The State of Play for Nuclear Energy in the United States

Wednesday, April 19, 2023

Materials will be available at: www.eesi.org/041923nuclear
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Non-partisan Educational Resources for Policymakers
A bipartisan Congressional caucus founded EESI in 1984 to provide non-partisan information on environmental, energy, and climate policies

Direct Assistance for Equitable and Inclusive Financing Program
In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop “on-bill financing” programs

Commitment to Diversity, Equity, Inclusion, and Justice
We recognize that systemic barriers impede fair environmental, energy, and climate policies and limit the full participation of Black, Indigenous, people of color, and legacy and frontline communities in decision-making

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Our mission is to advance science-based solutions for climate change, energy, and environmental challenges in order to achieve our vision of a sustainable, resilient, and equitable world.
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**Briefings and Webcasts**
Live, in-person and online public briefings, archived webcasts, and written summaries

**Climate Change Solutions**
Bi-weekly newsletter with everything policymakers and concerned citizens need to know, including a legislation and hearings tracker

**Fact Sheets and Issue Briefs**
Timely, objective coverage of environmental, clean energy, and climate change topics

**Social Media (@EESIOnline)**
Active engagement on Twitter, Facebook, LinkedIn, and YouTube
DOE Office of Nuclear Energy 2023 Outlook

Dr. Kathryn (Katy) Huff
Assistant Secretary for Nuclear Energy, Department of Energy
April 19, 2023
Mission
To advance nuclear energy science and technology to meet U.S. energy, environmental, and economic needs

Priorities
• Keep existing U.S. nuclear reactors operating.
• Deploy new nuclear reactors.
• Secure and sustain our nuclear fuel cycle.
• Expand international nuclear energy cooperation.
Enable continued operation of existing U.S. nuclear reactors

R&D programs enhance performance, extend lifetime, reduce operating costs, and develop advanced fuels.

Integrated energy systems research and hydrogen production demonstrations expand applications and markets for nuclear energy.

Nuclear power is carbon-free energy. It's the largest source of carbon-free electricity in the United States!

18% of all electricity generated in the U.S.
47% of all emissions-free electricity in the U.S.
Enable deployment of advanced nuclear reactors

- Essential to tackling climate crisis, supplying clean energy, and decarbonizing the economy
- Demonstrating reactors with advances in sustainability, safety and reliability, resource utilization, and economics
- Developing small modular reactors to offer siting flexibility, scalability, and energy uses beyond electricity
- Developing microreactors for off-grid communities, remote industrial locations, and disaster relief missions
Coal to Nuclear Transition

• Nuclear reactors are especially suited to leverage grid, workforce, and other assets at retiring or retired coal plant sites.
• Repurposing unabated fossil plants could deliver place-based solutions and ensure equitable energy transition.
• DOE analysis finds hundreds of coal power plant sites across the country could be converted to nuclear power plant sites.
• Study shows energy communities could benefit from adding 650 permanent jobs, additional economic activity of $275 million, and 86% reduction in greenhouse gas emissions.
• Leveraging existing infrastructure and highly skilled workforce can reduce system costs.

A recent @ENERGY report finds 80% of coal power plant sites could be converted to nuclear power plants—more than doubling U.S. nuclear capacity to more than 250 gigawatts.
Pathways to Commercial Liftoff

Figure: Select elements of nuclear energy's value proposition as compared to other power sources.

Figure: New nuclear build-out scenarios and implications for industrial base capacity requirements.
Secure and sustain the global nuclear fuel cycle

- Addressing gaps in the domestic nuclear fuel supply chain for existing and advanced nuclear reactors
- Encouraging expansion of domestic commercial capacity in conversion and enrichment services to assure the supply of low enriched uranium (LEU) and high-assay low-enriched uranium (HALEU)
- Developing strategy for the integrated waste management of spent nuclear fuel
- Developing a consent-based approach to siting interim storage facilities
Consent-Based Siting

While spent nuclear fuel is stored safely at over 70 U.S. sites, those communities never agreed to host that material in the long term.

DOE is committed to a consent-based process for siting one or more consolidated interim spent nuclear fuel storage facilities.

