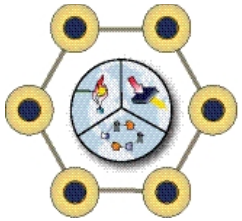
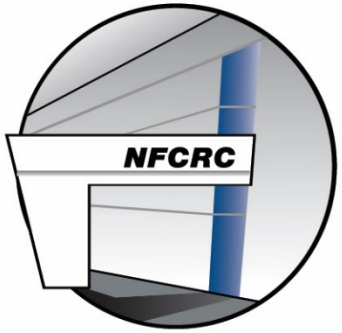
Hydrogen is Required for a 100% Renewable Energy Future

Center for Renewable Natural Gas

Riverside, CA



ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE



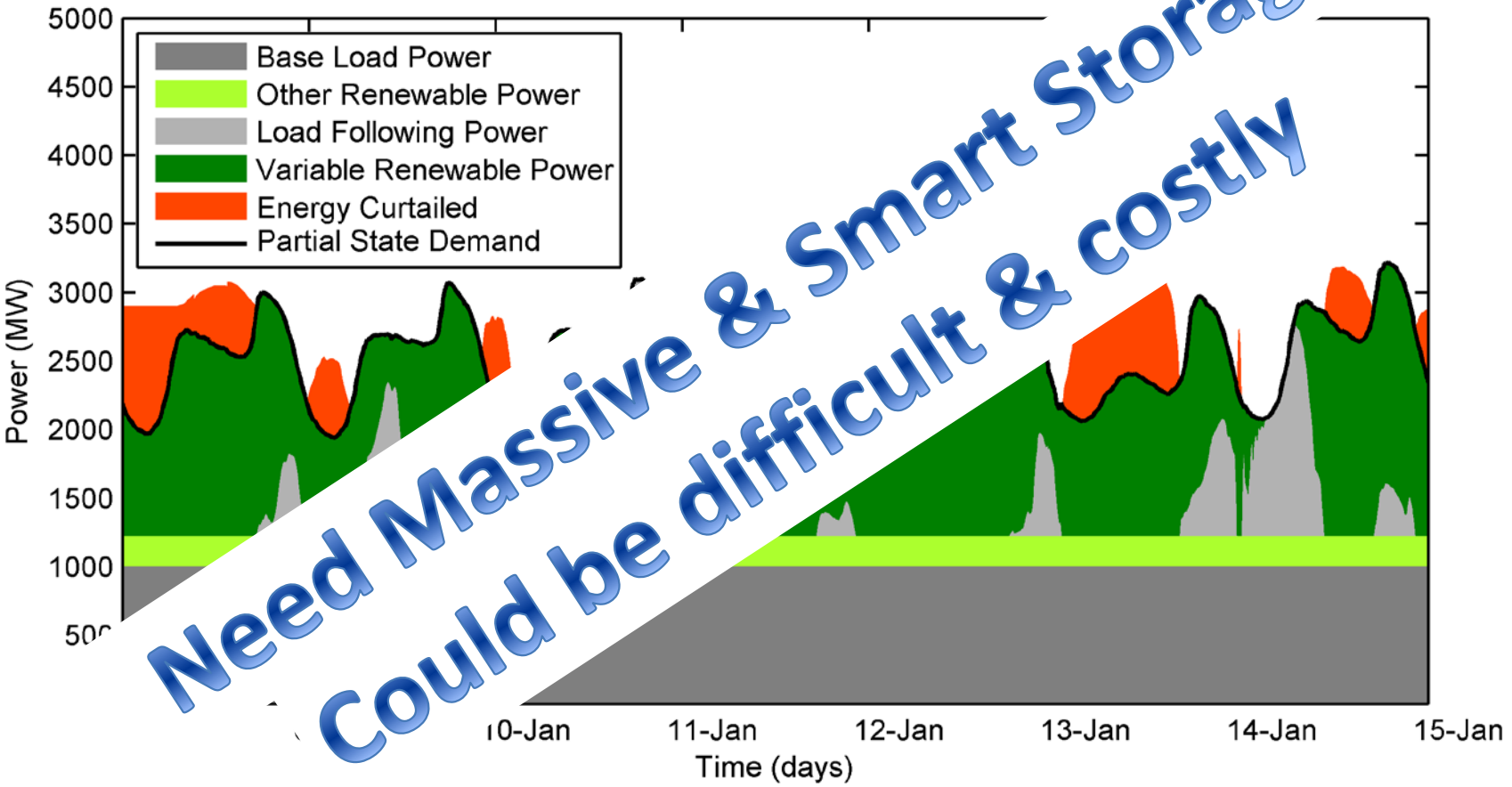
NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY of CALIFORNIA · IRVINE

