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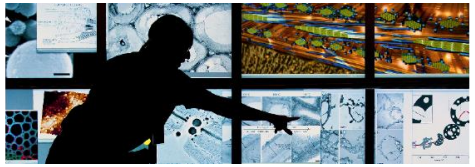
H_2 Grid Integration: Tools and Analyses

Hydrogen Energy Storage Workshop

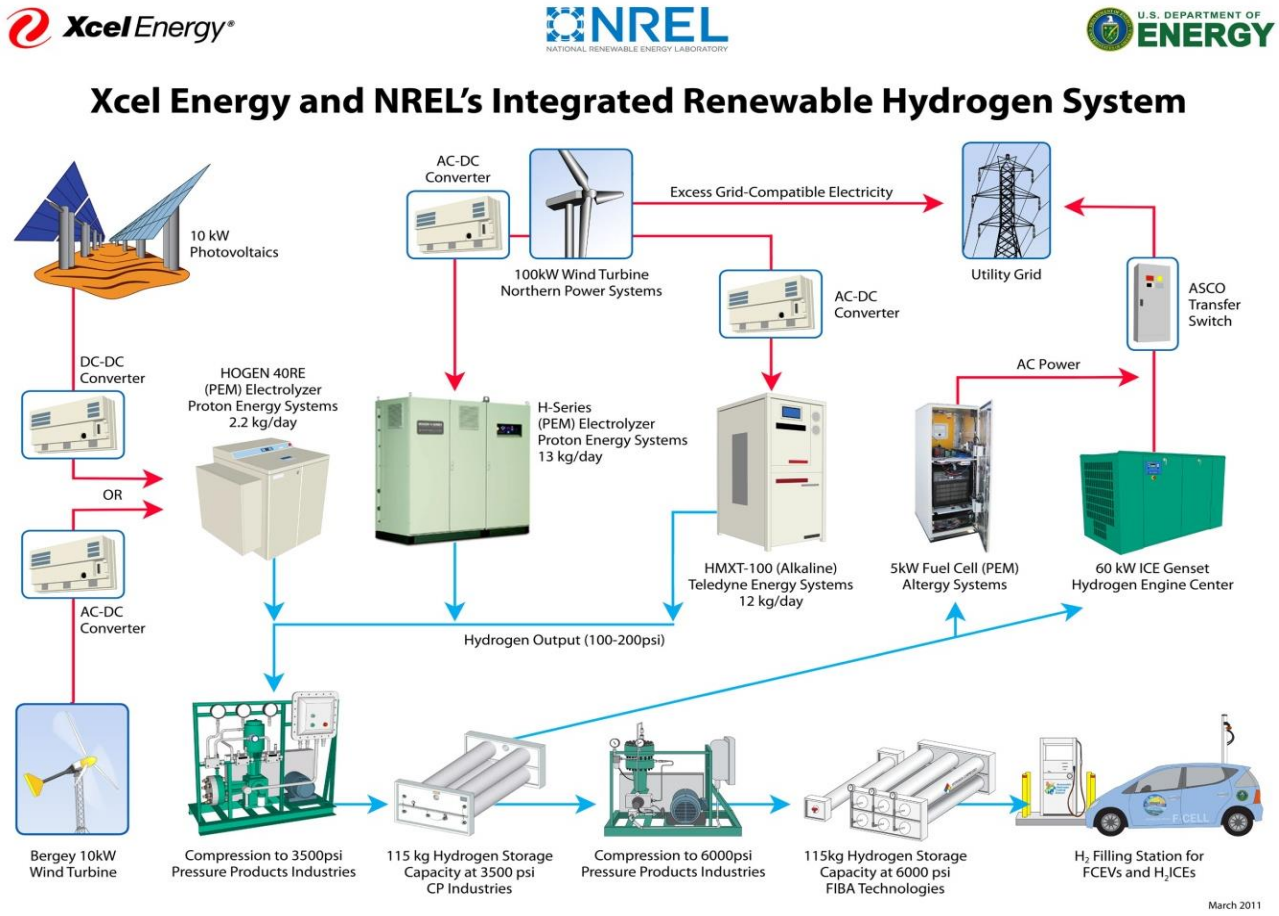
Josh Eichman, PhD

5/14/2014

Wind to Hydrogen Project

- **Xcel Energy, DOE and NREL collaboration**
- **Can explore the role of H_2 for…**

- **Renewable Integration**
- **Responsive loads (demand response)**
- **Energy Storage**
- **Multiple outputs streams**
  - Electricity
  - Transportation fuel
  - Industrial gas



Electricity market requirements

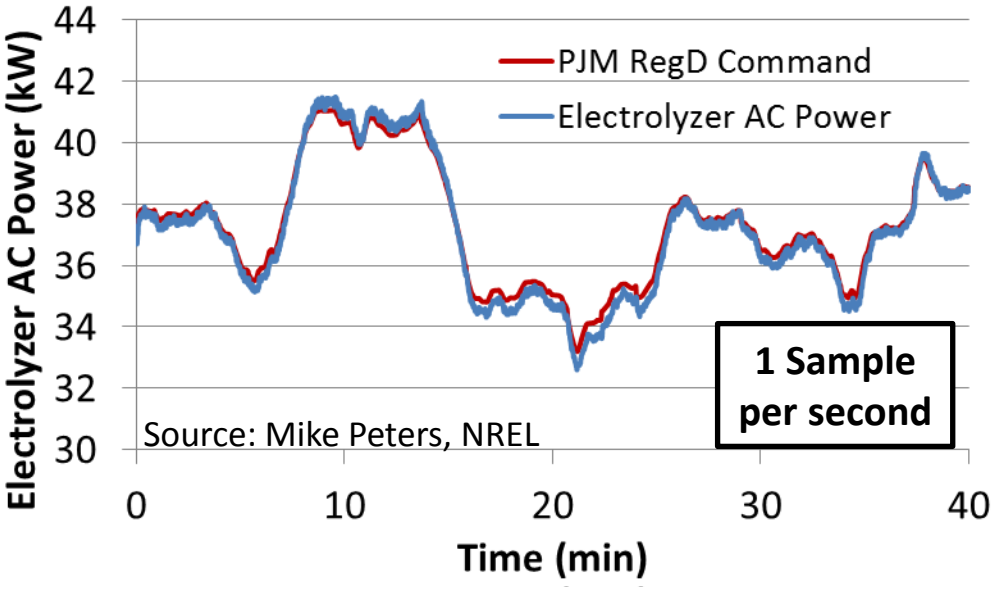
- **Important operational characteristics**
  - Power capacity — How much can you provide in response?
  - Energy capacity — For how long can you respond (duration)?
  - Response time — How quickly can you begin responding?
  - Ramp-rate — How fast can you change your response?
  - Min. turndown — What is your lowest operating point?
  - Startup time — How long does it take to start up?
  - Shutdown time — How long does it take to shutdown?

