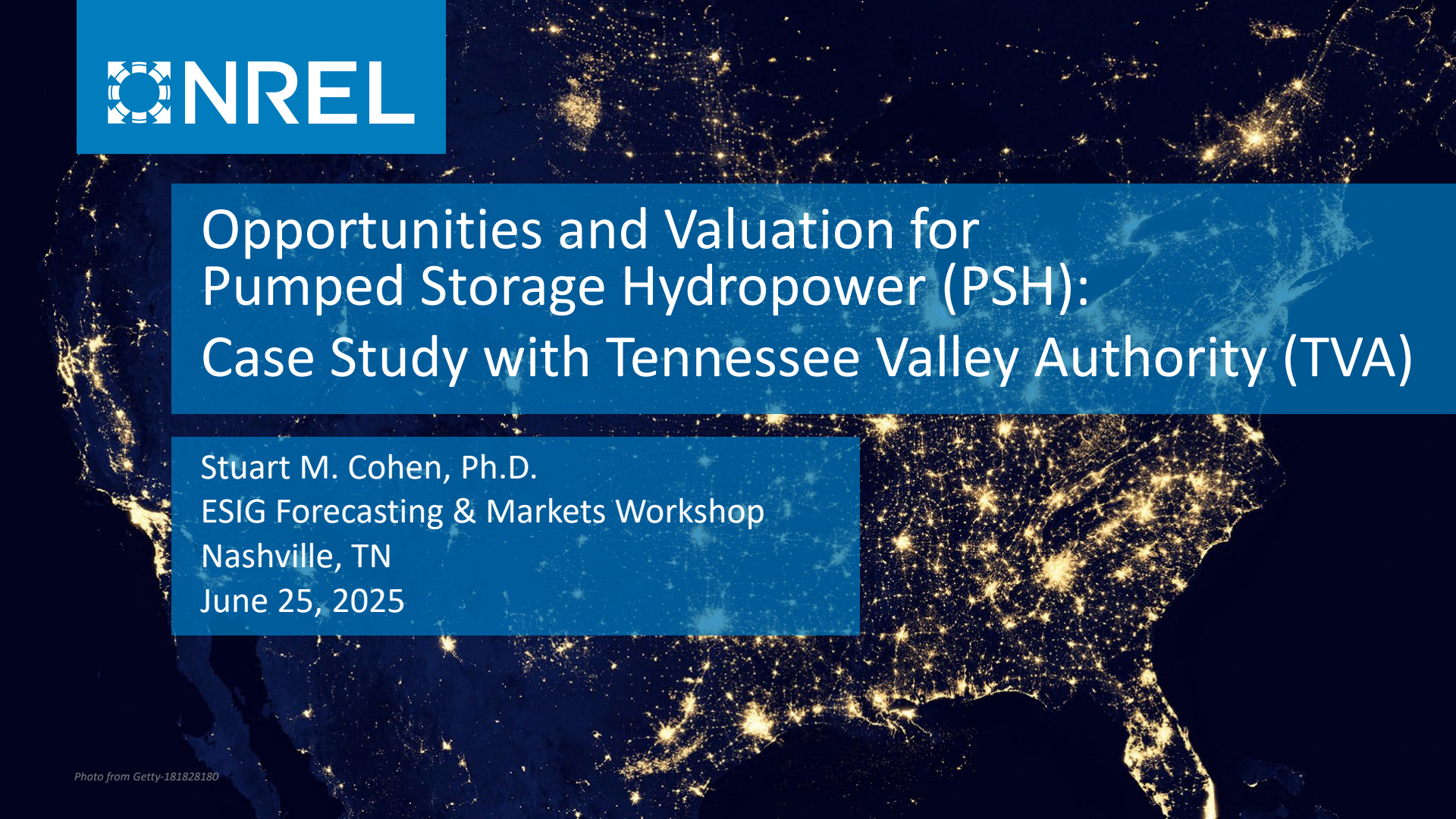


Opportunities and Valuation for Pumped Storage Hydropower (PSH): Case Study with Tennessee Valley Authority (TVA)

Stuart M. Cohen, Ph.D.

ESIG Forecasting & Markets Workshop
Nashville, TN
June 25, 2025

Photo from Getty-181828180

Contents

Motivation and Challenges for PSH Valuation

Why PSH?