- Prioritizes people and communities
- Seeks willing and informed consent
- Flexible, adaptive, and collaborative process
- Responsive to community concerns
- Centers equity and environmental justice
- Informed by public feedback

[energy.gov/consentbasedsiting](energy.gov/consentbasedsiting)
Expand International Nuclear Energy Cooperation

- Support Front-End Engineering Design studies for U.S. nuclear builds in foreign markets.
- Support nuclear safety in Armenia and Ukraine, including emergency support.
- Deploy Clean Energy Training Centers to inform small and emerging nuclear states of U.S. nuclear technology within clean energy systems.
- Increase U.S. technical presence through bilateral nuclear energy cooperation particularly in Central and Eastern Europe, the Baltic States, Southeast Asia, and the Americas including workforce capacity building, academic and professional training, joint studies, and regional technical events.
- Leverage U.S. sponsorship of subject matter experts in international organizations to advance U.S. nuclear equities.
Thank You!
Idaho National Laboratory:
The Role of Nuclear in Reaching Net-Zero Emissions
DOE labs support the entire technology lifecycle
Unique INL site, infrastructure, and facilities enable energy and security RD&D at scale

$1,630 M  FY22 Total Operating Cost
5,700+  Employees
569,178  Acres
890  Square Miles
INL's Roadmap to Net-Zero through Nuclear

Time to Market and Operability Case Study for On-Site Microreactor Deployment

Infrastructure & Siting
Developing infrastructure and siting resources necessary for onsite deployment

Licensing & Regulation
Determine efficient, timely and economical process

Fuel Cycle
Entire cycle from fuel identification to waste management

Financial & Contracting
Identify financial structure and funding methodology

Public Engagement: Communication, Outreach, and Education
NRIC/NRC Collaboration

• Congress recognized the importance of agency coordination in the Nuclear Energy Innovation Capabilities Act

• DOE/NRC MOU to “coordinate DOE and NRC technical readiness and sharing of technical expertise and knowledge on advanced nuclear reactor technologies and nuclear energy innovation, including reactor concepts demonstrations, through the [NRIC].”
  • NRIC Rotations

  Fred Sock
  Office of Nuclear Regulatory Research

  Allen Fetter
  Office of Nuclear Reactor Regulation

• Monthly Coordination Calls – DOE/NRC/NRIC
Accelerating advanced reactor demonstration & deployment
Collaborations

• National Labs
  – Partnering on key Net-Zero initiatives with all 17 national labs

• State of Idaho
  – EV infrastructure & workforce development

• Universities
  – Innovations, research, and workforce development

• Tribal Nations

• Net-Zero World
  – Ukraine
  – Indonesia
  – ASEAN
Transforming the world to a net-zero future

https://www.youtube.com/watch?v=DYD-Cz_T8cc
Contact Information

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Visit our website at inl.gov/net-zero/
Backup slides
Research, Development, & Demonstration at Idaho National Laboratory

• INL’s site characteristics and operations make it a highly relevant demonstration site
• Representative of a city or county.
• INL will lead by example; lessons learned can inform best-practices

<table>
<thead>
<tr>
<th>Total vehicles</th>
<th>600+</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE-owned buildings &amp; trailers</td>
<td>300+</td>
</tr>
<tr>
<td>MW purchased in FY20</td>
<td>~50</td>
</tr>
</tbody>
</table>

INL will lead by example; lessons learned can inform best-practices.
U.S. nuclear industry recognizes the demand for new nuclear power projects

Utilities recently identify the need to add 100 gigawatts of nuclear power by 2050, more than doubling current capacity.

- Utilities are prepared to invest in nuclear energy because it is a proven non-carbon-emitting solution
- New reactor designs are simpler, more versatile, and more economical at scale
- Utilities are evaluating reusing retired coal plant sites to leverage existing infrastructure and workforce
- Emissions avoided by adding 100 gigawatts of nuclear power is equivalent to taking more than 100 million cars off the road.

Today, 92 reactors provide nearly 20% of the electricity produced for our power grid and more than half of our carbon-free electricity – more than solar, wind, hydro, and geothermal combined.
U.S. domestic nuclear capacity has the potential to scale from ~100 GW in 2023 to ~300 GW by 2050.

