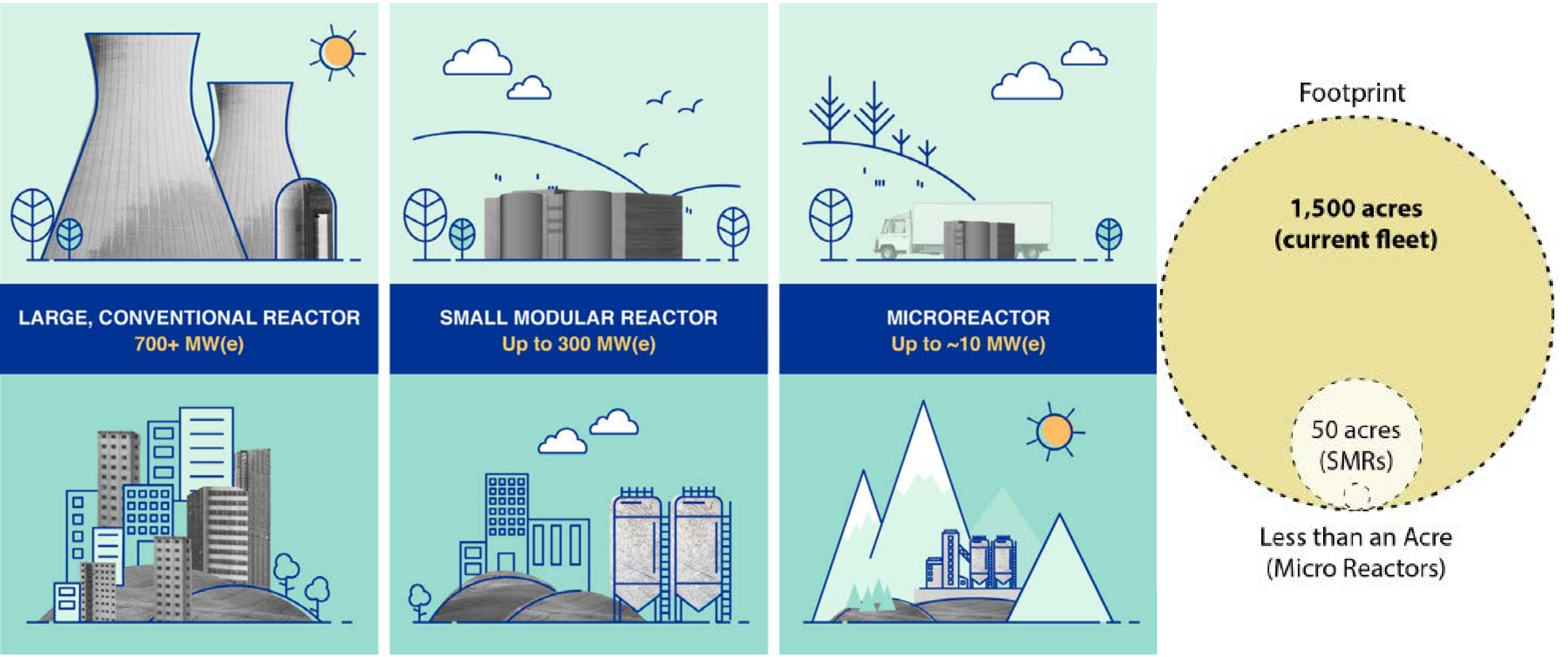

Small Modular Reactors (SMRs), Advanced Reactors, and Other Nuclear Technologies – State Perspectives

Jeff Semancik
Director, Radiation Division

Connecticut
Department of Energy & Environmental Protection
RADIATION DIVISION

Disclosures

- Speaker serves or has served in the roles of:
  - State Liaison Officer for Connecticut
  - Radiation Division Director for Connecticut Department of Energy and Environmental Protection (DEEP)
  - Chair for the Conference of Radiation Control Program Directors (CRCPD) Working Group on Commercial Nuclear Power (E-47)
  - Member, National Academies of Science, Engineering and Medicine (NASEM) committee on Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors
- The views and opinions expressed in this presentation on advanced nuclear reactors are solely those of the speaker. They do not represent or reflect the official stance or views of the State of Connecticut, CRCPD, or the NASEM.
- I have no financial interests, affiliations, or relationships that could be perceived as a conflict of interest regarding the content presented in this session on advanced nuclear reactors. I have no financial disclosures to make.

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Key Takeaways

- Key Questions for States:
  - Will they solve our waste problem?
  - What do they cost?
  - How soon can they be deployed?
- First of a Kind (FOAK) Deployment
  - Few new reactor designs have progressed enough to support reliable cost estimates
  - SMRs based on technology similar to existing light water reactor (LWR) fleet are closest to near term deployment with less uncertainty
  - First deployments (NuScale, Terrapower, X Energy) involve substantial (50%) and unique federal subsidy to be cost competitive
- Nth of a Kind (NOAK) Deployment
  - DOE advocating consortium approach to scale deployment, supply chain
  - DOE estimates $ 95/MWh target price; highly uncertain
  - DOE hoping for 5-year deployment schedules as scale; highly uncertain

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Not all new reactors are SMRs

SMRs - Light Water Reactors (LWRs)

- Mature Technology, supply chain, labor pool
- Planned deployment by 2030
- Standard, proven fuel
- Regulatory & operating experience

Advanced Rx's (Non-LWRs)

