Emerging resources: Small modular nuclear and alternative fuels

Public webinar

February 27, 2024

PUGET SOUND ENERGY

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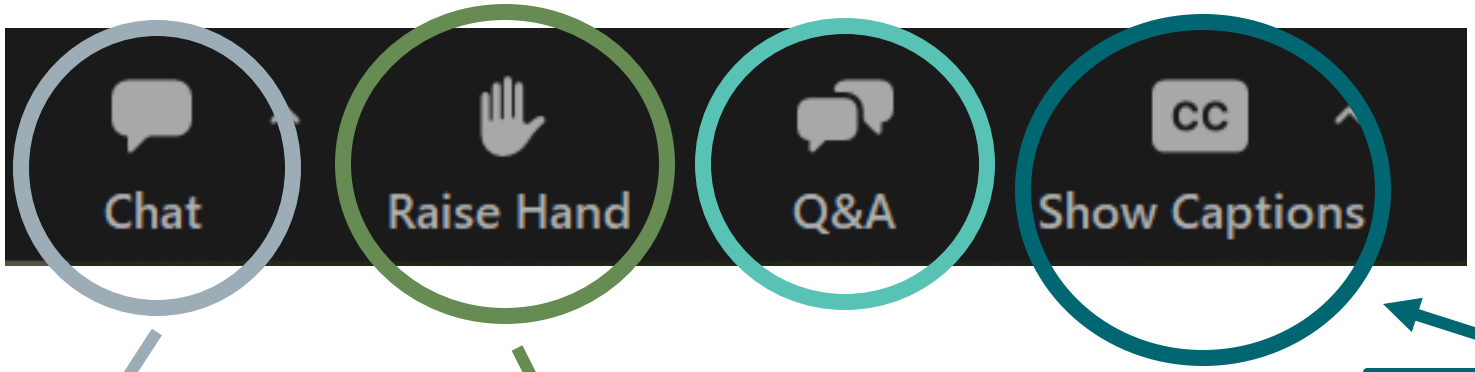

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Facilitator requests

- Engage constructively and courteously towards all participants
- Respect the role of the facilitator to guide the group process
- Avoid use of acronyms and explain technical questions
- Use the Feedback Form or email irp@pse.com for additional input to PSE
- Aim to focus on the webinar topic
- Public comments will occur after PSE's presentations

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Safety moment

Call before you dig!

- Call 811 2-10 days before any digging or excavating on your property
- 811 will notify all utilities in your area to mark lines
- Find more at DigSafeWa.org

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Today's speakers

Sophie Glass

Facilitator, Triangle Associates

Josh Jacobs

Vice President, Clean Energy Strategy and Planning, PSE

Chris Drobnicki

Emerging Tech Development Manager, PSE

Nathan Clark

Chief Research Analyst, Nuclear Energy Systems, Pacific Northwest National Laboratory (PNNL)

Mike Ostrowski

Senior Quantitative Risk Analyst, PSE

Thor Angle

Consulting Engineer, PSE

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Today's objectives

- Provide overview of advanced nuclear technology
- Provide overview of renewable diesel and renewable natural gas
- Discuss how these emerging technologies may help support PSE's clean energy goals

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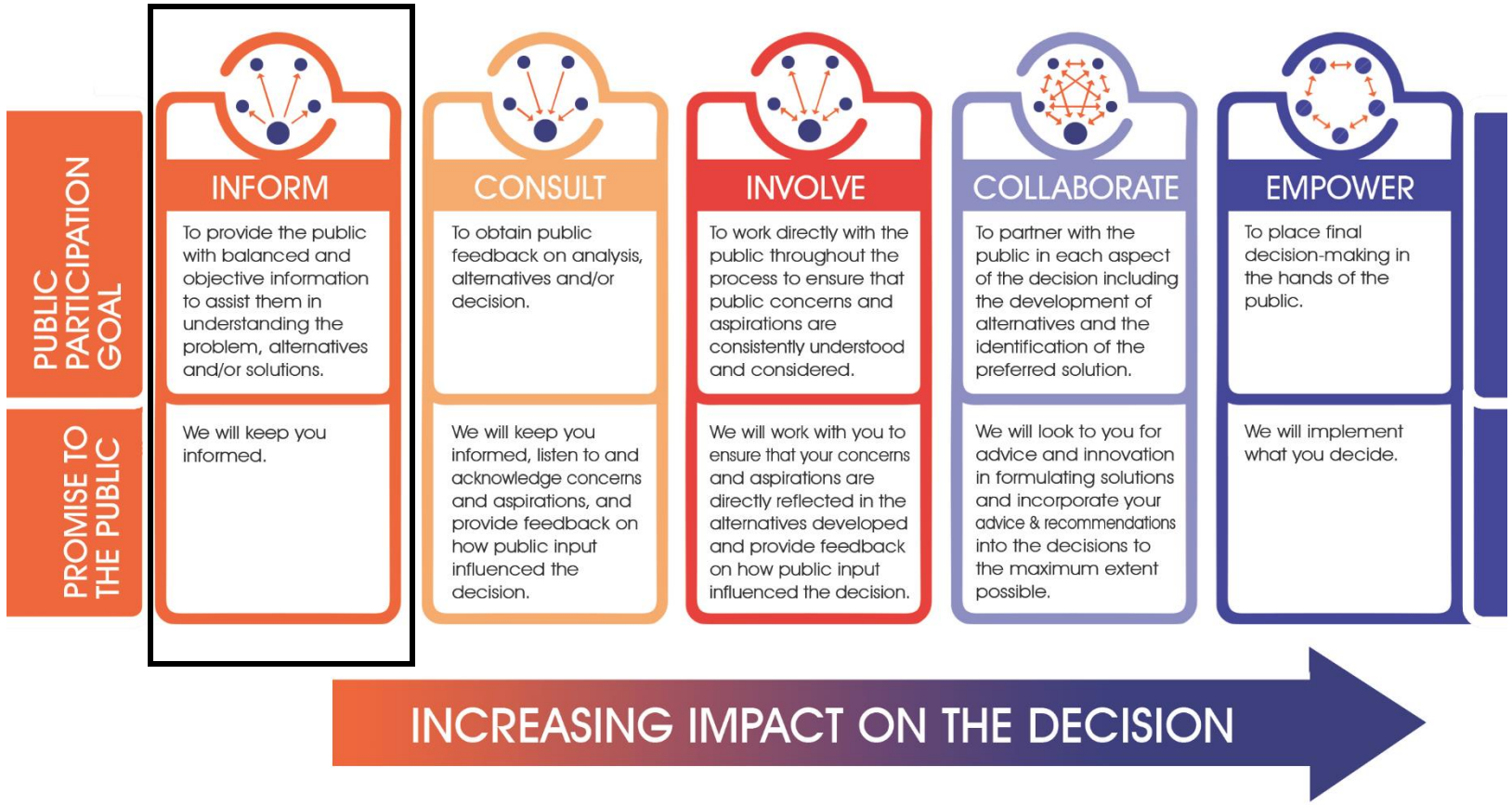
IAP2 Spectrum