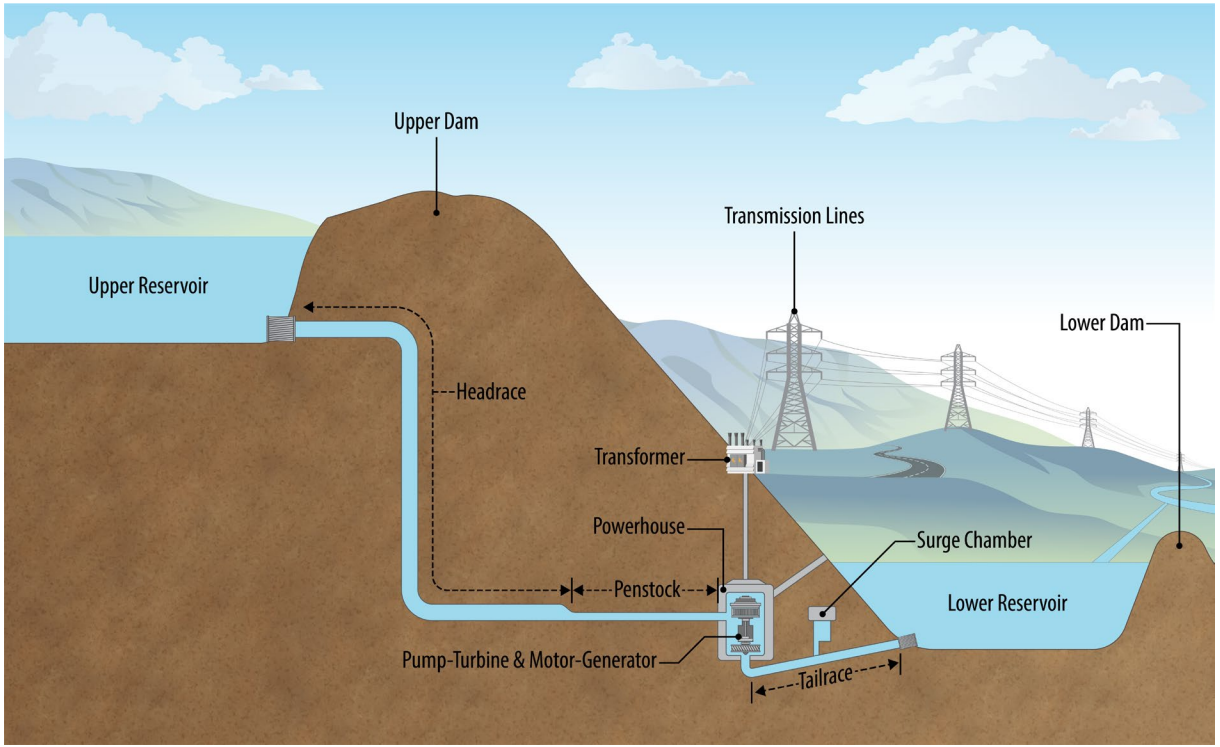
PSH is a Proven Long-Duration Storage Technology

22 GW existing PSH provides 96% of U.S. utility scale storage energy capacity and 70% power capacity.

PSH is the only widely deployed utility-scale long-duration (>10 hr) energy storage solution.

The U.S. development pipeline includes 99 GW with 1.9 GW in planning/construction (end of 2023), and over 50 GW is under construction globally.

Sources: 2023 and 2024 ORNL Market Reports



Credit: Besiki Kazaishvili, NREL

PSH Provides a Full Suite of Grid Services

Fast ramping, multiple units, and mode switching provides substantial energy flexibility.

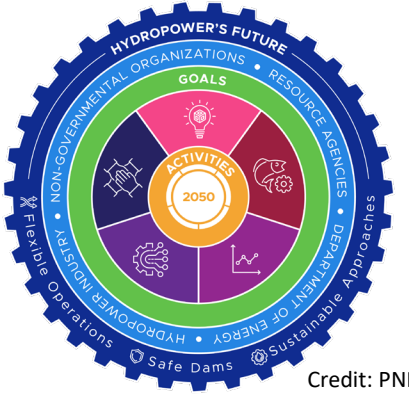
Fixed-speed pumps have operating limitations while pumping.

Variable-speed and ternary pumps allow frequency & voltage services while pumping.

Category	Service
Bulk	Capacity
	Energy
Frequency Response	<1s
	1s to 30s
	30s to 5 min
Reserves	Spinning
	Non-spinning <15min
	Non-spinning>15min
Ramping	Up
	Down
Voltage	Volt/VAR Control
System Restoration	Black Start

Valuation is a Key Challenge for the PSH and the Broader Hydropower Industry

- The U.S. Dept. of Energy & Natl. Labs worked across the hydropower industry to identify action areas, goals, and activities for the hydropower industry in the *Reimagined Hydropower Vision Roadmap*
- Improved Valuation is one of 5 core roadmap areas.



