Perspectives on the Application of Nuclear at Small Scales

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GAIN – EPRI – NEI Microreactor Program Virtual Workshop
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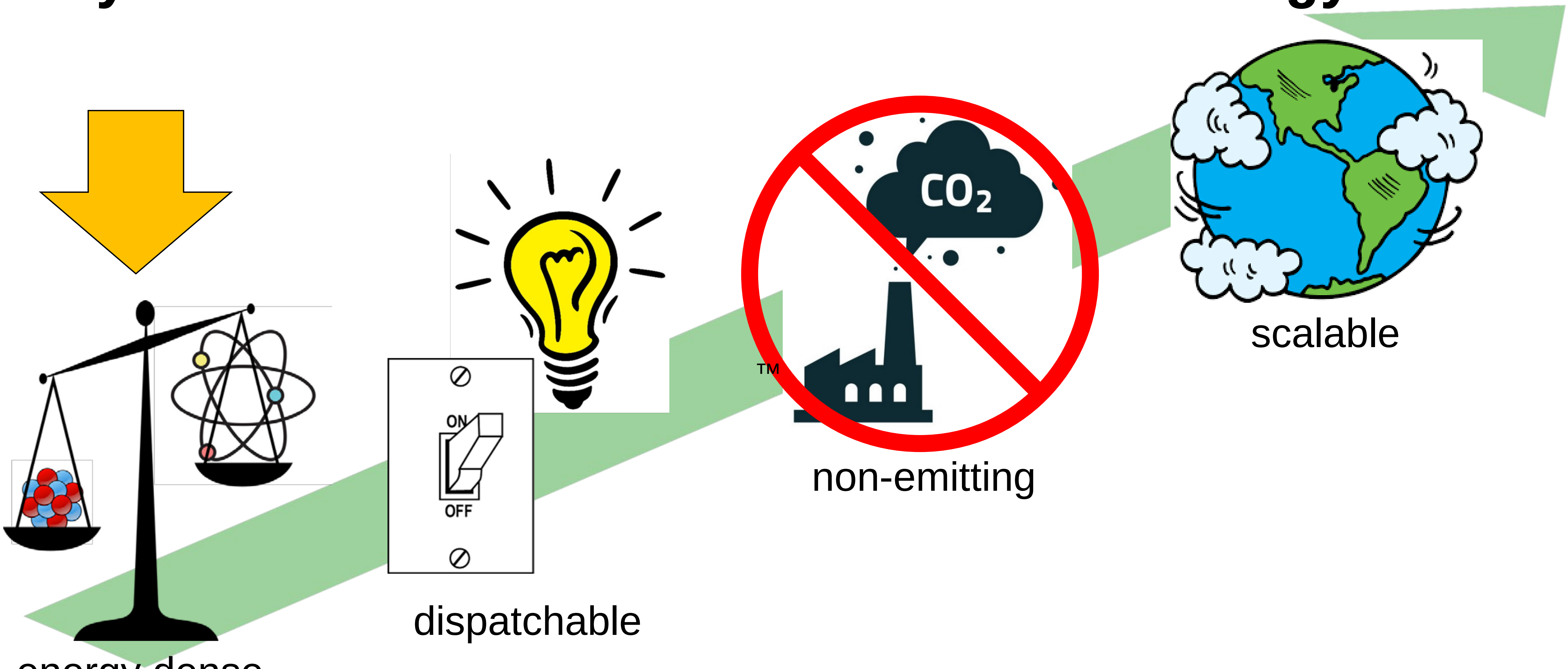
Why nuclear does "small" like no other technology...