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Agenda

Time	Agenda Item	Presenter / Facilitator
1:30 p.m. – 1:35 p.m.	Introduction and agenda review	Sophie Glass, Triangle Associates
1:35 p.m. – 1:40 p.m.	Emerging resources in context	Josh Jacobs, PSE
1:40 p.m. - 1:45 p.m.	Introduction to advanced nuclear	Chris Drobnicki, PSE
1:45 p.m. – 2:15 p.m.	Advanced nuclear technology	Nathan Clark, Pacific Northwest National Laboratory (PNNL)
2:15 p.m. – 2:50 p.m.	Alternative fuels: renewable diesel and renewable natural gas	Thor Angle, PSE Mike Ostrowski, PSE
2:50 p.m. – 3:00 p.m.	Next steps and public comment opportunity	Sophie Glass, Triangle Associates
3:00 p.m.	Adjourn	All

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Emerging resources in context

Josh Jacobs, Vice President, Clean Energy Strategy and Planning, PSE

February 27, 2024

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State policy identifies clean energy options

WAC 480-100-605 definitions

"**Renewable resource**" means water; wind; solar energy; geothermal energy; renewable natural gas; renewable hydrogen; wave, ocean, or tidal power; biodiesel fuel that is not derived from crops raised on land cleared from old growth or first growth forests; or biomass energy.

"**Nonemitting electric generation**" means electricity from a generating facility or a resource that provides electric energy, capacity, or ancillary services to an electric utility and that does not emit greenhouse gases as a by-product of energy generation.

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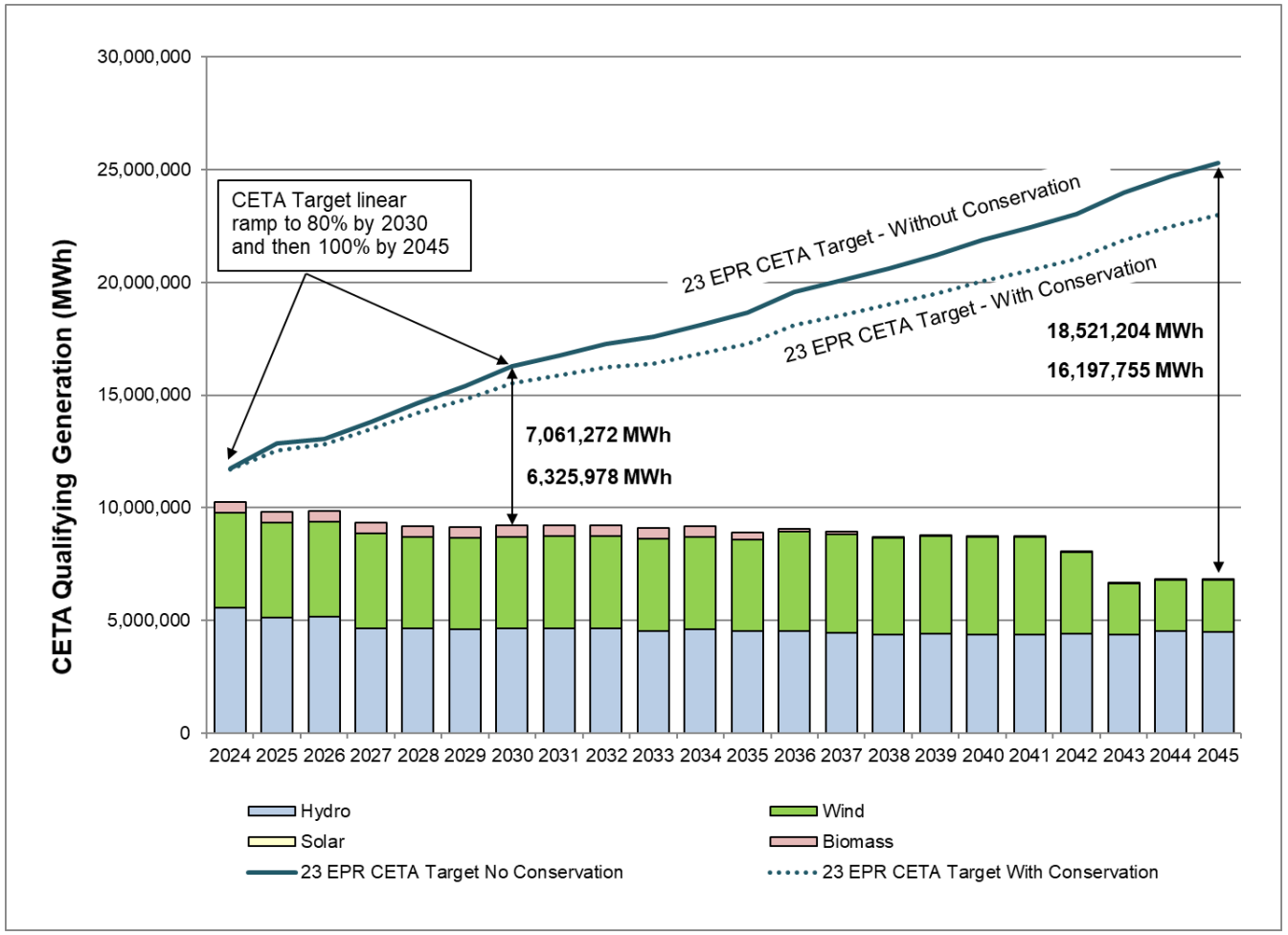
Scale of electric resource needs