Credit: PNNL

Improved Valuation Area and Goals	
Service Value Recognition	Power and non-power services are understood and valued
Service Compensation	Service compensation is commensurate with the value provided
Financing Support	Projects can access financing based on the services and value provided

https://hydropowervision.pnnl.gov/

Data and Tools to Support PSH Valuation

What is NREL doing about it?

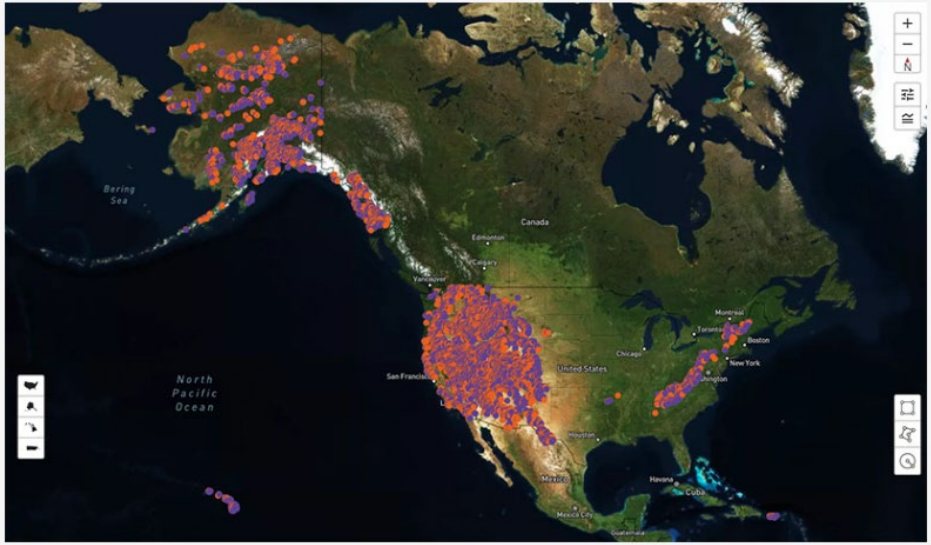
PSH Resource Assessment Data Demonstrates Potential and Helps Site Identification

- Geospatial analysis identifies potential sites based on topography, land use, design specifications, and cost.
- Data includes closed-loop sites, add-ons to existing reservoirs, and mine pit opportunities.
- Data can be explored and downloaded with an interactive web tool
- US has **>80 TW** technical potential including AK, HI, PR

Pumped Storage Hydropower Supply Curves

NREL has developed an interactive map and geospatial data showing pumped storage hydropower (PSH) supply curves, which characterize the quantity, quality, and cost of PSH resources.

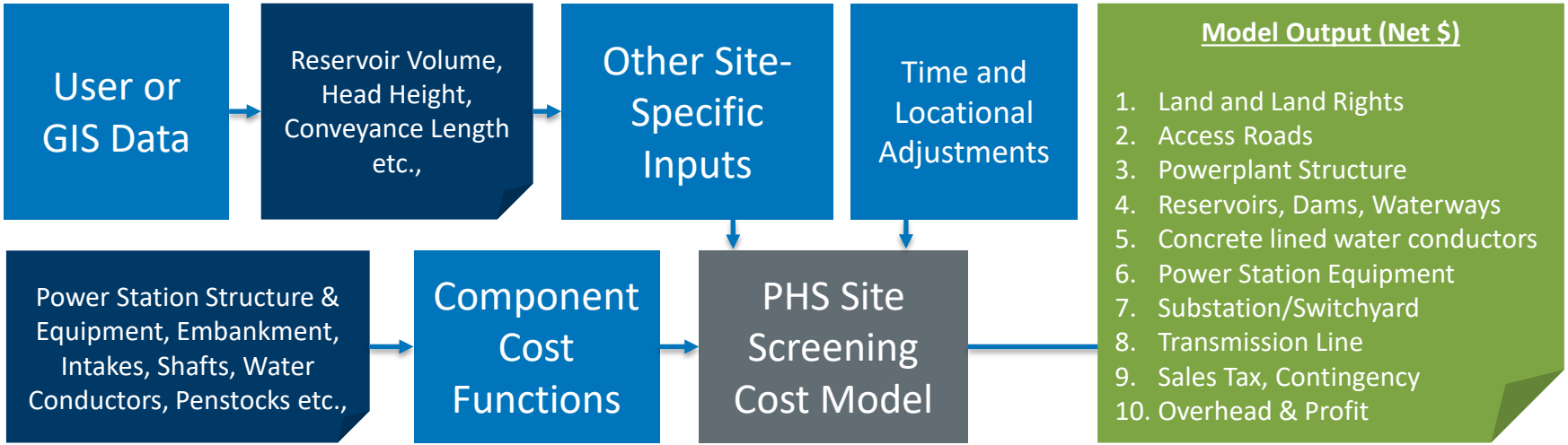
Interactive Map and Geospatial Data



The PSH geospatial data include storage duration, paired reservoir volume, capacity, distance between reservoirs, head height, transmission spurline distance, transmission spurline costs, and total cost. Data can be downloaded directly from the interactive map.

