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EverGREEN 2045: An Energy Mix to Decarbonize Washington State

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Brittany Tarufelli, PhD

Senior Economist, PNNL

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Acknowledgements

The research team:

K. Harris, S. Acharya, K. Mahapatra, B. Vyakaranam, A. Campbell, P. Maloney, D. Bhatnagar, M. Weimar, and A. Zbib

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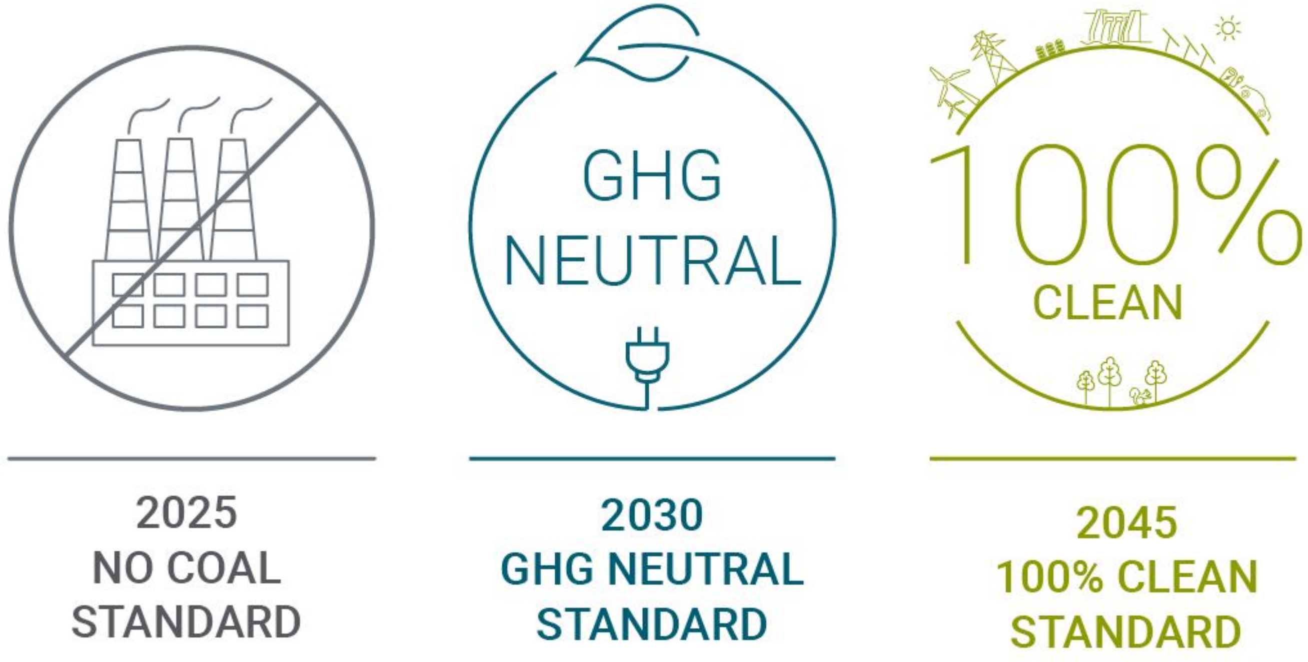
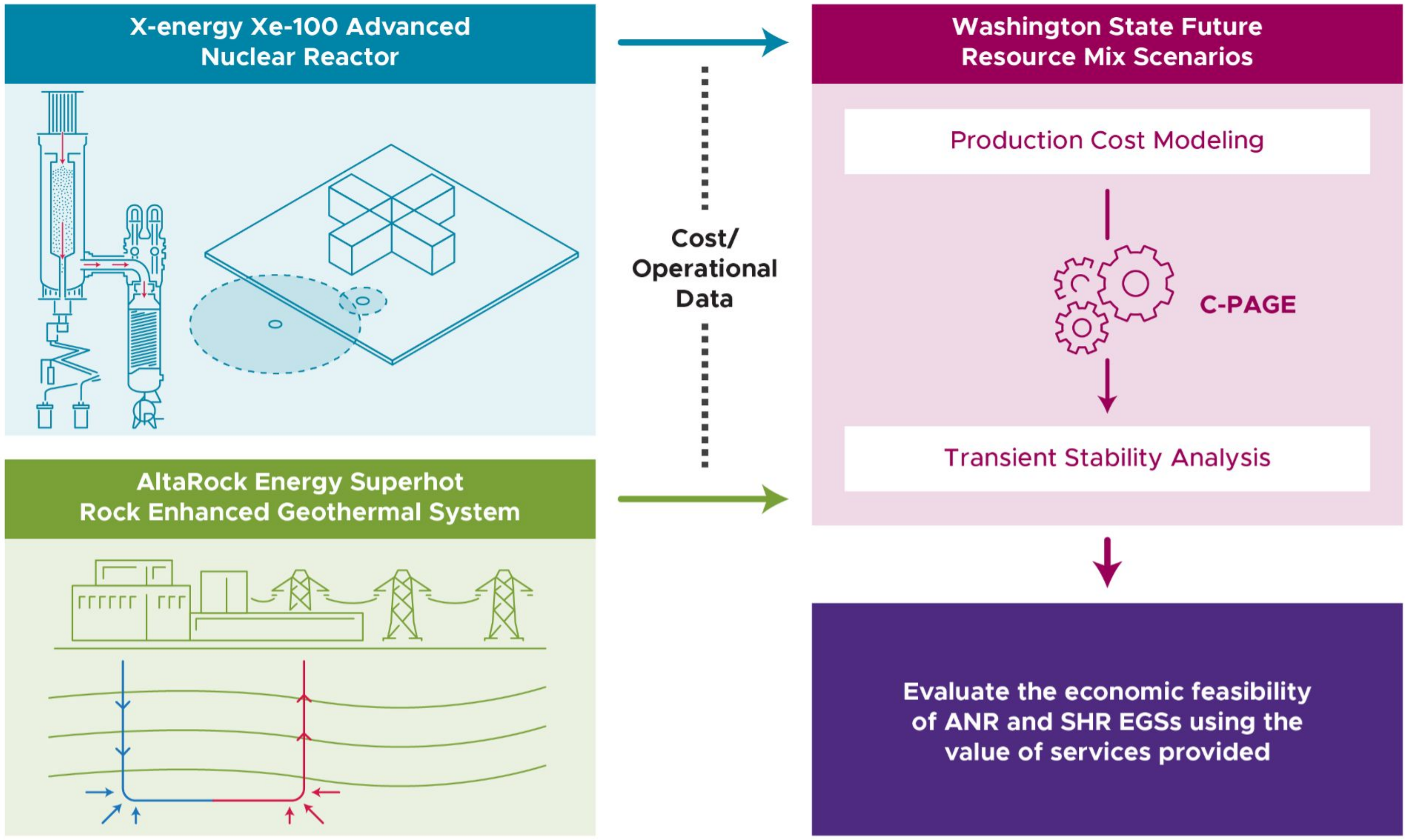
Project Motivation