2025
Coal-free electricity

2030
Carbon-neutral electric system

2045
100% clean electricity supply



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Emerging resources series

Hydrogen
- Electric generation
- Natural gas supplement

December 7, 2023

Advanced nuclear
- Electric generation

Renewable natural gas
- Natural gas alternative

Renewable diesel
- Electric generation (peak)

February 27, 2024

Energy storage (e.g., batteries)
- Peak capacity

April 23, 2024

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Introduction to advanced nuclear

Chris Drobnicki, Emerging Tech Development Manager, PSE

February 27, 2024

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PSE and nuclear energy

- PSE is taking an “all of the above” approach in exploring emerging tech
- Today, nuclear represents <1% of PSE’s electricity fuel mix
- Small modular reactors (SMRs) are approaching commercial readiness
- SMRs appear to be a promising technology that have the potential to provide carbon-free, baseload, and on-demand electricity
- Energy Northwest owns and operates Columbia Generating Station
- Energy Northwest is proposing to develop and operate an SMR plant, with the first unit anticipated to come on-line in 2030
- PSE is investing $10M with Energy Northwest to support early project development for this SMR plant in exchange for future energy offtake
- PSE does not incur future obligations by providing this funding

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Pacific Northwest
NATIONAL LABORATORY

Advanced Nuclear Reactors – Status & Technology Review

Puget Sound Energy
Public IRP Meeting

February 27, 2024

Nathan Clark
Chief Research Analyst
Nuclear Energy Systems

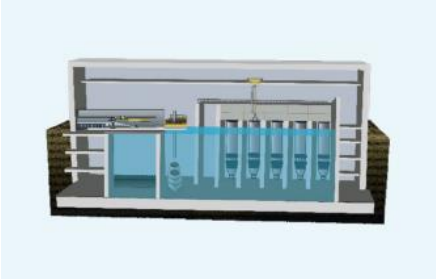
U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

What is an Advanced Nuclear Reactor?

Microreactors
1 MW - 20 MW

mobile, deployable,
small-scale application



Small Modular Reactors (SMRs)
20 MW - 300 MW

scalable, agile operation

Large Reactors
300 MW - 1000+ MW

baseload, large-scale

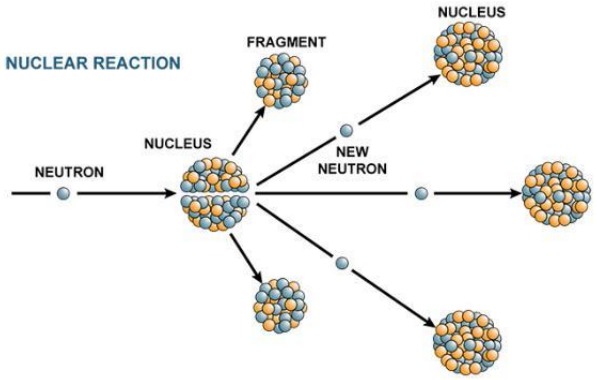
SMRs

Advanced Reactors

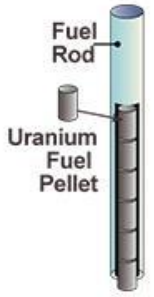
https://www.energy.gov/sites/default/files/2020/05/f74/Advanced-Reactor-Types_Fact-Sheet_Draft_Hi-Res_R1.pdf

