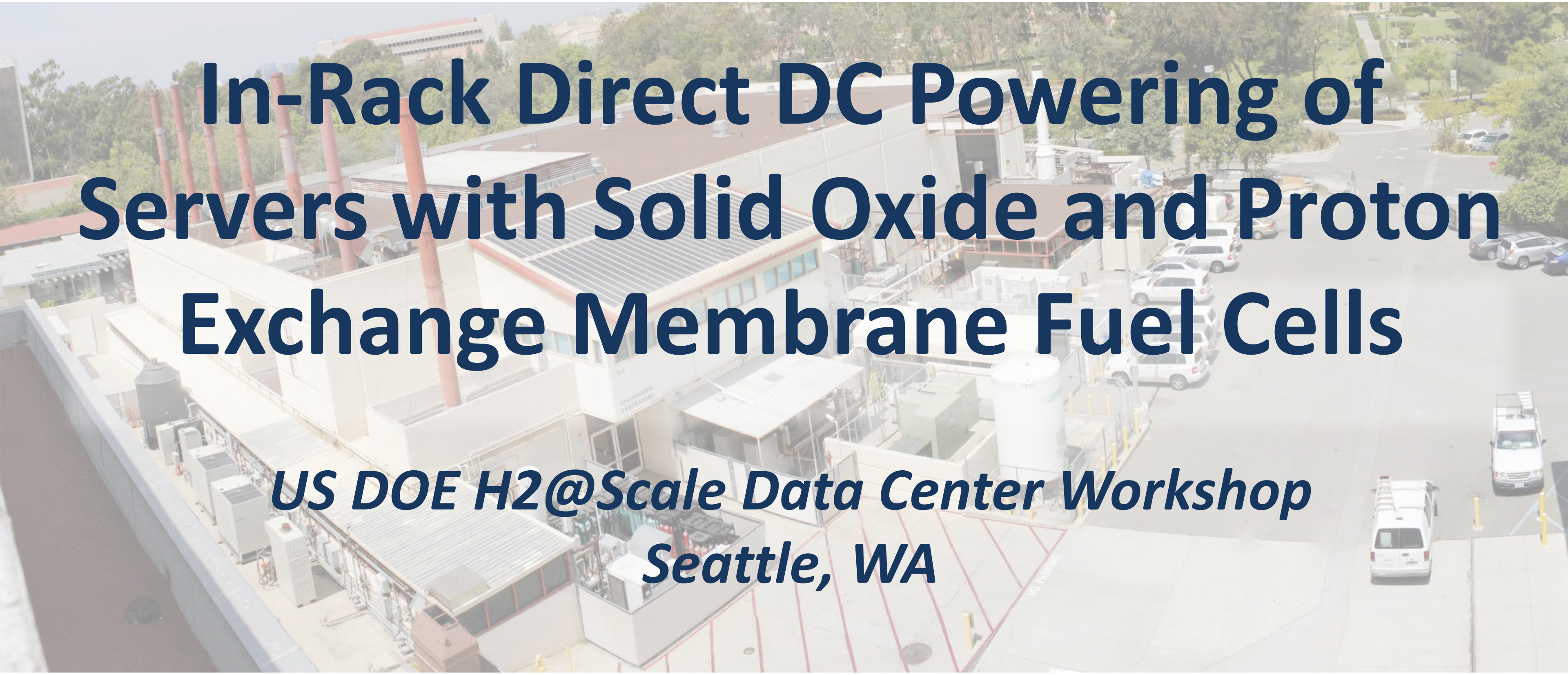


In-Rack Direct DC Powering of Servers with Solid Oxide and Proton Exchange Membrane Fuel Cells

US DOE H2@Scale Data Center Workshop
Seattle, WA

ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

National Fuel Cell Research Center
UCIrvine | UNIVERSITY OF CALIFORNIA

Jack Brouwer, Ph.D.