Jack Brouwer, Ph.D.
Associate Director

May 16, 2017

Renewable Energy and Demand DYNAMICS

Cost of Solar & Wind make 100% energy amount possib



CASE E: 20% Renewable, 80% Wind

Energy Storage Need

Gedankenexperiment – consider a completely solar world

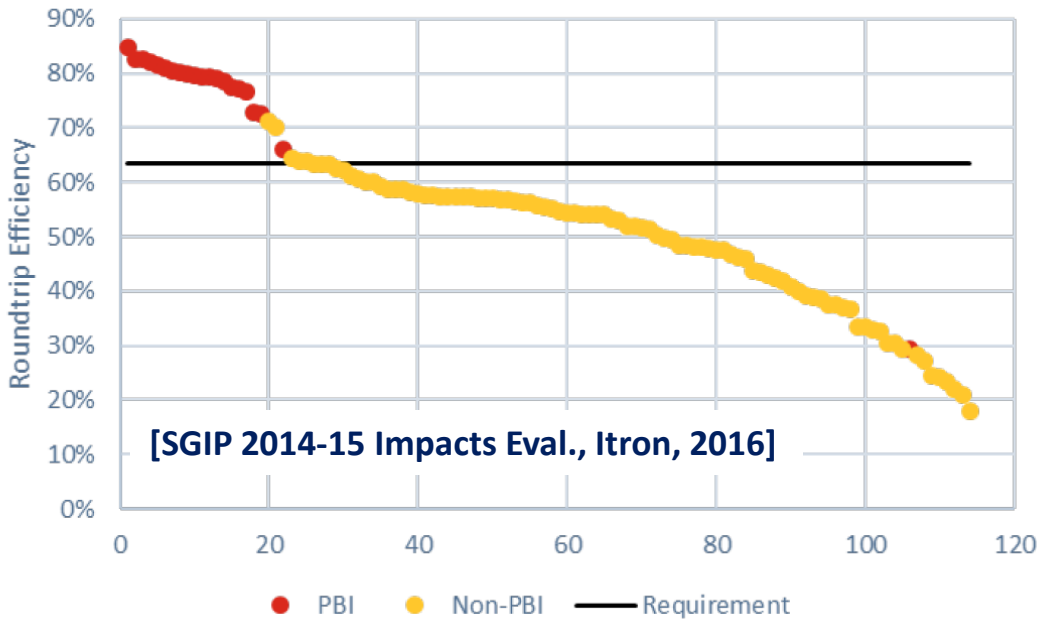
- Do as much conservation & efficiency as possible
  - How much storage is needed?

World Total (Mtoe)	kWh/toe	kWh	TWh
9,301	11,630	1.082E+14	108,171
Total Storage Needed		Daily shifting only:	**237**
		Seasonal shifting:	**28,846**

[Key World Statistics, IEA, 2015]

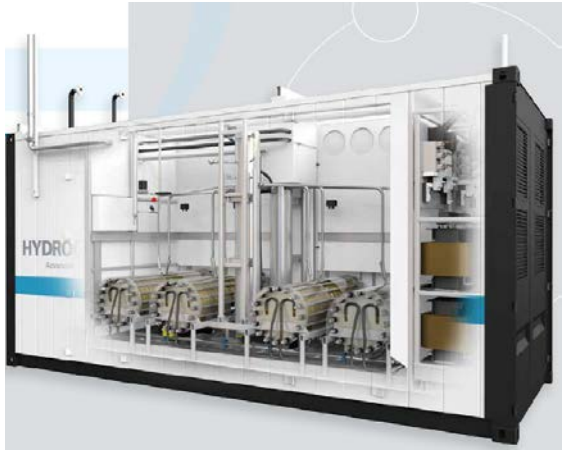
- Lots of Batteries needed
- But: cannot do it all!
  - Massive cost (connected power & energy scaling)
  - Self discharge (measured performance in utility applications)

Figure 1-7: Roundtrip Efficiency for Observed Projects (all non-residential)