energy dense

dispatchable

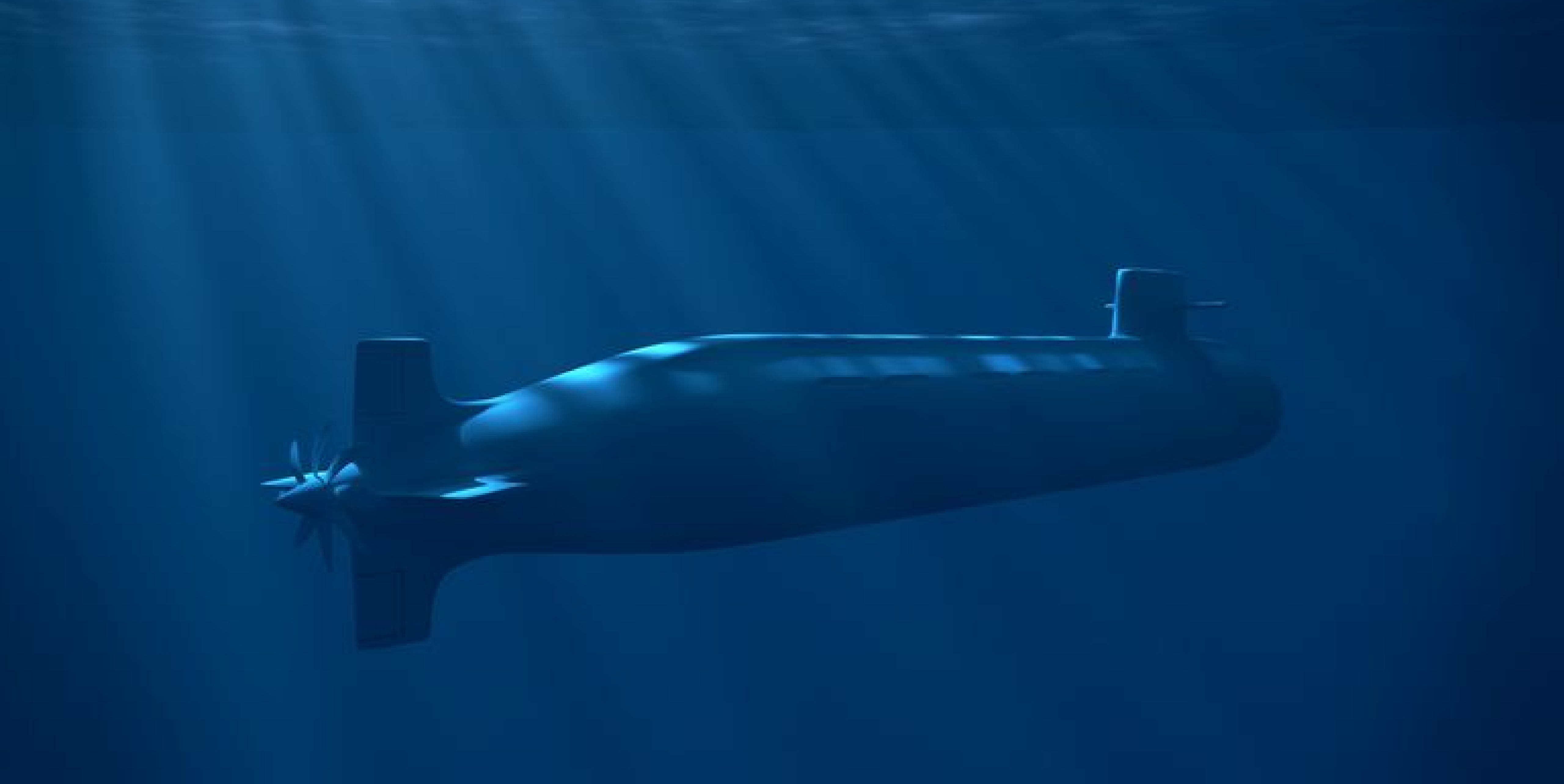
non-emitting

scalable

Fundamental attributes nuclear power uniquely offers in one package

What is the value of reliable power…

...to the submarine crew and mission at 500 m depth?



…to the research station cut off from resupply for months?

McMurdo Station, Antarctica

…to the urban hospital campus after a devastating storm?

Post-Katrina New Orleans, Louisiana

Credit: The Times-Picayune

...to the remote community above the Arctic Circle?

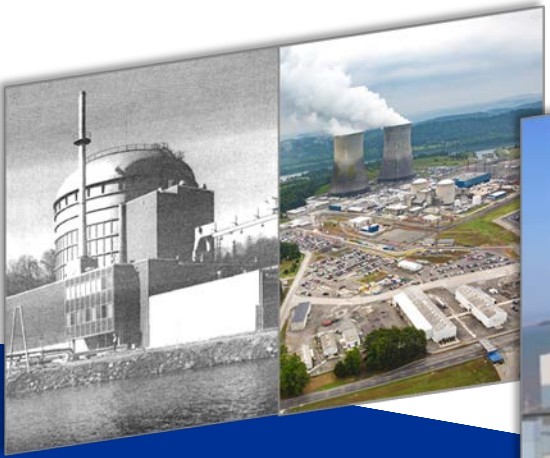
Utqiagvik (Barrow), Alaska

Credit: Galen Rowell/Corbis

Applications of Energy-Dense Power at MW-Scales

		Civilian	National Security and Defense	Grid Connection
Transportable	Fixed	• hospitals • data centers • industrial parks • airports • communication infrastructure • fuel terminals and pipelines • water treatment and distribution • wastewater pumping and treatment	• domestic military bases • national laboratories • government centers • other critical installations and infrastructure	**YES** grid connected but islandable to support micro-grid applications
		• remote communities • remote mining, oil recovery, and other industrial activities	• remote military installations	**NO** off-grid or micro-grid applications
	Portable	• disaster response and recovery	• forward and remote operating bases	

