State of the Near-Net Shape Manufacturing and Supply Chain Development in the USA– Infrastructure Needs

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ORNL MDF
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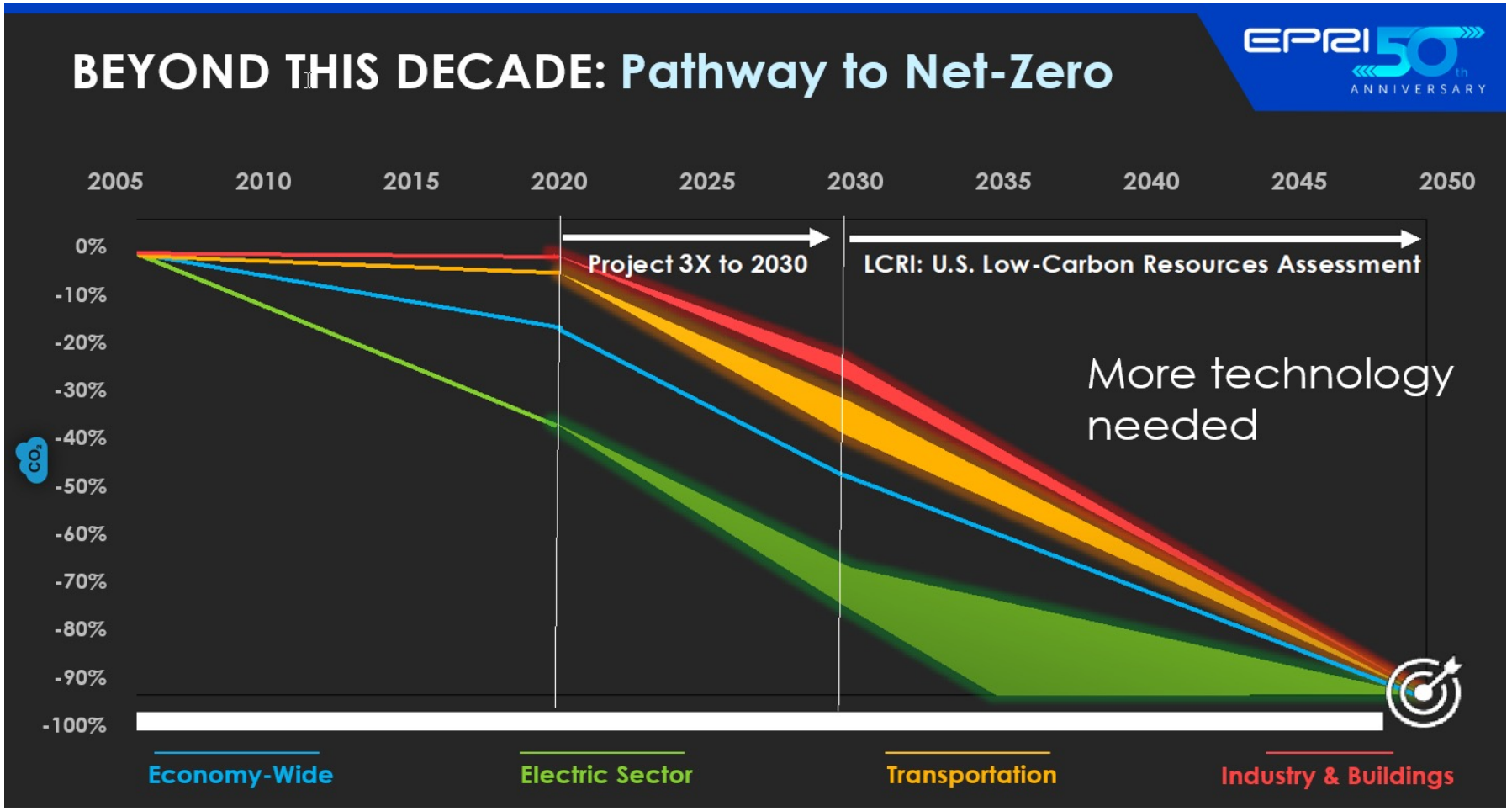
Overview

- Industry Electricity Demand/Projections
- Enabling Net-Zero by 2050
- Advanced Manufacturing & Deployment
- EPRI Advanced Manufacturing Methods & Materials (AM3)
- EPRI Supply Chain Workshop Overview & Results
  - Infrastructure Needs
  - Key Themes
  - Opportunities
- Summary