- Newer innovative technologies
  - Non water coolants – Sodium, Helium, Salt, Liquid lead
- Unproven technology, fuels, supply chains, labor force
- Likely 10-20 year deployment horizon
- Higher regulatory (NRC) uncertainty

	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)

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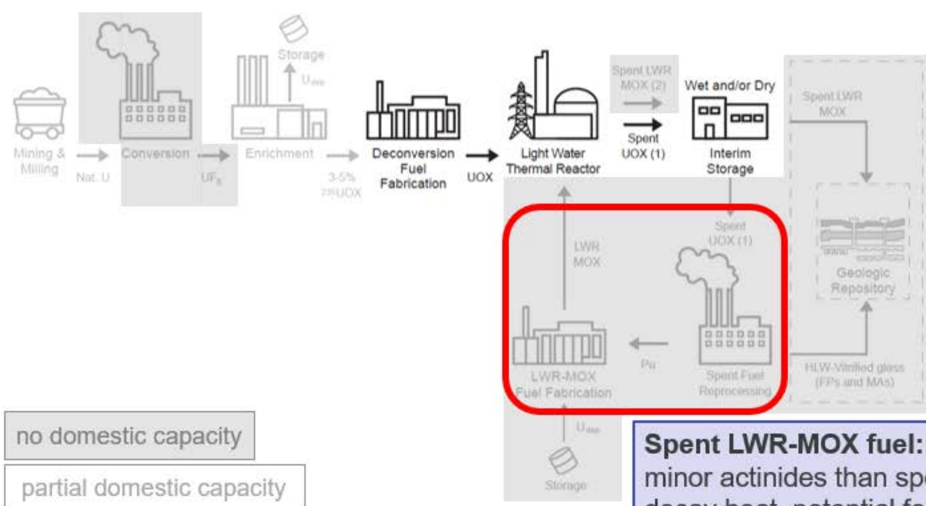
Can advanced reactors “solve the waste problem”?

- ***Not anytime soon***
- Findings of the NASEM:
  - The advanced reactor developers focus on the reactors themselves, with little or no attention to nuclear waste management or disposal because there is no incentive for them to do so.
  - Reducing the ~86,000 tonnes of legacy SNF using advanced reactors is not practicable to achieve in the near future.
  - The immediate-future focus of the U.S. nuclear waste management and disposal program should be to plan for geologic disposal of existing spent nuclear fuel

Mono-Recycle Pu Fuel Cycle for LWRs



Mono-recycling fuel cycle with existing LWRs as LWR-MOX (mixed oxide) fuel would add cost to power generation with no significant benefits, given the projected abundant supply of natural U and relatively low cost of U enrichment for the foreseeable future.

Spent LWR-MOX fuel: higher fissile inventory and minor actinides than spent UOX, giving rise to higher decay heat, potential for criticality, and radiation source term

NATIONAL ACADEMIES Sciences Engineering Medicine

Source: Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors, https://nap.nationalacademies.org/catalog/26500/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors

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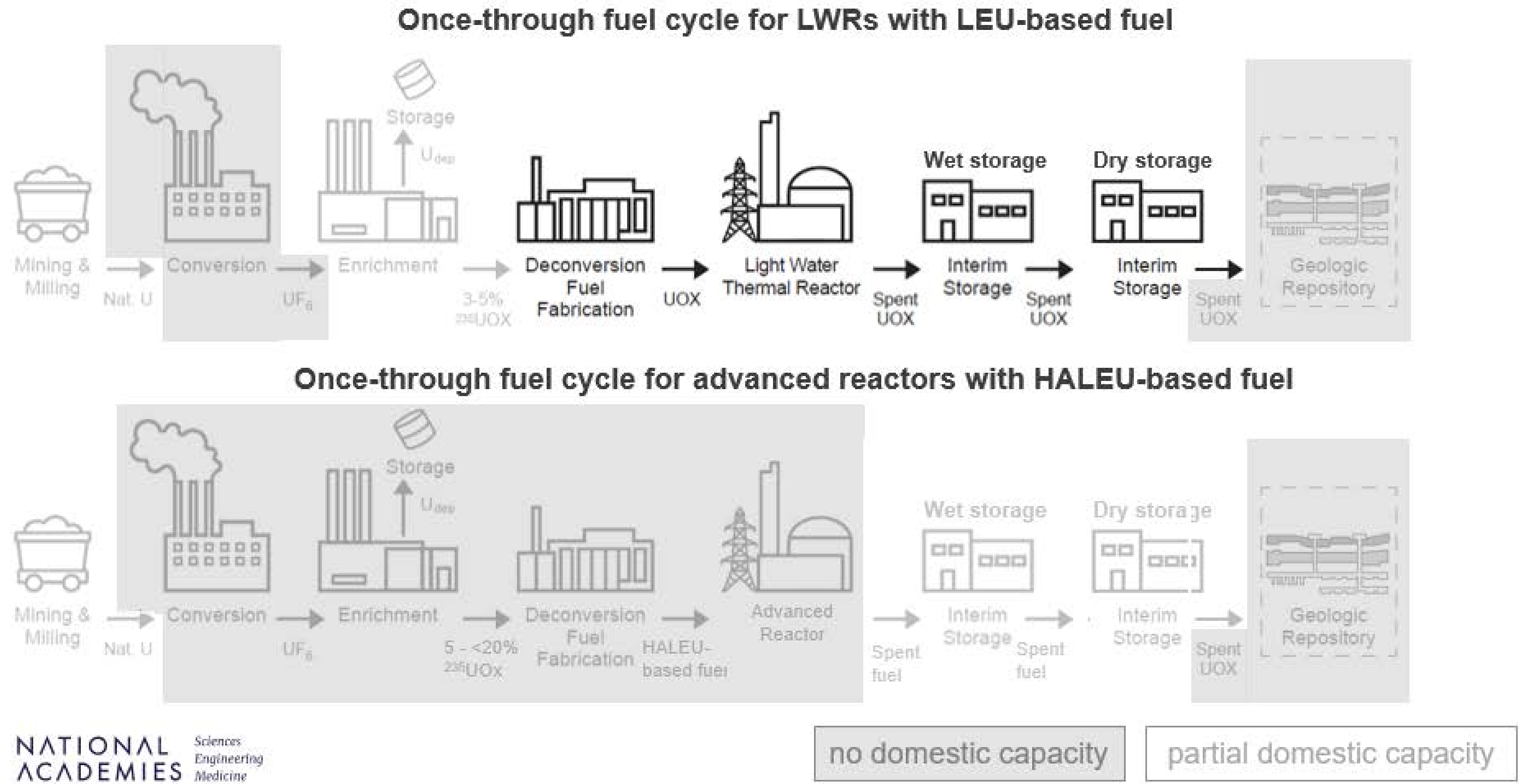
Fuel Cycle Options for Advanced Reactors – Once-through with HALEU



