Nuclear Energy State of Advanced Reactors

Minnesota Senate

Energy and Utilities Finance and Policy Committee

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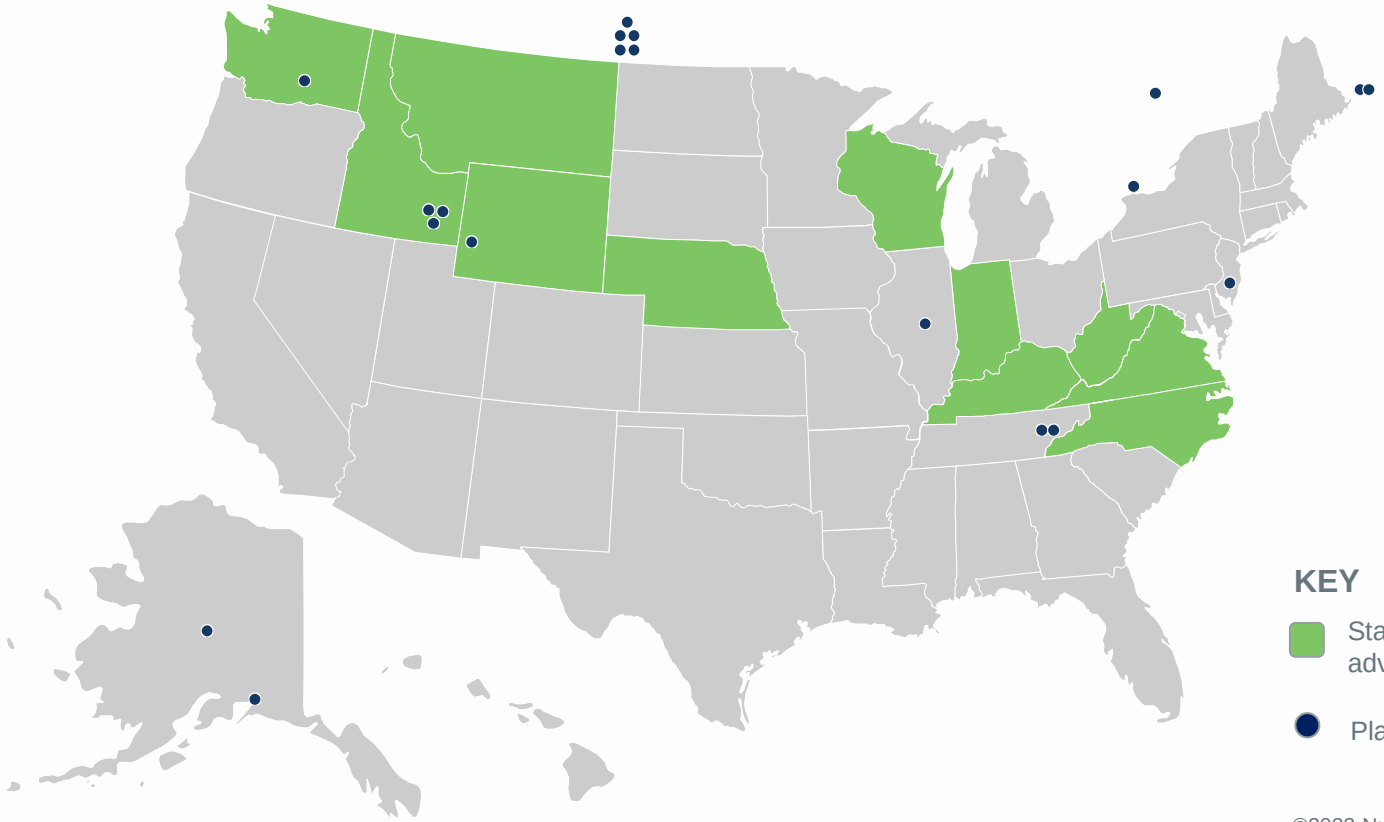
Advanced Nuclear Deployment Plans

More than 20 projects in planning or under consideration in U.S. and Canada; >30 globally



