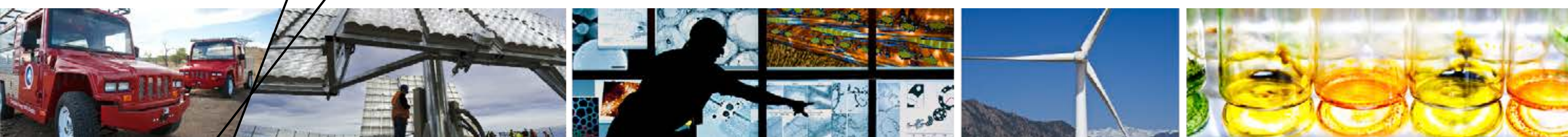
Hydrogen Energy Storage and Power-to-Gas

Establishing Criteria for Successful Business Cases



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Josh Eichman, Marc Melaina

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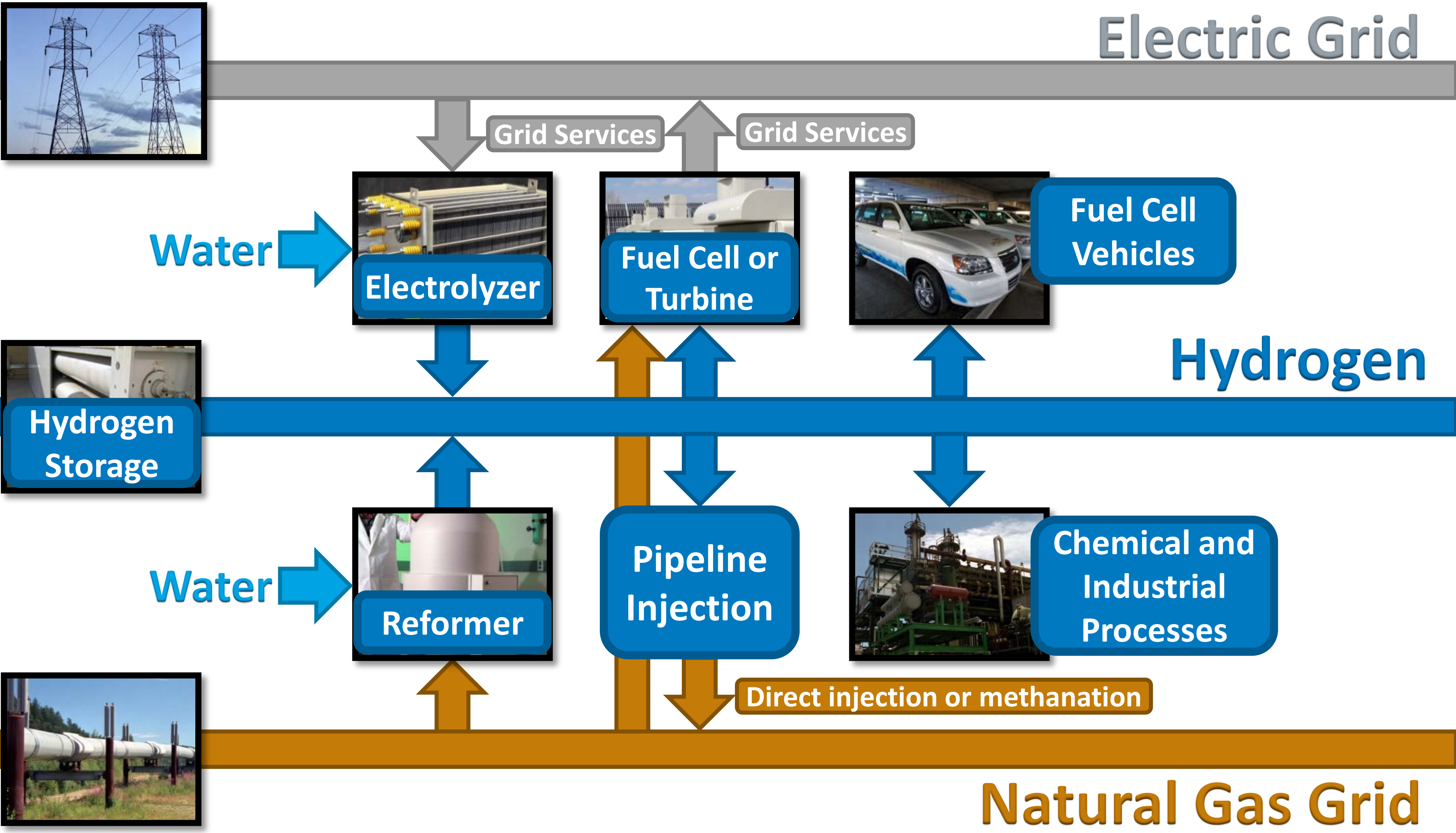
NREL/PR-5400-65386
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- Hydrogen System Configurations
- Hydrogen Storage Opportunity
- Approach
- Cost vs. Revenue Comparison
- Conclusions