HALEU = High Assay Low Enriched Uranium (enriched to 10% – 20% U^{235})

Source: Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors, https://nap.nationalacademies.org/catalog/26500/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors

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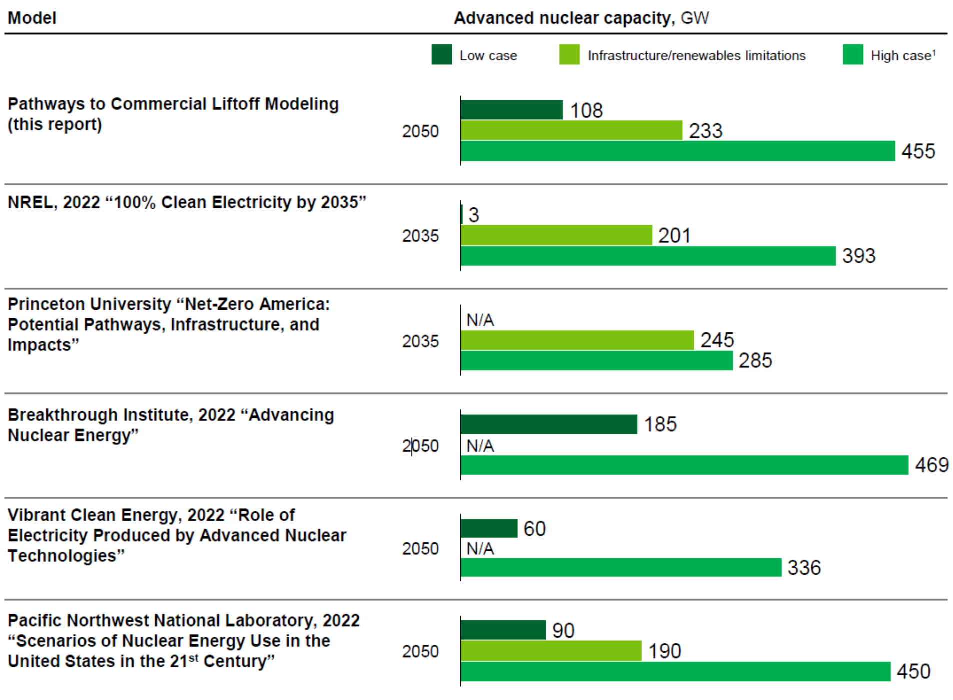
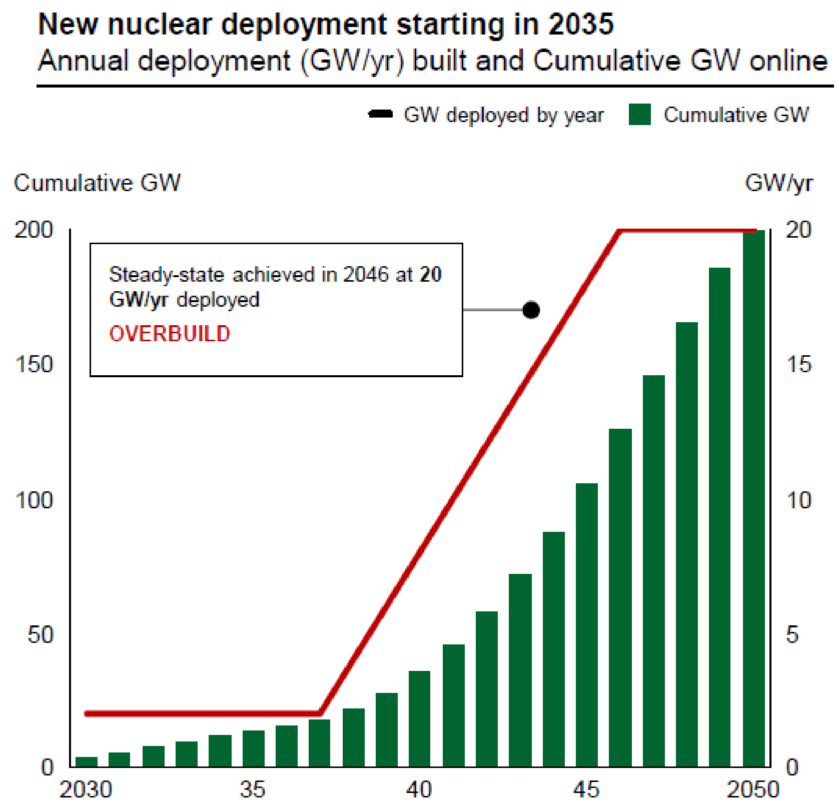
Clean, Firm, Dispatchable Power is Part of the Solution

New nuclear capacity in a net-zero grid, based on various modeling efforts.