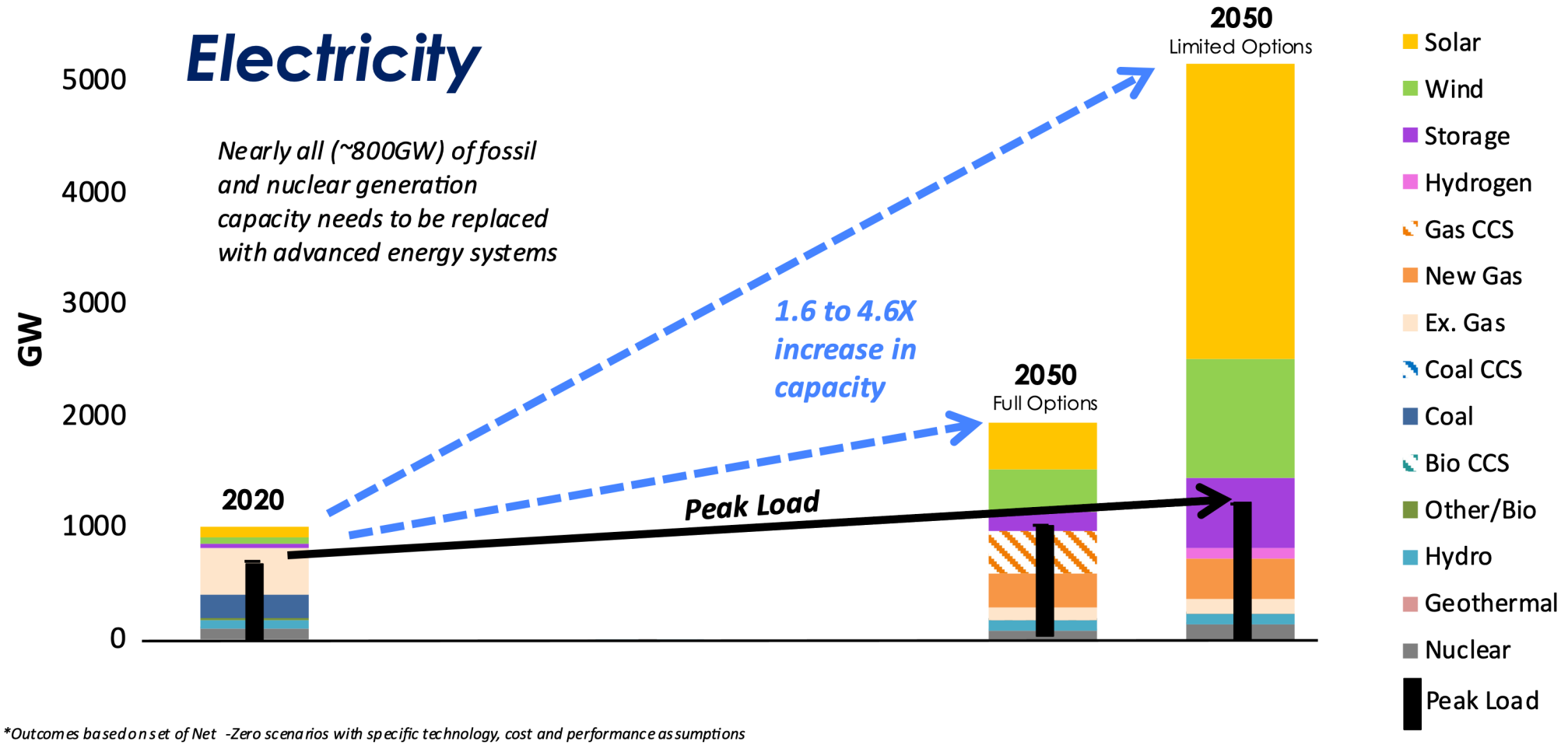
Examining The Pace of US Carbon Reduction



- 2005-2020 Reduction in CO2 Greenhouse Gas Emissions:
  - ~13% in USA overall
  - ~35% in electricity sector alone.
- 2030 goal:
  - 3X the rate of reduction is required
- 2050 goal:
  - Net Zero

CAPACITY

Firm Capacity Critical for Peak Load
growing peak load across all scenarios



*Outcomes based on set of Net -Zero scenarios with specific technology, cost and performance assumptions

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EPRI

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Advanced Reactor Deployment Plans

Grid-scale reactors

Courtesy of: NEI

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
	SaskPower	Sask., Canada	~300 MW (4 plants)	2032 to 2042
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	Purdue/Duke Energy	Indiana, USA	TBD	TBD

Advanced Nuclear Deployment Plans

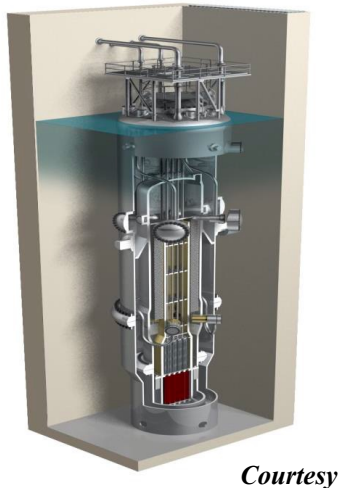
"The Inflation Reduction Act puts nuclear on the same playing field as renewables. It will stimulate more interest in nuclear. Adding 300 reactors that generate 90 gigawatts over 30 years might be on the low end once this plays out."