Complementary Hydrogen Systems



Source: (from top left by row), Warren Gretz, NREL 10926; Matt Stiveson, NREL 12508; Keith Wipke, NREL 17319; Dennis Schroeder, NREL 22794; NextEnergy Center, NREL 16129; Warren Gretz, NREL 09830; David Parsons, NREL 05050; and Bruce Green, NREL 09408

Environmental Challenges

U.S. GREENHOUSE GAS POLLUTION INCLUDES:

CARBON DIOXIDE (CO_2) 82%

Enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees and wood products, and also as a result of certain chemical reactions (e.g., manufacture of cement).

FLUORINATED GASES 3%

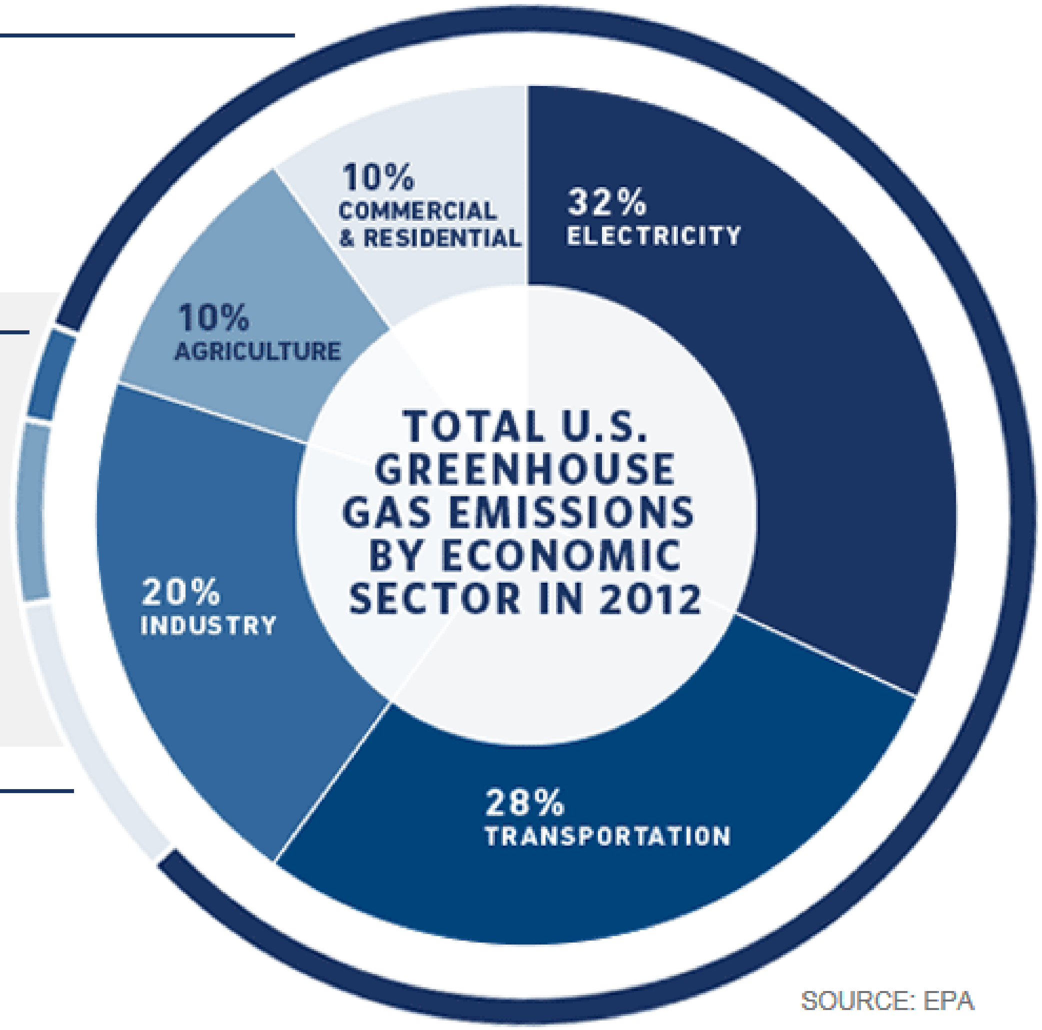
Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes.