Director

March 20, 2019

Fuel Cell Systems for Data Centers

Challenges

- eBay's Data Center in Utah loses $6,000 per second of downtime
- The company's sustainability mission was in conflict with UT's electric grid which sources 80% of it's electricity from coal

Solution

- 6 MW of fuel cell systems provide primary, onsite, reliable power matched to the operational requirements of the data center
- System provides 100% of electricity demand while drastically reducing carbon footprint

How it works

- Redundant, modular architecture provides highly reliable power
- System architecture replaces large, expensive & polluting backup generators and UPS components

Microsoft STARK Concept

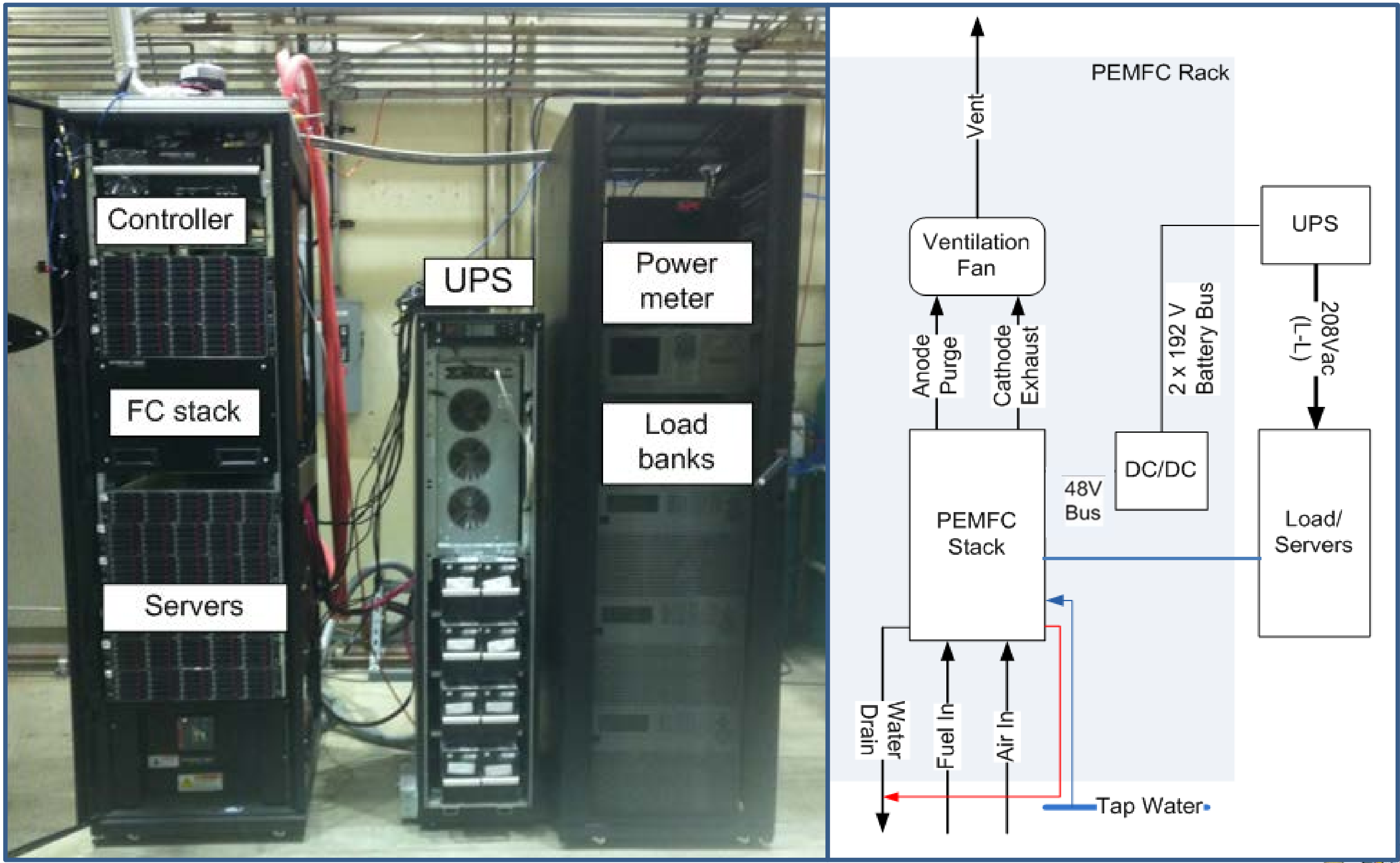
- **In-rack Distributed Generation**