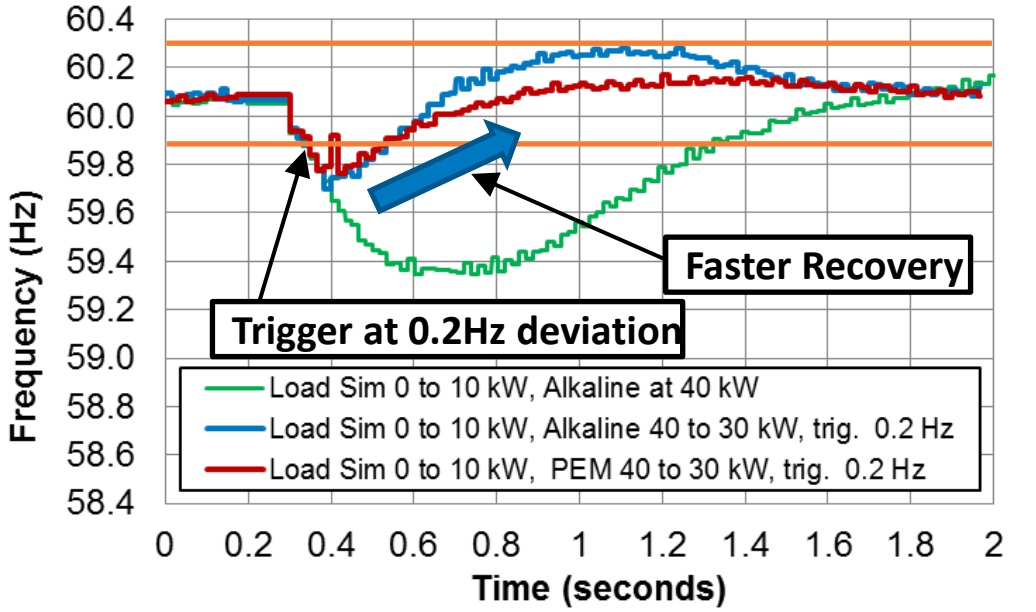
Electrolyzer Regulation Tests

- **Tested PJM regulation A and D signals**
- **Tested frequency response using a microgrid**

Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658

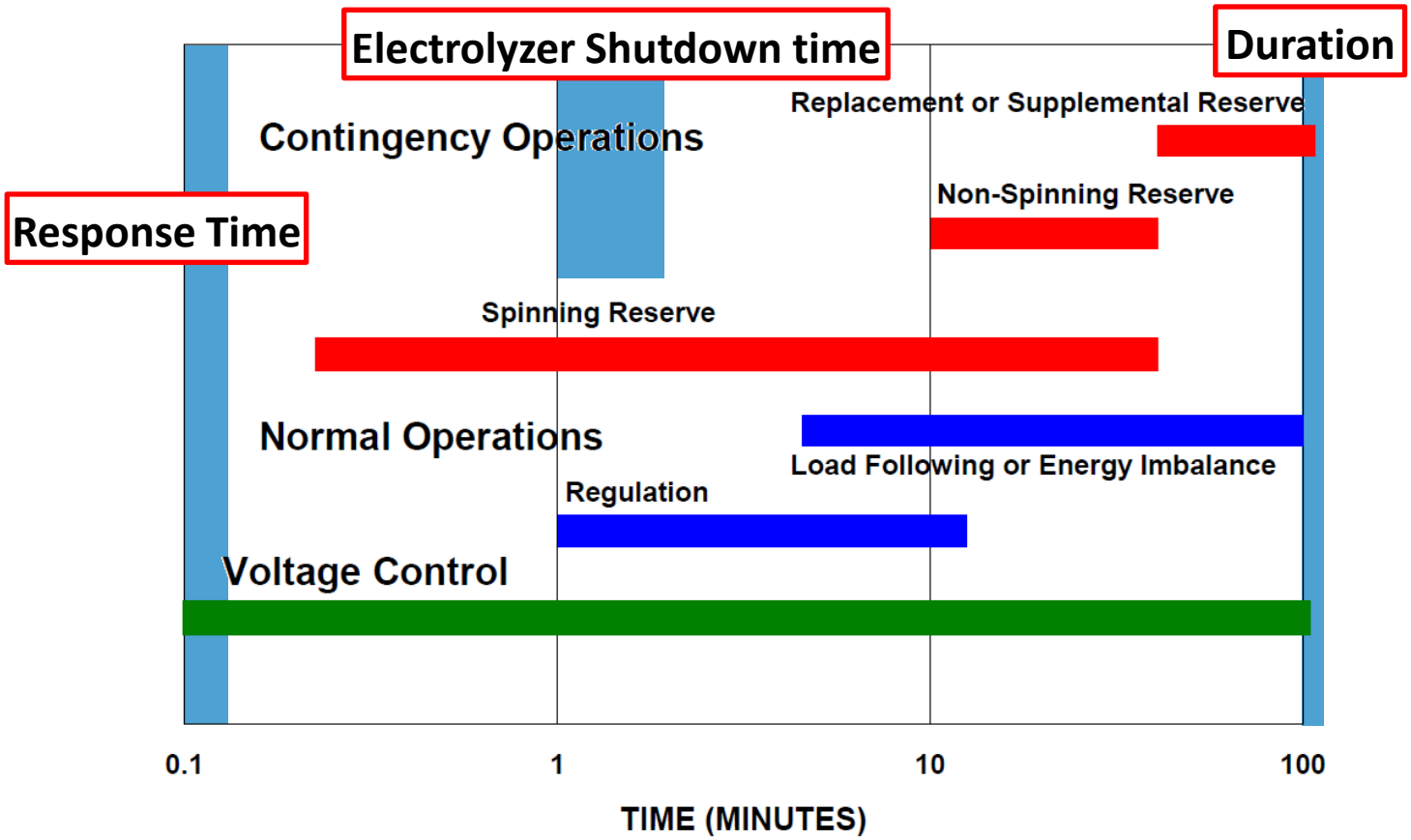
Electrolyzers can respond to rapidly varying input signal