- The Washington Clean Energy Transformation Act:
  - Transitions the state to carbon-free generation by 2045
  - Eliminates coal from Washington state's generation mix by 2025
  - Imposes a $60/MWh tax on natural gas generation in 2030
  - Prohibits the introduction of new conventional hydro



- Implies the flexibility of generating resources will be at a premium
  - Especially important with increasing amounts of wind and solar power
- Need for analysis of future energy resources, including **small modular reactors** to understand both the costs and stability of the future electric-power system.

Project Approach and Modeling Framework



- **Estimate** the costs of advanced nuclear reactors (ANR) and superhot rock (SHR) enhanced geothermal systems (EGS)
- **Design** future resource mix scenarios with optimal resource additions for Washington State
- Power systems **analysis**
- Evaluate **economic feasibility** of new generation technologies

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Cost Estimates

X-energy Xe-100 SMR

- Generation IV high-temperature gas-cooled nuclear reactor
- Modular design allows 80 MW reactors to be scaled into a 4-pack 320 MW plant, cogeneration options
- Online refueling allowed by pebble bed design, powered by TRISO fuel (94% capacity factor)

AltaRock Energy SHR EGS

- Drilling into superhot rock provides higher temperature steam and higher efficiency
- Leverages economies of scale not available for current geothermal systems
- Novel drilling technology

Nth of A Kind

Future Resource Mix Scenarios

- Designed to be compliant with Washington State’s Clean Energy Transformation Act

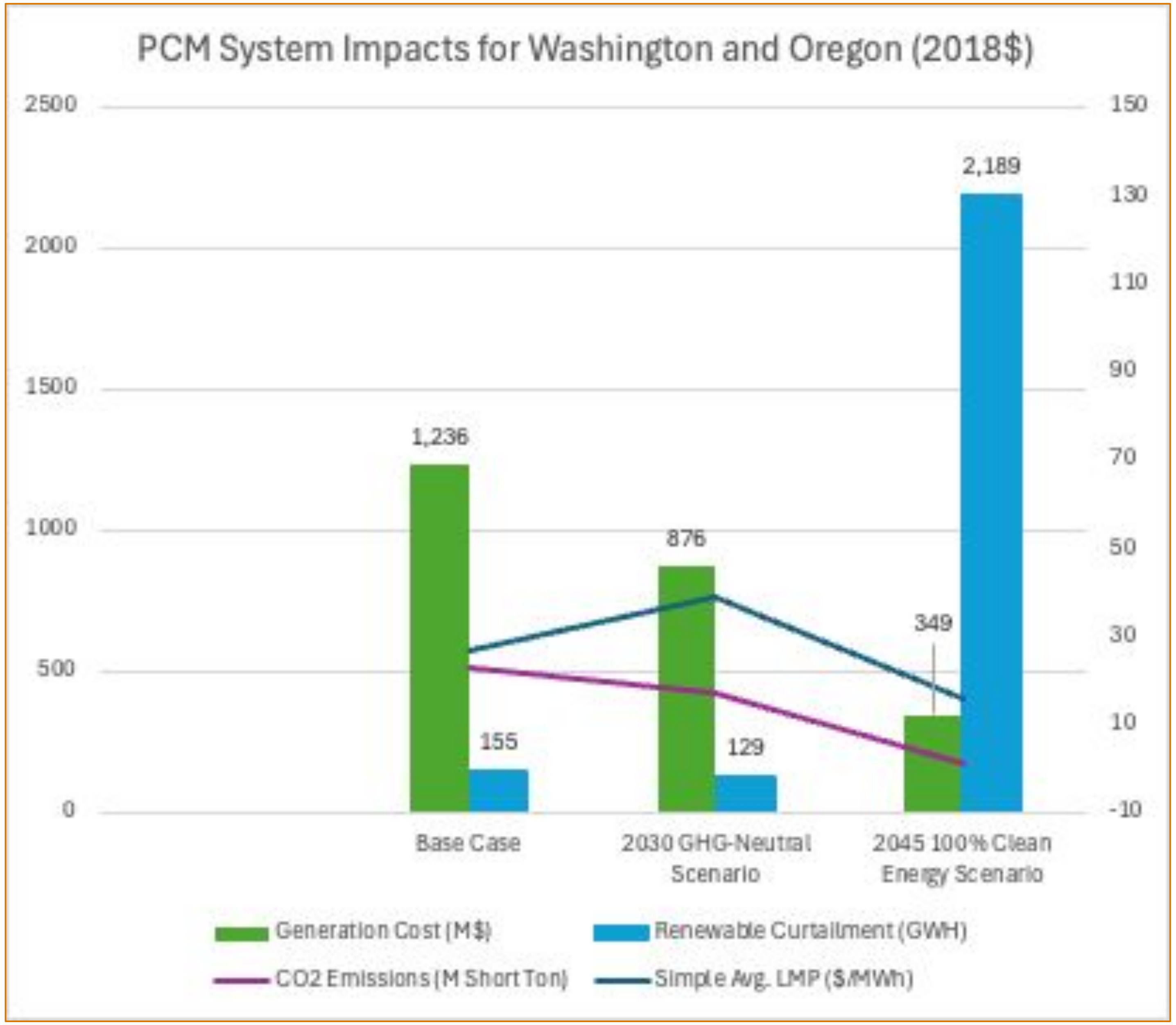
Base Case	2030 GHG Neutral Case	2045 100% Clean Energy Case
2028 WECC ADS • Onshore Wind: 3,025 MW • Conventional Nuclear: 1,170 MW	2028 WECC ADS + Penalties • \$150/MWh (Coal) • \$60/MWh (NGCC) • Onshore Wind: 3,025 MW • Conventional Nuclear: 1,185 MW • **100 MW SHR EGS** • **320 MW ANR**	2028 WECC ADS + • 100% Clean Energy Serving WA Load • Onshore Wind-6,221 MW Serving Load • Conventional Nuclear-1,170 MW • **1 GW SHR EGS** • **3 X 320 MW ANR** • **Additional 2,880 MW ANR**