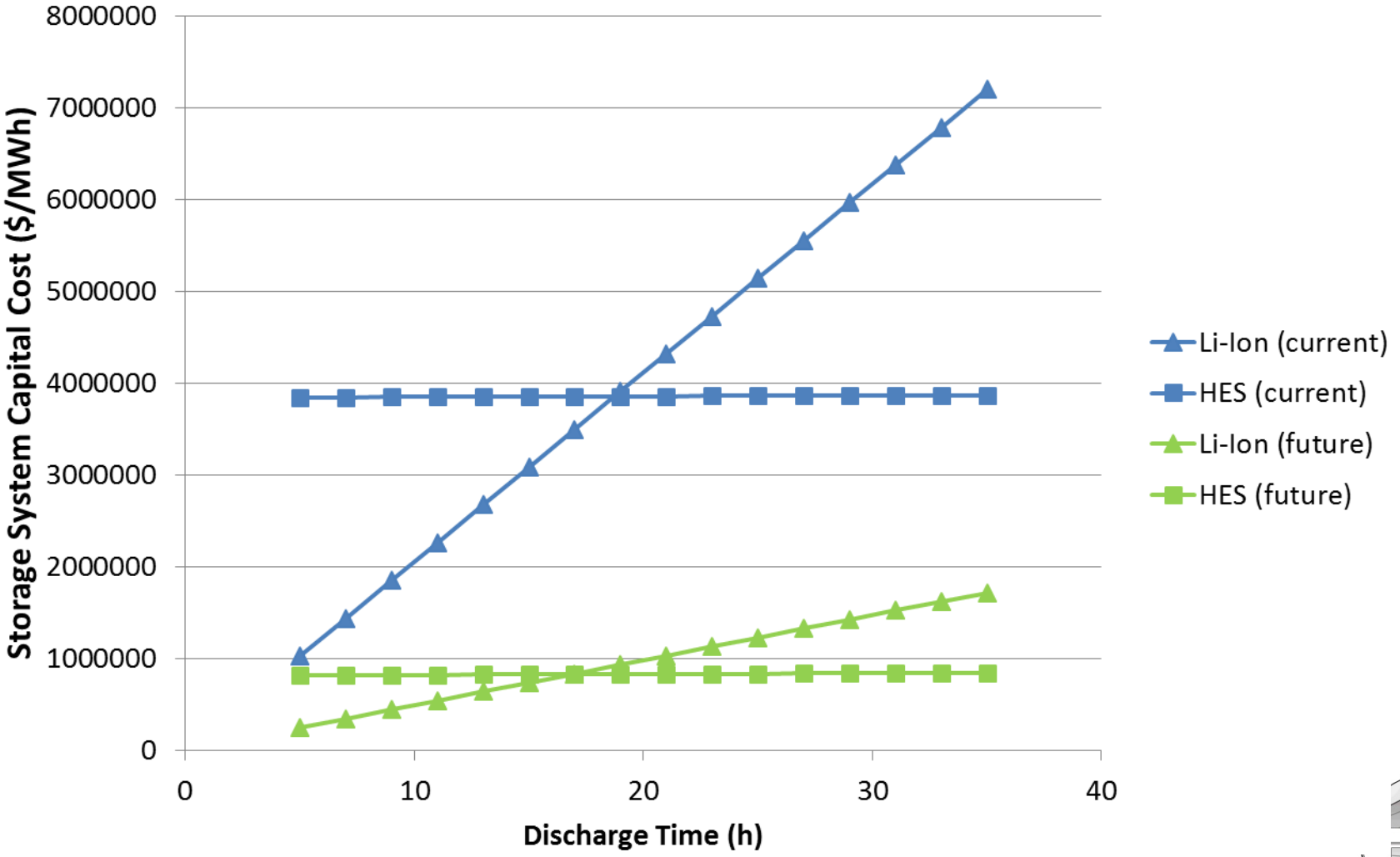
Electrolysis – A Flexible Load

- Electrolyzers (PEM, alkaline) produce hydrogen & oxygen from water
- Provide load when wind or solar would otherwise be curtailed
- Fast response allows for use with variable input (<2 sec)
- Fast response can provide other ancillary services (e.g., regulation, Volt/VAR support)
- Sizes range from 10's of KW to several MW (today)