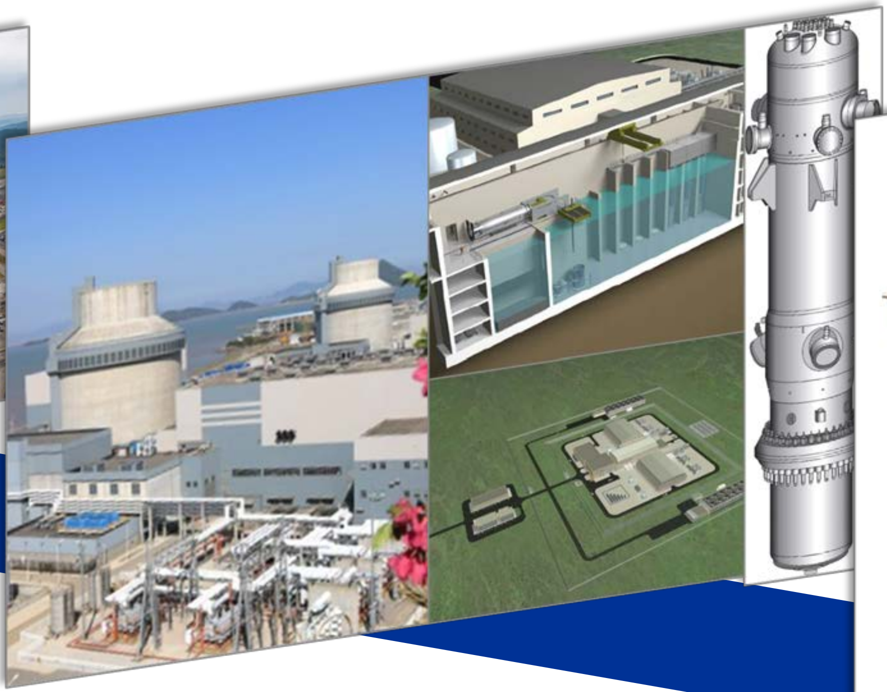
Evolving Technologies, Customers, Missions, and Requirements



GEN I & II

Early demonstrations through GW-scale commercial fleets

- Diversity of designs
- Diversity of vendors
- Diversity within vendors
- Limited standardization
- Aggressive build rates
- Evolving regulations

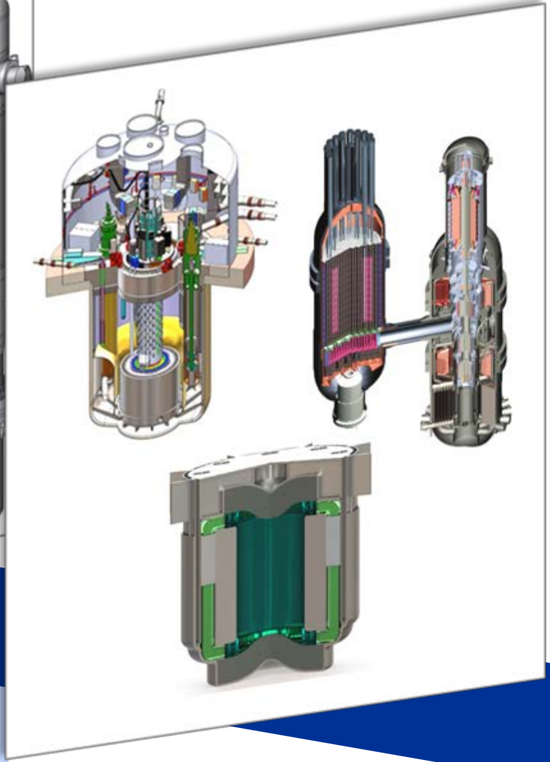


GEN III/III+

Evolutionary designs, GW-scale +

- Convergence on ALWRs
- Passive safety
- Standardization
- Integration with licensing
- Emergence of SMRs

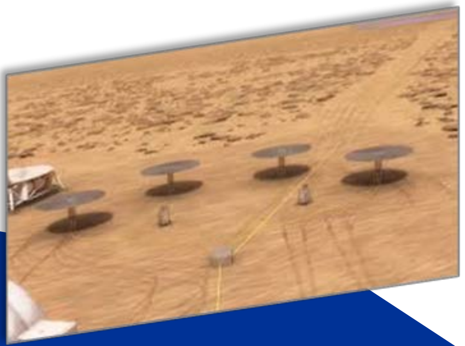
EPRI and European utilities establish LWR-centric requirements