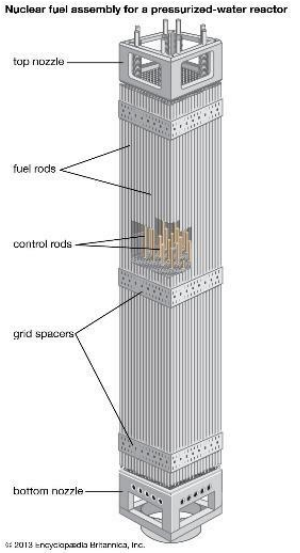
The Science of Nuclear

Nuclear Fission

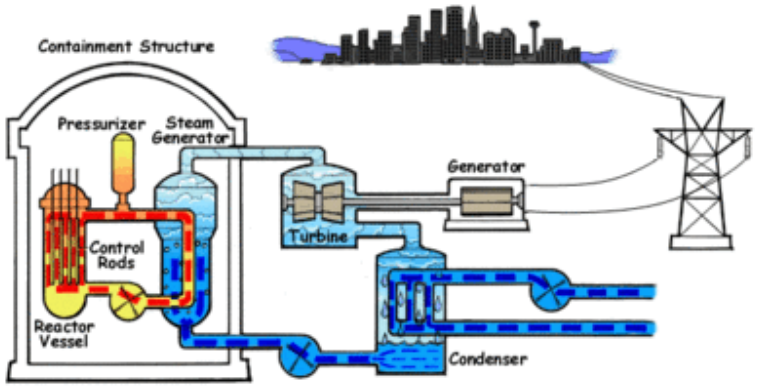


Uranium Fuel



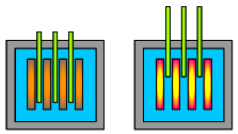


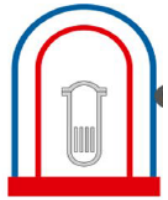
Reactor Power Systems



Nuclear Safety

- Reactivity Control
- Heat Removal
- Barriers





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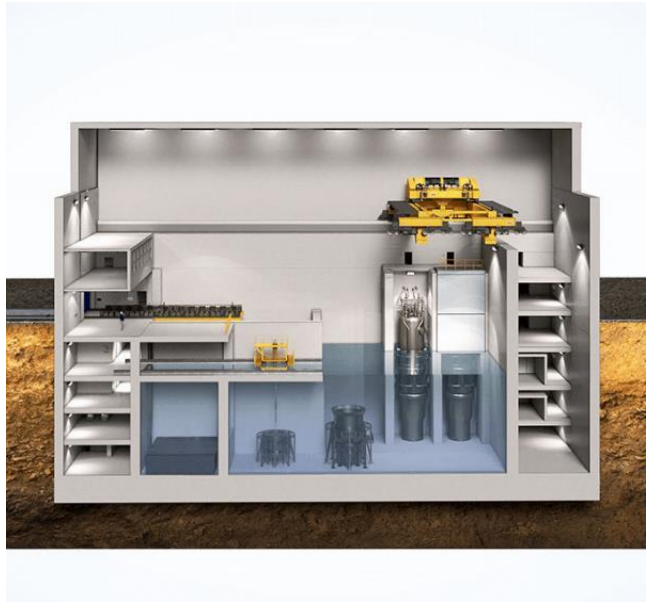
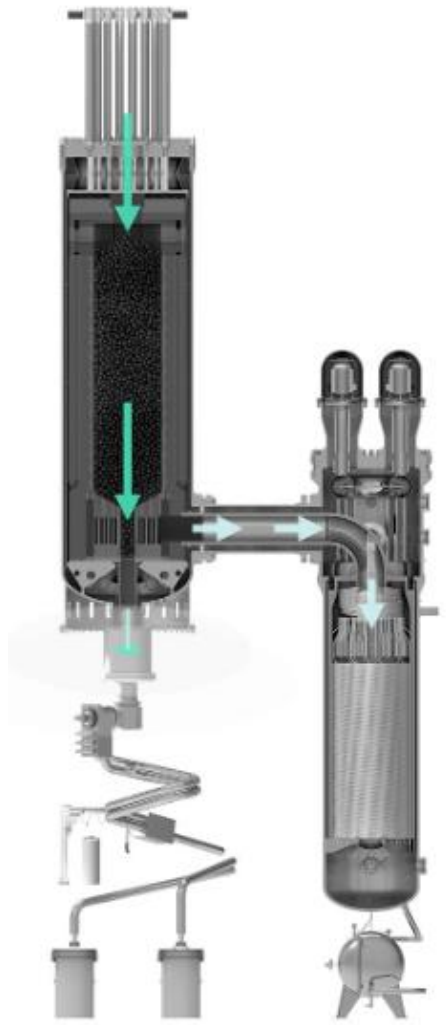
Nuclear Evolution

- **Gen II Light Water Reactors (LWRs)**
  large commercial fleet (>90 units)
- **Gen III Advanced LWRs**
  passive features, Vogtle 3&4
- **Gen III+ Evolutionary LWRs**
  simplified systems, NuScale
- **Gen IV Revolutionary**
  fail-safe fuels, innovative coolants, modular



What is driving the need?

- Carbon-free power laws ✓
- Resilient energy grids ✓
- Intermittent load balancing ✓
- Firm, reliable generation ✓
- Island mode (data centers) ✓
- Black start capability ✓
- Saturation of renewables ✓



https://x-energy.com/reactors/xe-100

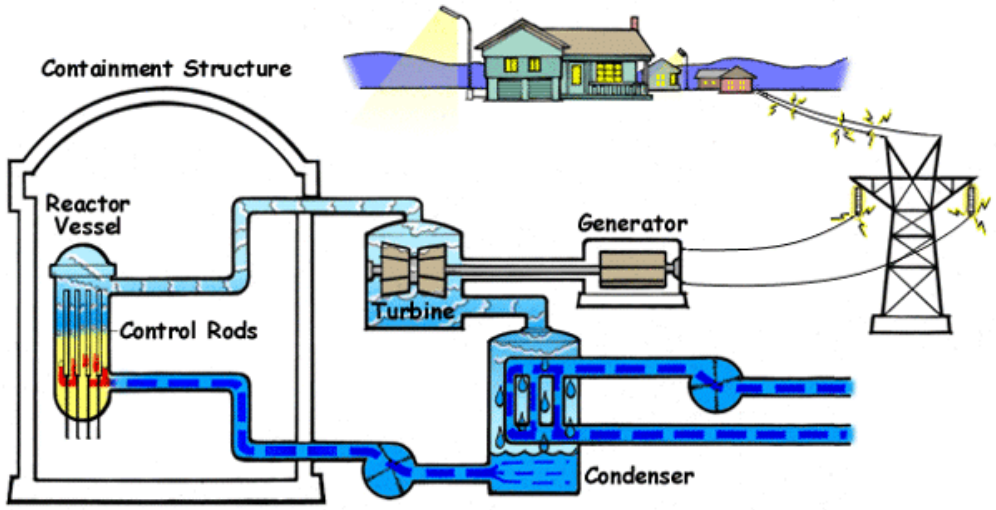
What are the holdups?

- Capital cost now (vs. reliability issues in ~2030)
- Capacity accreditation
- Cost modeling 60-100 year SMR lifespans
- Utility resource action plans favor commercially available technologies
- Dearth in construction of large thermal generation
- Supply chain (fuel)
- Public education and perception