https://www.nrel.gov/gis/psh-supply-curves.html

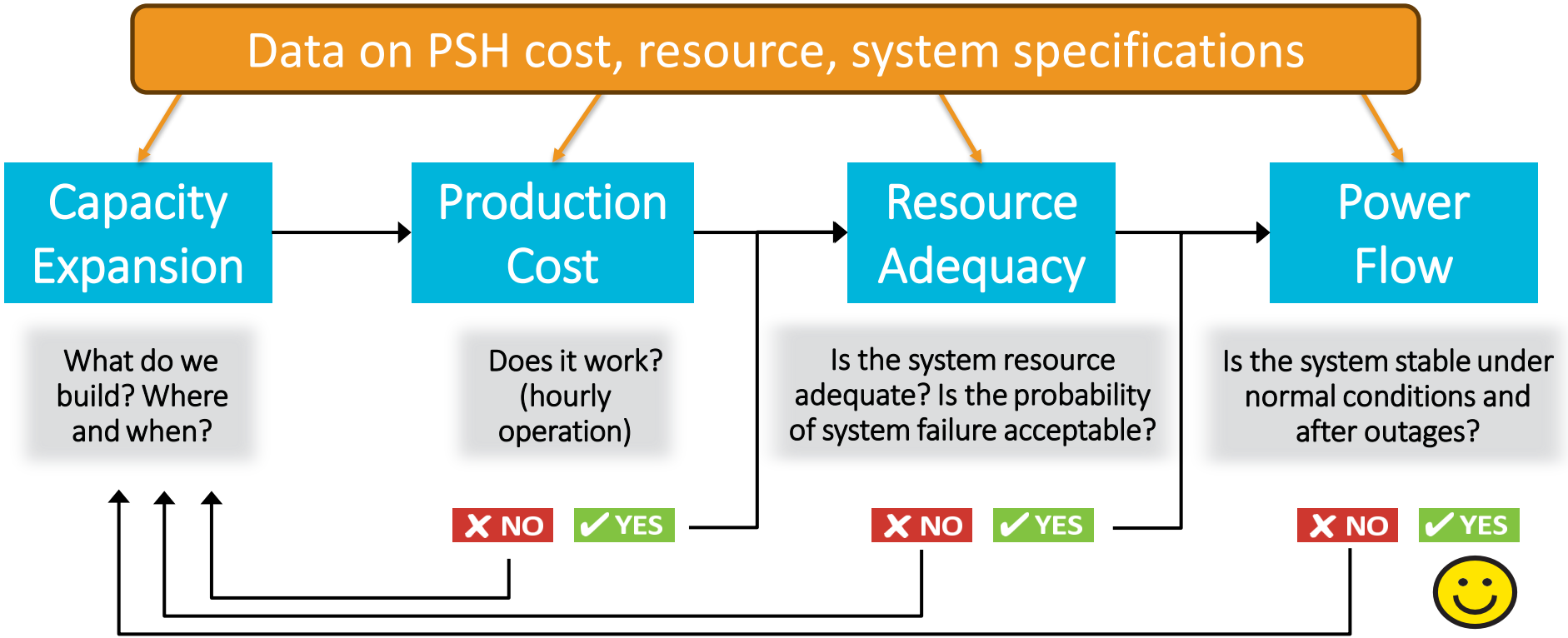
Site-Level Bottom-Up Capital Cost Modeling Facilitates Cost-Value Analysis



- Overnight capital cost is calculated for each site in the resource assessment from several component cost categories.
- Calculations uses site specifications, design assumptions, and industry-vetted formulas and data (e.g., from EPRI, HDR Inc.).
- The model is available as a downloadable spreadsheet (web app in development).

https://www.nrel.gov/water/pumped-storage-hydropower-cost-model.html

PSH Cost, Resource, and System Specifications Enable Value Assessment With Analytical Tools



TVA PSH Valuation Case Study

What does this look like?