Microsoft STARK Concept

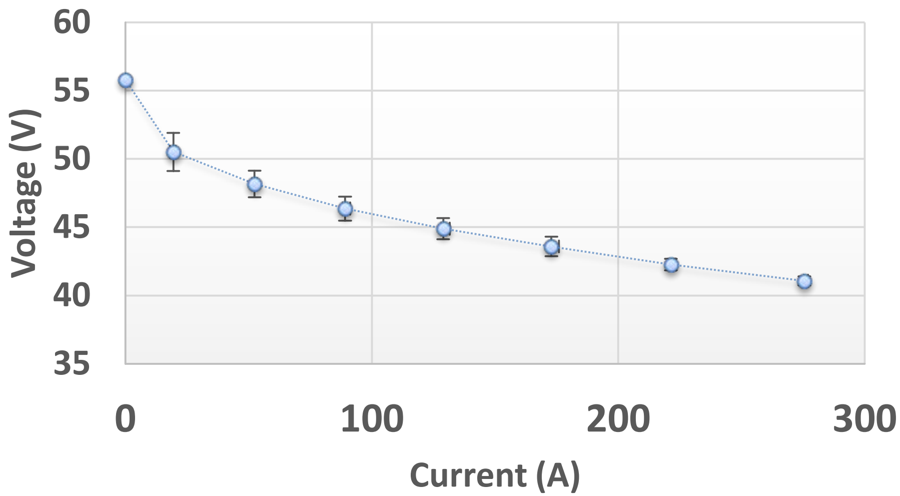
In-Rack Distributed Generation

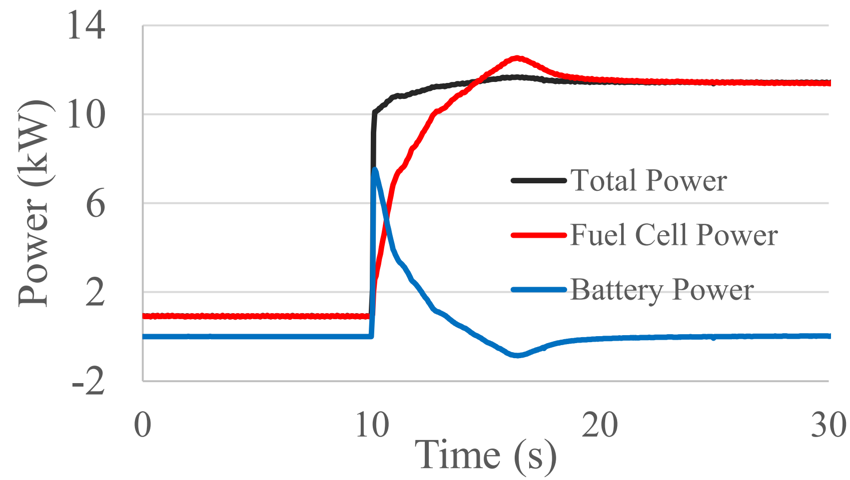
- **A direct generation method that places fuel cells at the rack level inches from servers**
  - limits the failure domain to a few dozen servers
  - Low voltage DC direct connection enabled
  - Equipment such as power distribution units, high voltage transformers, expensive switchgear, and AC-DC power supplies in servers could be eliminated
- **Hybrid fuel cell systems designed, installed and tested**
  - Use of a 10kW PEMFC stack and system as the distributed power source to power a server rack
  - Use of a 2.5 kW SOFC stack and system as the distributed DC power source to power a server rack