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



Source: "Pathways to Commercial Liftoff: Advanced Nuclear," US DOE (March 2023) available at https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf

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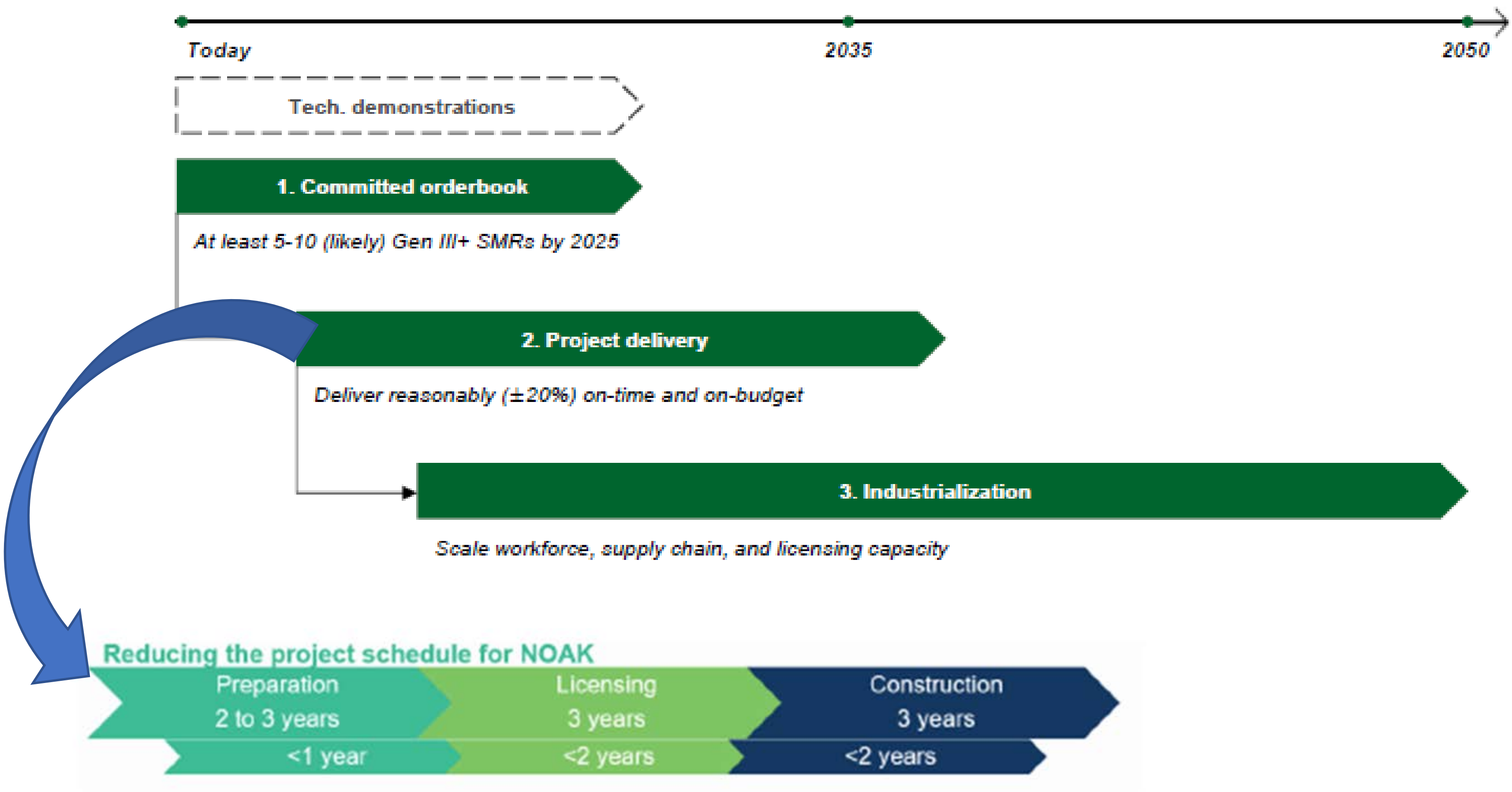
Building Nuclear Capacity



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US DOE Advanced Reactor Demonstration Support

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%

Source: "Pathways to Commercial Liftoff: Advanced Nuclear," US DOE (March 2023) available at https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf

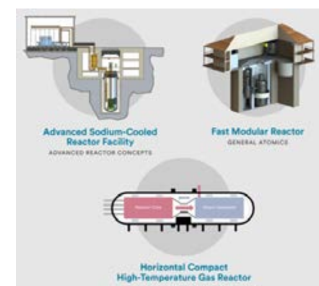
Advanced Reactor Demonstration Program
$160M Cost Share