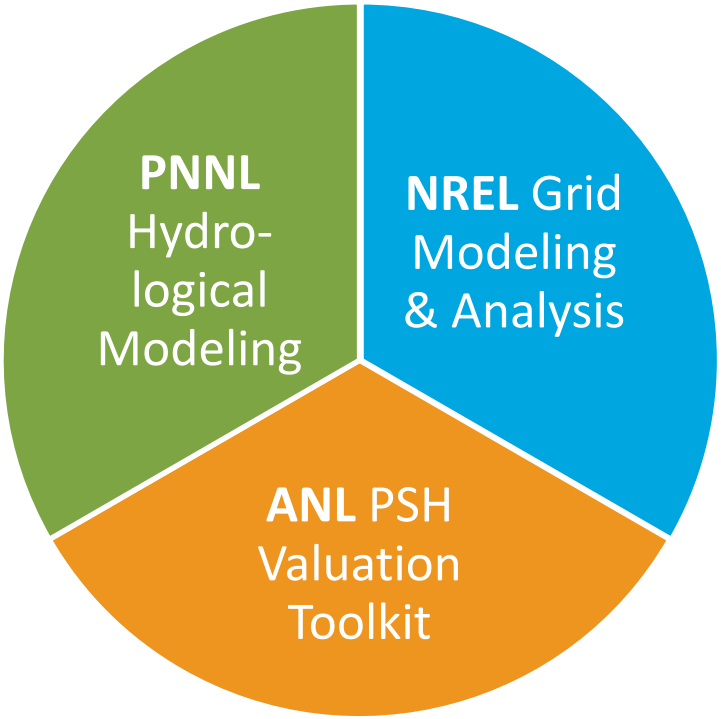
TVA Sought Dept. of Energy (DOE) National Lab Assistance to Value Potential New PSH Assets

Motivation: Vertically integrated utilities have difficulty valuing and justifying PSH despite its potential to provide flexibility and reliability.

Objective: Utilize state-of-the-art DOE lab tools and expertise for PSH valuation, grid modeling, and water modeling to improve utility PSH valuation practices.

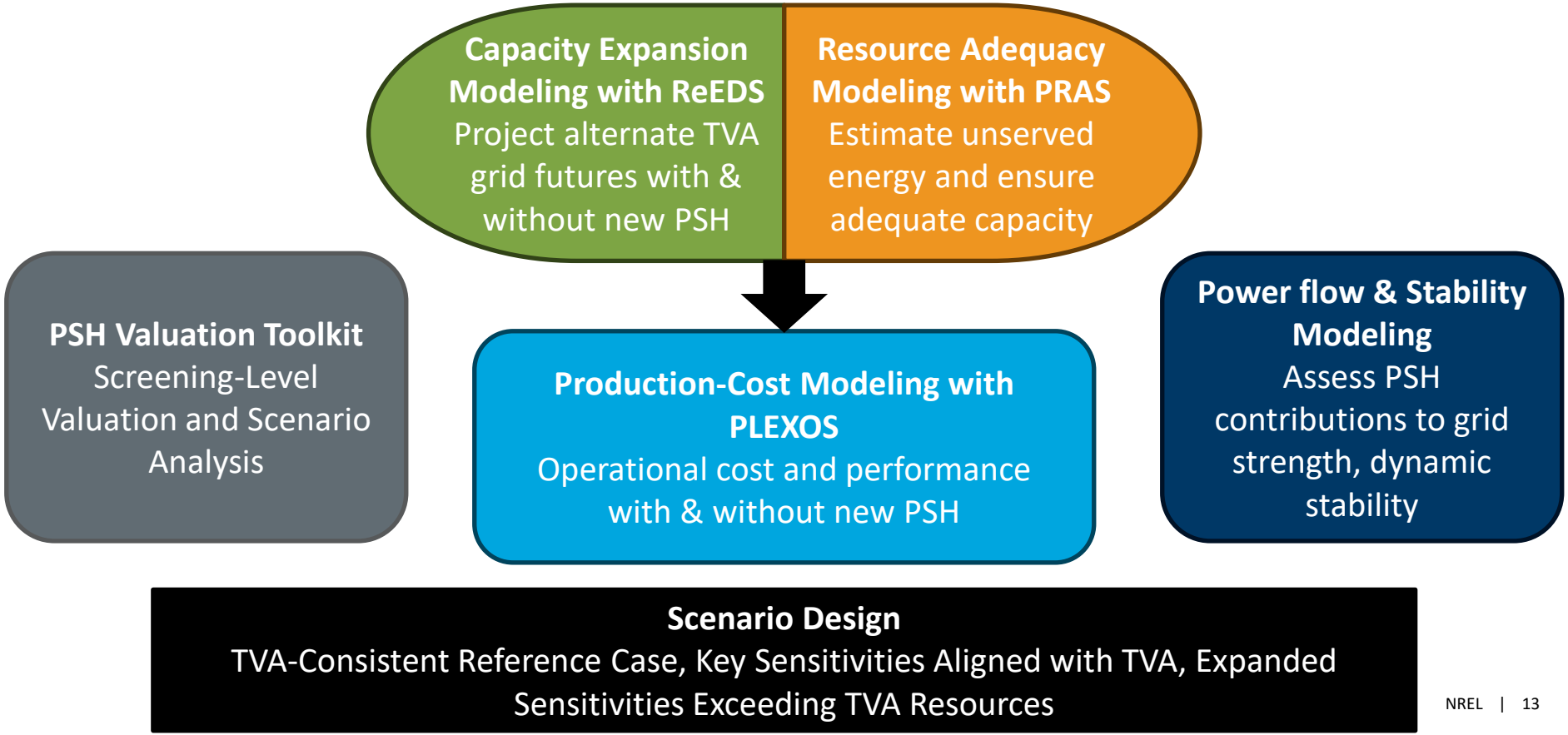
Approach: (1) Review utility modeling approaches (2) Conduct integrated grid modeling and PSH valuation to compare with TVA valuation.