Direct DC Powering of Servers

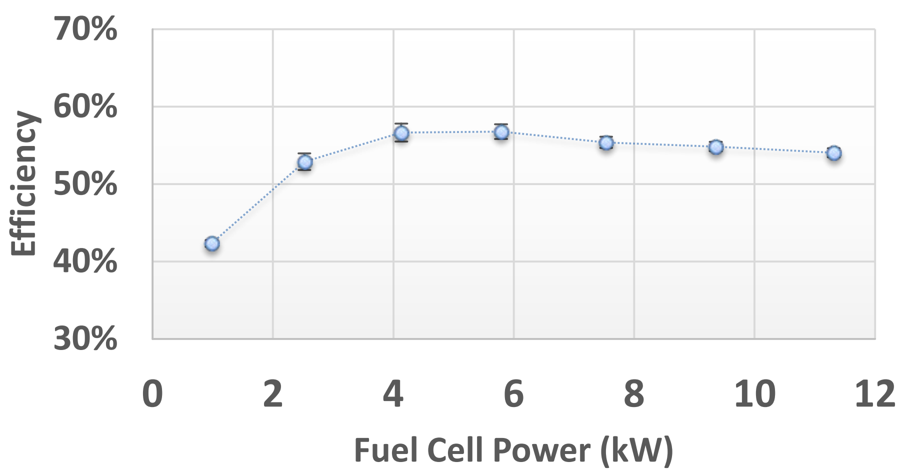


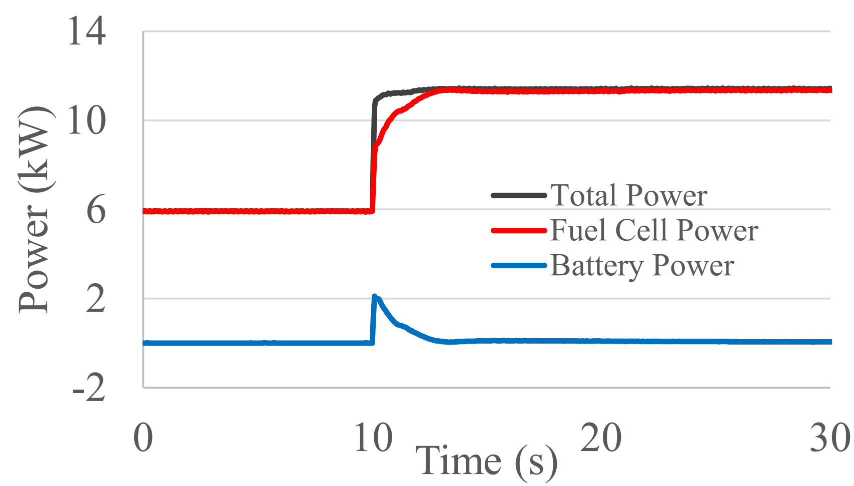
PEMFC Stack and System Performance