Nuclear is Key to a Clean, Reliable and Affordable Energy Supply

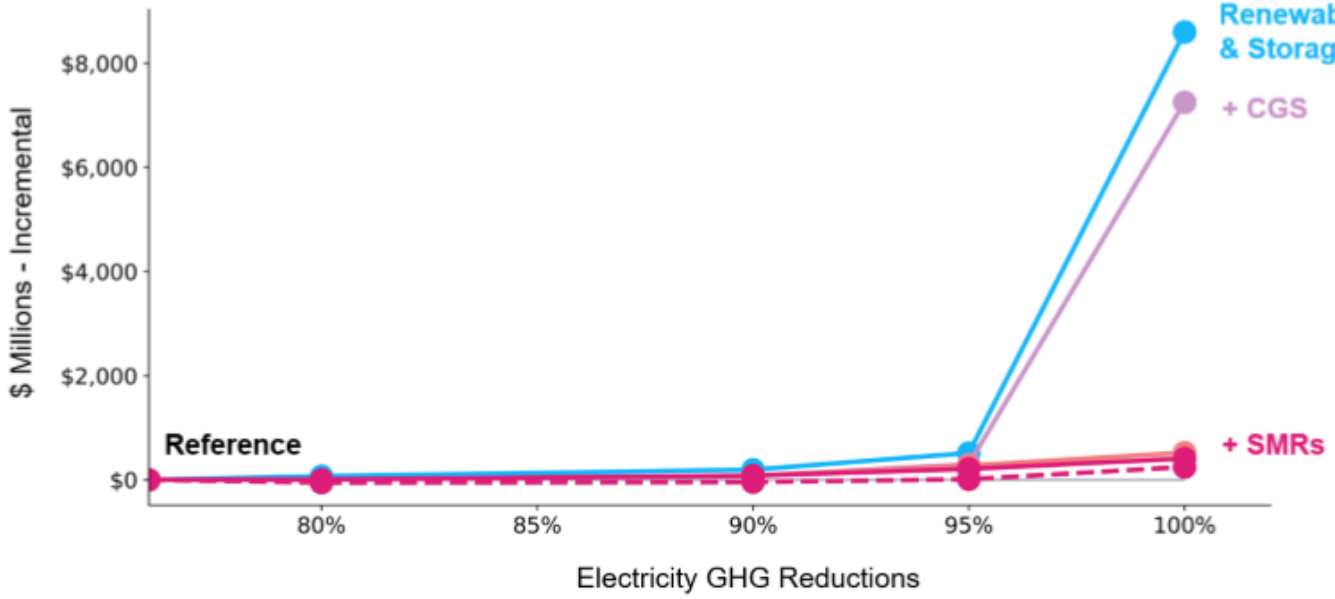


Figure 4: GHG abatement costs. The y-axis represents the incremental cost of each scenario compared to a Reference case that does not apply an emissions constraint.