NITROUS OXIDE (N_2O) 6%

Emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

METHANE (CH_4) 9%

Emitted during the production and transport of coal, natural gas, and oil as well as from landfills.

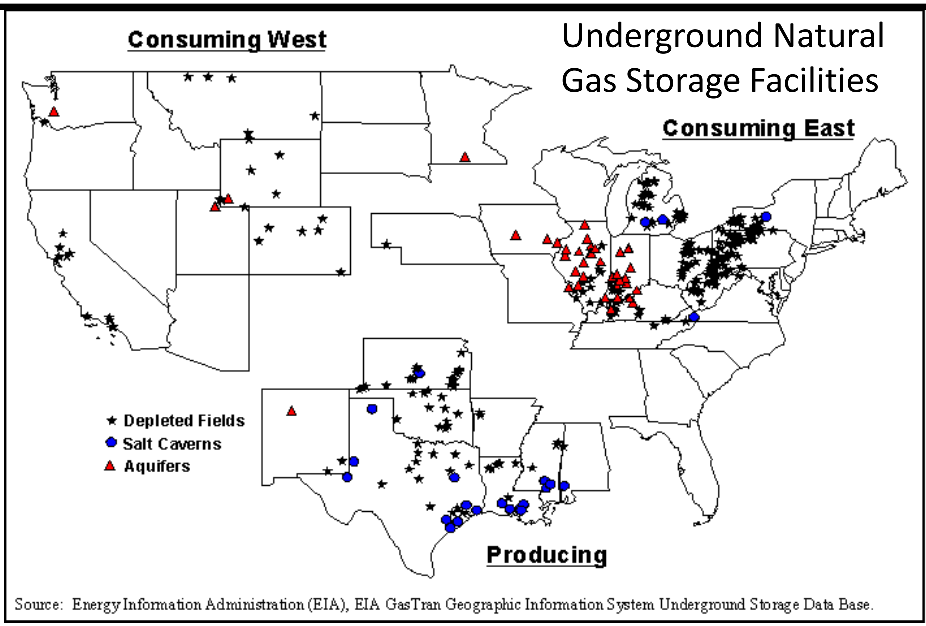


Source: www2.epa.gov/carbon-pollution-standards

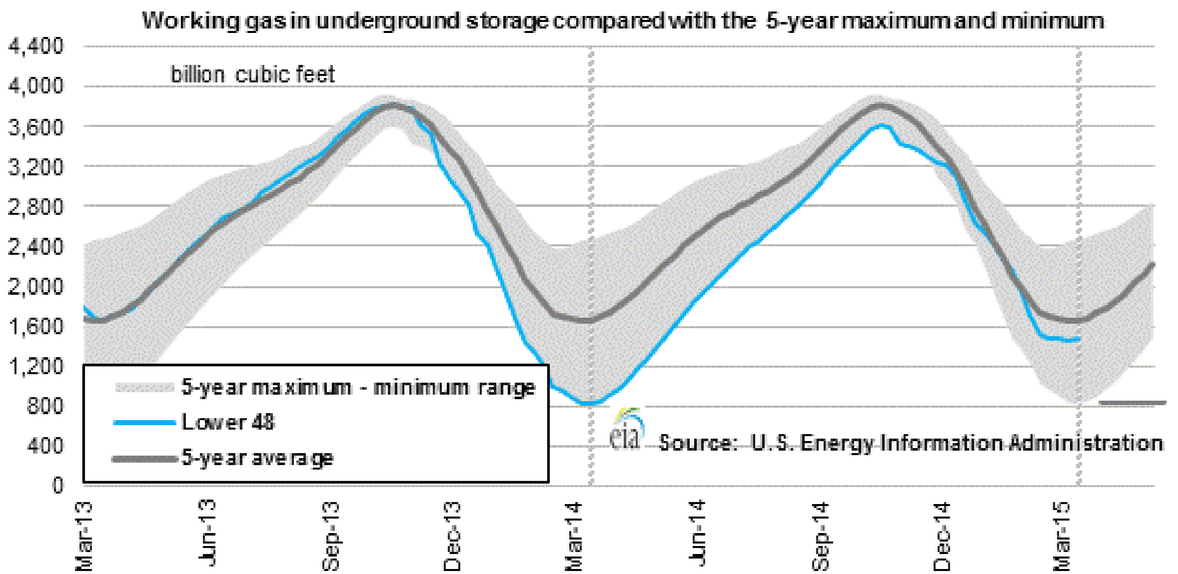
Opportunities for Power-to-gas

- **Natural Gas System**
  - 305,000 miles of transmission pipelines
  - 400 underground natural gas storage facilities
  - 3.9 Bcf underground storage working gas capacity

