Hydrogen Energy Storage for Renewable-Intensive Electricity Grids

A WECC Case Study

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Project Structure

Investigate the feasibility and costs/benefits of hydrogen energy storage (HES)

Analyze incorporating polymer electrolyte membrane (PEM) electrolysis into a high-renewable 2050 scenario to produce low-carbon H₂ for diverse energy applications

- Integration of intermittent renewables
- Grid supply and demand shaping
- Produce low cost H₂
- Reduced cost to operate the grid
- Grid services – ramping, frequency reg, black start, spinning reserve


Methodology – Developing an economic dispatch model

• Economic dispatch is utilized to optimize the operation of a hydrogen energy storage system

• Determine what characteristics are formative in optimally operating a hydrogen energy storage system

• Analyze these characteristics and their potential impact on a transition to alternative generation integration and long-term viability of alternative transportation fuels
Western Electricity Coordinating Council

- 2 Canadian Provinces
- 14 states (whole or fractional)
- Northern Baja, Mexico
- 82.2 mil in population
- 4.7 mil km²
- 284,300MW total installed capacity
- 80% of installed US solar capacity
- 30% of installed US wind capacity
- Coal trending down
- Solar and wind trending up

2015 WECC Nameplate Capacity (MW)

- Coal 39500
- Gas 117200
- Hydro 74800
- Nuclear 7700
- Solar 8400
- Wind 24300
- Other Renewable 7000
- Thermal 5400


WECC in 2050 – High Intermittent Renewables

Average Hourly Demand: 163.9 GWh
Peak Hour Demand: 248 GWh
Modeling Parameters and Assumptions

- FCEV ≈ 8-15% of WECC PLDVs in 2050 (Approximately 6.8 million in the WECC)
- 93% transmission efficiency
- Current policy goals are met
- Hydro dispatch constrained to 10 year monthly avg flowrate and ecological regulation
- Advanced H₂ storage technology (1000USD/MWh, 10yr lifespan)
- Polymer Electrolyte Membrane Electrolyzer (640/kW, 10yr lifespan)
- Polymer Electrolyte Membrane Fuel Cell (660/kW, 10yr lifespan)
- Perfect foresight for grid operation
- No outages or malfunctioning
- No ramping constraints or minimum operating time


2050 base case modeling

COSTS AND BENEFITS OF H$_2$ ENERGY STORAGE
Comparison of base case (no storage) to HES Scenario

**Base Case**

**HES Scenario**

Both demand profiles are equal
Comparison of base case (no storage) to HES Scenario

**Base Case**

**HES Scenario**

Activity
- Demand, MWh

Generation Technology
- Wind
- Solar
- CCGT
- Gas_Combustion_Turbine
- Gas_Steam_Turbine
- Coal_Steam_Turbine
- Hydro_NonPumped
- Geothermal
- Nuclear
Comparison of base case (no storage) to HES Scenario

Base Case

HES Scenario
Comparison of base case (no storage) to HES Scenario
Comparison of base case (no storage) to HES Scenario

<table>
<thead>
<tr>
<th>Metric</th>
<th>Base Case</th>
<th>HES Scenario</th>
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</thead>
<tbody>
<tr>
<td>Carbon Intensity (g CO₂/kWh)</td>
<td>77.61</td>
<td>64.89</td>
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<tr>
<td>Fossil Fuel Emissions (Mtonnes CO₂ annual)</td>
<td>30.28</td>
<td>26.54</td>
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<tr>
<td>Curtailed Wind + Solar (TWh annual)</td>
<td>133.1</td>
<td>115.1</td>
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<tr>
<td>H₂ generated for FCEV fuel (annual)</td>
<td>0</td>
<td>477</td>
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<tr>
<td>≈ 31% curtailment</td>
<td></td>
<td>≈ 26% curtailment</td>
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<tr>
<td>≈ 4.3M FCEVs @ $4.24/kg</td>
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</tbody>
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Change in dispatch relative to base case (no HES):
- Zero-Carbon Dispatchable: 4.7%
- Renewable Intermittent: 6.3%
- Fossil: -7.2%
Flexibility in storage allows bulk of generation to come from zero-cost zero-carbon generation sources

Average carbon intensity of H₂ = 1.59 kg CO₂/kg
Preliminary Conclusions

• High renewable penetration yielding a continuous surplus of (free) electricity results in a favorable scenario for HES
• Majority of the value of HES comes from providing $H_2$ for transportation fuel
• Majority of the value of HES for arbitrage is seen in < 24hr turn around
• Increased integration of HES results in
  – reduced cost to generate through increased utilization of low cost generation sources
  – reduced emissions of greenhouse gases through increased utilization of renewable generation sources
• HES systems have the capacity to, in a high renewable grid, produce $H_2$ for millions of FCEVs at projected competitive prices to gasoline
Future Work

• Exploration of various scenarios
  – High penetration FCEVs
  – Less optimistic H₂ production scenarios
  – High efficiency / high(er) electrification
  – Cheap fossil fuels
• Comparison of various storage techniques
  – Li-ion Battery Storage
  – Compressed Air Energy Storage
Questions?

References


Low carbon transportation fuel

Average carbon intensity of H₂ = 2.14 g CO₂/kg

≈3.5M FCEVs

DoE Hydrogen Threshold Price

Market Saturation: ~6.8M FCEVs
Notable California / WECC Policies, Initiatives, and Goals

• SB32 – California Senate  
  — Reduce GHG emissions to 40% below 1990 levels by 2030  
• Zero Emission Vehicle (ZEV) Mandate – California Air Resources Board  
  — Electric vehicles representing 15% of all new vehicle sales in 2025  
• Clean Vehicle Rebate Program (CVRP)  
  — Financial incentive available to purchasers of ZEVs  
• Renewable Portfolio Standards – Senate Bill 350  
  — Public utilities must procure at least 50% of electricity from renewable sources by 2030  
• CA Energy Storage Mandate  
  — 1,325 MWh by 2024  
• California Solar Initiative  
  — 3,000MW of distributed solar by 2016  
• Net Energy Metering  
  — CA subsidies for distributed generation