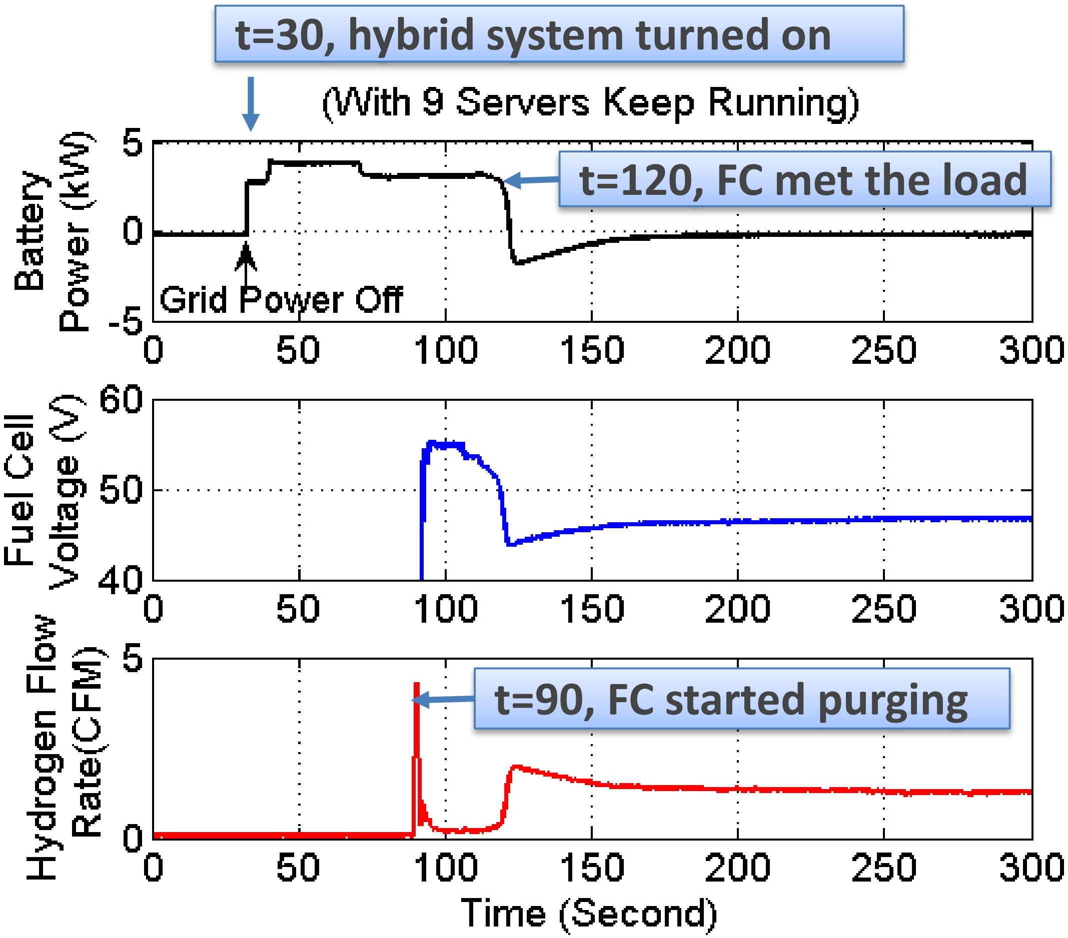
0kW to 9.0kW at t=10



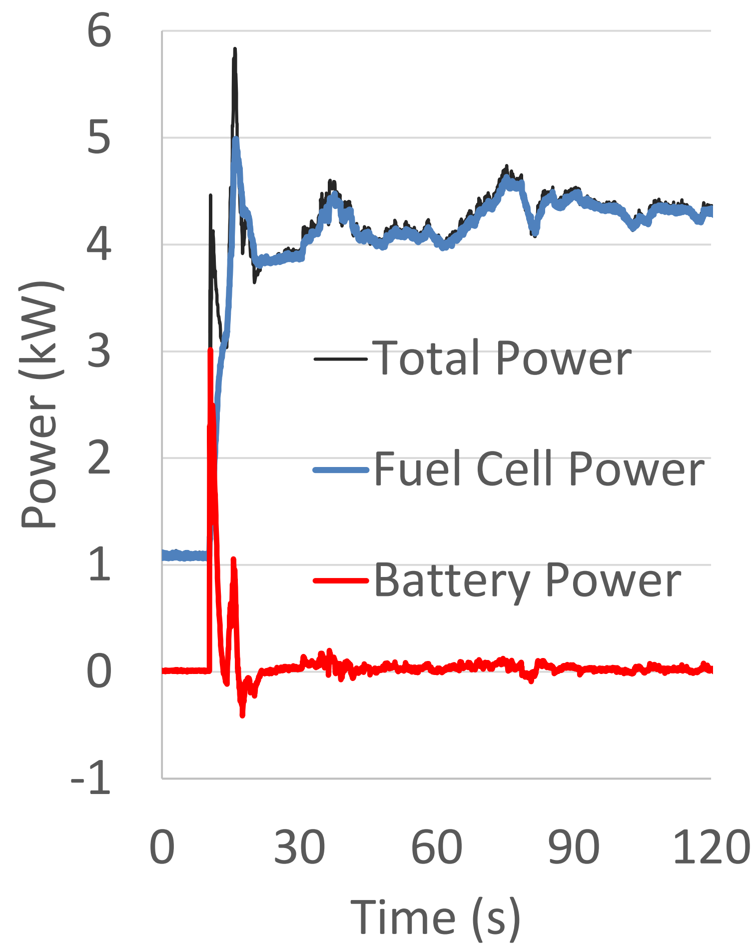


4.5kW to 9.0kW at t=10s.