“Power system decarbonization modeling, regardless of level of renewables deployment, suggests that the U.S. will need ~550–770 GW of additional clean, firm capacity to reach net-zero.”
Next level integrated energy systems –
*Demonstrating the pathway to commercial use*

Scaling up high temp electrolysis for hydrogen production

- 25 kW
- 250 kW
- 10+ MW
Nuclear Waste: Leading Environmental and Waste Technologies

Haruko Wainwright, MIT
Nuclear Waste: Key Facts

- Small/well accounted waste footprint across the life cycle
- Best managed/isolated waste
- Environmental monitoring for providing assurance
- Advancing interdisciplinary research and education
Lessons Learned from DOE’s Legacy Sites

Soil/groundwater Contamination
Radionuclides, Metal, Organic contaminants
→ 30+ years of remediation
Lessons Learned from DOE’s Legacy Sites

Tc-99, I-129, Sr-90, H-3, U, Cr, TCE, DCE

Mercury, nitrate

Large/problematic contamination
- Mobile elements
- Low-level radioactive and mining waste
- Non-rad elements (metal, organic)
**Nuclear Energy**

- **Mining and Milling:**
  - Natural U: ~250 t
  - Land excavated (or in situ mining): 1000-200,000 t

- **Conversion and Enrichment**:
  - Depleted U: ~220 t
  - Enriched U: ~30 t

- **Fuel Fabrication**

- **Generation**
  - 1GWy Generation

- **Re-use**
  - ~1/3

- **Storage**

- **Geological Disposal**

- **Construction**
  - ~9,000 t of concrete/metal

- **Coal Energy**

- **Mining**

- **1GWy Generation**

- **Coal ash**
  - ~500,000 t

- **Surface Disposal**

- **CO₂**
  - ~6,000,000 t

- **Re-use**
  - ~2/3

- **Surface Disposal**

- **Construction**
  - ~11,700 t of concrete

- **Coal ash** contains Hg, Cd, As, U etc
Waste Across Energy Life Cycle: Renewable?

Mining → Manufacturing → Generation → Waste

~3,000 t/year

- Cap. factor = 0.3
- 30 year life

(IEA-PVPS 2016)

Metal leaching from Lithium-ion and Nickel-metal hydride batteries and photovoltaic modules in simulated landfill leachates and municipal solid waste materials

M. Kayla Kilgo a, Annick Anctil b, Marian S. Kennedy c, Brian A. Powell a, c

a Department of Environmental Engineering and Earth Sciences, Clemson University, Clemson, SC 29634, United States
b Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824, United States
c Department of Materials Science and Engineering, Clemson University, Clemson, SC 29634, United States
Disposal: Waste Isolation Systems

High-level rad. waste
- Waste form/canister/clay
- Deep geology
- 10,000 - 1,000,000 years
- Probabilistic risk assessment

Low-level (U mining) waste
- High-level rad. waste
- Low-level (U mining) waste
- Hazardous waste
- Clay cover/geomembrane
- 30 years
- No risk assessment

Radioactive toxicity
- Decays over time
- Long-lived nuclides are internal exposure

Barrier systems
- Clay cover/geomembrane

Compliance
- 500 - 100,000 years
- Probabilistic risk assessment

Toxicity:
- Never decays: heavy metals etc
Disposal: Waste Isolation Systems

High-level rad. waste
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- Deep geology

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Hazardous waste
- Clay cover/geomembrane

Barrier systems

Toxicity:
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**Low-level (U mining) waste**
- Clay cover/geomembrane
- Disposal: Waste Isolation Systems
- 500 - 100,000 years
- Probabilistic risk assessment

**Hazardous waste**
- Clay cover/geomembrane
- 30 years + extension
- No risk assessment required

**Barrier systems**
- Disposal: Waste Isolation Systems

**Compliance**
- Disposal: Waste Isolation Systems
Disposal: Waste Isolation Systems

**High-level rad. waste**
- Waste form/canister/clay
- Deep geology
- Disposal depth: 1,000 - 1,000,000 years
- Probabilistic risk assessment
- Radioactive toxicity: Decays over time/Long-lived nuclides are internal exposure