Doug True, Chief Nuclear Officer

Nuclear Energy Institute

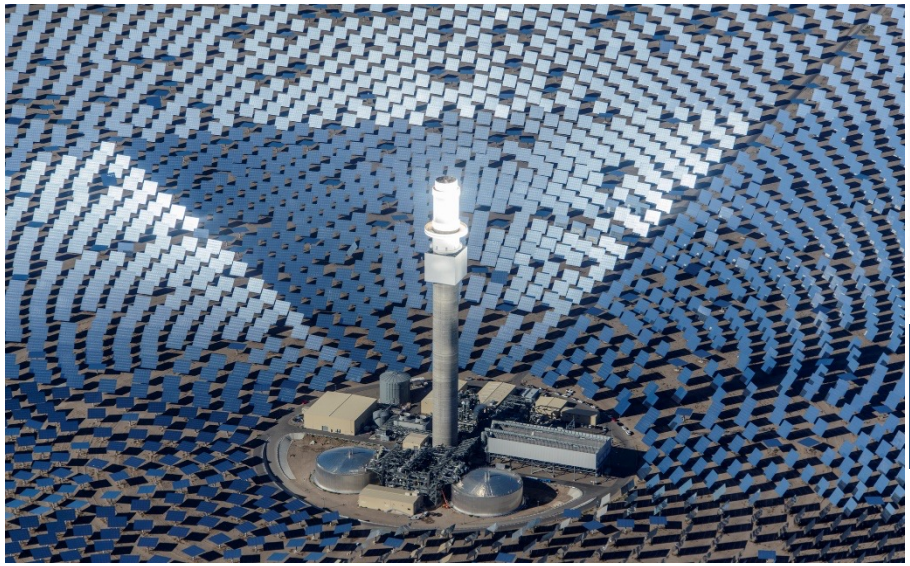
- https://www.forbes.com/sites/kensilverstein/2022/08/22/the-inflation-reduction-act-will-spawn-the-growth-of-nuclear-energy/?sh=2b6f0c5b4158

Potential Technologies to Enable Net-Zero Goal

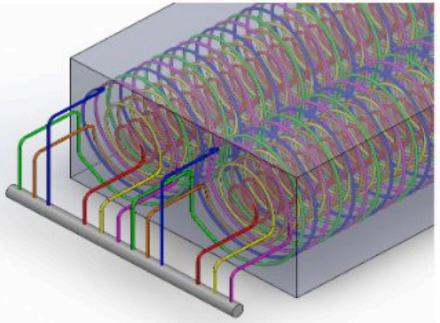


Courtesy of NuScale

Small Modular Reactors (SMRs)

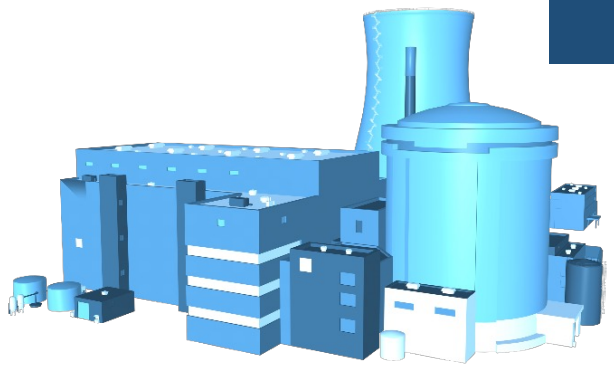


Concentrated Solar Power (CSP) with Thermal Energy Storage

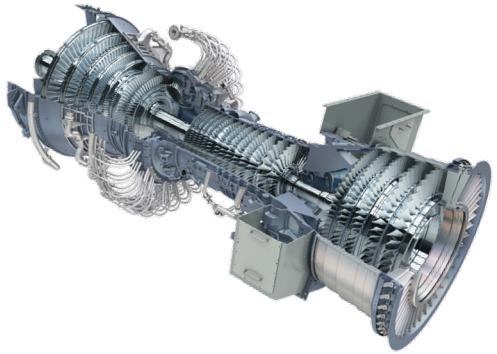


Courtesy of Bright Generation Holdings

Energy Storage (thermal, mechanical, chemical)



Advanced Nuclear (Molten salt, high-temperature gas, …)