Current Nuclear Power Generation

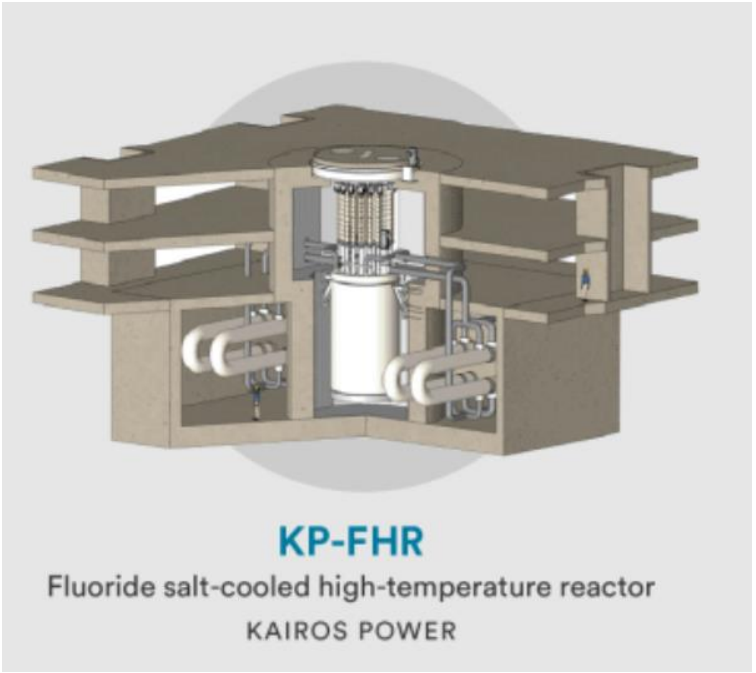
+ 90%+ capacity factor
+ Refueling 18-24 months
+ High reliability
+ Carbon-free
+ Firm, secure power

– High water consumption
– Radioactive Waste
– Exclusion zones (footprint)
– High investment cost
– Less agile



Benefits of Gen IV – Smaller Size

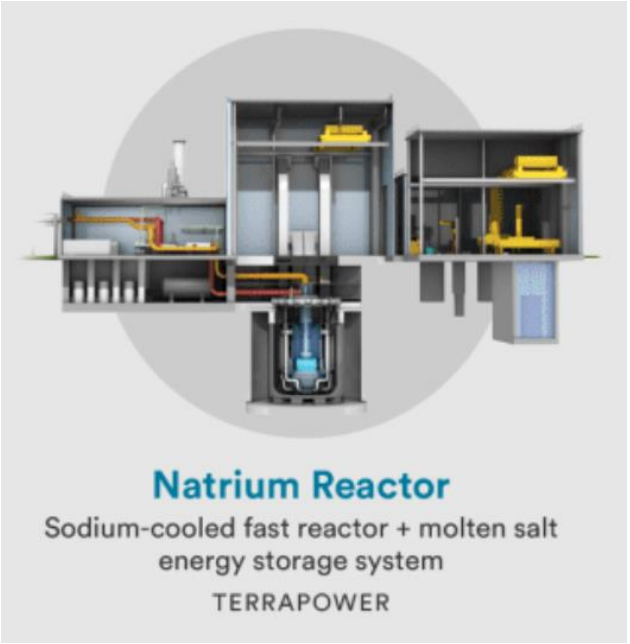
- Modular design
- Factory-built components
- Scalable designs, multiple unit stations
- Underground construction
- Smaller footprint
  (20-80 acres vs. 1000 acres)
- Smaller exclusion zones
  (0.25 miles vs. 10-50 miles)



https://www.energy.gov/ne/articles/infographic-advanced-reactor-development

Benefits of Gen IV – Versatility

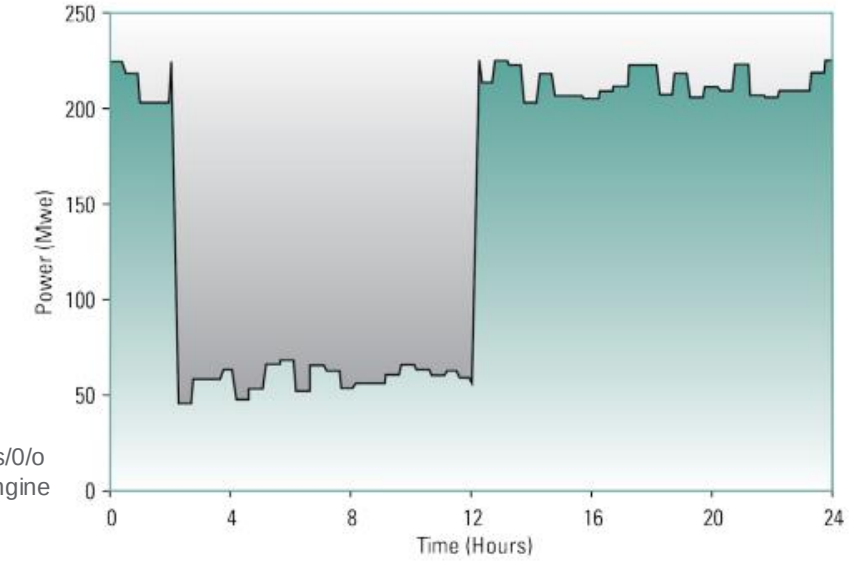
- Flexible operation
- Load follow capability
- Improved ramp rates (2 - 5 %/min)
- Black start / Island mode
- Shorter refueling
- Less water usage
- More siting options



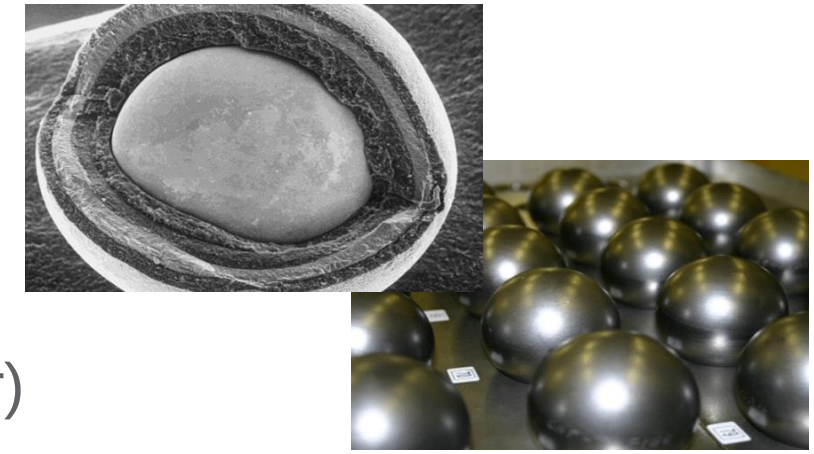
https://www.energy.gov/ne/articles/infographic-advanced-reactor-development