Electrolyzer Testing Results vs. Requirements

- **Ancillary Service Requirements**



Source: Kirby, B.J. 2006. Demand Response for Power Systems Reliability: FAQ. ORNL

Source: Eichman, J.D.; Harrison, K.; Peters, M. (Forthcoming). Novel Electrolyzer Applications. NREL/TP-5400-61758

Electrolyzers can respond fast enough and for sufficient duration to "technically" participate in electricity markets

Capacity req. for grid services is falling

- **Minimum capacity requirements to bid into market**
  - 50 MW for E.ON as of 2006 [2]
  - 30 MW for EnBW, RWE, and VET for minute reserve power in Germany as of 2006 [2]
  - 10 MW for ISO-NE and the primary and secondary control markets in Germany [2, 4]
  - 1 MW for NYISO, PJM and CAISO [3, 4]
  - 100 kW load reduction in the case of NYISO curtailment program [1]
- **Capacity can often be aggregated**

1. NYISO Auxilary Market Operations (2013). Emergency Demand Response Program Manual, New York Independent System Operator, http://www.nyiso.com/public/webdocs/markets_operations/documents/Manuals_and_Guides/Manuals/Operations/edrp_mnl.pdf.
2. Riedel, S. and H. Weigt Electricity Markets Working Papers: German Electricity Reserve Markets, Dresden University of Technology and Energy Economics and Public Sector Management, WP-EM-20, http://hannesweigt.de/paper/wp_em_20_riedel_weigt_Germany_reserve_markets.pdf.
3. Intelligent Energy Europe (2008). Market Access for Smaller Size Intelligent Electricity Generation (MASSIG): Market potentials, trends and marketing options for Distributed Generation in Europe, Energy Economics Group, Fraunhofer ISE, Technical University of Lodz, The University of Manchester and EMD International A/S, http://www.iee-massig.eu/papers_public/MASSIG_Deliverable2.1_Market_Potentials_and_Trends.pdf.
4. Cutter, E., L. Alagappan and S. Price (2009). Impacts of Market Rules on Energy Sorage Economics, Energy and Environmental Economics, http://www.usaee.org/usaee2009/submissions/OnlineProceedings/8025-Energy%20Storage_Paper%20E3.pdf

Grid capacity requirements are approaching manufacturer scale-up targets

Modeling Approach

Can perform time-resolved co-optimization of energy and ancillary service products very quickly

Historical or Modelled

- Energy Prices
- Reserve Prices
- H_2 Prices
- Operational parameters

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

Assumes

1.) Sufficient capacity is available in all markets

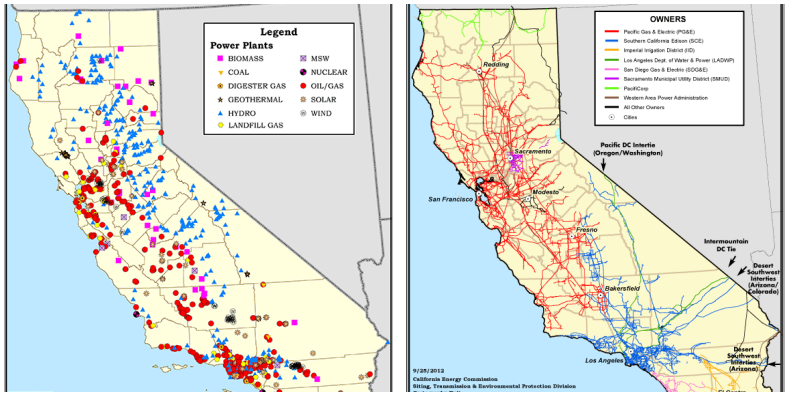
2.) Objects don't impact market outcome (i.e., small compared to market size)

Modeling Approach

- Transmission Network (electric and gas)
- Generator properties
  (coal, gas, nuclear, renewable, etc.)
- Load requirements
- Reliability requirements
- Other System Constraints

Grid Simulation Model

- Generator operation
  (starts, fuel, costs)
- Fuel use and cost
- Emissions
- Transmission operation
  (flow, congestion)
- Imports & Exports
- Load served
- Energy Prices
- Reserve Prices