Funding: DOE Water Power Technologies Office Technical Assistance Lab Call



PNNL = Pacific Northwest National Laboratory
ANL = Argonne National Laboratory

Integrated Grid Modeling Helps Capture Cumulative PSH Value Stack



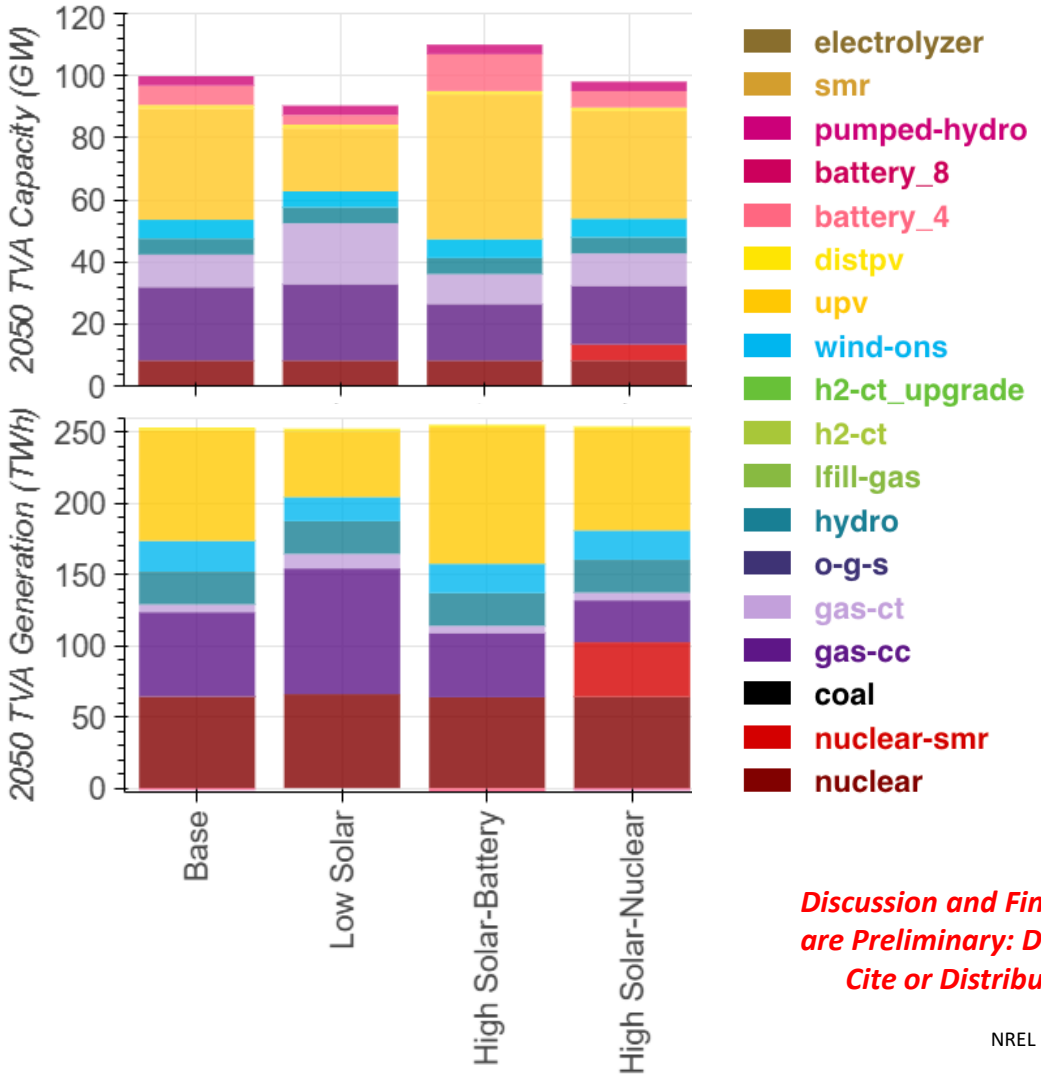
Alternative Technology Portfolios Vary Gas, Nuclear, and Renewable Shares

Scenarios are defined by varying fuel prices, technology costs, and deployment limits.