Concept Awards
$20M awarded

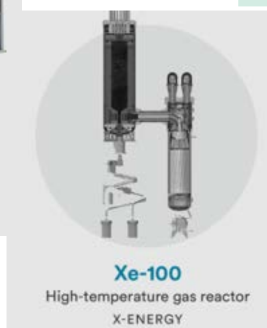
2040

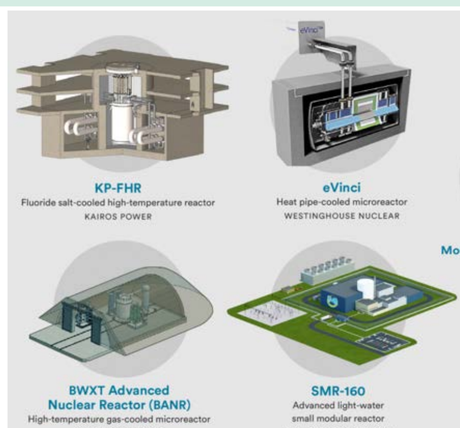
2030

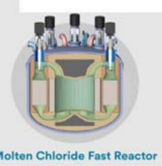
2050



Risk Reduction Projects
$30M awards







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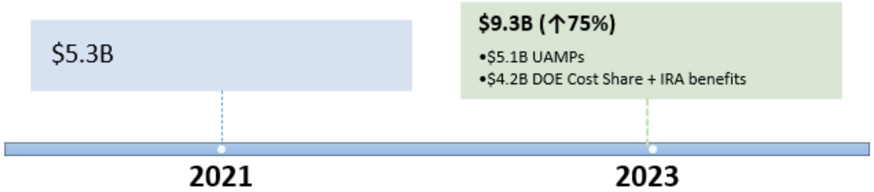
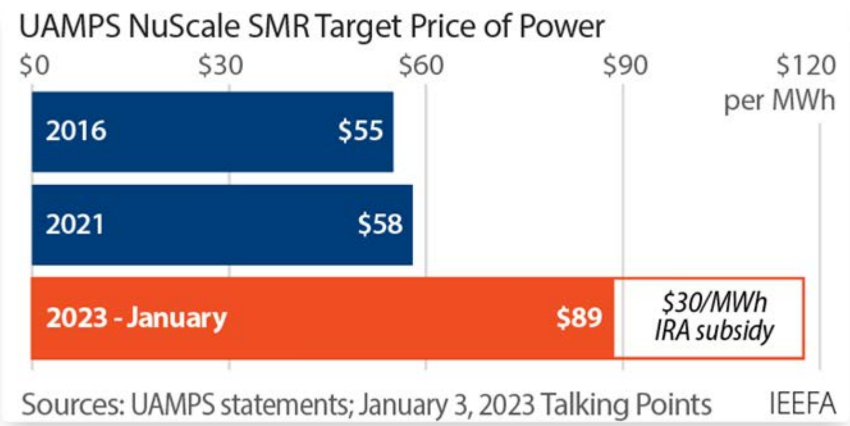
NuScale Carbon Free Power Project (CFPP)

- Likely first SMR deployment - power generation by 2029
- Small Modular Reactor
  - LWR – similar to large reactors
  - 462 MWe total from Six 77 MWe reactors
  - Air cooled
- Public power consortium Utah Associated Municipal Power Systems (UAMPS)
  - Construction at Idaho National Labs (INL)
  - US DOE Cost Sharing + IRA benefits



- *Drivers*
  - *Inflationary pressure on construction costs*
    - *fabricated steel ↑ 54%*
    - *carbon steel ↑ 106%*
  - *Interest rates ↑200 basis points*
  - *Common to most generation projects*
- *Public-private partnership says the project remains on schedule*
  - ***BUT** the new cost estimates opens the first window for the 27 participating consortium members to back out of the project and be reimbursed by DOE*



Source: https://www.nuscalepower.com/en/news/press-releases/2023/nuscale-reaches-key-milestone-in-the-development-of-the-carbon-free-power-project talking points available at https://ieefa.org/sites/default/files/2023-01/UAMPS%20Talking%20Points%20_%20Class%203%20_%2020230102%20_%20Final.pdf