Microreactors

MWe-scale expands technology options

- Heat pipe cooling
- Remote deployment
- New markets
- Competition with diesel



Advanced Reactors

Beyond large LWRs: GEN IV, non-LWRs, lwSMRs

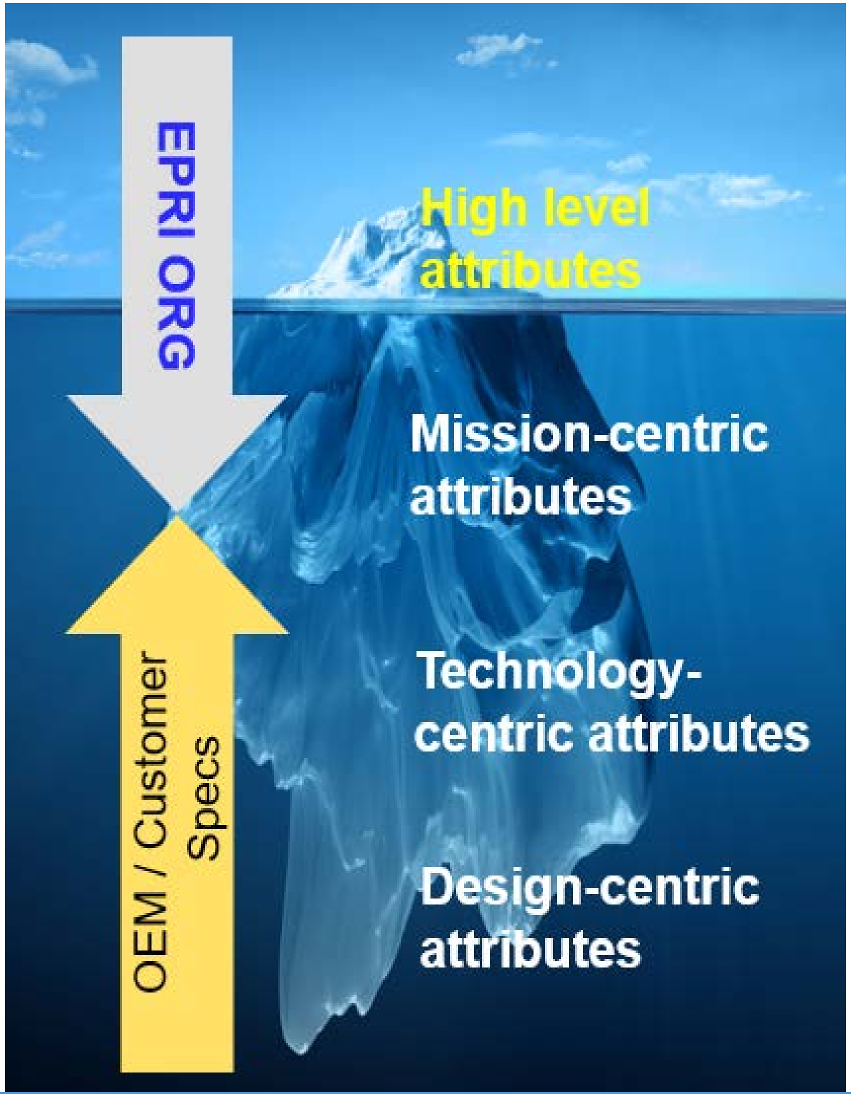
- Diversity of vendors and designs
- Aggressive cost and schedule targets
- Competitiveness via new missions and customers
- Focus on innovation, tension with standardization?
- Evolving regulatory frameworks

EPRI launches AR Owner-Operator Requirements

EPRI Owner-Operator Requirements Guide (ORG) for Advanced Reactors

Rev. 1 Published June 2019 [Report 3002015751]

- Technology and mission inclusive <u>framework</u> (vs. prescriptive specification) to:
  - Align design attributes with customer needs
  - Standardize terms, attributes, and requirements rather than prescribing them
  - Facilitate communication with key stakeholders, including regulators
- Sharing common origin and purpose with EPRI URD, the EUR, and other LWR guidance



Compelling business cases for advanced reactors have yet to be clearly elaborated.