Utility solar deployment is 20—47 GW in 2050 scenarios shown (a lower solar case is in development).

Relative shares of gas, nuclear, and solar depend on fuel and technology cost assumptions.

Generation mix and underlying cost assumptions affect value from cost savings.



Discussion and Findings are Preliminary: Do Not Cite or Distribute

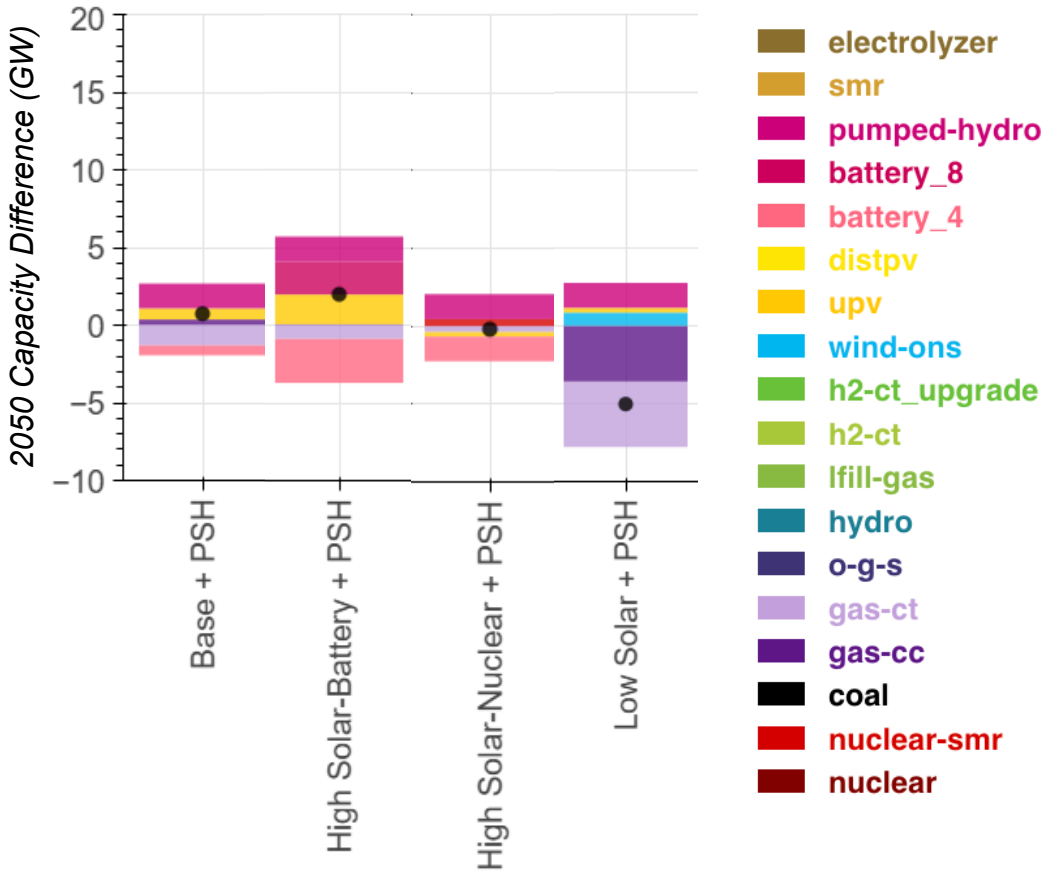
System Outcomes are Compared With and Without the New PSH in 2035

Market drivers influence how new PSH impacts the grid mix.

- Displaces gas, battery
- Complements nuclear, solar

Infrastructure changes characterize PSH impacts on investment costs.

Cost impacts will inform detailed financial analysis.