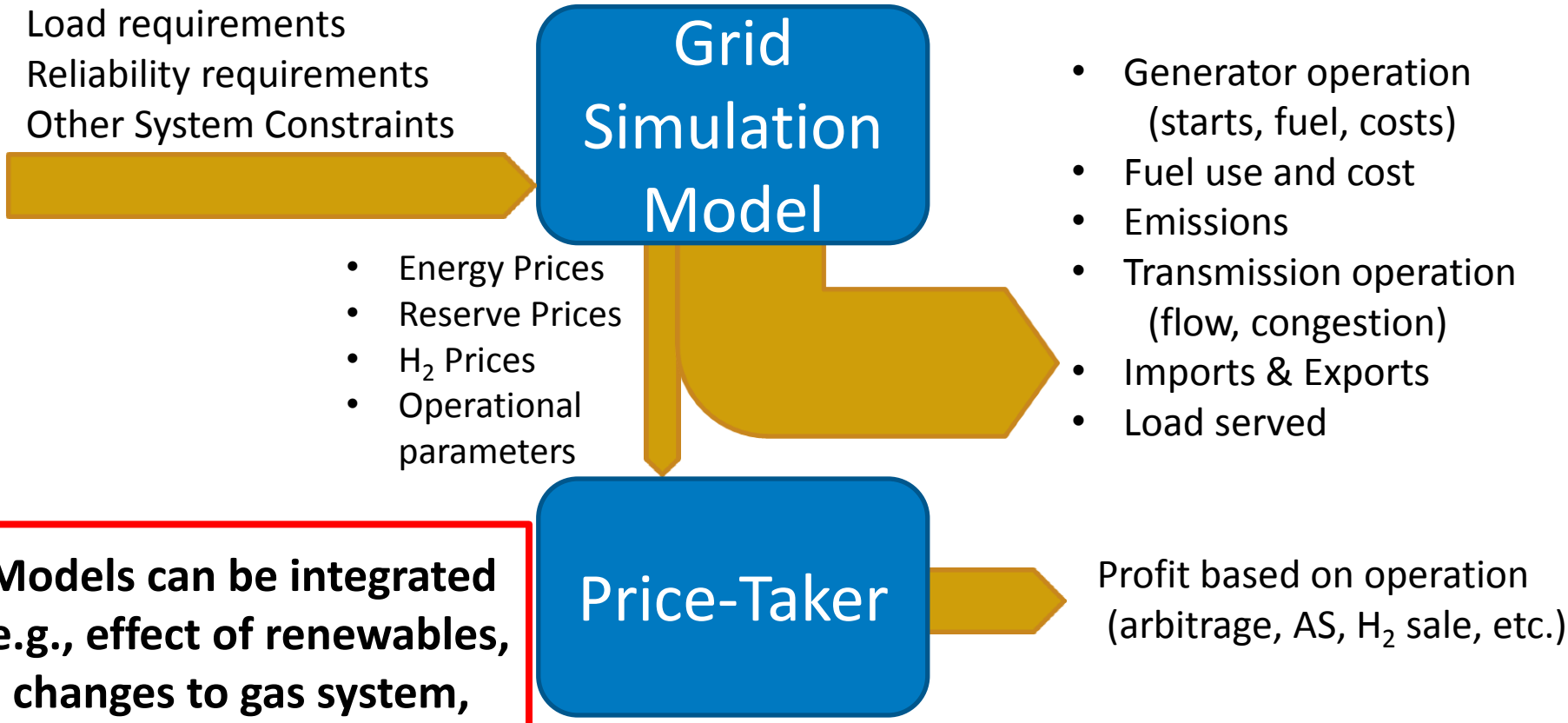


California Power Plants and Transmission Lines (energyalmanac.ca.gov/)

Perform temporal and spatial co-optimization of energy and ancillary service products
(days or weeks of runtime)

Modeling Approach

- Transmission Network (electric and gas)
- Generator properties
  (coal, gas, nuclear, renewable, etc.)
- Load requirements
- Reliability requirements
- Other System Constraints



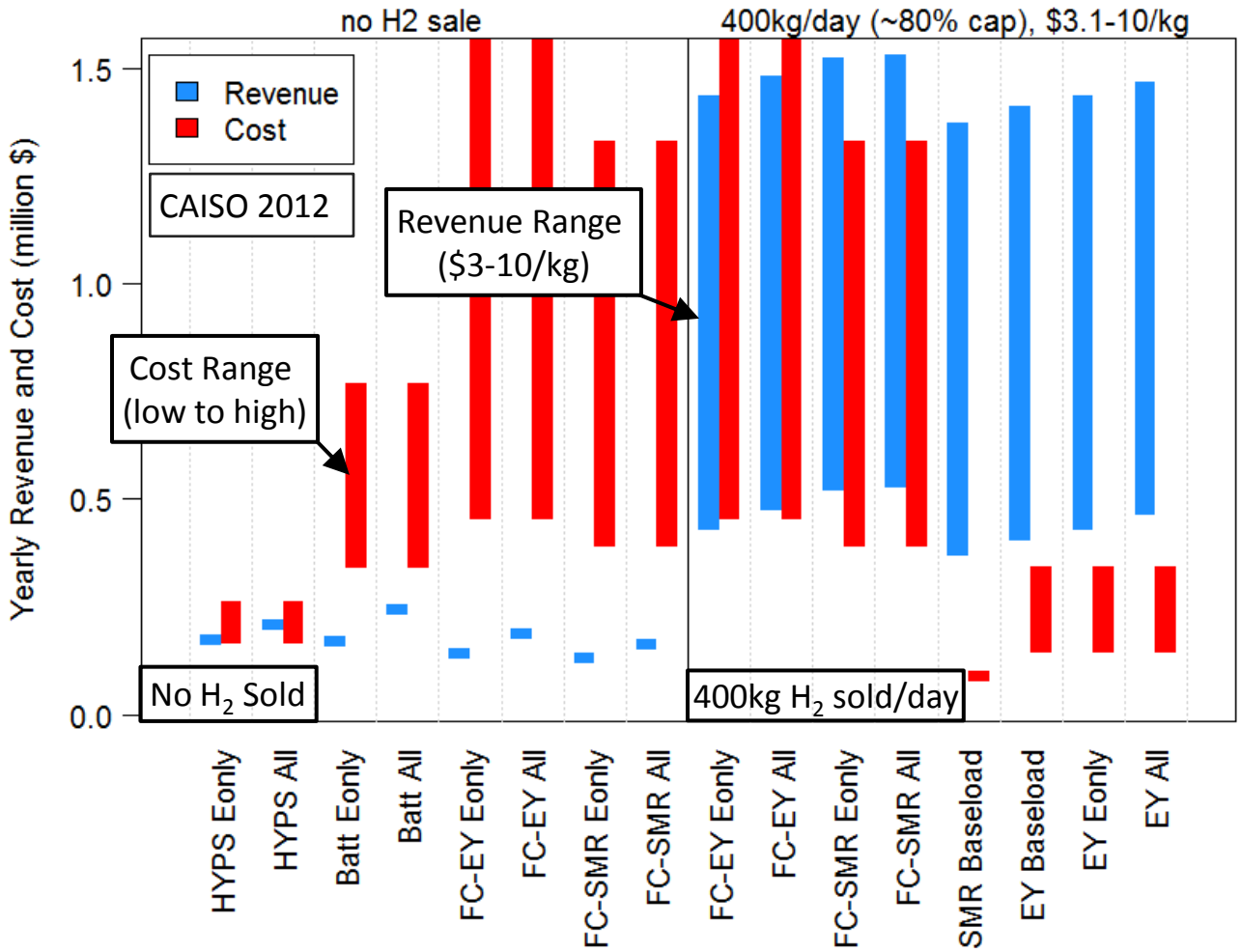
Models can be integrated (e.g., effect of renewables, changes to gas system, market design)