Sample power change during load follow and frequency control event (Westinghouse SMR)

https://www.westinghousenuclear.com/Portals/0/operating%20plant%20services/fuel/fuel%20engineering%20services/NF-FE-0040%20SMR%20Operating%20Strategy.pdf



Benefits of Gen IV – Revolutionary Designs

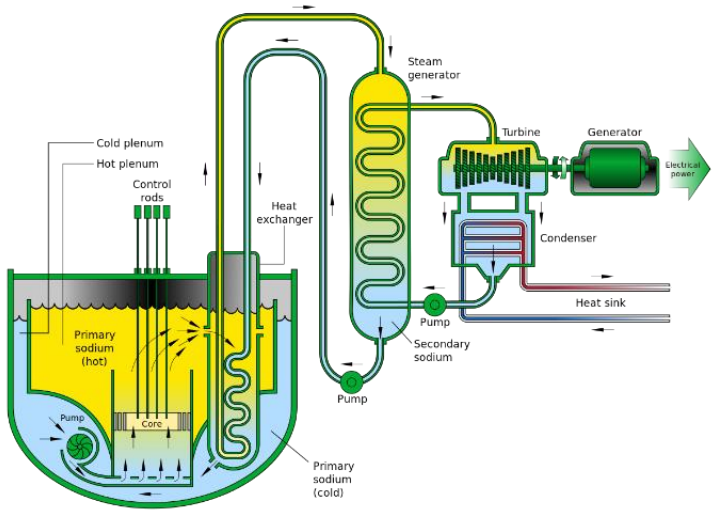


FUEL

- Higher enrichment and utilization (HALEU*)
- Self-contained, non-meltable fuel (TRISO)
- Shorter or online refueling (>95% capacity factor)

COOLANTS

- Improved efficiency (Higher temperatures)
- Simpler containment (Lower pressures)
- Less reactive and corrosive
- Fewer redundant and backup cooling systems



*HALEU – high-assay low enriched uranium

What is the status of advanced nuclear projects?

- 20 Nuclear Projects under consideration in US
- NuScale VOYGR, UAMPS at Idaho National Laboratory, Carbon Free Power Project – 6 units each 77 MW – 50+ municipality subscription, cancelled November 2023
- Energy Northwest getting support from Puget Sound Energy to develop site/technology feasibility study
- TerraPower Natrium and PacifiCorp in Kemmerer WY – 1 unit (345 MW, 500 MW peak), land purchased, suppliers chosen, draft environmental assessment of salt testing facility complete

Regional Nuclear Innovators

- Pacific Northwest National Laboratory (Richland)
  - DoD and DOE nuclear research programs
- Energy Northwest (Richland)
  - Columbia Generating Station
  - New Nuclear Division
- Framatome Nuclear Fuel (Richland)
- VERTical Clean Energy Hub (Tri-Cities)
- TerraPower (Bellevue)
  - Natrium and Integrated Energy Storage project
- Microsoft (Redmond)
  - Carbon Free Future and Advanced Nuclear initiative

PNW Region…a feasible producer

- Need for power ✓
- Existing infrastructure ✓
- Coal retirement ✓
- Clean Energy Transformation Act (CETA) ✓
- Complement to renewables ✓
- Technology options ✓
- Suitable Sites (WNP Site 1 or 4, Centralia) ✓
- Energy Northwest ✓

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Thank you

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Renewable diesel

Thor Angel, Consulting Engineer, PSE

February 27, 2024

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State policy identifies clean energy options

WAC 173-425-110 definitions

"**Biodiesel**" means a motor vehicle fuel consisting of mono alkyl esters of long chain fatty acids derived from vegetable oils, animal fats, or other **nonpetroleum resources**, not including palm oil, designated as B100 and complying with ASTM D6751.

"**Biodiesel blend**" means a fuel comprised of a **blend of biodiesel with petroleum-based diesel fuel**, designated BXX. In the abbreviation BXX, the XX represents the volume percentage of biodiesel fuel in the blend.

PSE PUGET SOUND ENERGY

State policy identifies clean energy options

WAC 173-425-110 definitions

"**Renewable hydrocarbon diesel**" or "**renewable diesel**" means a diesel fuel that is **produced from nonpetroleum renewable resources** but is not a monoalkylester and which is registered as a motor vehicle fuel or fuel additive under 40 C.F.R. Part 79. This includes the renewable portion of a diesel fuel derived from co-processing biomass with a petroleum feedstock.

"**Renewable hydrocarbon diesel blend**" or "**renewable diesel blend**" means a fuel comprised of a **blend of renewable hydrocarbon diesel with petroleum-based diesel fuel**, designated RXX. In the abbreviation RXX, the XX represents the volume percentage of renewable hydrocarbon diesel fuel in the blend.

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Why renewable diesel?

- Sustainable fuel with lower carbon intensity than petroleum-derived diesel
- Meets same composition standard as petroleum diesel, ASTM D957

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Supporting our clean energy goals

- PSE uses petroleum diesel as a backup fuel for curtailment
- R99 could help “keep the lights on” during extreme cold weather
- 1:1 displacement of petroleum diesel
- Availability from local vendors
- Successful R99 fuel tests at Crystal Mountain emergency generator and Frederickson Generating Station

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Renewable natural gas

Mike Ostrowski, Senior Quantitative Risk Analyst, PSE

February 27, 2024

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What is Renewable Natural Gas?

- Renewable Natural Gas (RNG) is a gas consisting largely of methane and other hydrocarbons derived from the decomposition of organic material in landfills, wastewater treatment facilities, and anaerobic digesters. (RCW 54.04.190)
- Methane from an organic process is captured and used to displace fossil natural gas
- "Biogas" must be processed to meet pipeline quality standards in order to become RNG

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Why are we considering RNG?

- Beyond Net Zero Carbon initiative
- WA Climate Commitment Act (CCA) necessitates decarbonization
- There are limited options available for decarbonizing the gas system
- RNG is just one part of the picture for decarbonization
- RNG is a solution available today with real, immediate impacts on our carbon footprint

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Why are we considering RNG?