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

Advanced 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

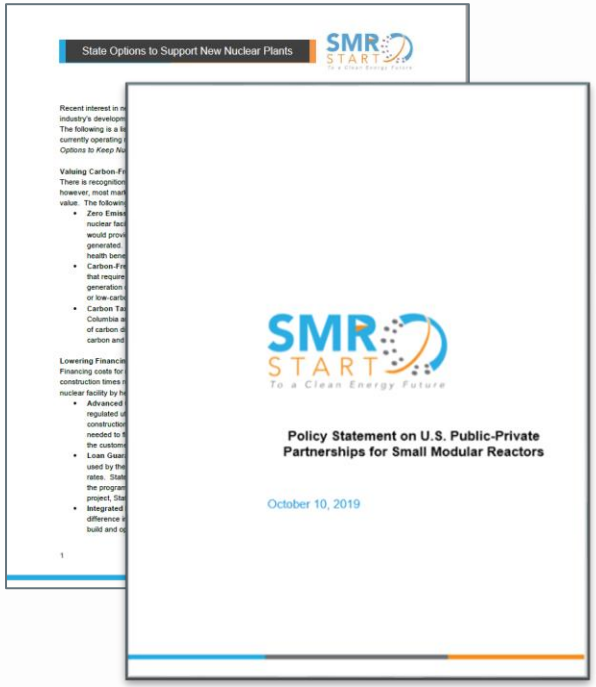
Water

Concrete

Factories

Government Deployment Support

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



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/

Utility and State Interest

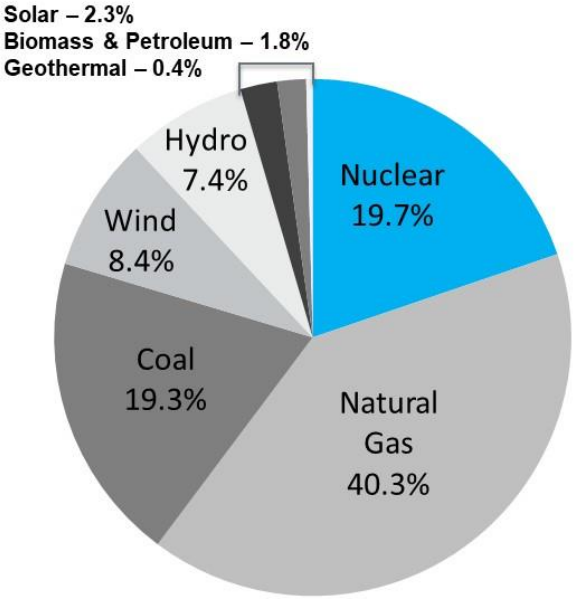
State	Legislative Action	Utility Action
Idaho	Tax incentives passed	Host of UAMPS/NuScale SMR
Indiana	SMR enabling bill passed	Duke Energy includes SMRs in IRP
Montana	Passed bill to study coal to SMR Repealed voter approval to site	NorthWestern Energy interested in coal to nuclear
Nebraska	Passed bill on SMR tax incentives	Broad support for SMRs in state
North Carolina	Passed decarbonization plan bill	Duke Energy includes SMRs in IRP
Virginia	Nuclear Energy Strategic Plan SMR Task Force bill passed	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
West Virginia	Repealed moratorium on new nuclear	Dominion and AEP interested in SMRs
Wyoming	Passed bill calling for coal retirements to be replaced with SMRs	Rocky Mt. Power siting for TerraPower demo

QUESTIONS?

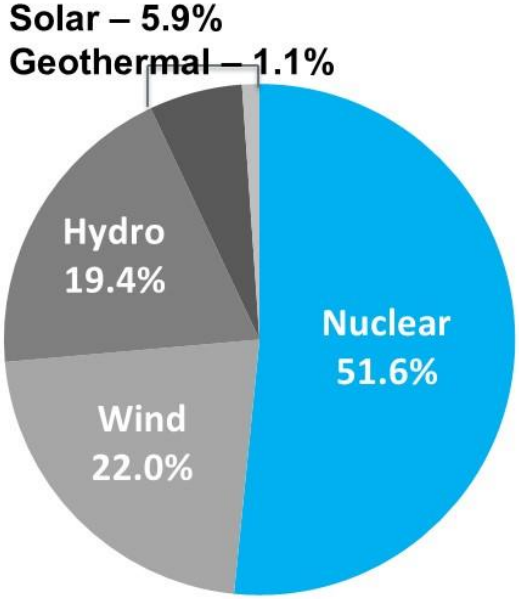
By Third Way, GENSLER

Additional Information

Nuclear is the **second-largest** generation source in the U.S.



And provides **more than half of emissions-free electricity** in 2020



Source: U.S. Energy Information Administration. Updated: March 2021

Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

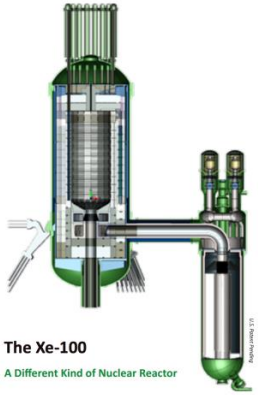
Micro Reactors (< 20MW)