**Low-level (U mining) waste**
- Clay cover/geomembrane
- Disposal depth: 500 - 100,000 years
- Probabilistic risk assessment

**Hazardous waste**
- Clay cover/geomembrane
- Disposal depth: 30 years + extension
- No risk assessment required
- Toxicity: Some never decay: metals etc

**Barrier systems**
- Canisters in clay
- drainage system

**Compliance**
- High-level rad. waste: 500 - 100,000 years
- Low-level (U mining) waste: 500 - 100,000 years
- Hazardous waste: 30 years + extension
- Probabilistic risk assessment
Waste Management History

### General Hazardous Waste
- Solid Waste Disposal Act, 1965
- Clean Air Act, 1970
- Clean Water Act, 1972
- Resource Conservation and Recovery Act, 1976
- Comprehensive Environmental Response Compensation and Liability Act, 1980
- Coal ash rule, 2015

### Nuclear Waste
- 1955 Nuclear power to generate electricity
- 1957 National Academy recommend geologic disposal of high-level waste
- 1970 U.S. begins search for sites
- 1980 Nuclear Waste Policy Act (NWPA)
- 1985 Low-level Radioactive Waste Policy Amendments Act
- 1987 NWPA to focus on Yucca Mountain
- 2015 Consent-based siting
Dry Cask Storage for Spent Fuel

- Annual spent fuel: 2–3 casks per year
- Passive safety: no active cooling
- Probabilistic risk assessment for earthquakes, floods, high winds, lightning strikes, accidental aircraft crashes, and pipeline explosions
- No accident/leak since 1986

Advanced Reactors

Advanced reactor companies have waste management plans

Different types of waste

- Different fuel: TRISO fuel
- Structural material: Graphite
- Coolant: Molten salt, sodium

→ Many research activities on managing/disposing these wastes

Independent spent fuel storage: 0.8 acre pad for 60-yr operation
Is it really safe?
Environmental Monitoring

• Data/evidence provides assurance to local communities
• Detection of anomalies if they happen
• Critical ways to keep operators accountable/responsible
Monitoring for Consent-based Siting

Waste Isolation Pilot Plant
- First deep geological disposal in the world for transuranic waste
- Successful consent-based siting

Carlsbad Environmental Monitoring and Research Center (CEMRC)
- Independent/state-funded center
- Characterized background radiation and its fluctuation
- Outreach and surveys to understand people’s concerns
- Detected the 2014 accident first, and provided assurance
Advanced Long-term Environmental Monitoring Systems

New paradigm for long-term environmental monitoring
Importance of environmental monitoring for consent-based siting of nuclear facilities

Sat, Nov 19, 2022, 6:04AM | Nuclear News | Haruko Wainwright and Carol Eddy-Dilek
Transforming Education

Nuclear Waste Educators' Network

Share resources and ideas for interdisciplinary nuclear waste education and research
Changing Mindsets

- Develop a diverse and inclusive community. Antagonistic views are important for protecting the environment and improving safety.

- Send waste to the middle of nowhere → Engineers should design waste isolation in a way that they can have it in their “backyard.”

- Engineers should design reactors and technologies from the “waste up”
Nuclear Waste: Key Facts

- Small/well accounted waste footprint across the life cycle
- Best managed/isolated waste
- Environmental monitoring for providing assurance
- Advancing interdisciplinary research and education
Commercializing Advanced Nuclear Energy

4/19/2023

EESI Briefing: *The State of Play for Nuclear Energy in the United States*

Dr. Patrick White (pwhite@nuclearinnovationalliance.org)
Who is Nuclear Innovation Alliance (NIA)?

• NIA is a “think-and-do” tank working to ensure advanced nuclear energy can be a key part of the climate solution.