- In 2019, it became a legal requirement for WA natural gas utilities to offer a voluntary RNG option to all customers. (RCW 80.28.390)
- Also in 2019, WA legislature allowed natural gas utilities to integrate RNG into their natural gas supply (RCW 80.28.385):

  (a) Renewable natural gas provides benefits to natural gas utility customers and to the public; and

  (b) The development of renewable natural gas resources should be encouraged to support a smooth transition to a low carbon energy economy in Washington.

- Subject to requirements later explained in a 2020 policy statement

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Supporting our clean energy goals

- In 2023, PSE reduced the amount of fossil natural gas delivered to customers by about 0.7% by replacing it with RNG
- In 2024, we expect that number to be around 3%
- PSE is confident that it can continue acquiring RNG **without significant capital investment by PSE**, using staggered Long-Term contracts of 3-20 years.

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RNG supply and future planning

- PSE's goal is to build its portfolio of RNG supply
  - Further analysis will be made in the IRP
- RNG we contract today will also be available to supply “hard to electrify” loads in the future
- RNG production outlook in the US is positive

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Next steps

Sophie Glass, Triangle Associates

February 27, 2024

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Upcoming activities

Date	Activity
March 5, 2024	Feedback form for Emerging Resources: Small Modular Nuclear and Alternative Fuels closes
March 12, 2024	RPAG meeting: Resource adequacy modeling and resource needs (electric)
March 25, 2024	RPAG meeting: Gas and electric resource alternatives (supply-side)


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Public comment opportunity

Please raise your “hand” if you would like to provide comment.

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Thanks for joining us!

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Acronyms

Acronym	Meaning
BPA	Bonneville Power Administration
CCA	Climate Commitment Act
CETA	Clean Energy Transformation Act
CEIP	Clean Energy Implementation Plan
DoD	Department of Defense
DOE	Department of Energy
HALEU	High assay low enriched uranium
IAP2	International Association of Public Participation
IRA	Inflation Reduction Act
IRP	Integrated Resource Plan
LWR	Light water reactor
MW	Megawatt
PNNL	Pacific Northwest National Laboratory
RNG	Renewable natural gas
RPAG	Resource Planning Advisory Group
SMR	Small modular reactor
UTC or Commission	Washington Utilities and Transportation Commission

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Appendix

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PNNL's Capabilities in Support of Reactor Deployment Efforts

Capabilities leveraged in support of industry

Reactor chemistry & physics
- Safeguards & signatures
- Molten salt properties measurements
- Molten salt properties modeling
- Handling of Be, Pu, transuranic bearing and radioactive salts
- Synthesis of irradiated salts
- Reactor physics and neutronics

Non-destructive evaluations (NDE)
- High temperature sensing technology
- Online monitoring of structural components
- Component Integrity

Online monitoring of molten salts, reactor coolant & effluent

Advanced fuels designs
- Fuel material & fabrication space
- Metallic fuel fabrication
- Post irradiation examination
- Fuel Processing

Reactor materials
- Material design and modeling
- Material testing
- Material characterization

Technical Evaluations & Assessments
- Techno-economics assessments
- FFTF legacy and lessons learned

Licensing
- Reactor regulation & licensing
- Human factors engineering

Environmental impact assessments

Probabilistic risk assessment (PRA)

Systems & components design
- Metal organic frameworks & off-gas systems
- Advanced Manufacturing & cold spray technology
- Buried piping inspection
- Cable aging management
- Cyber security

Irradiation Sciences
- Radiological risks and hazards assessment
- Radiation protection and dose assessment

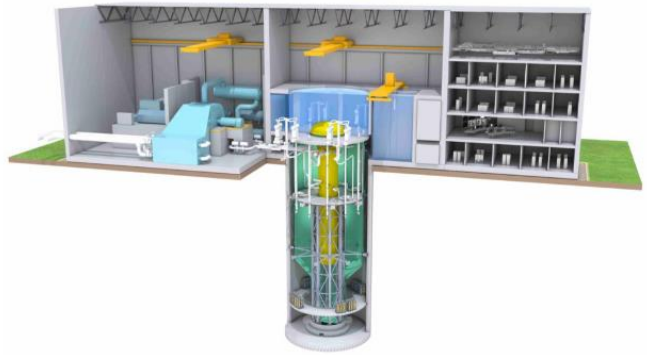
Spent fuel management & decommissioning
- Spent fuel recycling
- Spent fuel storage and transportation
- Reactor decommissioning

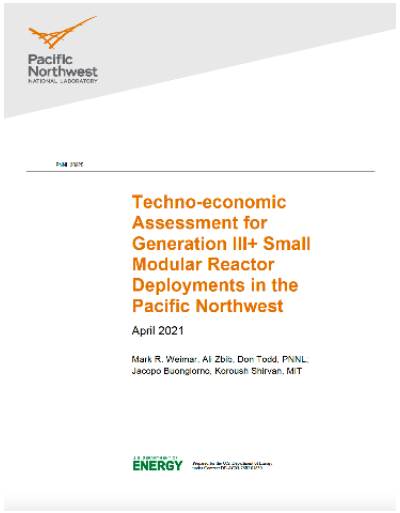
2021 PNW Techno-Economic Assessment

- 2 Technologies
- 3 Sites, 5 case studies
- Cost estimates from reactor developers (n^{th} of kind) and construction sites
- Sensitivity Analysis
- Account for cost savings ($300M) for deploying on Site 1
- Calculate Levelized Cost of Electricity (LCOEs)
- Compare to other potential flexible sources

NuScale's SMR

GEH's BWRX-300





Hanford site, Centralia, UAMPS/INL

Nuclear News

- NuScale VOYGR, UAMPS at INL, Carbon Free Power Project – 6 units each 77 MWe – 50+ municipality subscription, cancelled November 2023 **[DOE-NE]**
- NuScale working with Standard Power (Ohio and Pennsylvania). Manufacturing of 6 units still underway, 55 MWe design licensed, 77 MWe design under review
- X-energy Xe-100 in Grant County, Energy Northwest – 4 to 12 units each 80 MWe, put on hold as X-energy preferred site now in Texas with Dow Chemical, PNW partnerships still intact **[DOE ARDP]**
- TerraPower Natrium and PacifiCorp in Kemmerer WY – 1 unit (345 MWe, 500 MWe peak), land purchased, suppliers chosen, draft EA of salt testing facility **[DOE ARDP]**

Nuclear News (cont.)