Oklo (shown)
Approximately a dozen in development

Light-water SMRs <300MW

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

High Temp Gas Reactors

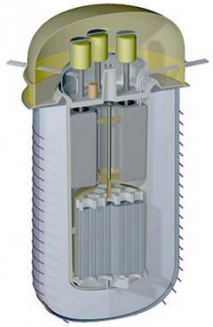


X-energy (shown)
Several in development

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

Affordable, Resilient and Flexible

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

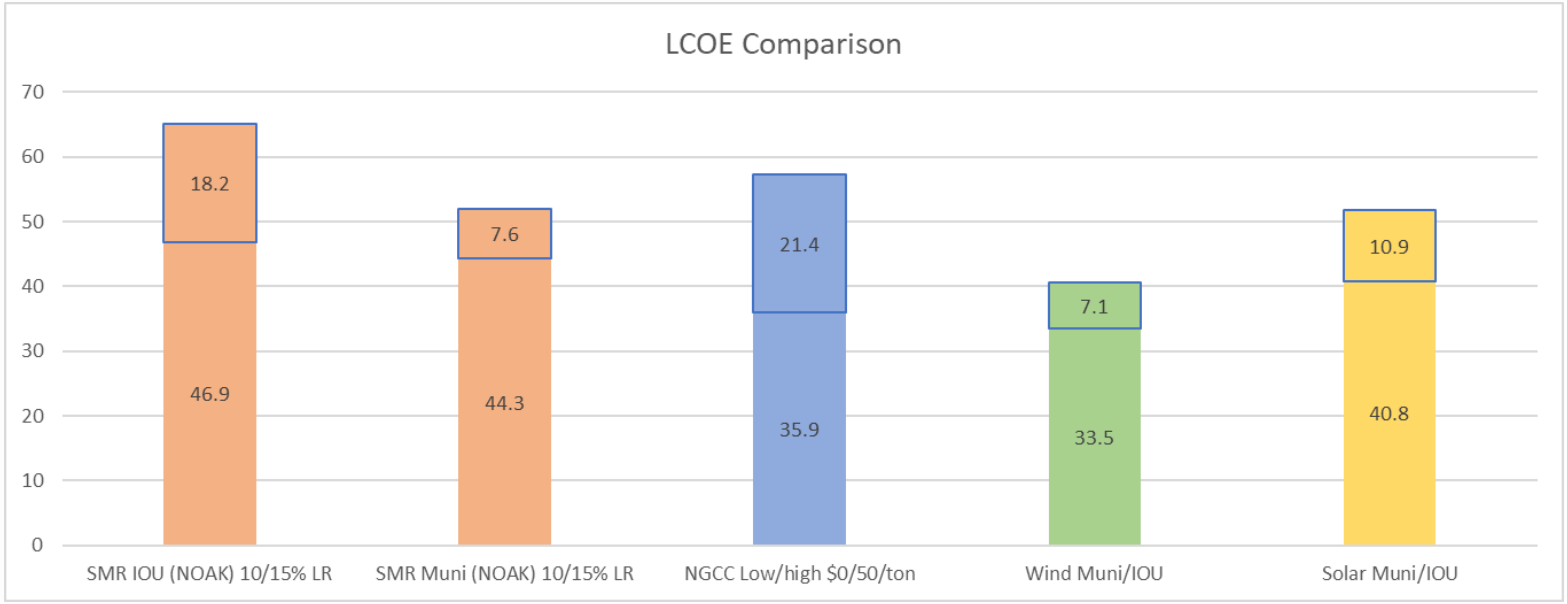
FASTER CONSTRUCTION

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

IMPROVED PERFORMANCE

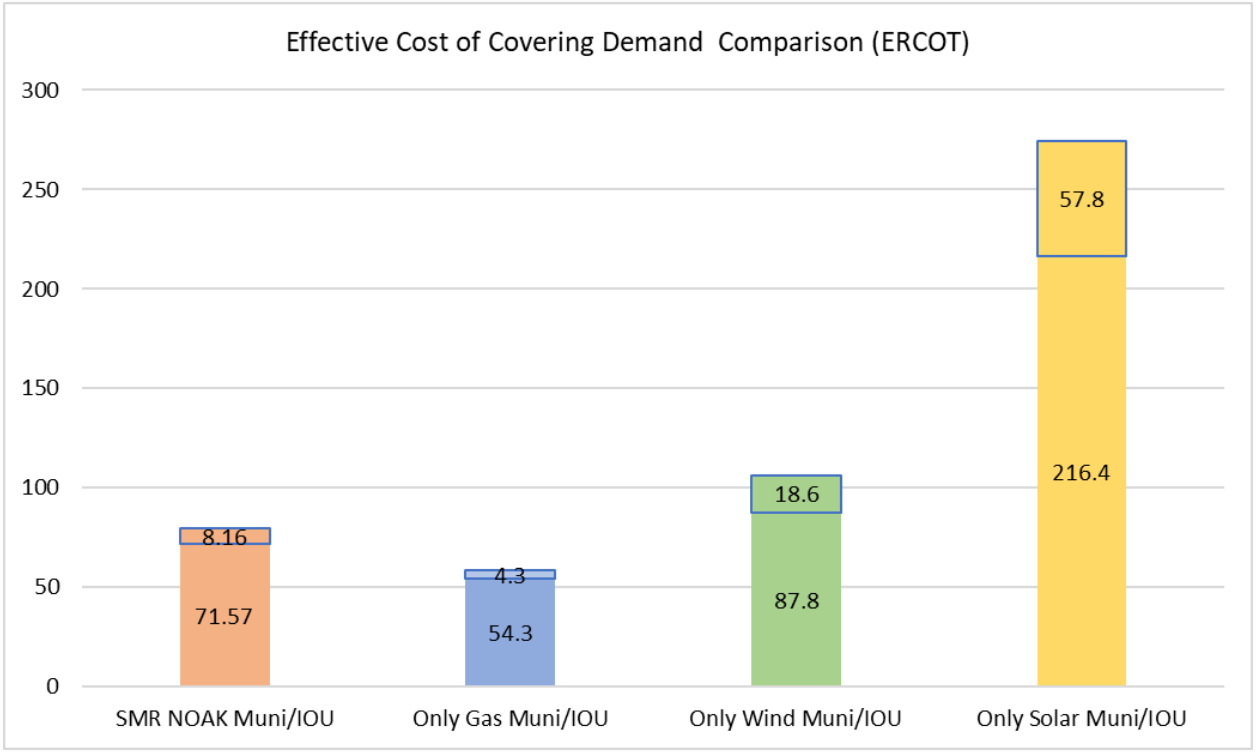
- Higher Thermal Efficiency
- Design and Construction Best Practices
- Operational Excellence

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 the need for system reliability makes nuclear even more affordable



Source: SMR Start, *Economics of Small Modular Reactors*

Economic Benefits of SMRs

- Employment
  - 900 manufacturing and construction jobs over 4 years (average)
  - 300 permanent positions during 60+ years of operation
  - Multiplier effect: additional 1.66 jobs in local economy, 2.36 rest of the state
  - Nuclear jobs pay 20% more, on average, than jobs at other energy sources
  - Nuclear jobs pay 36% more than average salaries in local area
- Economic Activity