Price-Taker Results with historical prices

Selling H_2 increases competitiveness

Providing ancillary services > Energy only > Baseload

- **Comparison of yearly revenue and cost**



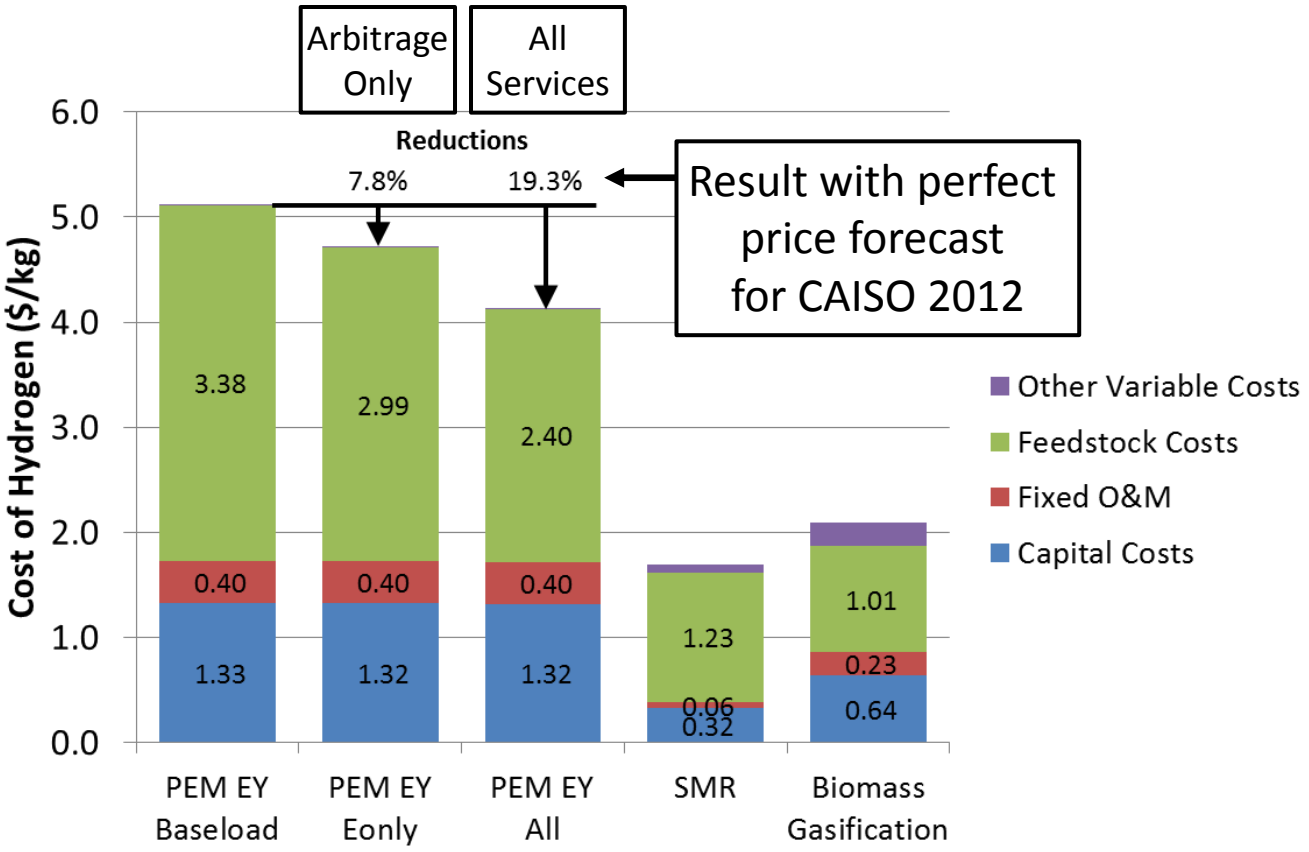
Name	Technology
HYPS	Pumped Hydro
Batt	Battery
FC	Fuel Cell
EY	Electrolyzer
SMR	Steam Methane Reformer

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

Comparison to H2A

Integration with the grid can lower feedstock costs and increase revenue

- **H2A Current Central Hydrogen Production Scenarios**



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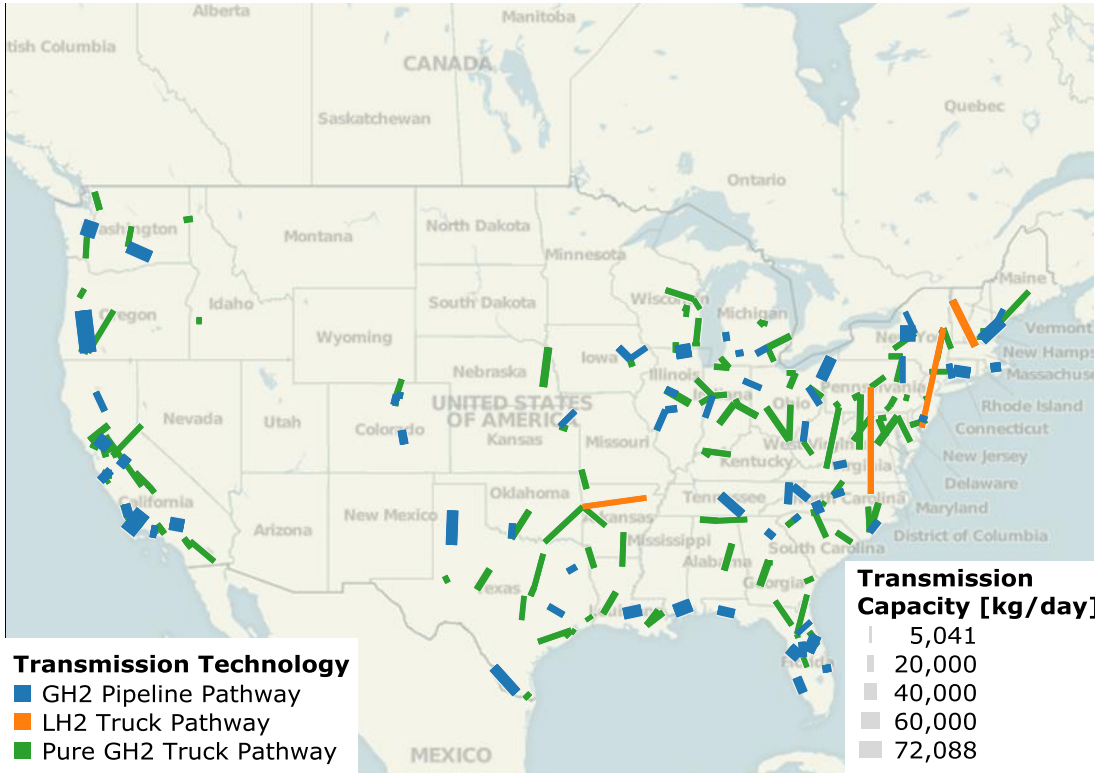
Transportation infrastructure modeling

- **Scenario Evaluation, Regionalization and Analysis (SERA) Model**
  - Integrates various models and datasets
    - H2A
    - HDSAM
    - ADOPT
    - MA3T
    - VISION
    - IRS data
    - Census data
    - Polk data
    - Vehicle data
  - Locates least cost geographic infrastructure options



Important to explore interactions between electric, gas and transportation sectors

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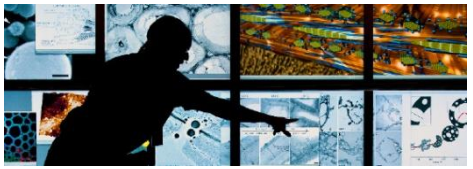

Questions?