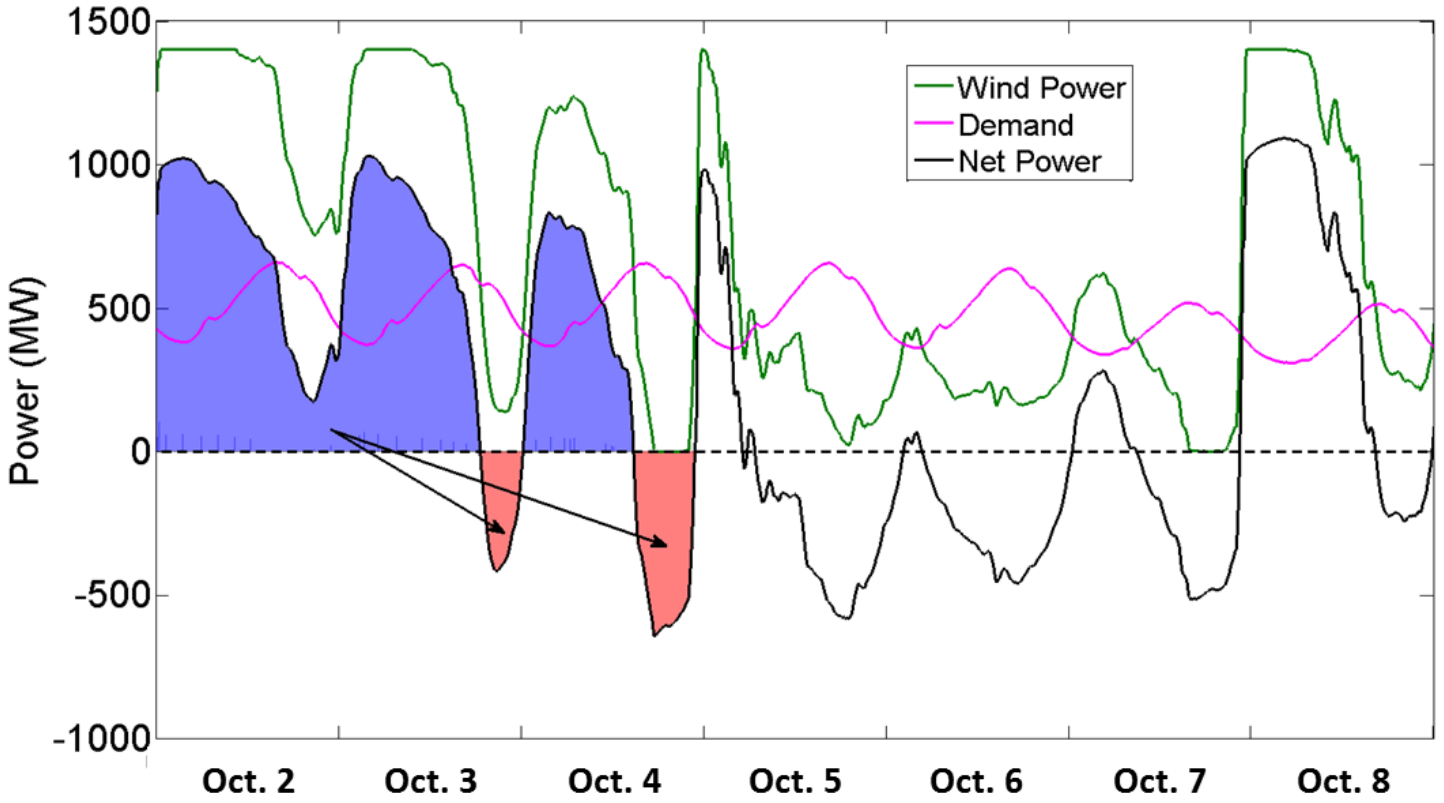
Hydrogen Energy Storage Economics

- HES better for long-term energy storage – fundamental difference of independent energy and power capacity scaling