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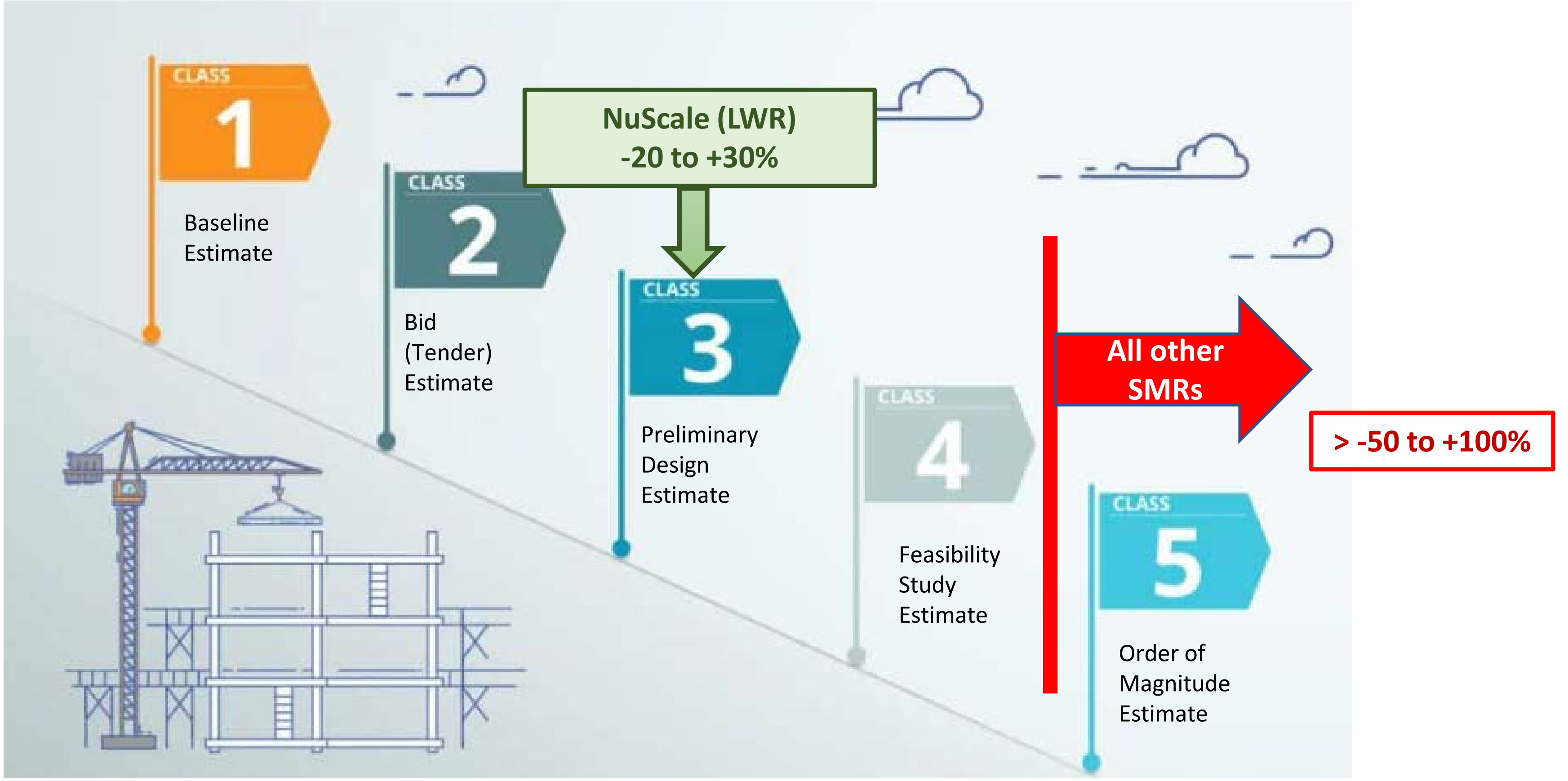
SMR Cost Estimates have Large Uncertainties



AACE (Association for the Advancement of Cost Engineering) International construction cost estimate classifications

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Inherent and significant uncertainty in projecting costs

- Conceptual designs
- Uncertainty with Regulatory Process
- Lack of nuclear construction experience
- Dependence on large construction companies
- New fuels - not qualified and lack domestic supply
- Tightening of capital markets
- Immature supply chains and labor pools
- Poor track record in completing nuclear projects on time or budget
  - Mega-Project Challenges
  - Vogtle cost escalation $12B to $35B

- Potential Interventions to Catalyze the Orderbook
  - Cost overrun insurance
  - Tiered grants
  - Government as owner
  - Government as off-taker


NRC NEWS
Office of Public Affairs, Headquarters
Washington, DC 20555-0001
www.nrc.gov ■ opa.resource@nrc.gov

No: 22-002
CONTACT: Scott Burnell, 301-415-8200

January 6, 2022

NRC Denies Oklo Combined License Application for Lack of Information; Company May Reapply in the Future

The Nuclear Regulatory Commission has denied, without prejudice, Oklo Power, LLC.'s

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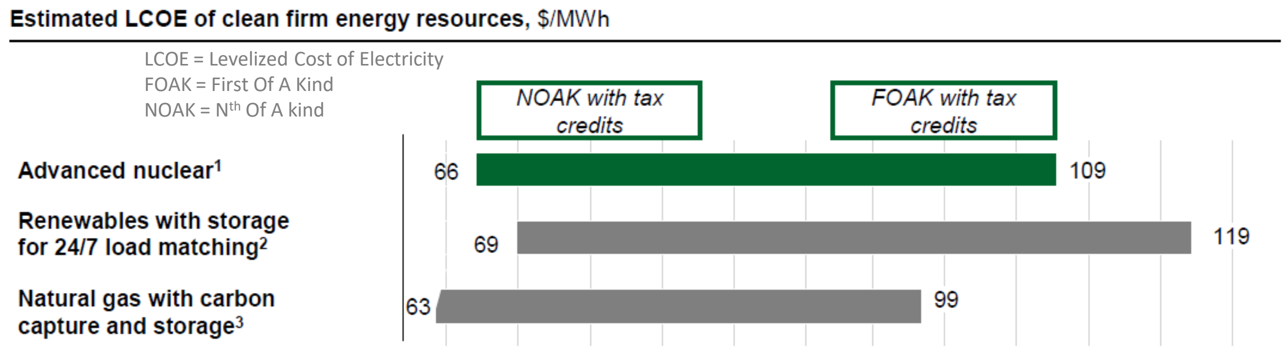
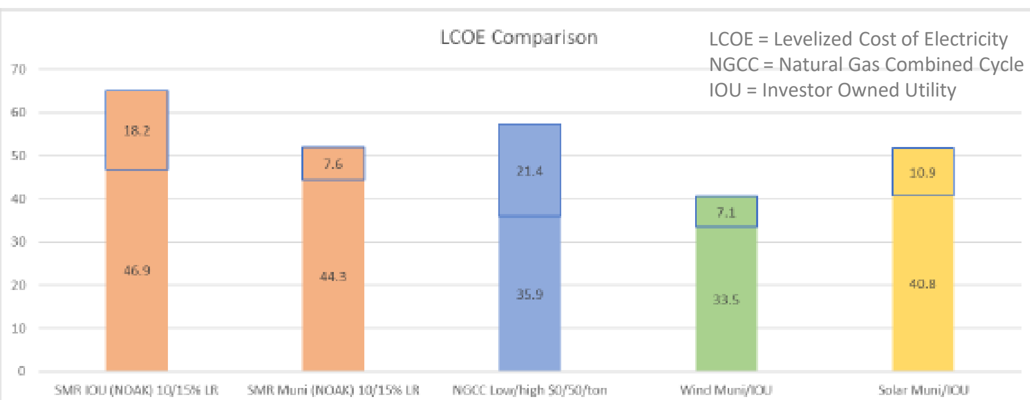
SMRs and Adv Nuclear Can Be Cost Competitive