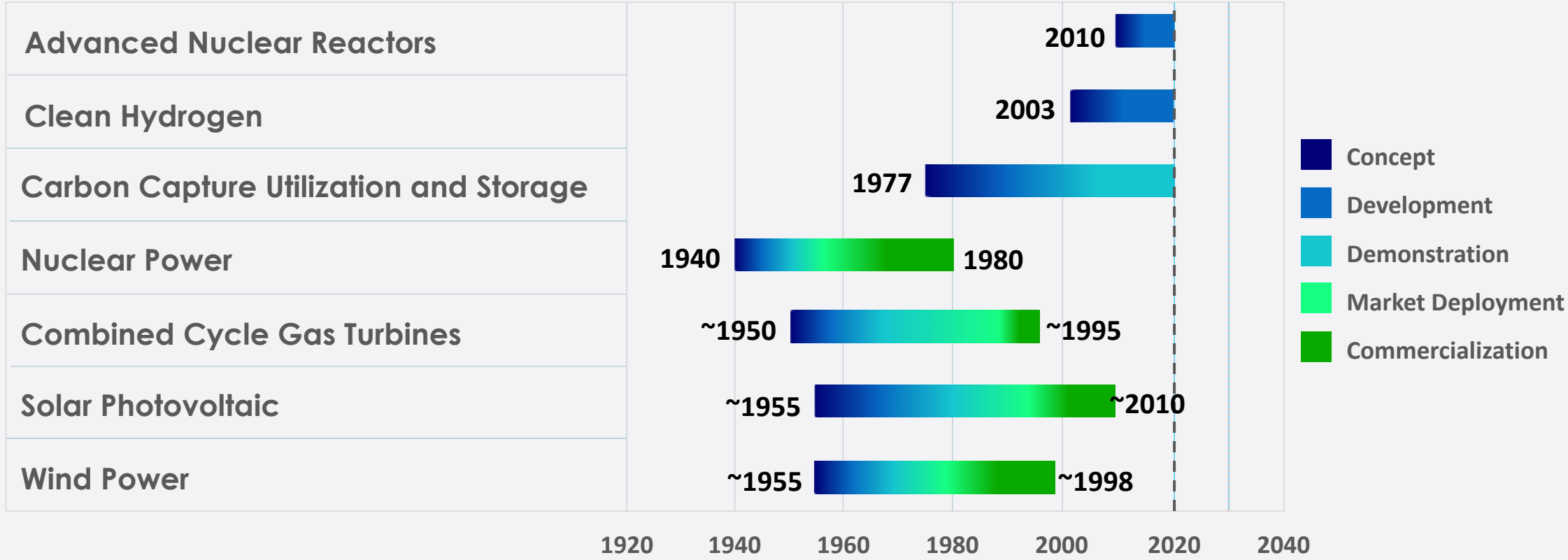


Hydrogen Turbines

Used with permission from 8 Rivers LLC

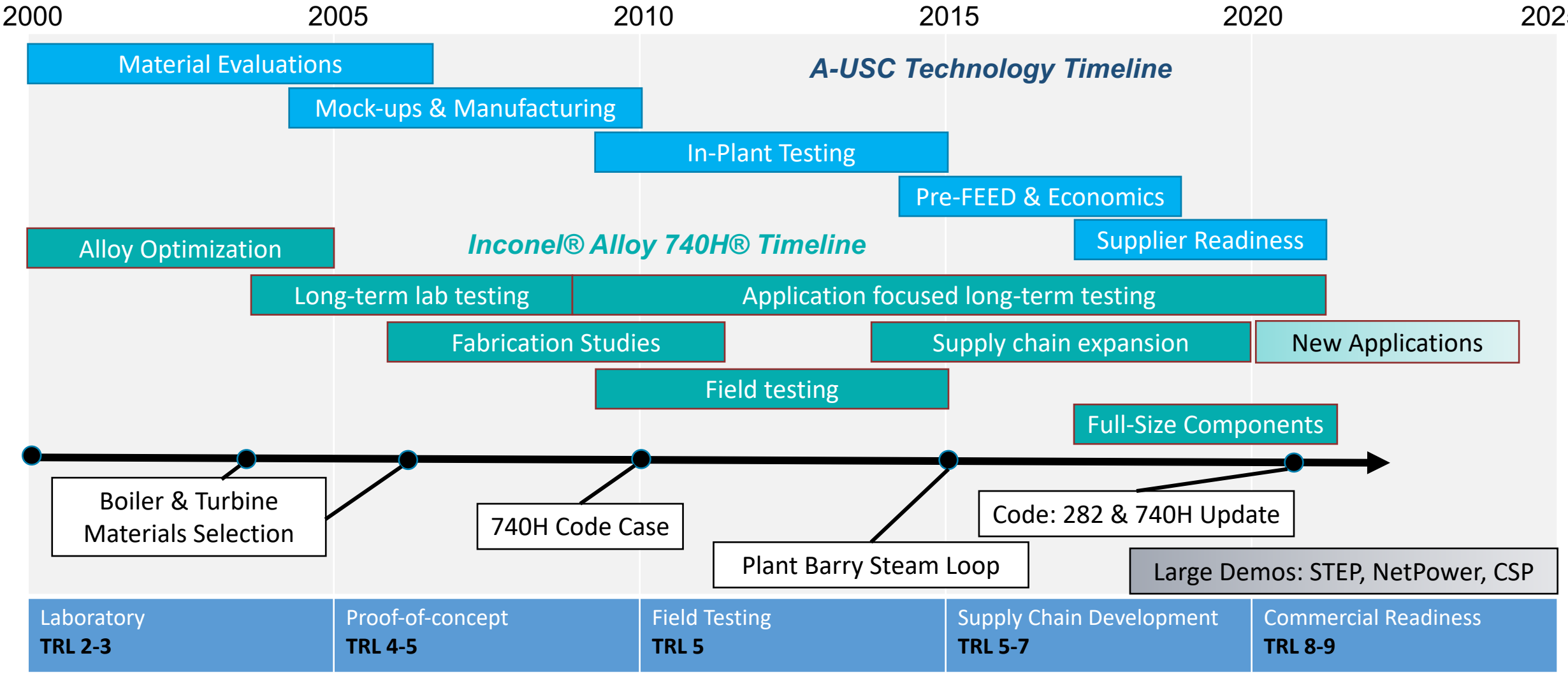
Advanced Power Cycles (e.g. sCO2 w/CCS)