SMRs added at existing sites. New wind power supply added in the Lower Snake River region, along the Columbia Gorge, and on the west side of the Cascades. New wind power supply from Montana (winter peaking) added and assumed to serve Washington load. Solar PV added along the Lower Snake region, in the Hanford site area, and the retired Centralia coal plant site area. Four-hour battery energy storage distributed with added solar generation. New, closed-loop pumped storage hydropower added on the east side of the Cascades (where surplus wind and solar exist), as well as along the Columbia Gorge and Mid-Columbia area.

Power Systems Analysis

Production Cost Modeling

- Inputs to the model include detailed cost and operational data (including those estimated for new, flexible generation technologies)
- Adjusted the PCM, a linearized DC optimal power flow model, to reflect our future resource mix scenarios and evaluated results for several criteria including unserved load, production costs, carbon emissions and costs, and renewable curtailments



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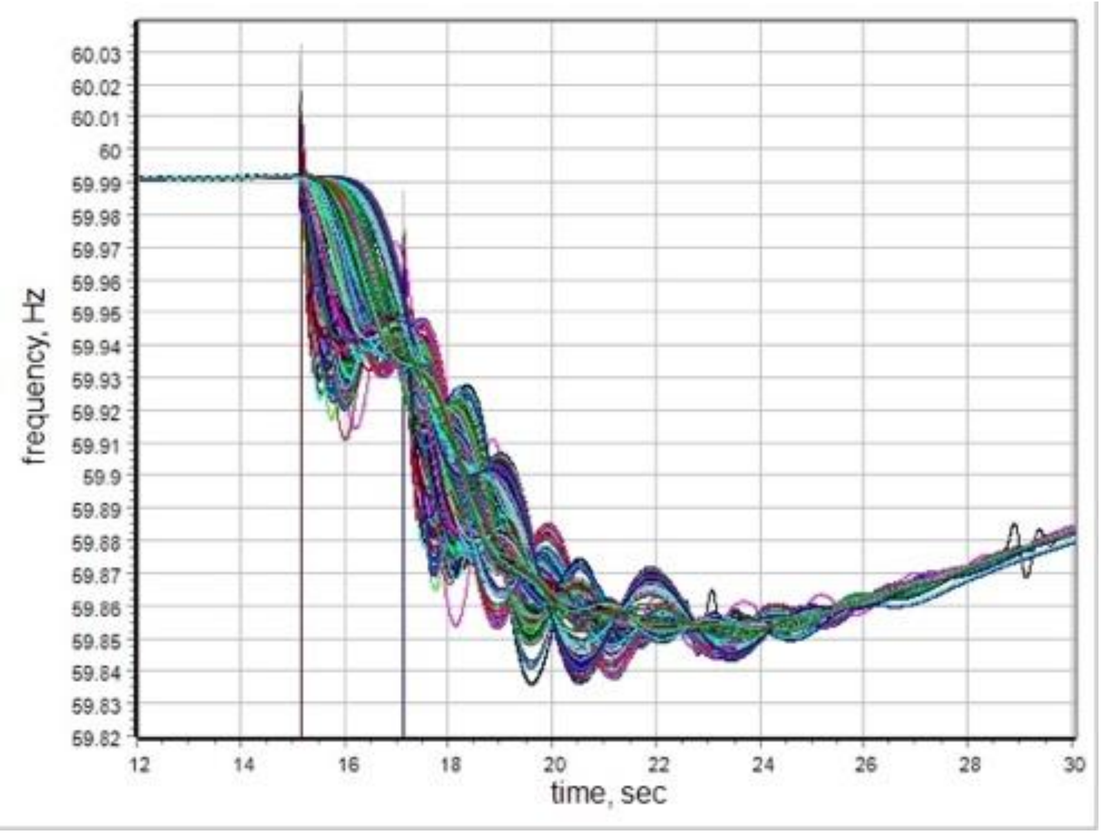
Power Systems Analysis