- NuScale and DOE Oak Ridge National Laboratory (ORNL) are collaborating on a techno-economic assessment for a cost-effective steam heat design, November 2023.
- Kairos Hermes I at ORNL – demonstration of KP-FHR technology (no power), NRC issued Final Safety Evaluation Report (FSER) in June 2023, construction license soon
- Kairos HERMES II at ORNL – 2-unit power producing plant, 14 MWe each, small version of KP-FHR, NRC reviewing construction application

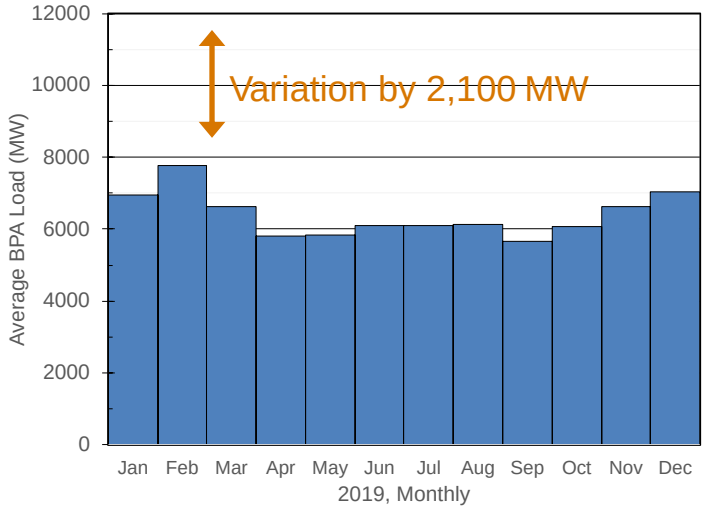
Nuclear News International

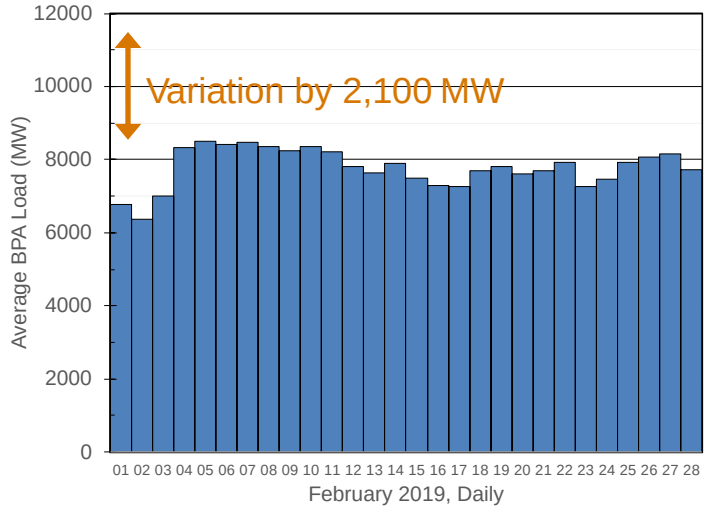
- GE-Hitachi BWRX-300 and Ontario Power Generation near Toronto, 4 units (each 290 MWe), pre-application activities
- COP28 climate conference – pledge by over 20 nations to trip nuclear deployment this decade.
- Westinghouse and UAE Emirates Nuclear Energy Corporation (ENEC) MOU to explore deployment of the eVinci microreactor.
- TerraPower and ENEC MOU to study the potential development of advanced reactors in the UAE and abroad.
- NuScale working with Poland copper and silver producer KGHM to build SMRs in support of industry.

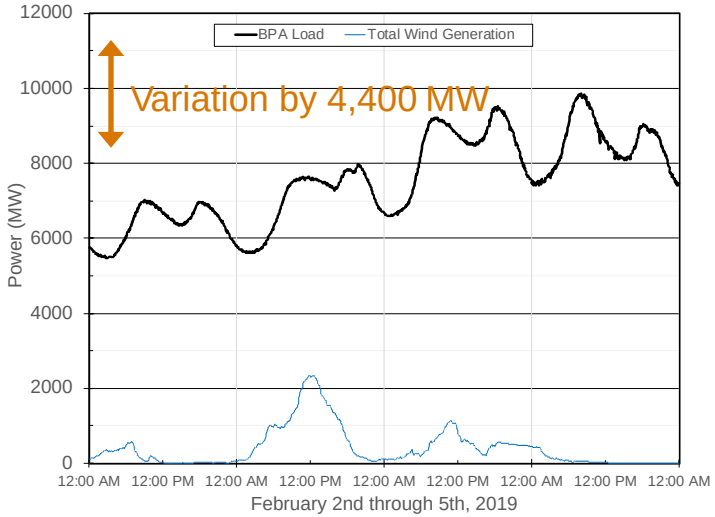
Microreactors

- BWXT and X-energy each designing separate portable microreactors for the US Army's Pele Project (DoD)
- US Air Force issuing RFP for microreactor at Eielson Air Force Base in Anchorage Alaska (DoD) (recently retracted the award to Oklo (Aurora) due to contracting oversight)
- Expect proposals from Oklo, Westinghouse, X-energy, BWXT, USNC, Radiant, and others
- BWXT and Wyoming Energy Authority assessing viability of microreactors with fund-matching under a state program.
- Westinghouse (eVinci) and Saskatchewan Research Council exploring options in Canada

The Fundamental Challenge – Electricity is Ephemeral







- Average Bonneville Power Administration (BPA) load variation at the equivalent of 2-4 times the total output of Columbia Generating Station (BWR/5 in WA)
- As wind and solar power penetration into the grid ramps up, and carbon-emitting resources are retired, flexible carbon-free resources will be increasingly needed.

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