Decades of Effort



Notional timelines

Materials & Manufacturing Deployment Timeline



Advanced Manufacturing

Higher Quality | Reduced Lead Times | Alternative Supply Chains | Cost Competitive

Additive Manufacturing

Powder-Bed Based Methods (New Components, Code Acceptance)

Directed Energy Deposition (DED) for Large Components

Near Net Shape & Surface Modification

Powder Metallurgy Hot Isostatic Pressing (PM-HIP)

Diode Laser Cladding (DLC)

Advanced Welding & Fabrication

Modular In-Chamber Electron Beam Welding (MIC-EB)

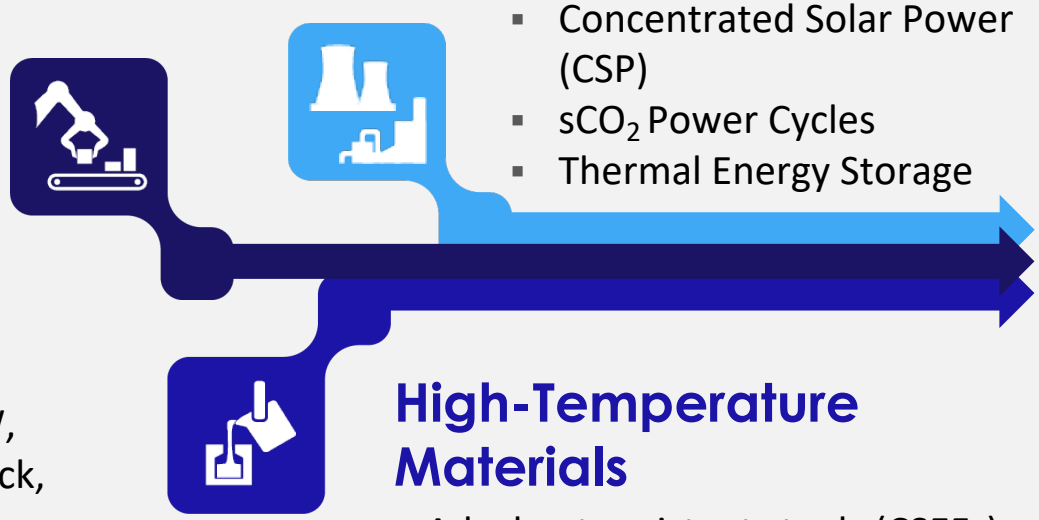
Adaptive Feedback Welding

Advanced manufacturing is more than 3-D printing

Addressing Common Themes for Emerging Advanced Technologies

Advanced Fabrication Processes

- PM-HIP
- Additive Manufacturing (DED, LPFB, …)
- Adv. Welding & Fabrication (EBW, Adaptive Feedback, New Alloys, …)



Energy Supply Applications

- SMRs
- Advanced Reactors (molten salt, Gen IV, …)
- Low/no-carbon (H_2 Turbine)
- Concentrated Solar Power (CSP)
- sCO_2 Power Cycles
- Thermal Energy Storage

High-Temperature Materials

- Adv. heat-resistant steels (CSEFs)
- Stainless steels
- Nickel-based alloys
- Claddings
- Dissimilar metal welds

AM3

Advanced manufacturing methods and materials

Technology Transfer

- Codes & Standards
- Specifications
- Energy Supply Chain Engagement
- Demonstrations

EPRI Supply Chain Workshop For Structural Components In Advanced Energy Systems (AES)

Workshop Goals

- Communication and assembly of manufacturing and materials requirements by AES developers and manufacturers
- Identification of needs/gaps that industry must focus on to achieve large-scale deployment readiness by 2030-35 timeframe
- Identification of specific industry pinch-points that need to be addressed near-term
- Discussion of areas where further manufacturing and development is necessary to enable the energy transformation.

