HydroVision INTERNATIONAL

ENVISIONING A HYDRO FUTURE

NREL Transforming ENERGY

# Grid Integration and Market Analysis of Adjustable-Speed Pumped Storage Hydropower

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# NREL at a Glance

**2,200**

**Employees,**

including postdoctoral researchers, interns, visiting professionals, and subcontractors

**World-class**

facilities, renowned technology experts

**over 800**

**Partnerships**

with industry, academia, and government

**Campus**

campus operates as a living laboratory

**$400M+ annually**

**Approximate Operating Budget**

# How Valuable is Adjustable-Speed Pumped Storage Hydropower?

**Situation**

Variable renewable energy is increasing, affecting variability and range of energy prices and requiring extra power system flexibility

**Opportunity**

Adjustable-speed pumped storage hydropower (AS-PSH), can provide value to ancillary service markets and take benefit of energy arbitrage

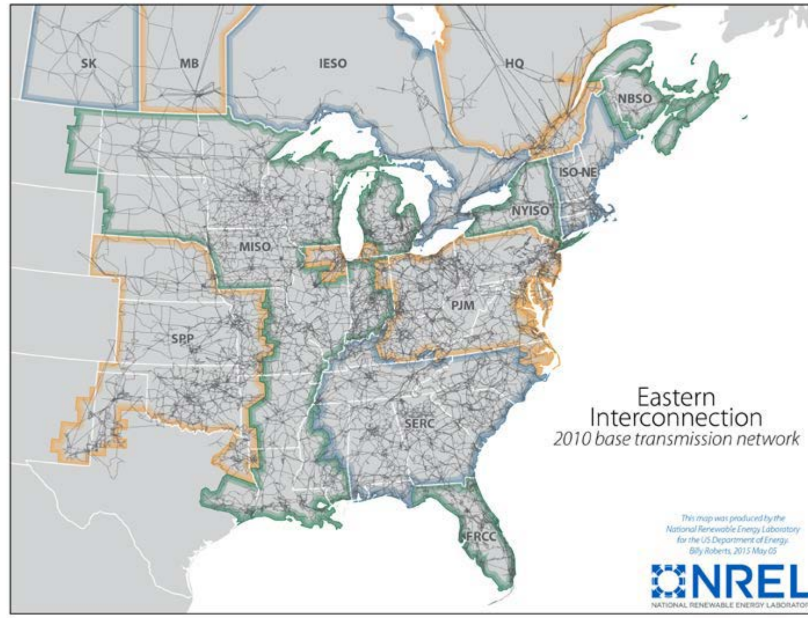
**Research**

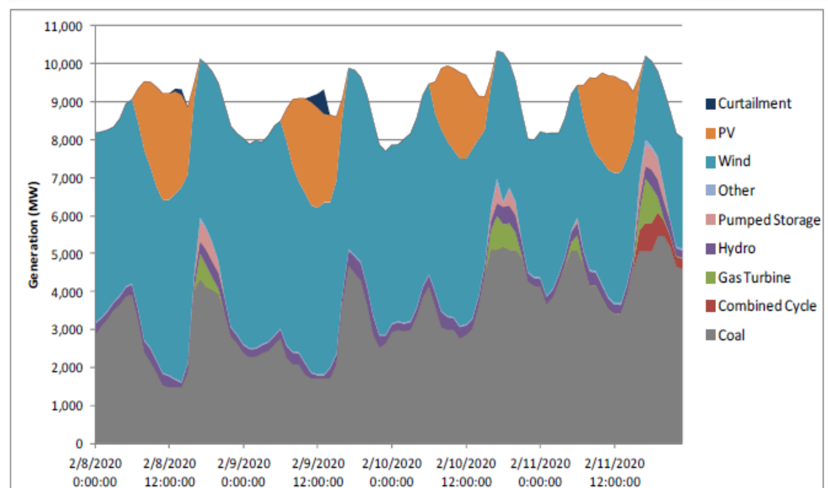
Present results from production cost models showing the effects of adding 50 MW of AS-PSH to three Independent System Operators (ISOs)