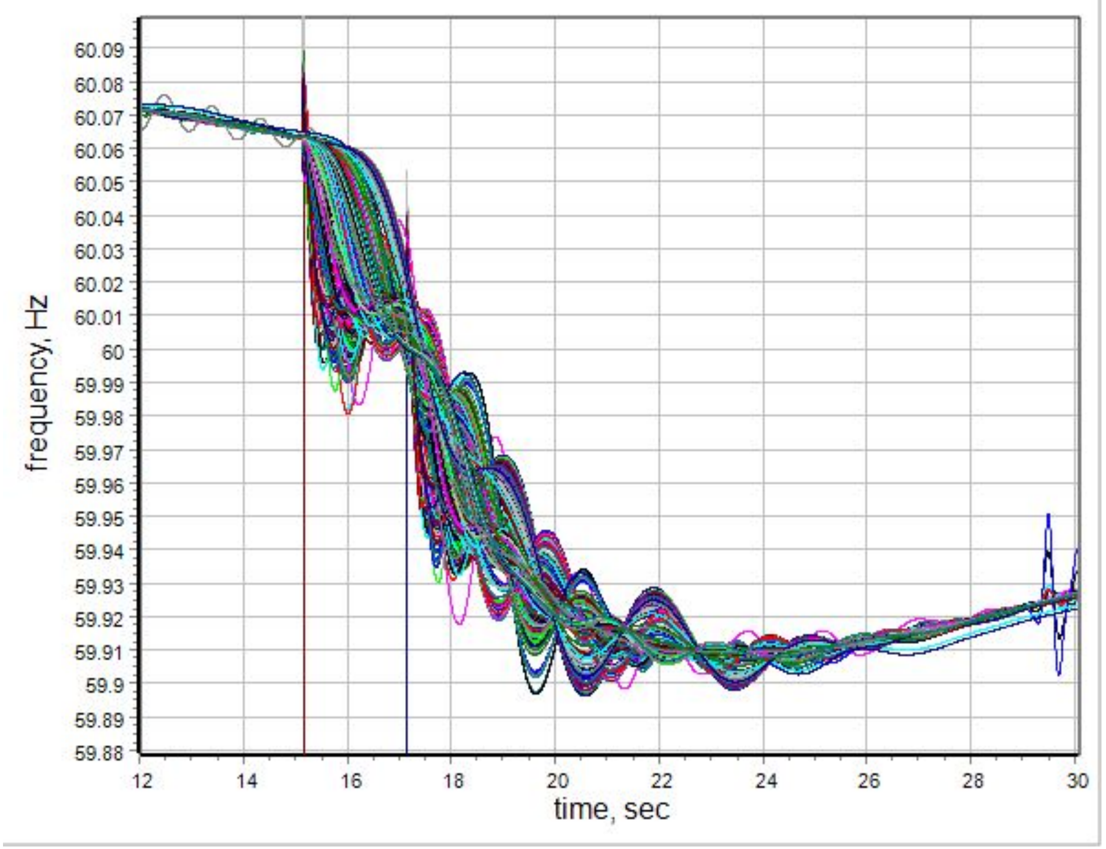
Transient Stability Analysis

- Expose the system to a large N-2 contingency
- Observe the response of the system
- Compare the response of the system with and without SMRs and SHR EGSs
- Compare the response of the system with and without a large addition of renewables
- Inertia and frequency response characteristics improved, and voltage profile remained stable

Frequency Response: Base Case

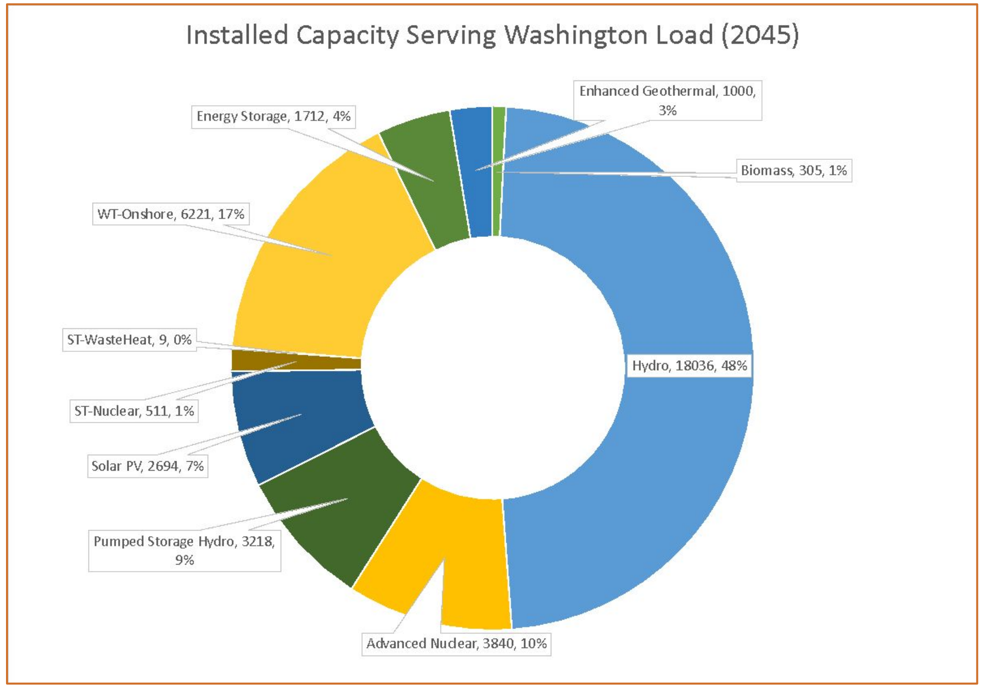


Frequency Response: Added 1960 MW SMRs / EGS



Economic Feasibility

- Examined economic feasibility by generator type
  - Were revenues earned sufficient to cover variable O&M and fuel costs?
  - Were revenues earned sufficient to cover total costs (LCOE)?



Small Modular Reactors require a capacity payment of up to $12 (unsubsidized) in 2030. Capacity payments increase from $26 (subsidized) to $38 (unsubsidized) in 2045

Conclusion

- Our research contributes to our understanding of the economic feasibility and stability of the future research mix
- We also consider the role and economic feasibility of two future technologies that could provide valuable flexibility services to the future resource mix
- More detailed analyses could incorporate:
  - Transmission upgrades to better integrate renewable power
  - Development of a bid-based model to analyze potential price and revenue impacts to address inherent limitations of the development of prices (based on production costs and system constraints)

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Thank you

Brittany Tarufelli
Brittany.Tarufelli@pnnl.gov