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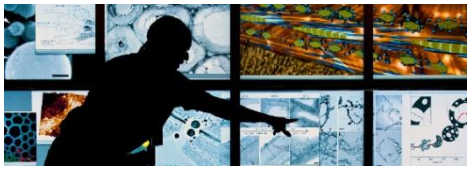
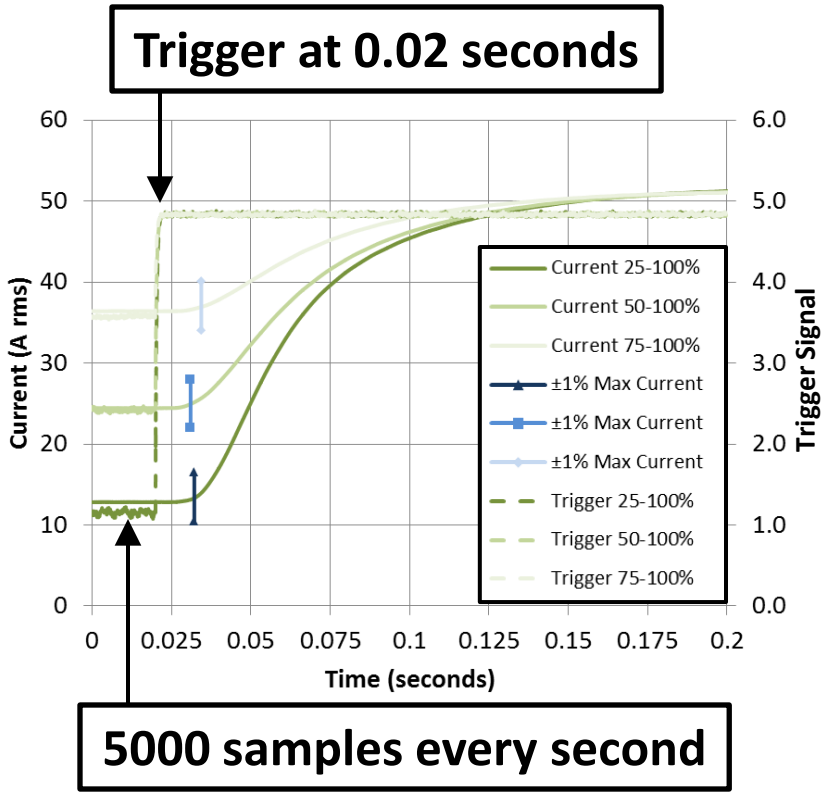
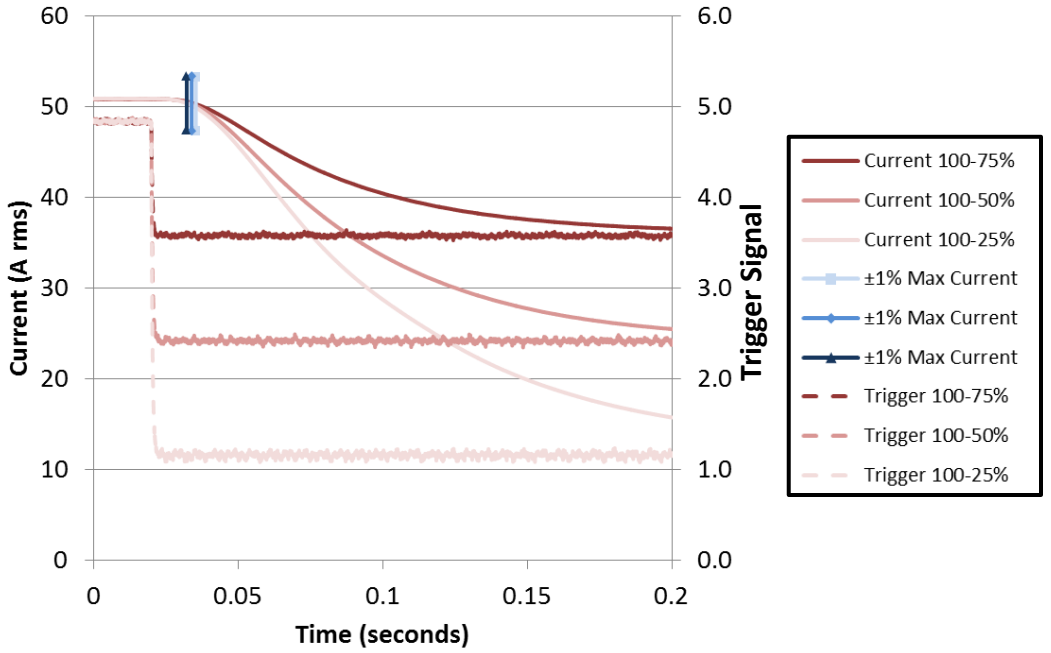


Backup Slides

Electrolyzer Response Time

- **Power set-point was changed (PEM unit shown below)**
  - Ramp Up: 25%, 50%, and 75% →100%
  - Ramp Down: 100% → 75%, 50% and 25%





