Outline

Motivation

Methods

Results: Storage dispatch

Results: Cost reductions and curtailment

Conclusions & future work
Motivation: The Renewable Electricity Futures Study (RE Futures)

This study explores the implications and challenges of very high renewable electricity generation levels—from 30% up to 90%, focusing on 80%, of all U.S. electricity generation—in 2050.

*Source: [https://www.nrel.gov/analysis/re-futures.html](https://www.nrel.gov/analysis/re-futures.html)
Motivation: Electricity storage applications and technologies

“Hydrogen-based electricity storage covers large-scale and long-term storage applications (including seasonal energy storage)” (EIA, 2015)
**Goal:**

Quantify the opportunity of utilizing flexibility from hydrogen systems to support the electric grid.

**Research Questions:**

- Is there any cost reduction opportunity for hydrogen-based seasonal energy storage in current and future U.S. power systems?
- How do the hydrogen seasonal storage technology benefits compare to the technology costs (Cost-Effectiveness)?

**Scenarios**

Renewables *(43% & 85% renewable penetration incl. large hydro)*

Sensitivities: Storage power capacity and Storage efficiency
Methods: Modeling tools for the WECC power system

System to be modeled

Optimization frameworks

Inputs: Technology costs, fuel cost, etc.

ReEDS
(Capacity planning model)

Grid resource mix

Plexos
(Production cost model)

Outputs: Dispatch order, Production cost, Value of storage, ..

Renewable penetration scenarios were drawn from the ReEDS Standard Scenarios “National RPS 80%”

WECC: Western Electricity Coordinating Council
ReEDS: Regional Energy Deployment System
RPS: Renewable Portfolio Standards
Currently considering 3 techniques for PLEXOS

<table>
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<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
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</table>
| Internal model optimization \(\text{(Plexos MT-ST decomposition)}\) | • Easy constraint formation and model implementation  
• Can leverage entire existing network model | • New feature: Must learn how to properly implement                  |
| External model optimization \(\text{(Price-taker model, e.g., RODeO)}\) | • Familiarity with model formulation | • Does not include explicit consideration for network constraints       |
| Bid price or other heuristics               | • Provides unique ways to integrate real-world decisions  
• Simple implementation                 | • Requires significant amount of time and testing to select appropriate setpoints |

Selected methods: “Internal model optimization” (preferred) & “External model optimization”

**Plexos MT:** mid-term operational planning (one-year time frame based on load duration curve)

**Plexos ST:** short-term operational optimal power flow (one-day optimization window (hourly resolution) with one day look-ahead (four-hour resolution))

**RODeO:** Revenue Operation and Device Optimization (one- or three-years optimization windows with hourly temporal resolution)
• Target penalties are used in Plexos ST to match the daily end volume targets
• Weekly or monthly target could be explored
Examined several years to understand how the system is operating.

<table>
<thead>
<tr>
<th>Target Year</th>
<th>Renewable Penetration (with large hydro)</th>
<th>Total Load (TWh)</th>
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<tbody>
<tr>
<td>2018</td>
<td>43%</td>
<td>746</td>
</tr>
<tr>
<td>2050</td>
<td>85%</td>
<td>1128</td>
</tr>
</tbody>
</table>

- Renewable penetrations: 43% and 85% driven by wind and solar
### Storage device:
- **500 MW storage with 3 months of storage duration,**
- **40% roundtrip efficiency (hydrogen-based storage),**
- **located in P10 region**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Storage device and power system</th>
<th>Modeling approach</th>
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</table>
| **2018 no-storage**       | • No seasonal storage  
                           • WECC 2018                                                           | • Plexos MT-ST                           |
| **2018 MT-ST (5% I. V.)** | • Seasonal storage @ 5% initial volume  
                           • WECC 2018                                                           | • Plexos MT-ST                           |
| **2050 no-storage**       | • No seasonal storage  
                           • WECC 2050                                                           | • Plexos MT-ST                           |
| **2050 MT-ST (5% I. V.)** | • Seasonal storage @ 5% initial volume  
                           • WECC 2050                                                           | • Plexos MT-ST                           |
| **2050 MT-ST (9.6% I. V.)** | • Seasonal storage @ 9.6% initial volume (based on RODeO)  
                           • WECC 2050                                                           | • Plexos MT-ST                           |
| **2050 RODeO-ST (9.6% I. V.)** | • Seasonal storage @ 9.6% initial volume (based on RODeO)  
                           • WECC 2050                                                           | • RODeO-Plexos ST (energy price signal and daily targets) |
Results: Price-taker dispatch based on energy price signal

- Using 3-year time frame in RODeO helps to eliminate end-effects.

P10 energy price signal for WECC 2050

RODeO dispatch based on P10 energy price signal and three years time frame
Results: Dispatch for Plexos MT-ST & RODEo-Plexos ST (WECC 2050)

- Plexos MT and RODEo optimally dispatches the storage seasonally for WECC 2050.
- There are no seasonal shifts but just diurnal storage dispatches for WECC 2018 (not shown here).
Results: Seasonal dispatch for the RODEO-Plexos ST approach
Results: Cost reductions and curtailment for each scenario

- Fuel and Start & Shutdown costs are drivers of cost reductions (regardless of the scenario).
- PV curtailment is reduced regardless of the scenario, while wind curtailment increases or decreases depending on the scenario. This is expected given the daily and seasonal patterns of solar generation profiles and the randomness of wind generation.
Conclusions & future work

Conclusions

• There are cost reduction opportunities for seasonal energy storage in the WECC 2050 power system (61% VRE penetration).

• The Plexos MT-ST modeling approach provides higher cost reductions than the RODeO-Plexos approach.

• Seasonal energy storage reduces solar PV curtailment, while wind curtailment increases or decreases depending on the scenario.

Future work

• Determine methodology for probing system impact of storage: (1) remove storage from the ReEDS grid mix, then add back in or (2) remove power generation capacity.

• Develop cost-benefit analysis: Cost reduction versus capital and operating cost for the seasonal storage device.
Thank you!
Methods: Modeling of hydrogen-based seasonal energy storage in Plexos

Pumped-storage hydroelectric (PSH) power station object is used to model hydrogen production and storage devices.