE
- No offtaker yet
- Testing HTSE skid at INL in Q1 ‘22

Arizona Public Service - Palo Verde, AZ

Not yet awarded

- NE FOA with EERE
- Raising funds with offtakers and private investment
- 20 MW LT electrolysis
- APS will purchase H2 for 30H2:70NG co-firing in CCPP
- Production at CCPP with PPA from Palo Verde
- Online goal in ‘25

Nuclear Legislative Initiatives

Policy Initiatives	Overview
Bipartisan Infrastructure Bill	Authorizes and appropriates funding for the ARDP; authorizes feasibility studies for siting advanced reactors; and creates existing nuclear credit program.
American Nuclear Infrastructure Act (ANIA) (S.2373)	A broad bill that establishes multiple programs supporting both currently operating nuclear reactors as well as the next generation of reactor technologies.
Energy Sector Innovation Credit (S.2475/H.R.4720)	Creates a new “technology neutral” tax incentive that facilitates investment in innovative new dispatchable clean energy technologies.
Nuclear Power Purchase Agreements Act (H.R. 4834)	Allow the Secretary of Energy to enter into long-term power purchase agreements (PPAs) with new nuclear power plants with federal facilities, and must enter one long-term PPA by December 31, 2026.
Hydrogen Production Tax Credit (multiple bills)	Creates a production tax credit for hydrogen that is based on the emissions intensity of production.
Multiple other bills to incentivize nuclear energy deployments	Nuclear Licensing Efficiency Act (H.R.1578); Modernize Nuclear Reactor Environmental Reviews Act (H.R. 1559); Advanced Nuclear Deployment Act (H.R.1746); Strengthening American Nuclear Competitiveness Act (H.R.7405)

Senate-Passed Infrastructure Bill Includes Key Provisions

INVEST in America Act

Funding for Advanced Reactor Demonstration Program

Includes advance funding $2.48 billion for the two large demos, the TerraPower Natrium reactor and the X-Energy high temperature gas reactor. This fulfills most of the federal share of these projects.

Funding for Civil Nuclear Credit Program

Establishes a program to support economically struggling nuclear reactors with clean energy credits through a reverse auction system. Appropriates $1.2 billion per year for five years to initiative the program.

Other Clean Energy Demonstrations

Includes $500 million for demonstrations of clean energy on former mine land, including nuclear. Also establishes a ~$2 billion hydrogen “hub” to be primarily supported by nuclear energy.

Path Forward

Federal

- Effective policies can spur innovation and deployment
- Many projects require additional support
- Still need to address gaps like HALEU supply

State

- Projects are built at the state level
- Advanced nuclear reactors can be sited at different locations
- Ensure that nuclear is incorporated into resource planning

Projects

- Must execute on ARDP and other commercial projects
- New ideas, like integrated energy systems and replacing decommissioning coal plants with nuclear, further increase nuclear's potential impact