EPRI Expansion of Owner-Operator Requirements for ARs

1990 (Rev 0) → **2014 (Rev 13)**

Utility Requirements Document (URD)

Retrospective, proven technology

One customer and mission

Advanced LWRs (& lwSMRs)

Fukushima lessons learned

2018 (Rev 0) → **2019 (Rev 1)**

Owner-Operator Requirements Guide (ORG)

Prospective, new technologies

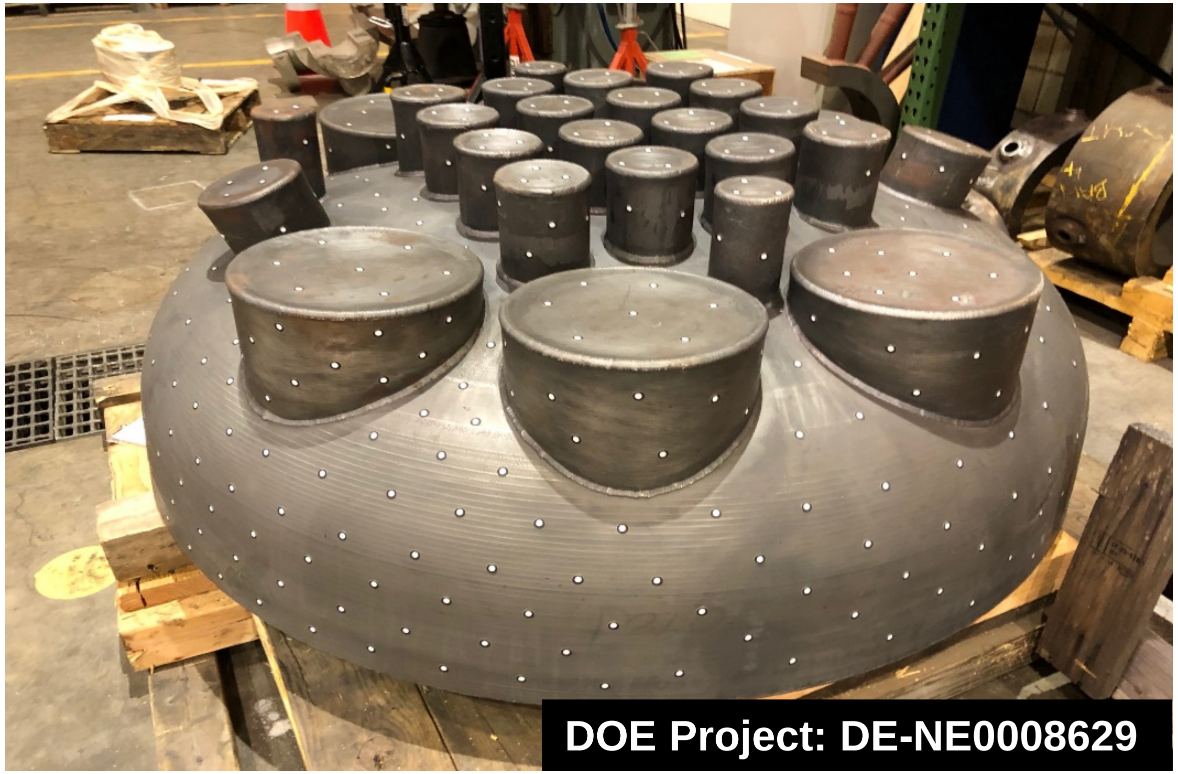
Multiple customers, missions

Advanced (non-LWR) reactors

Expanded technologies	Light water small modular reactors
Heat pipe cooled reactors	Expanded non-electric mission goals

EPRI Advanced Manufacturing – Toolbox of Methods

Powder Metallurgy – Hot Isostatic Pressing (PM-HIP)