# Production Cost Modeling

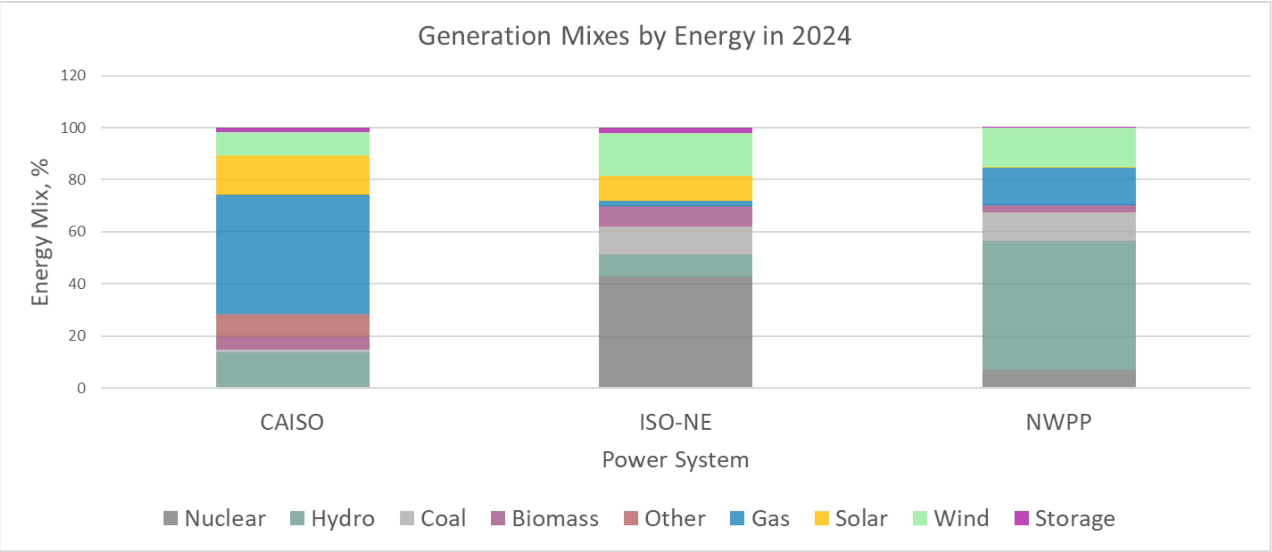
- Hourly or sub-hourly chronological
- Commits and dispatches generating and storage units based on:
  - Electricity demand
  - Operating parameters of generators and storage units
  - Transmission grid parameter
  - Reserve requirements

- Outputs for all generation, storage and transmission objects, including:
  - Generation profiles, start & shutdown costs, curtailment, emissions Reserve shortages and provision
  - Storage levels and operational profiles
  - Line and interface flows and congestion
  - Local marginal prices, unserved and dump energy



# Regions Modeled and Methodology




- Modeling 2024
- Minimizing total production cost
- Added AS-PSH can provide all modeled reserve services, as well as perform energy arbitrage

Independent System Operator for New England (ISO-NE)

- 3327 nodes with thermal transmission constraints activated
- Contingency Spinning Reserve – 10-minute timeframe, 824MW
- Regulation up / down reserve – based on wind power forecast errors and a load component

Californian Independent System Operator (CAISO) and North West Power Pool (NWPP)

- Flexibility reserve – based on wind power and solar power forecast errors and load forecasts
- Spinning reserve – 10-minute timeframe, 3% of regional load

# Further Methodology

1 Linear run of WECC Day step-size

2 MIP – Day Ahead

Non-focus regions take generation and inter-regional transmission flows from step 1

Day step-size with 1 day look-ahead of 4 hour resolution

Day ahead wind and solar forecasts

3 MIP – Real Time

Unit Commitment taken from the day ahead for all generation, except for solar, wind and combustion turbines

5 minute step-size with 1 hour look-ahead, or 1 hour step-size

Real time wind and solar profiles

- CAISO and NWPP were taken from a larger study, Low Carbon Grid Study
- Save run-time and improve fidelity

For all three modeled regions:

1. Simulate the base case
2. Add the AS-PSH unit and simulate again
3. Compare differences

# The AS-PSH Turbine

| Property | Value |
|---|---|
| Generation Capacity | 50 MW |
| Pumping Capacity | 50 MW |
| Storage Quantity | 12 hours |
| Round Trip Efficiency | 80 % |
| Ramp Rate | Infinite |
| Variable Operational and Maintenance Cost | 0, $ |
| Minimum Generation Level | 0 MW |
| Minimum Pumping Level | 0 MW |

Note: The production cost model optimizes each time-step as a mixed integer linear program, MILP. In CAISO, 8 turbines were added; following results are all for a single turbine.

Minimizing system cost – we can analyze production cost and curtailment savings.