Electrolyzers can rapidly change their load point in response to grid needs

Approach – Assumptions

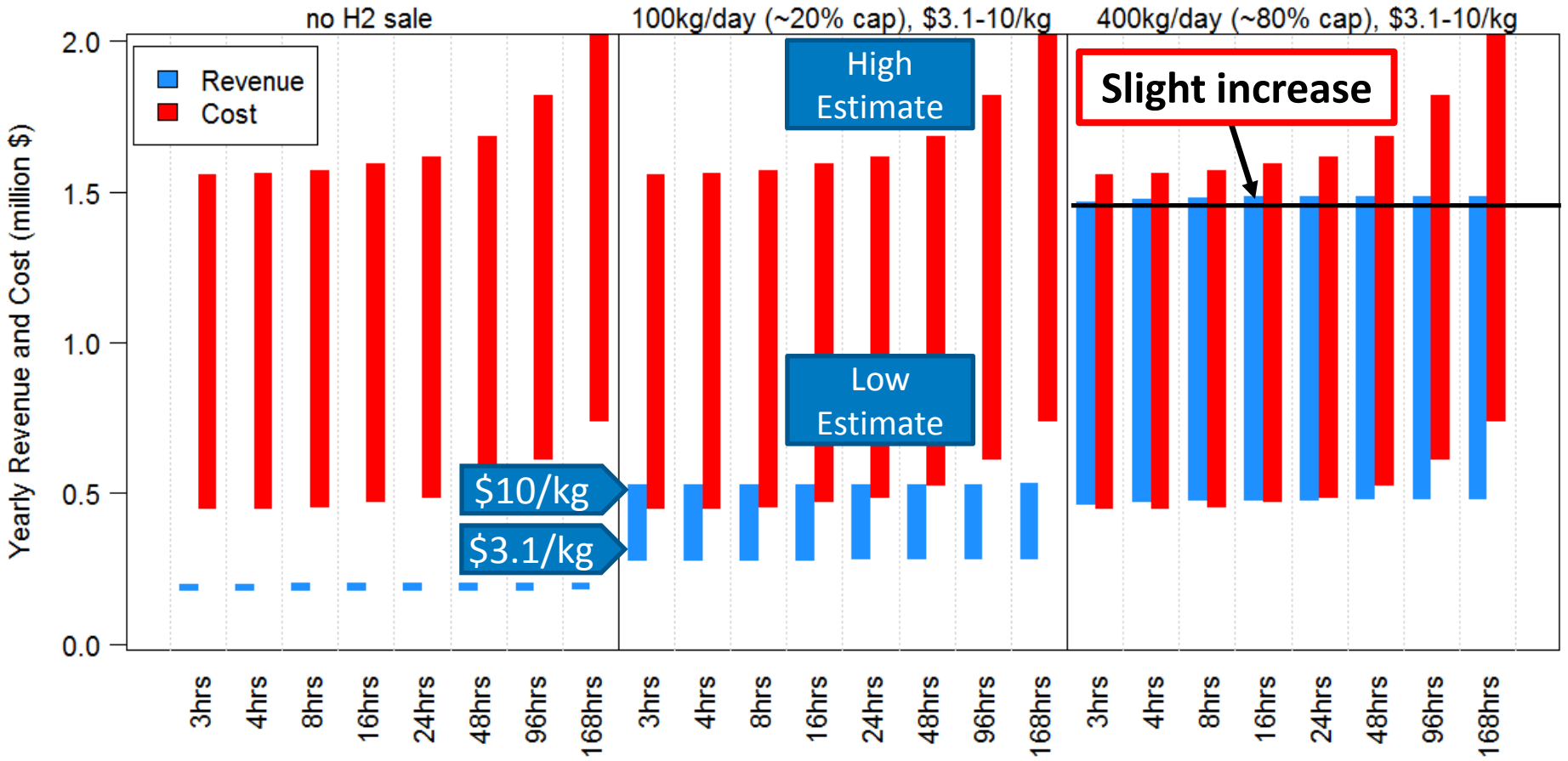
Properties	Pumped Hydro	Pb Acid Battery	Stationary Fuel Cell	Electrolyzer	Steam Methane Reformer
Rated Power Capacity (MW)	1.0	1.0	1.0	1.0	500 kg/day
Energy Capacity (hours)	8	4	8	8	8
Capital Cost ($/kW **Low to High**)	1500[1] - 2347[2]	2000[1] - 4600[1]	1500[3] - 5918[2]	430[3] - 2121[6]	427 – 569 $/kg/day[4]
Fixed O&M ($/kW-year **Low to High**)	8[1] - 14.27[2]	25[1] - 50[1]	350[2]	42[4]	4.07 – 4.50 % of Capital[4]
H_2 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] (4400hrs)	20	20[4]	20[4]
Interest rate on debt	7%	7%	7%	7%	7%
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)

Results

More storage is not necessarily more competitive in current energy and AS markets

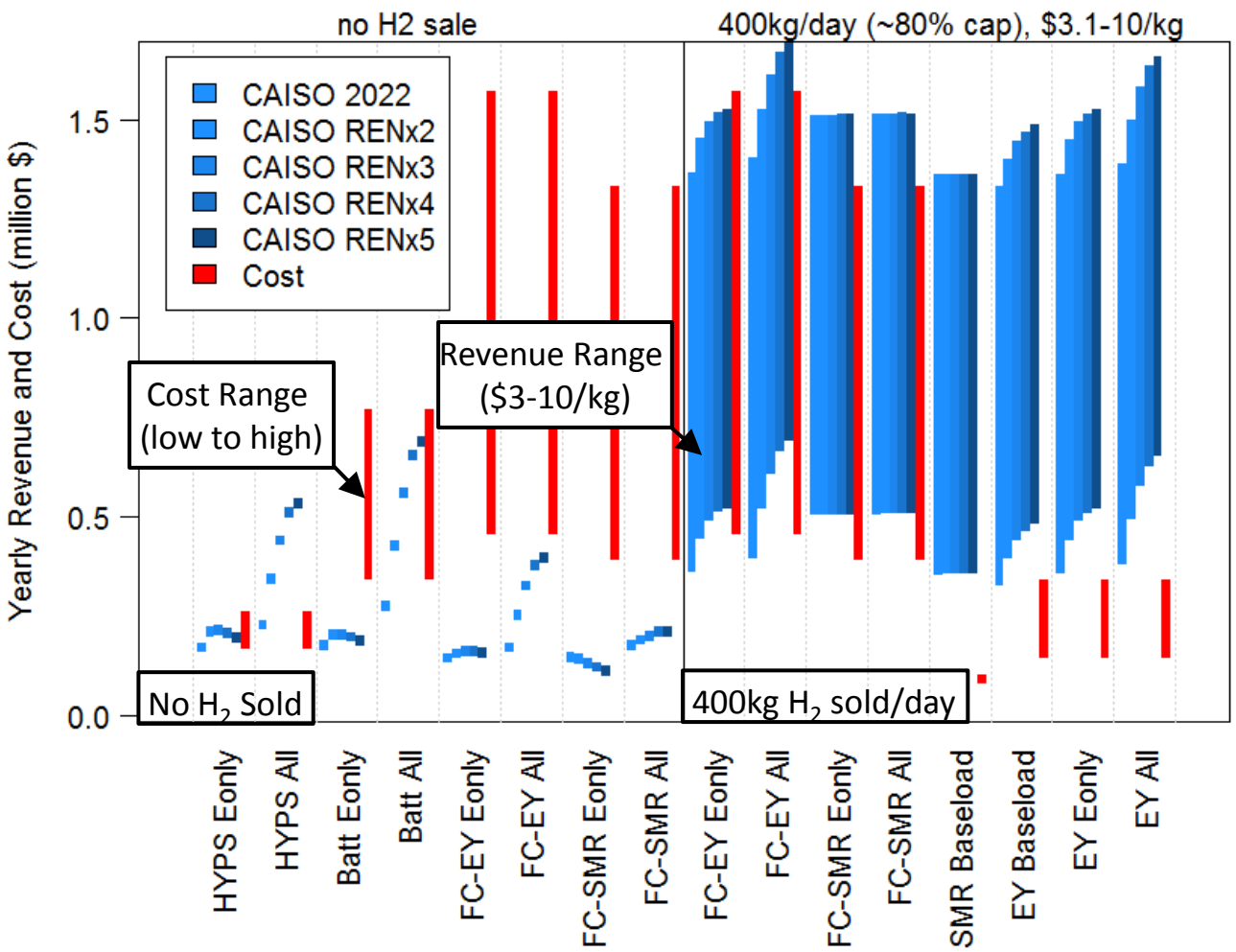
- **Capacity Sensitivity**
  - FC-EY storage device