Source: www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/index.html



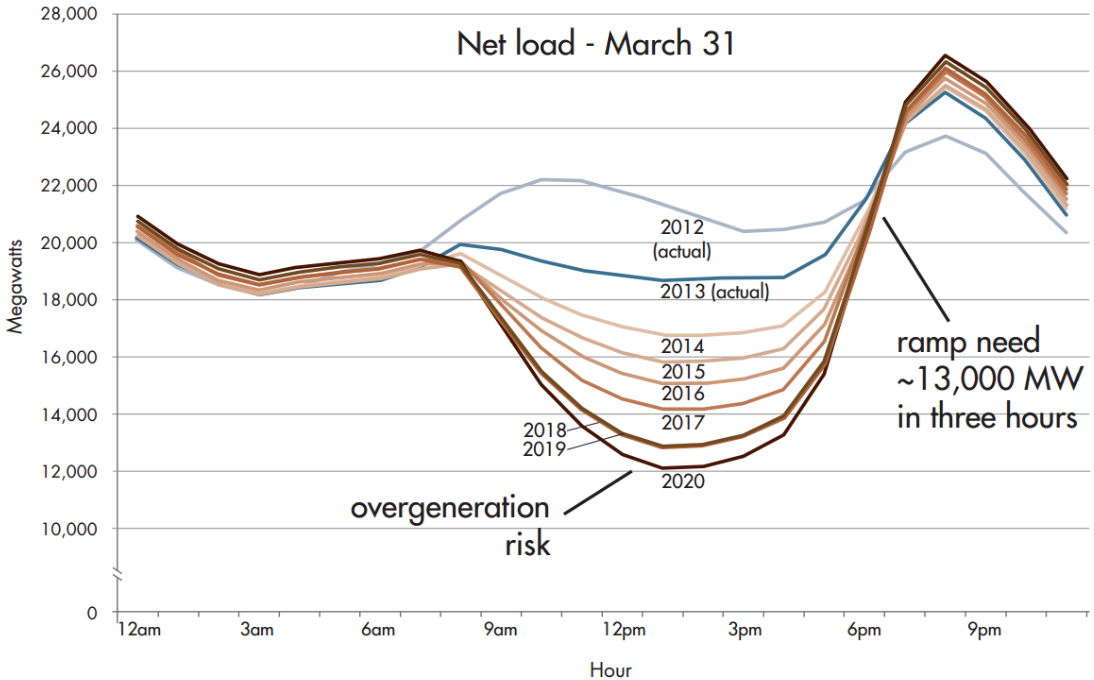
- **Storage equates to…**
  - ~60days of NG use across the U.S.



Impacts with high renewables

- **Challenges**
  - Increased ramping needs
  - Risk of overgeneration
  - Maintain sufficient system capacity

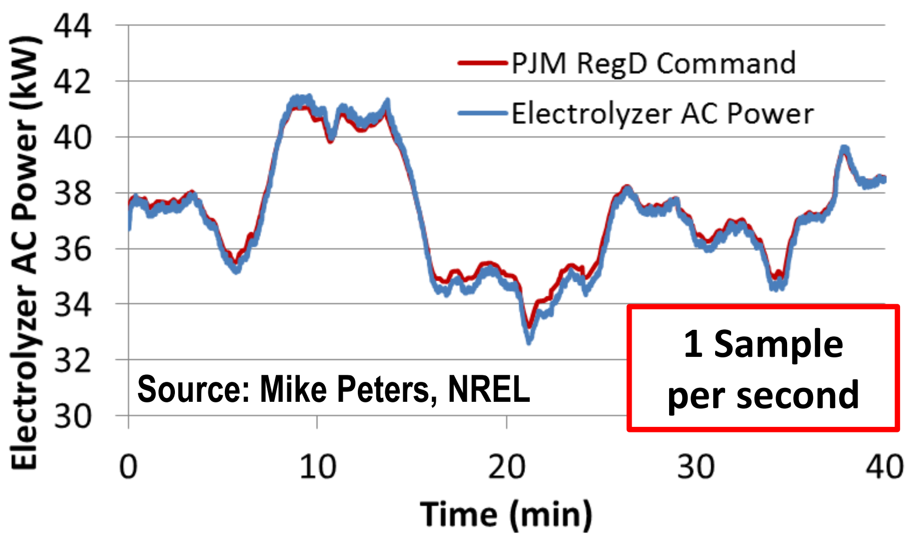
- **Opportunity**
  - Provide flexibility
  - Utilize low or negative energy prices
  - Variety of products (e.g., transportation fuel, industrial gas)