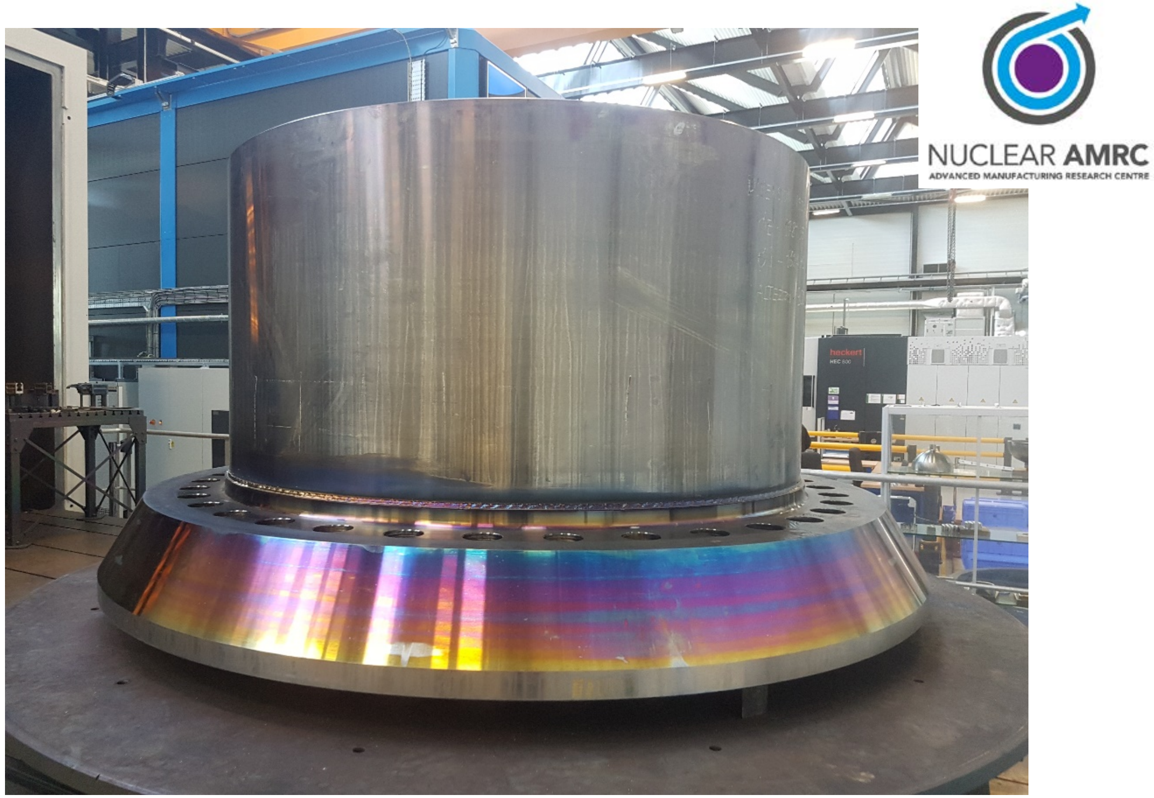
- 44% scale; A508 Class 1, Grade 3; 27 penetrations
- Largest single monolithic structure for existing HIP
- 1650kg (3650lbs), 1270mm (50 inches) diameter

Expanded HIP w/ ATLAS

- 3.55m (140in) Diameter x 2m (79in) (T) HIP Vessel
- Load capacity = 250,000 lbs (113,000kgs)

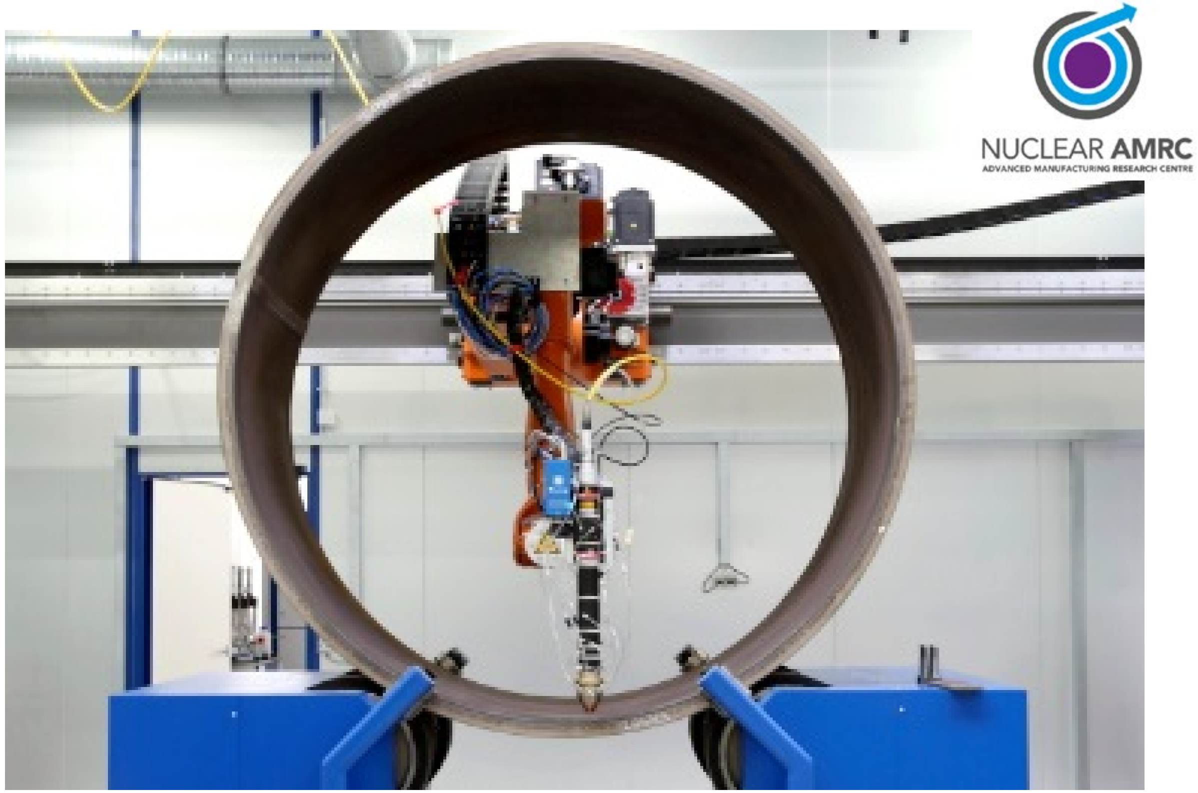
EPRI Advanced Manufacturing – Toolbox of Methods