• NIA identifies barriers, performs analysis, engages with stakeholders and policy makers, and nurtures entrepreneurship through its Nuclear Innovation Bootcamp.
Takeaways on Commercializing Advanced Nuclear Energy

Nuclear energy can play a major role in creating a clean energy economy

Advanced reactors have a wide array of different commercial use cases

Developers are leveraging DOE support to accelerate reactor deployment

Continued federal support and incentives can catalyze private investments
Advanced nuclear energy is an important complementary clean energy source to help fully decarbonize U.S. energy production.
Large (and growing) group of private companies are developing advanced nuclear energy to meet clean energy needs.
Utility partners and industrial energy users have expressed interest in deploying advanced nuclear energy
Public-private partnerships are accelerating the demonstration and deployment of first-of-a-kind advanced reactors.
Developers are preparing to submit a large number of formal license applications for review to the NRC in FY23

**Site-Specific Applications**
- Kairos: Hermes (in progress)
- ACU: NEXT MSR (in progress)
- X-energy: Xe-100
- TerraPower: Natrium
- GEH: BWRX-300
- Oklo: NCSFR-1
- Oklo: NCSFR-2

**Design-Specific Applications**
- NuScale: VOYGR (complete)
- NuScale: NPM-20 (in progress)
- Terrestrial Energy: IMSR
- Westinghouse: eVinci

**Pre-Application Interactions**
- NuScale: UAMPS (COL)
- Holtec: SMR-160 (CP)
- GA: EM2 (CP)
- BWXT: BANR
- FLiBe: LFTR (ESP)
- ARC: ARC-100
- Radiant Energy: Kaleidos
- USNC: UIUC MMR (CP)
- TerraPower: MCFR
- GA: FMR (CP)
Pathway from first-of-a-kind to widescale deployment requires an orderbook, on-time and on-budget delivery, and supply chains.

Figure from 2023 DOE Report Pathways to Commercial Liftoff - Advanced Nuclear

Example: BWRX-300

Link: BWRX-300 Partnership Announcement
Successful commercialization could dramatically increase demand for advanced nuclear energy for a wide variety of applications.

Figure from 2023 DOE Report *Pathways to Commercial Liftoff - Advanced Nuclear*

- **Heat**
- **Electricity**
- **Hydrogen / Ammonia**

**2022 Nuclear Energy Institute survey of 19 member utilities:**

- More than 300 new SMRs deployed for electricity generation by 2050
- More than 90 GW of new nuclear generation by existing owners alone
- Evaluations of sites that currently host operating or retired coal plants for new nuclear reactors
Continued federal support and incentives can catalyze private investments in advanced nuclear energy.

- **Inflation Reduction Act (IRA) Funding for HALEU**
  - Fuel Cycle Development Support: $700M
- **Demonstration Reactor Support**
  - $4600M
- **DOE ARC 20 Risk Reduction Awards in Appropriations**
  - $650M
- **IRA Nuclear Hydrogen Production Credits**
  - Non-electric Deployment Incentives: $3.00/kg H₂
- **Commercial Deployment Incentives**
  - 2.5¢/kWh* OR 30% of costs*
- **Advanced Reactor Licensing at the Nuclear Regulatory Commission**
  - Effective, Efficient, and Predictable Regulation
- **Infrastructure Investment and Jobs Act (IIJA) Funding and Appropriations**
  - IRA Nuclear Production and Investment Tax Credits (see [NIA Fact Sheet](#) for Details)

*4/19/2023*
Takeaways on Commercializing Advanced Nuclear Energy

- Nuclear energy can play a major role in creating a clean energy economy
- Advanced reactors have a wide array of different commercial use cases
- Developers are leveraging DOE support to accelerate reactor deployment
- Continued federal support and incentives can catalyze private investments
Back-up Slides
Advanced nuclear energy adds flexibility and versatility in comparison to conventional nuclear through innovative design.

<table>
<thead>
<tr>
<th>Conventional Nuclear Energy</th>
<th>Advanced Nuclear Energy</th>
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<tbody>
<tr>
<td>Reactor Size</td>
<td>Reactor Technology</td>
</tr>
<tr>
<td>Versatile: 1.5 MW e to 300+ MW e</td>
<td>Wide Variety of Reactor Technologies</td>
</tr>
<tr>
<td>Reactor Technology</td>
<td>Generation Type</td>
</tr>
<tr>
<td>Predominantly Large: More than 1000 MW e</td>
<td>Flexible and Dispatchable Generation</td>
</tr>
<tr>
<td>Predominantly Light-Water Reactors</td>
<td>Safety Approach</td>
</tr>
<tr>
<td>Primarily Baseload Generation</td>
<td>Designed with Inherent Safety Systems</td>
</tr>
<tr>
<td>Designed with Active Safety Systems</td>
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4/19/2023
Definition of advanced nuclear energy includes a variety of nuclear technologies with different advantages.