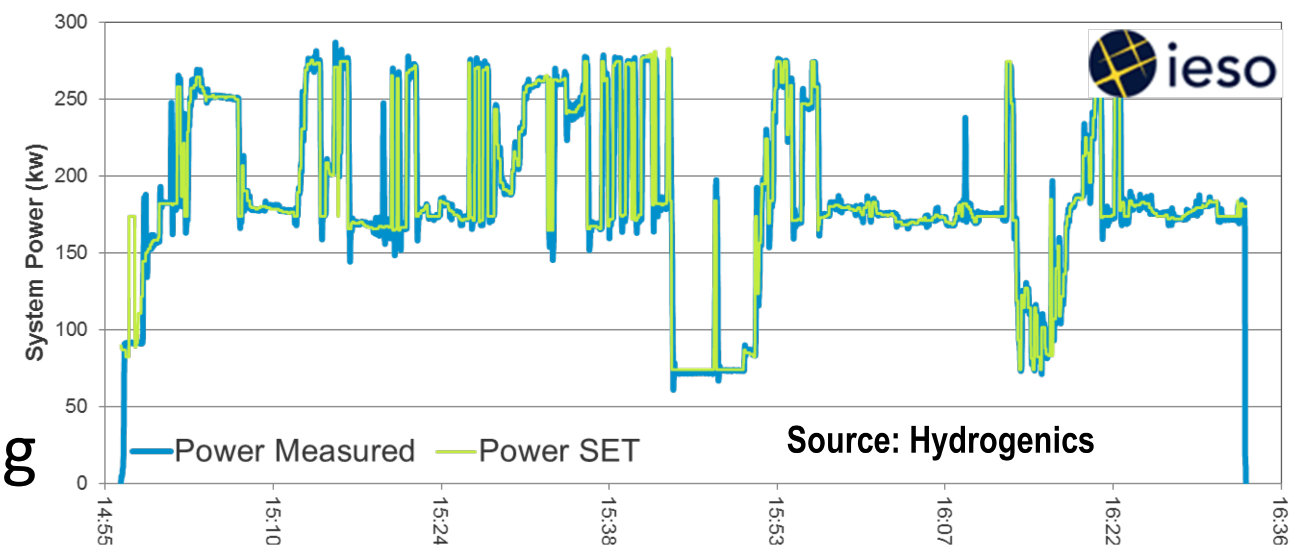


Source: www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Electrolyzer Response

- **Very fast response**
- **Sufficient to participate in energy and ancillary service markets**
    - Energy Markets
    - Regulation
    - Spinning Reserve
    - Nonspinning Reserve





Quantify the value

- **Operations optimization model (price-taker) can perform time-resolved co-optimization of energy, ancillary service and hydrogen products quickly**
- **Assumptions**
  - Sufficient capacity is available in all markets
  - Objects don't impact market outcome (i.e., small compared to market size, and early market)
  - Capacity is valued at $150/kW-year

Source: Pfeifenberger, J.P.; Spees, K.; Newell, S.A. 2012. Resource Adequacy in California. The Brattle Group

Historical or Modelled

- Energy Prices
- Reserve Prices
- Hydrogen Price
- Operational parameters

→ Optimization model →

Profit based on operation (arbitrage, AS, H_2 sale, etc.)