Electron Beam Welding (EBW)



Lower Flange Shell Mockup e-Beam Weld:
~6 ft (1.82m) diameter
completed in 47 minutes (vs. a week or more)

Diode Laser Cladding (DLW)

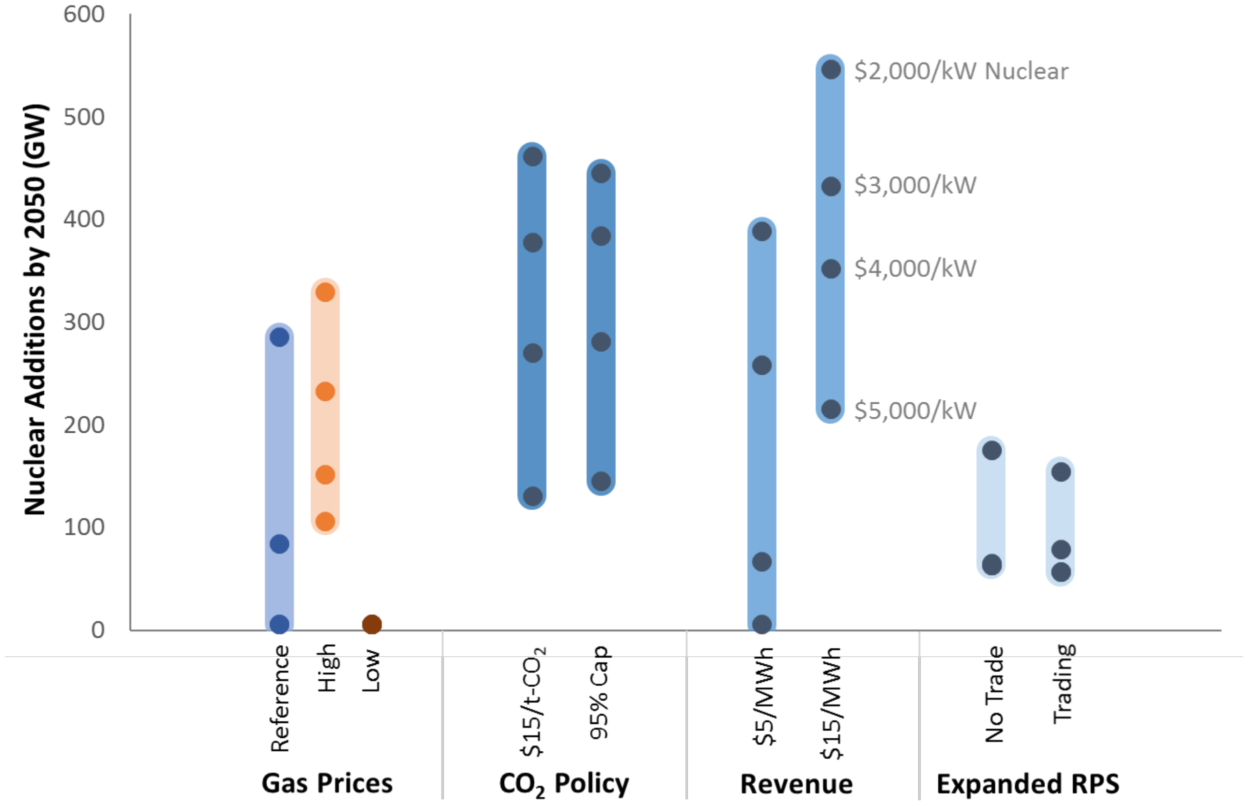


- Robotic machine welding; reasonable deposition rates
- Significantly reduces cladding thickness required (~3-4mm)
- Post cladding machining NOT required

Economics and Competitiveness of Advanced Nuclear

Exploring the Role of Advanced Nuclear in Future Energy Markets. March 2018, Report 3002011803

- EPRI developed and maintains its REGEN model as a state-of-the-art resource for projecting capacity expansion to meet future energy market needs.