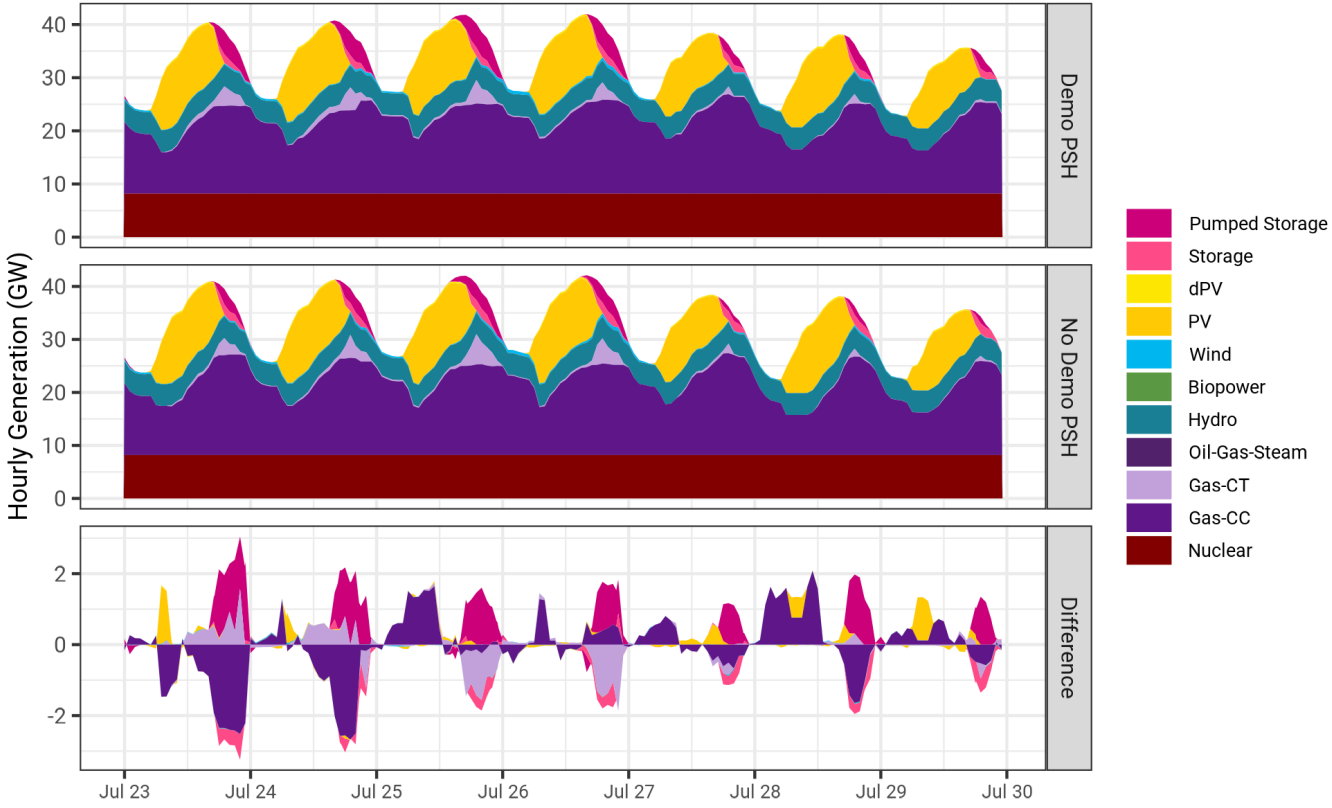


Hourly Operations of Future Infrastructures are Being Examined in PLEXOS

PLEXOS uses detailed operating parameters in 8760-hour dispatch solutions.

In 2044 Base case, PSH primarily generates in evening hours.

Key metrics will include operating costs, unserved energy, & curtailment.



Discussion and Findings are Preliminary: Do Not Cite or Distribute

Preliminary Stability Analysis is Quantifying PSH Contributions to Stability Services

PSS®E model is provided by TVA

Analysis cases compare peak load operations without new PSH to system with new PSH in pumping mode.

Stability Service	Variable-speed PSH Pumping Mode		
	Capability	Dynamic Performance	
Voltage Support	532 Mvar	660 Mvar	
Inertia Response	8200 MW	**Generation Loss (MW)**	**PSH Inertia Response (MW)**
		662	17
		1324	49
		1986	68
Droop Response	0.816	**Generation Loss (MW)**	**PSH Primary Freq. Response (MW)**
		662	5.2
		1324	11.6
		1986	17.8

Key Takeaways

1. PSH is an established storage solution, but service valuation and compensation creates challenging deployment prospects.
2. New NREL data and tools are publicly available to help examine PSH cost-value tradeoffs.
3. Research-grade national lab capabilities can expand upon utility economic analysis to demonstrate PSH and other storage value propositions across broad scenario ranges.

Thank You

Stuart.Cohen@nrel.gov

This work was authored by the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Water Power Technologies Office and the Tennessee Valley Authority. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from Getty-181828180

NREL