White Paper: 3002025254

Presentations

1. Voice of the Customer
2. AES Technology Overview—Component Needs and Supply Chain Opportunities
3. Material and Heavy Product Form Suppliers
4. Valve and Pump Suppliers
5. Materials Fabricators and Suppliers
6. Advanced Manufacturing Options for Large Components
7. Broader Supply Chain Perspectives

70 attendees from 48 organizations across the entire supply chain giving 35 presentations + panel discussions in 2 days!!!

White Paper: 3002025254

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Infrastructure Needs
--Heavy Forging Capabilities

Need/Gap

- Projections suggest: 1) 800GW replacement nuclear/fossil and 2) up to 4000GW of new production capabilities by 2050.
- In US alone, NEI identified ~40 units slated for production by 2032.
- Clearly **there is not sufficient manufacturing capacity to support** these numbers by 2030 or 2050.

Call To Action

- Multiple forgers called for need to work directly with AES manufacturers now, not to wait to 2030-35 to place orders.
- EPRI sees two key activities to address this gap:
  - Open communication to enable robust supply chain discussions through workshops which foster open dialogue between heavy forging houses and AES developers.
  - Joint qualification of new materials to foster engagement with forging houses in the interim period, before larger-scale deployment

Image supplied by Lehigh Heavy Forge Corp.

4.9 m diam. X 1.2 m thick at ~91,000 kg forging. Image sup by North American Forgemasters/Scot Forge

Infrastructure Needs
-- Directed Energy Deposition-AM

Need/Gap

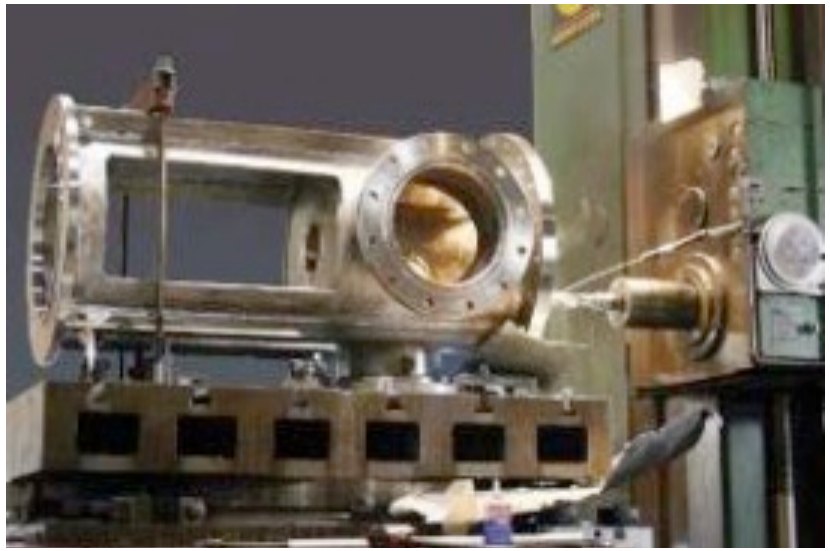
- Near-term potential to supplement availability and quality needs for valve bodies/pump housings. EPRI is working with ASME/Industry to accept both wire-arc and electron beam DED-AM manufacturing.
- Additional work is required to understand acceptance criteria, including how to manufacture for inspectability.
- Also, research is required to address performance in time-independent regime to build industry confidence.

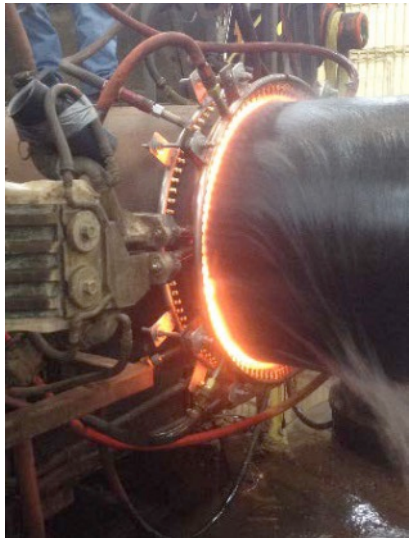
Call to Action

- Once “over the finish line”, DED-AM will provide an alternative/supplement to existing forging/casting capabilities.
- The degree of adoption will dictate the overall need for investment by industry.
- The processes will rely on robotics and welding technologies that can be easily, and cost effectively scaled.

1,600-lb 316-L stainless steel valve body printed using DED-AM (Lincoln Electric)

Infrastructure Needs
--Large Fabricators





Need/Gap

- Only a handful of large fabricators exist in the USA today.
- If AES developers begin to build all at once, there will be insufficient fabricators to meet industry needs.

Call To Action

- Multiple fabricators will be invited to the planned March EPRI Supply Chain Workshop to discuss capabilities and experience.
- Based on these discussions, definitive steps will be identified to move industry forward.