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

Source: "Pathways to Commercial Liftoff: Advanced Nuclear," US DOE (March 2023) available at https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf



	Nuclear SMR	NGCC	Wind	Solar
Max. Capacity factor (%)[11]	>95	90	35	25
Land requirements (acres)[12, 13, 14]	50[15] see below	343	85,240	7,900
Jobs during operation	500	50	50	-
Plant lifetime (years)	60 to 80	40 to 50	20 to 25	20 to 25

Source: "The Economics of Small Modular Reactors," SMR Start (March 2021) available at https://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf

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Competitive Pricing Requires Public-Private Partnership

<u>Note</u>: US DOE Loan Program Office has $300B in loan authority

Source: "The Economics of Small Modular Reactors," SMR Start (March 2021) available at https://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf

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State Legislative Activity to Incent Advanced Nuclear

- Most moratoriums on construction of nuclear power facilities, prohibit construction until "*…the United States Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste.*"
  - ***Any*** new reactor will still generate Spent Nuclear Fuel (SNF) and/or High Level Radioactive Waste (HLRW)
  - US Government is ***not*** close to final disposal solution
    - Yucca Mountain will not be completed
    - Nuclear Waste Policy Act (NWPA) only allows Yucca Mnt for disposal of SNF and HLRW
    - NRC Continued Storage Rule
  - Legislative changes used:
    - Redefining to provide specific exemptions for existing plants
    - Redefine to say "unless NRC determines that SNF can be safely stored or disposed"
- Other statutory proposals
  - Expedited siting process (automatic certificates of need)
  - Recycling
  - Fiscal – carbon free power, tax incentives for domestic Uranium use, incentives for C2N
  - Agreement to regulate (despite current AEA)
  - Studies

POLICY

West Virginia lifts ban on nuclear power plants

Thu, Feb 10, 2022, 7:58AM | Nuclear News

West Virginia Gov. Jim Justice signed a bill yesterday that repeals the state's quarter-century-old ban on nuclear power plant construction. The legislation, S.B. 4, passed the West Virginia Senate and House of Delegates last month with no substantial opposition and will go into effect in May.

S.B. 4 rescinds article 27A of the West Virginia Code, which prohibited "the construction of any nuclear power plant, nuclear factory, or nuclear electric power generating plant until such time as the proponents of any such facility can adequately demonstrate that a functional and effective national facility, which safely, successfully, and permanently disposes of radioactive wastes,

Justice

CLIMATE & ENERGY

Bill Allowing Construction of Nuclear Reactors in Indiana Clears First Hurdle

Senate Bill 271 would pave the way for the first small modular nuclear reactor in the state.

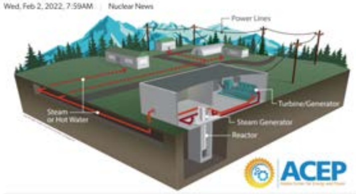
Arkansas Democrat Gazette

Senate approves measure laying groundwork for recycling facility for spent nuclear fuel

POWER & OPERATIONS

Alaska bill would simplify microreactor siting: Here's what you need to know

Wed, Feb 2, 2022, 7:59AM | Nuclear News



ENERGY

Governor signs new Wyoming nuclear regulations into law; tax exemptions for using domestic uranium start in 2035