  - $500M+ in direct and indirect economic output annually
    - $270 million in electricity sales
    - Spending at local ($10M), State ($48M) and national ($236M) level
  - Taxes: $10M in state and local, and $40M in federal annually

Source: SMR Start, *Economics of Small Modular Reactors*
Based on a 600 MWe SMR plant

Similar Jobs and Limited Retraining

Coal Plant Position	# Dedicated Coal Positions	SMR Position	# Dedicated SMR Positions	Position Type	Degree of Retraining Required
Operations Supervisor	5	Senior Reactor Operator	5	Supervisor	High
Control Room Operator	10	Reactor Operator	15	Operator	High
Field Operator	15	Non-Licensed Operator	25	Operator	Low
Lab Operator/Chemistry/Scrubber	4	Chem Tech	14	Craft	Medium
Maintenance Supervisor	2	Maintenance Supervisor	3	Supervisor	Medium
Mechanical Craft	12	Mechanical Craft	21	Craft	Low
I&C Craft	9	I&C Craft	10	Craft	Medium
Electrician Craft	5	Electrician Craft	11	Craft	Low
Technician	11	Technician	13	Laborer	Low
Security Officer	20	Security Officer	48	Laborer	Low
Sub-Total	**93**		**165**		
All Other Positions	14		72	42 are O&M Support (Planners, Outage, etc.)	Medium
Total On-Site Positions	**107**		**237**		
Possible Centralized Positions			33		
Total Positions			**270**		