Infrastructure Needs

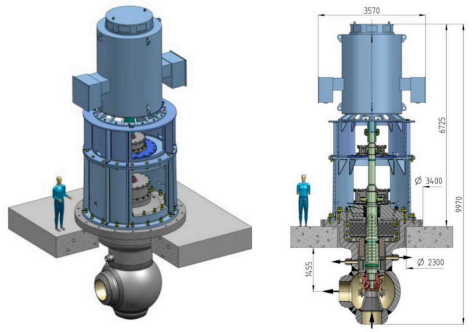
Heavy Machining Capabilities

Need/Gap

- Attendees identified the lack of heavy machining capability as a gap.

Call To Action

- EPRI has many contacts in this area. The plan is to invite several organizations to the March SC Workshop to determine if we can pull from existing infrastructure.



Piping, Pump, and Valve Production

Need/Gap

- Many manufacturers in this space around the world, but few have worked on high temperature (>550C) alloys/components.

Call To Action

- Development of critical test loops are required to evaluate new designs, materials, and manufacturing methods.
- Collaborative Projects are necessary to identify the best potentials for loop testing.

Infrastructure Needs

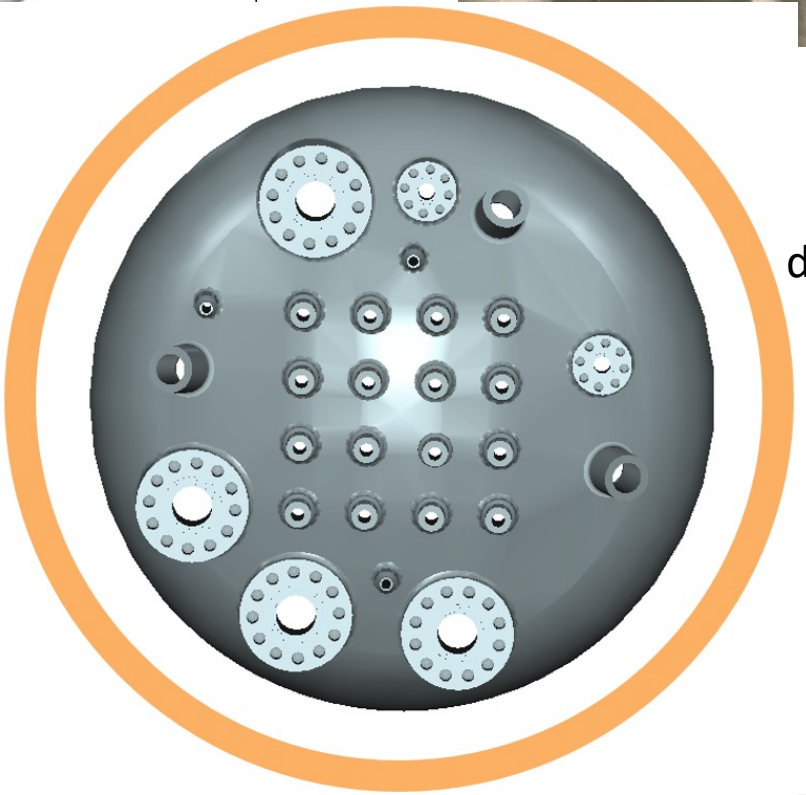
--Large Hot Isostatic Pressing (HIP) Capabilities

Need/Gap

- The largest HIP vessel in the:
  - USA is 1.6m diameter X 2.5m in length.
  - World is in Japan. It is 2.06m diameter.
- To produce larger components for AES applications (reactor heads, nozzles, pump housings, valve bodies, etc.), a much larger HIP is required.
- Could also be used for post-processing of DED-AM components.

Call To Action

- USA group is working to design/secure at 4.05m HIP (called ATLAS)
- UK group is also looking toward a larger HIP, >4.0m (called Titan)
- Both units would enable industry to produce more complex, NNS components



4.05m diameter HIP

Robust Supply Chain

Need/Gap

- Several AES developers expressed a need for more qualified suppliers, particularly as industry begins to ramp up to supply multiple systems annually.
- Many suppliers, though supportive of AES, expressed concern about spending a lot of time to set up a nuclear ASME N-Stamp program within their organizations, however, until they see actual orders being placed (the conventional chicken-and-egg conundrum).
- Many suppliers expressed reluctance simply based on their earlier experience with the “nuclear renaissance” that never happened more than a decade ago in the United States.