Wind & Hydrogen Energy Storage Dynamics

- Measured Texas Wind & Salt Cavern Hydrogen Storage

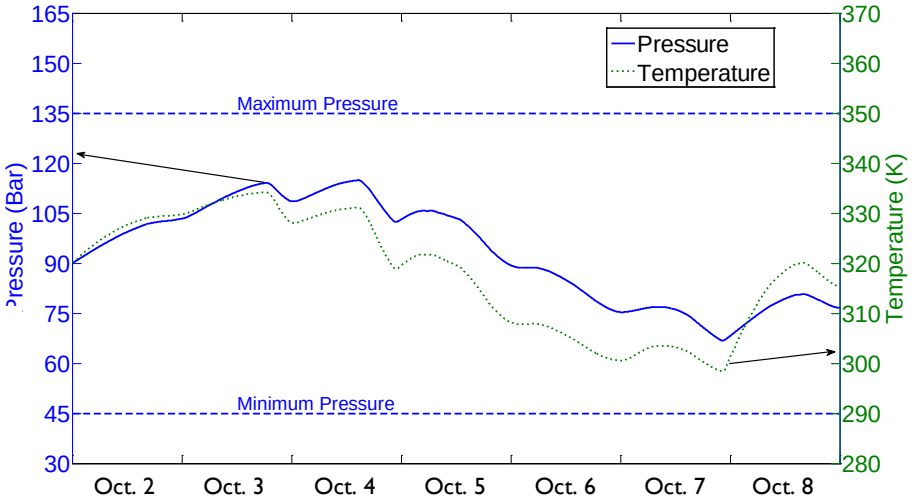


- Load shifting from high wind days to low wind days
- Excess wind energy (blue) is captured for later use (red) by highly dynamic electrolyzers & fuel cells (fast and flexible response)

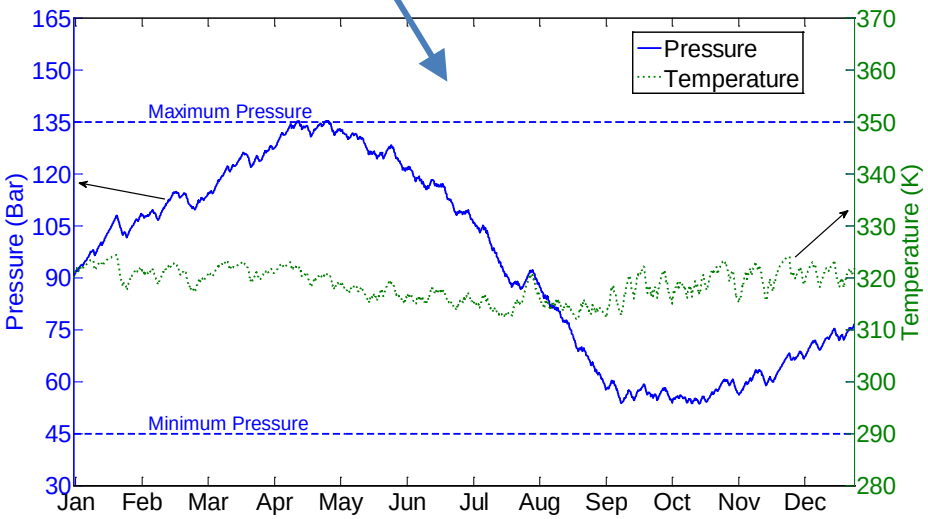
Maton, J.P., Zhao, L., Brouwer, J., Int'l Journal of Hydrogen Energy, Vol. 38, pp. 7867-7880, 2013

Hydrogen Energy Storage Dynamics

- Dynamic Models of Electrolyzers, Storage, Solar & Wind Power developed at UC Irvine
- Storage pressure dynamics don't look too severe



- Seasonal energy storage possible

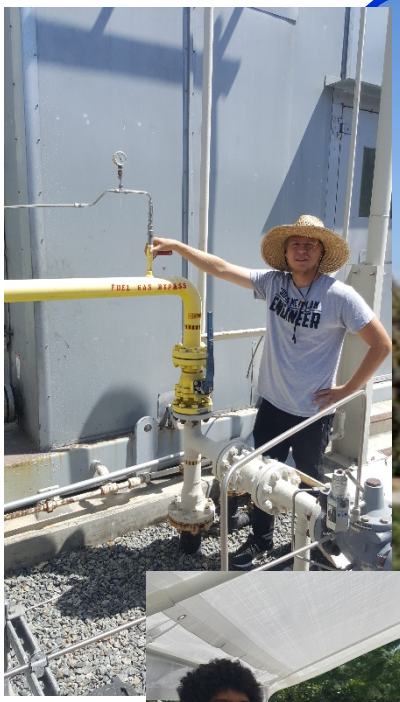


Maton, J.P., Zhao, L., Brouwer, J., Int'l Journal of Hydrogen Energy, Vol. 38, pp. 7867-7880, 2013

APEP Research & Power-to-Gas Demo

Injection and conversion of H2/NG mixture in NGCC (400 psi line)

- Up to 0.78 volume % H2 in natural gas



Thanks for your attention!