Approach – Assumptions for Price-taker

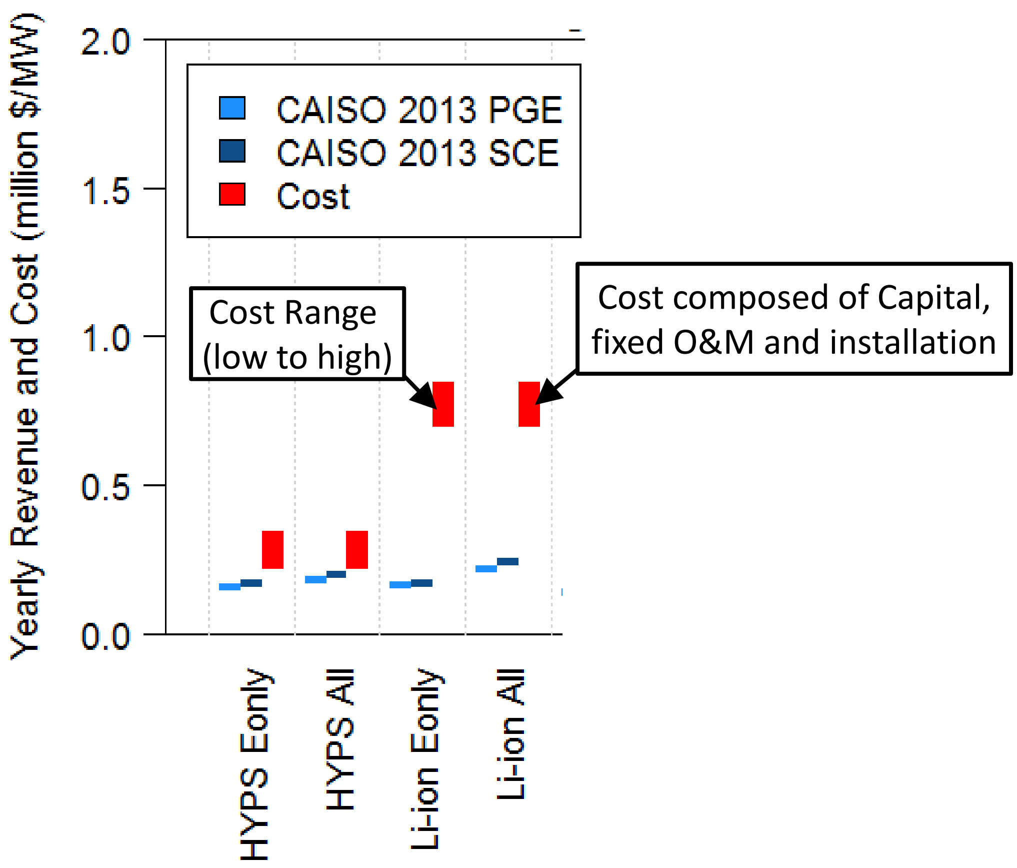
Properties	Pumped Hydro	Lithium Ion Battery	Stationary Fuel Cell	Electrolyzer	Steam Methane Reformer
Rated Power Capacity (MW)	1.0	1.0	1.0	1.0	500 kg/day
Energy Capacity (hours)	8	4	8	8	8
Capital Cost ($/kW)	1500[1] - 2347[2]	3850[1] - 4100[1]	1500[3] - 5918[2]	430[3] - 2121[6]	427 – 569 $/kg/day[4]
Fixed O&M ($/kW-year)	8[1] - 14.27[2]	25[1] - 50[1]	350[2]	42[4]	4.07 – 4.50 % of Capital[4]
Hydrogen Storage Cost ($/kg)	-	-	623[5]	623[5]	623[5]
Installation cost multiplier	1.2[4]	1.2[4]	1.2[4]	1.2[4]	1.92[4]
Lifetime (years)	30	12[1] (4500cycles)	20	20[4]	20[4]
Discount Rate	10%	10%	10%	10%	10%
Efficiency	80% AC/AC[1]	90% AC/AC[1]	40% LHV	70% LHV	0.156 MMBTU/kg[4] 0.6 kWh/kg[4]
Minimum Part-load	30%[7]	1%	10%	10%	100%

Source: [1]EPRI 2010, Electricity Energy Storage Technology Options, 1020676
[2]EIA 2012, Annual Energy Outlook
[3]DOE 2011, DOE Hydrogen and Fuel Cells Program Plan
[4]H2A Model version 3.0
[5]NREL 2009, NREL/TP-560-46719 (only purchase once if using FC&EY system)
[6]NREL 2008, NREL/TP-550-44103
[7]Levine, Jonah 2003, Michigan Technological University (MS Thesis)

Price-Taker Results with historical prices

Conventional storage technologies are often not competitive based on direct market revenue