<table>
<thead>
<tr>
<th><strong>Thermal Fission</strong></th>
<th><strong>Fast Fission</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Light-Water Reactors</td>
<td>Gas-cooled fast reactor (GFR)</td>
</tr>
<tr>
<td>Evolutionary design from existing reactors with inherent safety features</td>
<td>An evolution of HTRs, GFRs operate at very high temperatures while using a more sustainable fuel cycle</td>
</tr>
<tr>
<td>High-temperature reactors (HTRs)</td>
<td>Sodium-cooled fast reactor (SFR)</td>
</tr>
<tr>
<td>High temperatures drive high efficiency, well-suited for process heat or hydrogen production. Uses TRISO fuel</td>
<td>With many existing experimental reactors, SFRs offer increased fuel efficiency, reduced waste, and passive safety features</td>
</tr>
<tr>
<td>Molten Salt-Fueled Reactors (MSRs)</td>
<td>Lead-cooled Fast Reactor (LFR)</td>
</tr>
<tr>
<td>Using molten salt for coolant and a fuel form, MSRs can bring significant safety benefits</td>
<td>Similar in design to SFRs, LFRs are advantageous as lead is operationally safer than sodium</td>
</tr>
</tbody>
</table>
Variety of reactor sizes and low-carbon products enable integration of advanced nuclear into future energy systems.
Both NRC and companies play a role in improving licensing under current rules and creating a new regulatory framework.

**Optional Licensing Tools**
- Preapplication Interactions
- Topical Reports
- Early Site Permits
- Standard Design Approvals
- Standard Design Certifications

**Licensing Paths**
1. **Construction Permit**
   - Licensing Path 1 ("Part 50")
2. **Operating License**
   - Licensing Path 2 ("Part 52")
3. **Combined Operating License**
   - Licensing Path 3 ("Part 53")

**New Regulatory Framework**
Advanced reactor commercialization requires coordination and planning across all stages of a sustainable fuel cycle.
Some advanced reactor technologies will require nuclear fuel cycles with higher uranium enrichment levels.

- **Natural Uranium**
  - 99.3% U-238
  - 0.7% U-235

- **Low-Enriched Uranium (LEU)**
  - 95% U-238
  - 5% U-235

- **High-Assay, Low-Enriched Uranium (HALEU)**
  - 80% U-238
  - < 20% U-235

- **High-Enriched Uranium (HEU)**
  - > 10% U-238
  - < 90% U-235

- **LWR Reactor Fuel**
  - 95% U-238
  - 5% U-235

- **Advanced Reactor Fuel**
  - 80% U-238
  - < 20% U-235

- **Historic Research Reactor Fuel**
  - > 10% U-238
  - < 90% U-235
Advanced reactors that require HALEU or recycled fuels will need new fuel cycle infrastructure and facilities.
Stakeholders can get up to speed on advanced nuclear energy and engage with policymakers on clean energy deployment.
Briefing Series: Farm Bill in Focus

Every Other Wednesday Starting April 26

The Process and Path Forward for Passing a Bipartisan Farm Bill | April 26, 2:00-3:30 PM

Climate, Energy, and Economic Win-Wins in the Farm Bill | May 10, 1:30-3:00 PM EDT

Unlocking Rural Economies: Farm Bill Investments in Rural America | May 24, 2:00-3:30 PM EDT

The Future of Forestry in the Farm Bill | June 07, 2:00-3:30 PM EDT

Conservation Practices from Farms to Forests and Wetlands | June 21, 2:00-3:30 PM EDT
What did you think of the briefing?

Please take 2 minutes to let us know at:
www.eesi.org/survey

Materials will be available at:
www.eesi.org/041923nuclear

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Wednesday, April 19, 2023