Call To Action

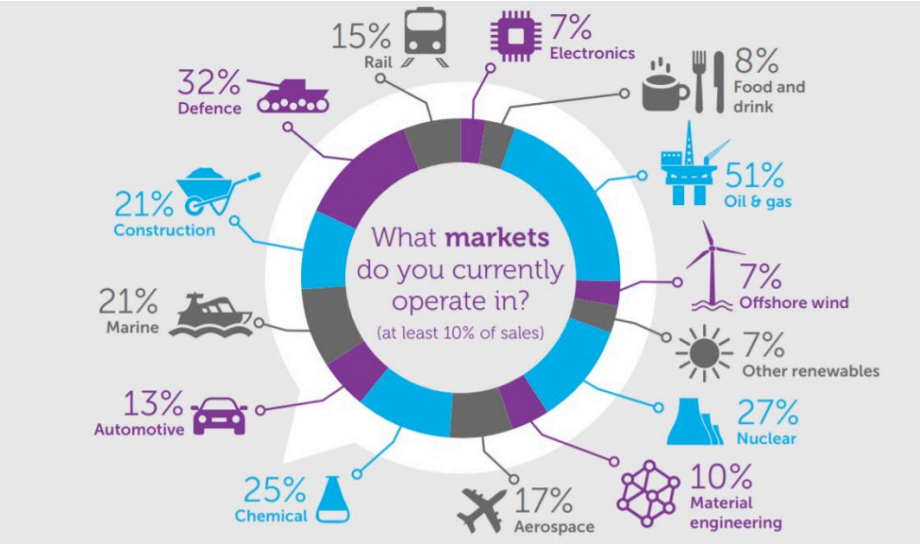
- Work with suppliers from the oil and gas market to integrate them into the AES supply chain
- Implement a program similar to the Fit-For-Nuclear (F4N) program that has been hugely successful in the United Kingdom

ASME

N, NA, NPT, NS

Robust Supply Chain
--Fit-For-Nuclear North America

- F4N was established in the UK to help companies measure their operations against the standards required to supply components to the nuclear industry—in new build, operations, and decommissioning—and to take the necessary steps to close any gaps that may be identified within an organization's supplier program.
- F4N was developed by the Nuclear AMRC (U.K.) with the support of its top tier partners (members), which include both new build developers and the decommissioning authority in the UK.
- Both are now using F4N to identify suppliers that can support their respective organizations.
- More than 950 companies across the United Kingdom have completed the F4N assessment, with many receiving ongoing support/development from the F4N team.



Current industries represented in the F4N database (note that the percentage is greater than 100% since many companies serve multiple industries).

EPRI Pilot Program – Just Initiated

- It is envisioned that a similar "structured program" could be established in North America to support organizations that want to enter the nuclear market but do not know how or are reluctant for some other reason.
- Additionally, for the United States, the program would need to include assessment of readiness for an N-Stamp program to ensure organizations are ready to supply nuclear-quality components.

Supply Chain Opportunities --Based on Key Themes

1. **Joint industry qualification programs** should be pursued to accelerate **new materials** development into the existing supply chain.
2. Strategies to expand and support the future **skilled workforce** in the areas of **machining and welding** are needed.
3. Improved coordination, collaboration, and qualification are needed to maximize the value of the existing supply chain, develop new supply chain partners from other industries, and provide a **robust supply chain**.
4. There is a need for broad engagement and advancement for the approaches to **qualification of advanced manufacturing methods** into ASME codes and other standards.
5. **Test loops, pilot facilities, and demonstration projects** provide a key opportunity to gain practical supply chain experience and accelerate acceptance and industry adoption of new materials and manufacturing methods; more are needed.
6. Despite recent investments in new forging capabilities and advanced manufacturing methods, **additional infrastructure investment** will likely be needed to meet future demands.
7. Improved **collaboration** is needed at an earlier stage in the development process between **AES developers** and prospective **supply chain partners**.

Actions—Next Steps

- Continue to host **AES supply chain workshops** to enable **early and continuous industry collaboration**
  - possible additional topics where more focused discussion is needed include *machining technologies, workforce development, powder and wire supply, and strategies for accelerated codes qualification.*
- Develop **joint industry qualification** programs for new conventionally produced **advanced materials**
  - *candidates already identified include F6NM andXM-19.*
- **Engage other industries**, including oil and gas companies, in future EPRI AES workshops.

- **Pilot an F4N program** in North America.
- Continue, expand, and accelerate **ASME code-qualification activities** for advanced manufacturing methods
  - *including new approaches, database development, and expanded engagement across codes for DED-AM, PM-HIP, and PBF-AM.*
- Explore **test loop opportunities** to accelerate end-user confidence in new technology.
- Engage the larger stakeholder community to understand possible **infrastructure needs** through publicly available white papers, presentations, and so on.

NNS Infrastructure Summary

- Many new AES planned over next 3-1/2 decades worldwide.
  - Will need to **replace 800 GW** by 2050!!!!!!!!!!!!!!!!!!
    - Note – One GW ~750,000 homes (or two coal-fired power plants)
  - Recent congressional legislation "Inflation Reduction Act" made it much more attractive for utilities to source new nuclear units.

- Supply chain needs/gaps/actions identified many **Infrastructure Needs** in June 2022 EPRI Workshop:
  - Heavy Forging
  - DED-AM
  - Large Fabricators
  - Heavy Machining
  - Piping, Pump, & Valve Production
  - Large HIP Capability
  - Fit-4-Nuclear
- Additionally, many Key Themes highlighted in Workshop.