- **Comparison of yearly revenue and cost**



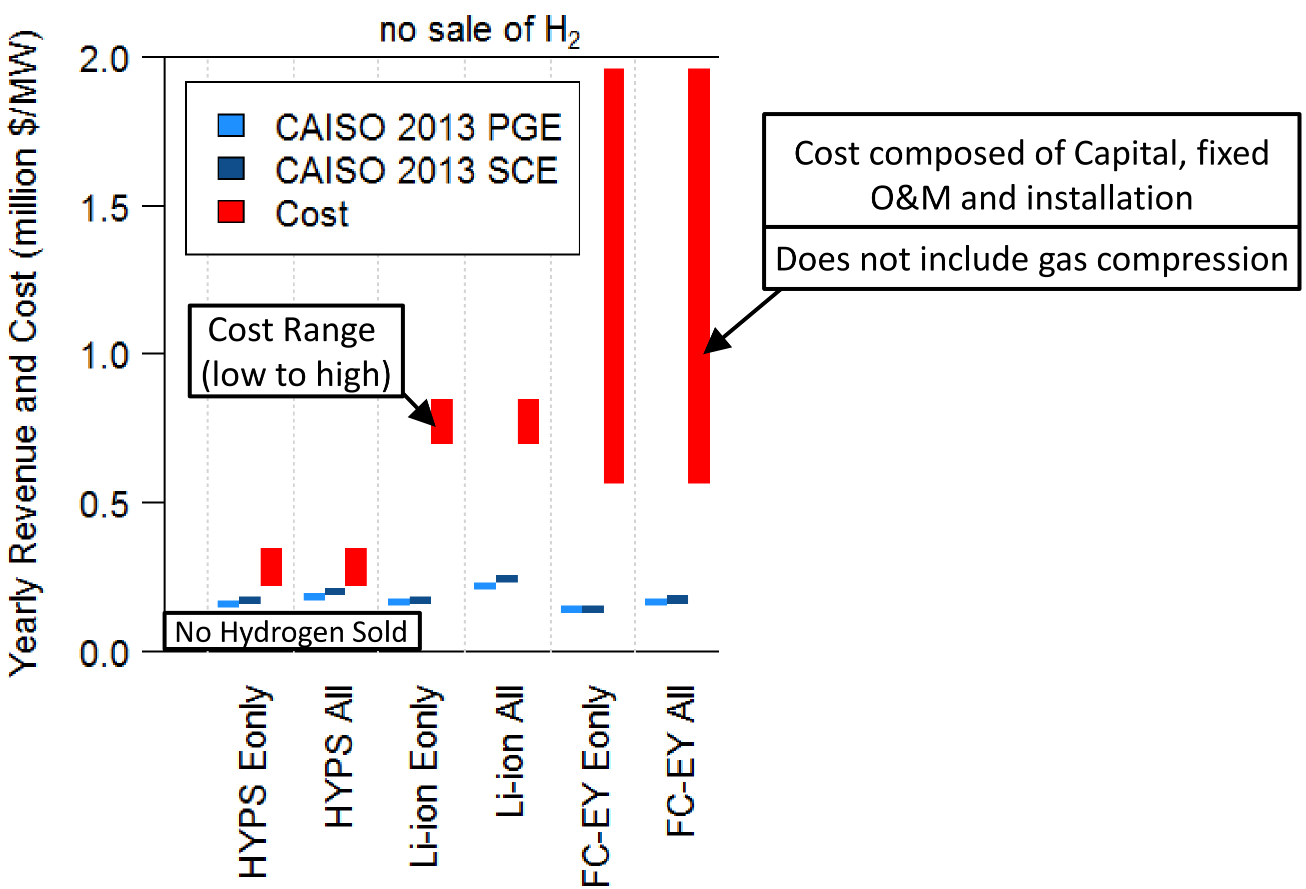
Name	Technology
HYPS	Pumped Hydro
Li-Ion	Lithium-Ion
FC	Fuel Cell
EY	Electrolyzer
SMR	Steam Methane Reformer

Name	Services
All	All Ancillary Services
Eonly	Energy Arbitrage only
Baseload	"Flat" operation

Price-Taker Results with historical prices

For electricity-in, electricity-out storage, system costs must be reduced to improve competitiveness