By BRENDAN LACHANCE | March 21, 2022

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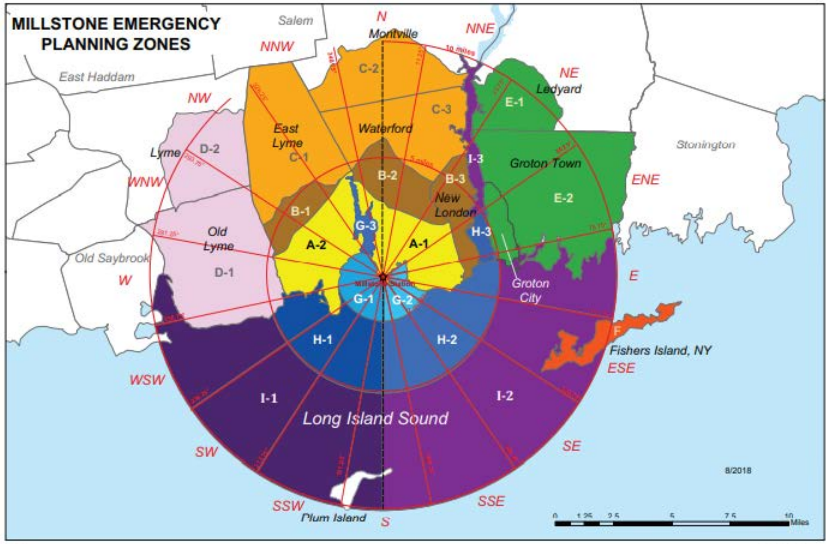
Potential State Concerns

- Offsite emergency response capabilities
  - SMRs rely on all hazards planning
  - Do NOT require ***any*** offsite emergency planning zone
- Non-nuclear impacts of advanced nuclear
  - For example – Sodium is pyrophoric in air and water
  - May have state regulatory impact (RCRA)
- Waste and Spent Nuclear Fuel (SNF)
  - Will still generate SNF that must be stored on site
  - Claims to re-use SNF are decades away at minimum
- Local Stakeholder engagement
  - Intervenors impact licensing and schedule
  - Community Engagement will be critical



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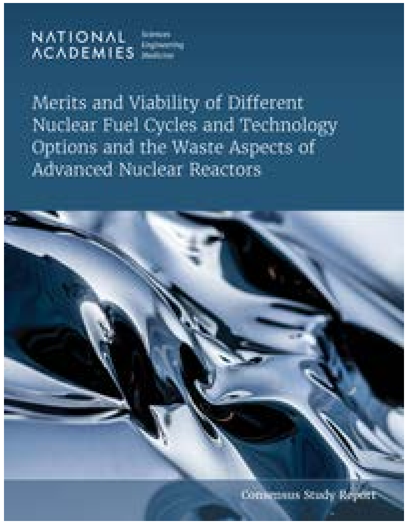
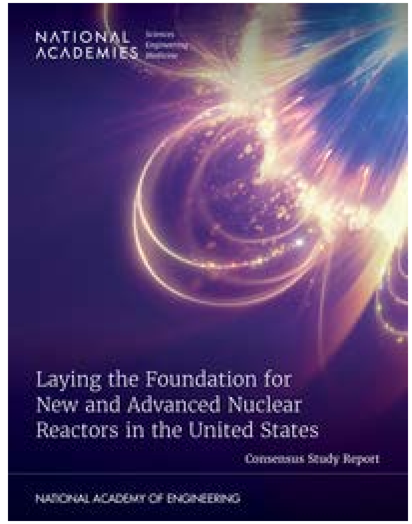
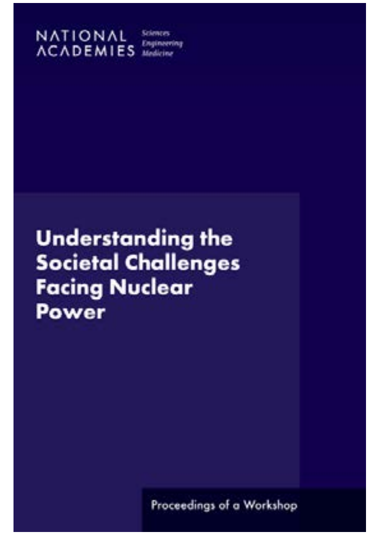
Good References from National Academies



https://www.nationalacademies.org/our-work/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors



https://www.nationalacademies.org/our-work/laying-the-foundation-for-new-and-advanced-nuclear-reactors-in-the-united-states



https://nap.nationalacademies.org/catalog/26606/understanding-the-societal-challenges-facing-nuclear-power-proceedings-of-a

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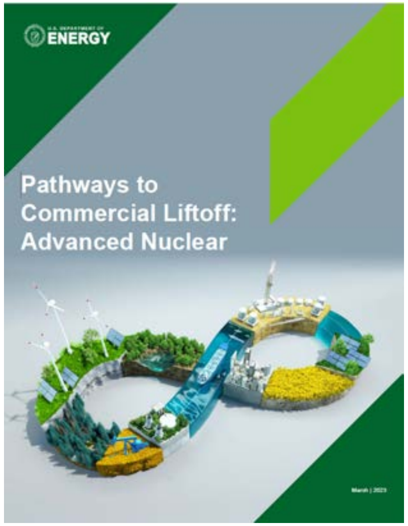
Other Good References for SLOs



https://liftoff.energy.gov/wp-content/uploads/2023/05/20230320-Liftoff-Advanced-Nuclear-vPUB-0329-Update.pdf

https://nuclearinnovationalliance.org/advanced-nuclear-reactor-technology-primer

From NEI
- Policy options for states to incentivize new nuclear
- Federal policy Tools for New Nuclear
- Advanced Nuclear Community FAQs

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Key Takeaways

- Nuclear likely to play a key role in decarbonizing
- Achieving 2050 Decarbonization goals will require aggressive action
- There is a lot of work ahead for the industry

Questions?

Jeff Semancik

Director, Radiation Division

jeffrey.semancik@ct.gov

860-424-4190

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