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| Region | Day-Ahead | Real-Time | Day-Ahead | Real-Time |

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | | | | |
| ISO-NE (modeled with transmission constraints) | | | | |
| NWPP (modeled with no transmission constraints) | | | | |

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | Negligible | | | |
| ISO-NE (modeled with transmission constraints) | Negligible | | | |
| NWPP (modeled with no transmission constraints) | Negligible | | | |

"Negligible" refers to results within the error tolerance.

The day-ahead has a 24-hour foresight.

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | Negligible | | Negligible | |
| ISO-NE (modeled with transmission constraints) | Negligible | | None | |
| NWPP (modeled with no transmission constraints) | Negligible | | None | |

ISO-NE and NWPP had no curtailment in the base case. CAISO did, due to a high penetration of variable renewable energy.

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | Negligible | Negligible | Negligible | |
| ISO-NE (modeled with transmission constraints) | Negligible | | None | |
| NWPP (modeled with no transmission constraints) | Negligible | Negligible | None | |

Storage is a net-user of energy and generally adds production cost, unless there is significant variation of prices (energy arbitrage) or reserve shortage.

Running as a single region suppresses prices.

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | Negligible | Negligible | Negligible | |
| ISO-NE (modeled with transmission constraints) | Negligible | 2,850,000 – 5,293,000 | None | |
| NWPP (modeled with no transmission constraints) | Negligible | Negligible | None | |

The AS-PSH unit can contribute to reserves in the real-time market.

Variable renewable energy forecast errors encourage higher reserve provisions.

As ISO-NE is multi-nodal, the analysis was done for a selection of nodes.

# Results

| | Production Cost Saving, $ | | Curtailment Saving, % | |
|---|---|---|---|---|
| **Region** | **Day-Ahead** | **Real-Time** | **Day-Ahead** | **Real-Time** |
| CAISO (modeled with no transmission constraints) | Negligible | Negligible | Negligible | Saves 1.3% compared to Base |
| ISO-NE (modeled with transmission constraints) | Negligible | 2,850,000 – 5,293,000 | None | Negligible |
| NWPP (modeled with no transmission constraints) | Negligible | Negligible | None | Negligible |

CAISO experiences significant curtailment in the real-time market.

Due to an ability for variable pumping output, the AS-PSH unit absorbs this well.

# Conclusion

ISO-NE saw large savings in production costs. With the additional value of load-shifting, this production cost saving would be potentially even higher.

The flexibility of NWPP in 2024 is expected to be sufficient, without considering transmission constraints.

In CAISO, the pump turbine provides system value, which is expected to increase as variable renewable energy penetration increases.

# Thank you,

Any Questions?

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# Results – ISO-NE Nodal

| | Production Cost for All Regions from Real-Time ($000) | | |
|---|---|---|---|
| Node | Base | Pump Turbine | Savings |
| Highest load | 6,354,238 | 6,351,126 | 3,112 |
| Day-ahead highest peak price | 6,354,238 | 6,348,945 | 5,293 |
| Large wind power plant | 6,354,238 | 6,349,712 | 4,526 |
| Day-ahead highest energy generated | 6,354,238 | 6,350,251 | 3,988 |
| Real-time highest peak price | 6,354,238 | 6,351,388 | 2,850 |

Real-time – therefore all reserve contribution.

Order of savings magnitude is the same as the order of reserve provision met.

# Results – ISO-NE Nodal

| Node | Up-Regulation Reserve (GWh) | Down-Regulation Reserve (GWh) | Contingency Spinning Reserve (GWh) | Total (GWh) |
|---|---|---|---|---|
| Day-ahead highest load | 3.6 | 0.5 | 33.5 | 37.6 |
| Day-ahead highest peak price | 6.3 | 0.5 | 31.7 | 38.6 |
| Large wind power plant | 7.3 | 0.4 | 30.2 | 37.9 |
| Day-ahead highest energy generated | 3.8 | 0.5 | 33.4 | 37.7 |
| Real-time highest peak price | 4.6 | 0.4 | 32.3 | 37.3 |

# Price-Taker Results (400 MW)

| Turbine Type | ISO-NE Energy Arbitrage Revenue Potential, $million | | CAISO Energy Arbitrage Revenue Potential, $ | |
|---|---|---|---|---|
| | Day-Ahead | Real-Time | Day-Ahead | Real-Time |
| C-PSH | 11.8 | 39.9 | 7.7 | 50.4 |
| AS-PSH | 11.8 | 40 | 7.7 | 50.4 |