Source: NuScale and Scott Madden, *Gone with the Steam*

System Benefits of SMRs

- Fuel diversity
  - Lowest cost systems have fuel diversity
  - Long term price stability
- Reliable dispatchable generation
  - 24/7, 365 days per year, years between refueling
  - Capacity factors of 95% or more
- Integration with renewables and storage
  - Paired with heat storage and able to quickly change power
- Carbon-free generation
  - Zero-carbon emissions, one of the lowest total carbon footprints
- Resilience for mission critical activities
  - Black-start capability and able to operate independent from the grid
  - Protect against natural phenomena, cyber threats and electro-magnetic pulses
- Use existing transmission infrastructure

Source: SMR Start, *SMRs in Integrated Resource Planning*

SMRs Are Environmentally Friendly

- Air Quality
  - Zero-carbon emissions, one of the lowest total carbon footprint
  - No emissions of SOx, NOx or other air pollutants
- Water Use
  - Many SMRs are being designed with ability for dry air cooling
  - Would enable SMRs to be located where water is scarce or expensive
- Land Use (per 1,000 MWe)

	SMR	NGCC	Wind	Solar
Capacity factor (%)[12]	95	55[13]	35	25
Plant life (years)	60 to 80	40 to 50	20 to 25	20 to 25
Lifetime TWh	647	241	76	55
Land required (acres)[14,15,16]	50[17]	343	85,240	7,900
Land Utilization (acres per Lifetime TWh)	<0.1	1.4	1,125	144

Source: SMR Start, *SMRs in Integrated Resource Planning*

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:
  - Saving jobs and local economy
  - Benefiting the electric grid system
  - Generating environmentally friendly power
- Pursuing policy actions to encourage coal to nuclear

1. Scott Madden, *Gone with the Steam*, October 2021
2. INL, *Transitioning Coal Power Plants to Nuclear Power,* December 2021
3. Good Energy Collective, *Opportunities for Coal Communities through Nuclear,* December 2021
4. ORNL, *Evaluation of Suitability of Selected Set of Coal Plant Sites for Repowering with Small Modular Reactors*, March 2013
5. ORNL, *TVA Coal-Fired Plant Potential for Advanced Reactor Siting*, September 2021
6. NuScale SMR Technology: An Ideal Solution for Repurposing Coal Plant Infrastructure and Revitalizing Communities

Advanced Reactor Deployment Plans (1/2)

Grid-scale reactors

Developer	Utility / User	Location	Size	Target Online
NuScale	UAMPS	Idaho, USA	6 @ 77MW	2029
	KGHM Polska Miedz	Poland	6 @ 77MW	2029
	Nuclearelectrica	Romania	6 @ 77MW	2028
GEH BWR X-300	OPG	ON, Canada	300 MW	2028
	TVA	TN, USA	300 MW	2032
	Synthos & Orlen	Poland	300 MW (>10 plants)	Early 2030s
Holtec SMR-160	TBD	NJ, USA	160 MW	2030
X-energy Xe-100	Grant County PUD	WA, USA	4 @ 80MW	2027
TerraPower	Pacific Corp.	Wyoming	345 - 500MW	2028
ARC	NB Power	NB, Canada	100 MW	2030
Moltex	NB Power	NB, Canada	300 MW	2032
TBD	SaskPower	Sask., Canada	~300 MW (4 plants)	2032 to 2042

Advanced Reactor Deployment Plans (2/2)

Micro-reactors and low scale test reactors

Developer	Utility / User	Location	Size	Target Online
Oklo	Oklo	Idaho, USA	1.5 MW	2025
	Compass Mining	TBD	TBD (150 MW total)	TBD
Ultra Safe Nuclear	Global First / OPG	CRL, Canada	5 MW	2025
	University of Illinois	Illinois, USA	5 MW	2027
	Copper Valley (CVEA)	Alaska, USA	5 MW	TBD
Westinghouse	TBA	West Canada	5 MW	2027
	Bruce Power	ON, Canada	5 MW	2027
	Univ. (TBA)	USA	5 MW	2027
Radiant	TBA	Idaho, USA	1.2 MW	2026
TBD	Eielson AFB	Alaska, USA	1 – 10 MW	2027
X-energy or BWXT	DoD SCO	Idaho, USA	1.5 MW	2025
Kairos Power	Kairos	TN, USA	35 MW	2026