- **Comparison of yearly revenue and cost**



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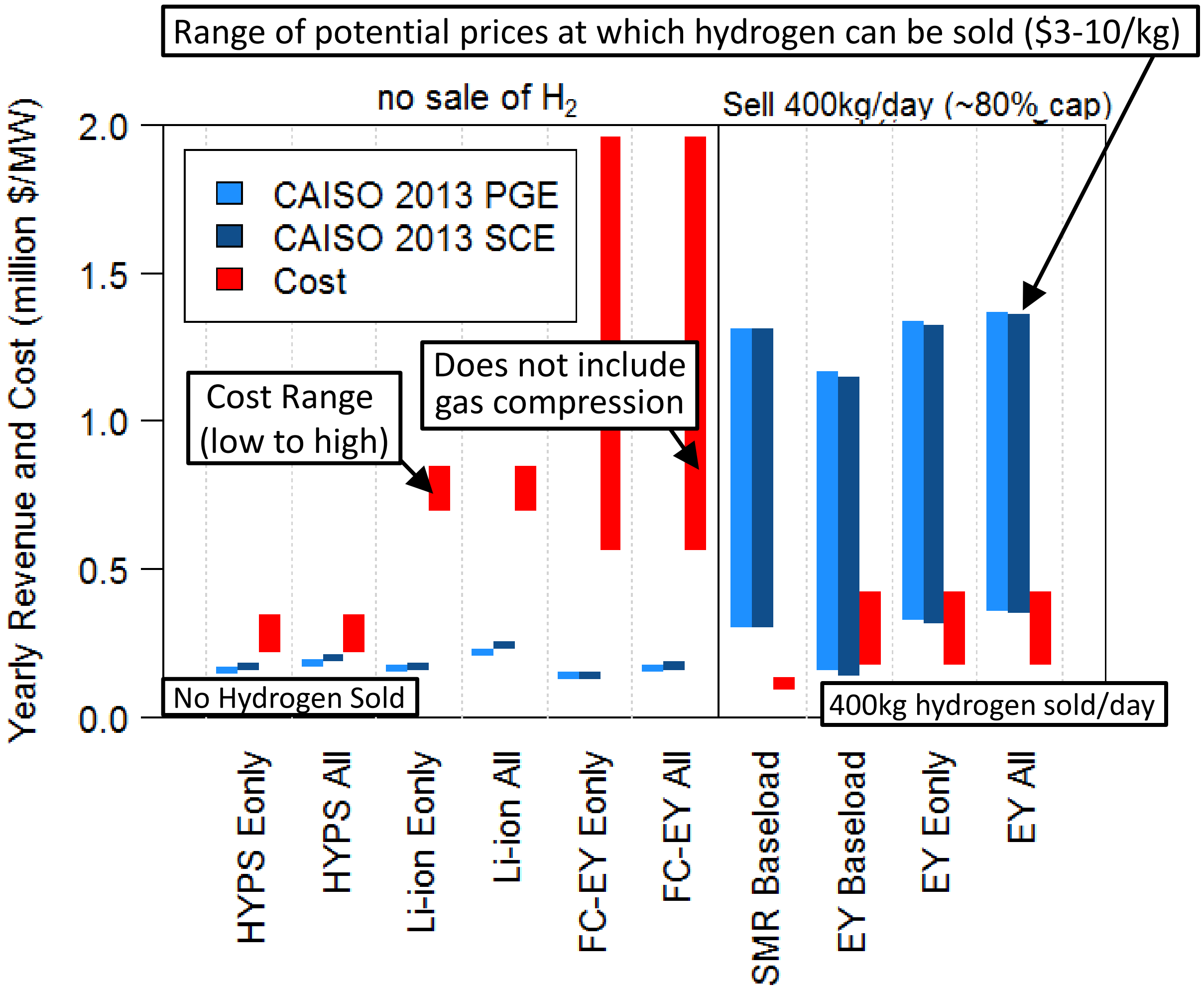
Price-Taker Results with historical prices

Selling hydrogen increases competitiveness

Providing ancillary services > Energy only > Baseload

Electrolyzers providing demand response are promising opportunity



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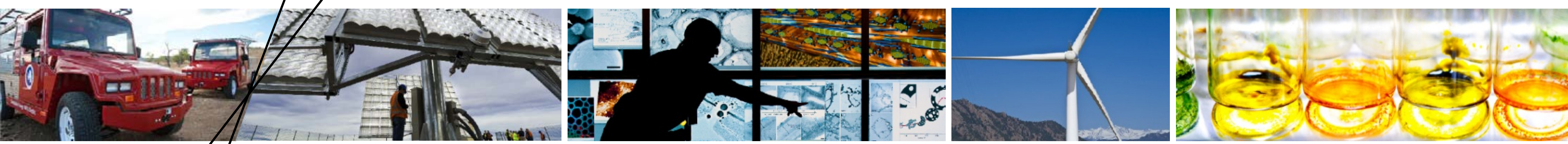
Conclusions

Economic Viability

1. **Sell Hydrogen: Systems providing strictly storage are less competitive than systems that sell hydrogen**
2. **Revenue w/ ancillary service > energy only > baseload**
3. **Electrolyzers operating as a "demand response" devices are particularly favorable**



Questions?