Grid Simulation Model Coupled with Price-Taker

More renewables increases the value for devices participating in ancillary service markets

- **Effect of renewables on revenue and cost**



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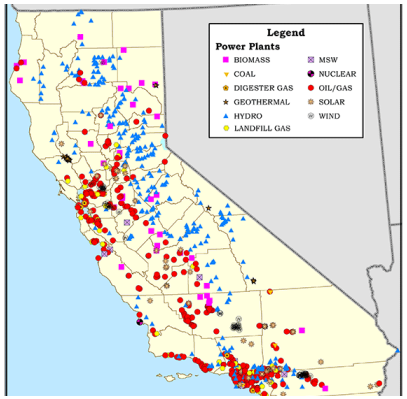
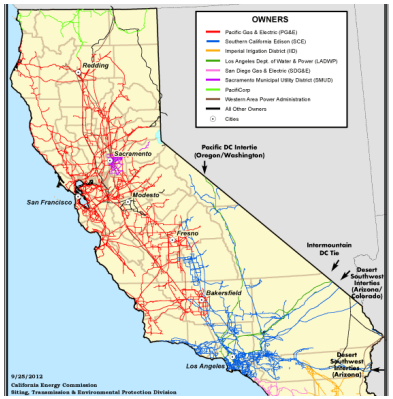
Results

- **Integrating H_2 devices into a large-scale grid simulation tool shows how the grid will be affected**
  - Emissions
  - Production cost
  - Generation mixture
  - Prices





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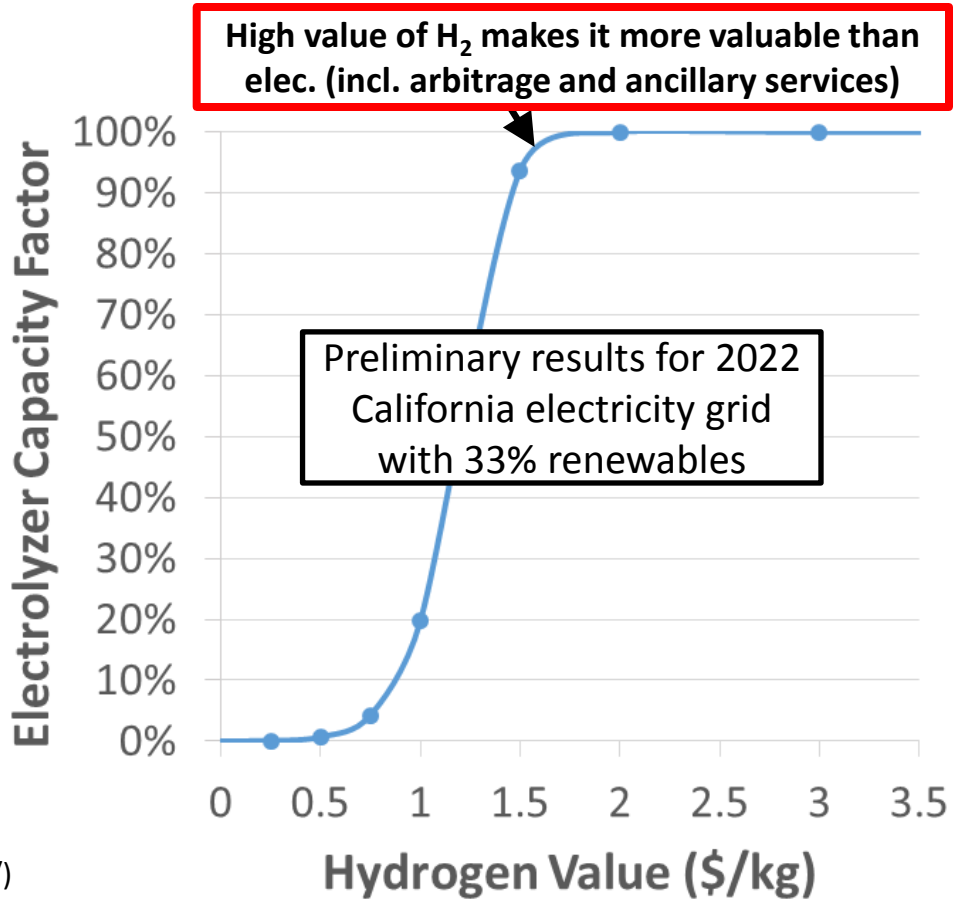

Conclusions

1. Sell H_2: FC-EY systems providing strictly storage are less competitive than systems that sell H_2
2. Revenue w/ ancillary service > energy only > baseload
3. Electrolyzers operating as a “demand response” devices have very favorable prospects
4. More storage is not necessarily more competitive in current energy and ancillary service markets (but may add value in capacity market)
5. More renewables increases the competitiveness for electrical hydrogen equipment (i.e., EY and FC... not SMR)
6. Hydrogen technologies show interesting results when integrated into large-scale grid simulation models