Factors influencing deployment

- Competition (technology)
- Capital costs
- Revenue
- Regional factors
- Energy and environmental policies

Advanced reactor competitiveness dependent on multiple factors…not just cost.

EPRI Techno-Economic Assessment of Generation Technologies

- EPRI developed and maintains TAGWeb™ as a credible source of power generation and storage technology cost and performance data and as a financial analysis tool for utility resource planning.

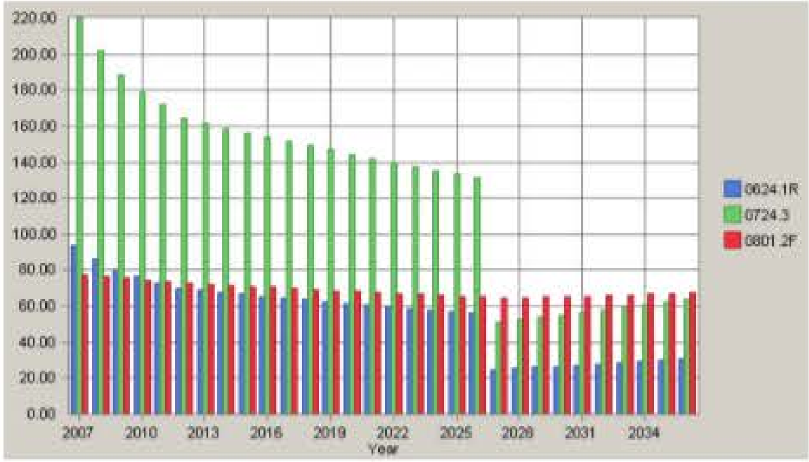


Figure 1: Annualized Costs by Technology Selection

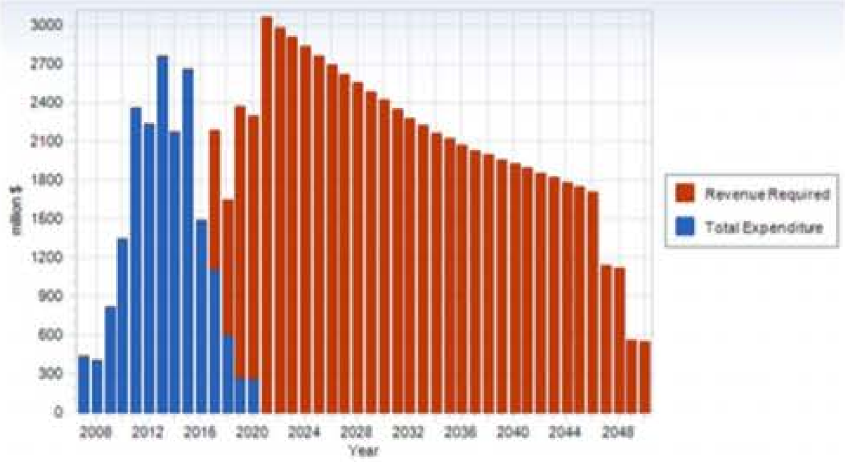


Figure 2: Revenue Requirements

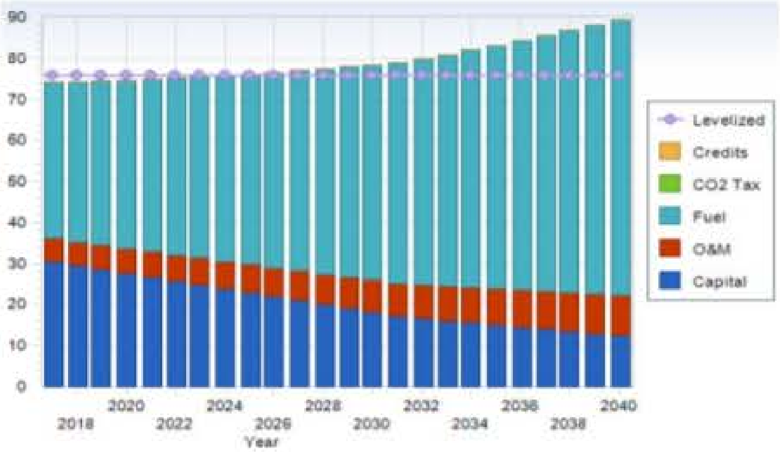


Figure 3: Levelized Costs of Electricity, $/MWh (LCOE)

TAGWeb™ provides credible cost and performance data on generation technology.

Credit: Third Way

Atoms for ... resilience, continuity, civilization