PEMFC Stack and System Server Dynamics

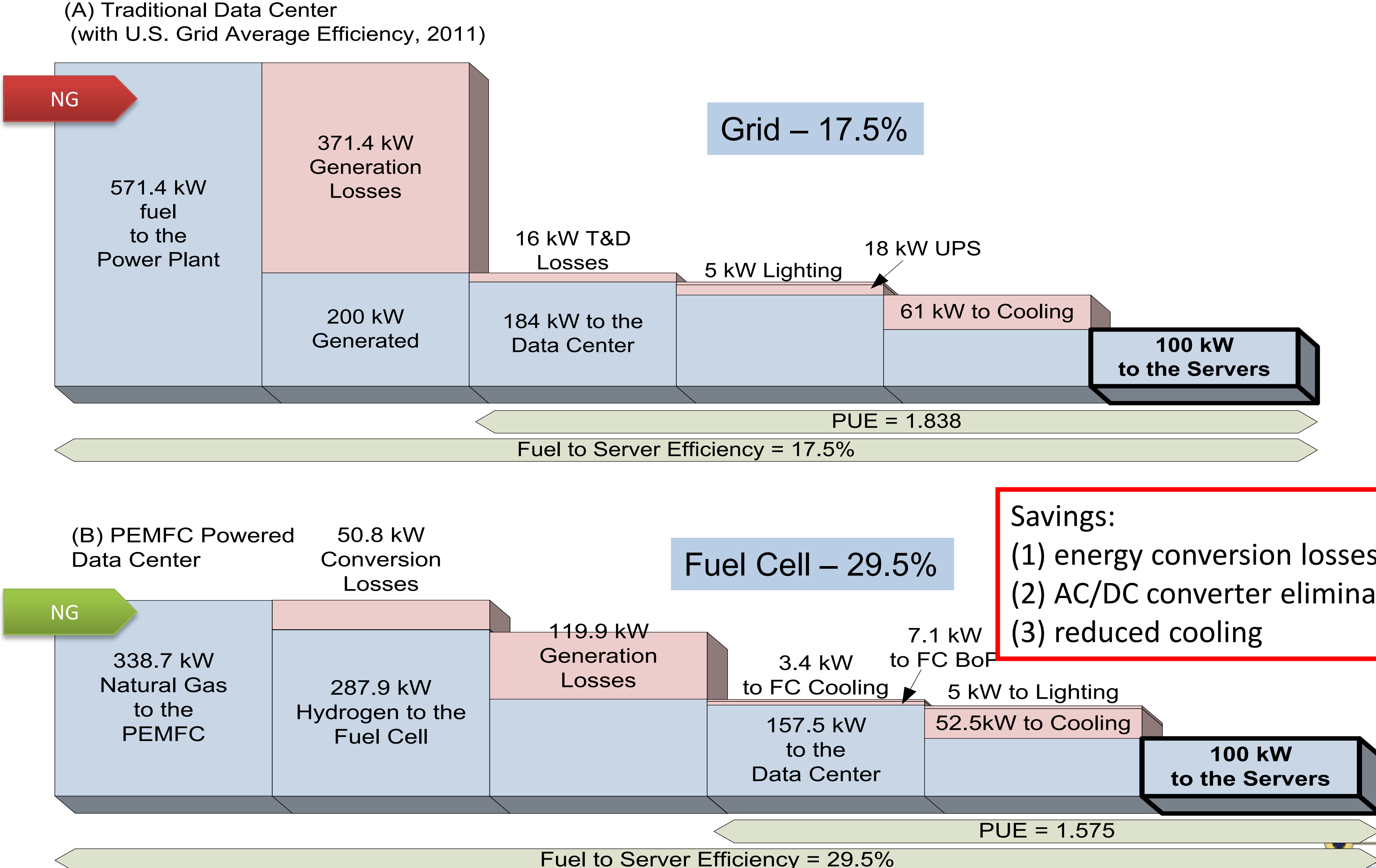


Cold startup time = 90s



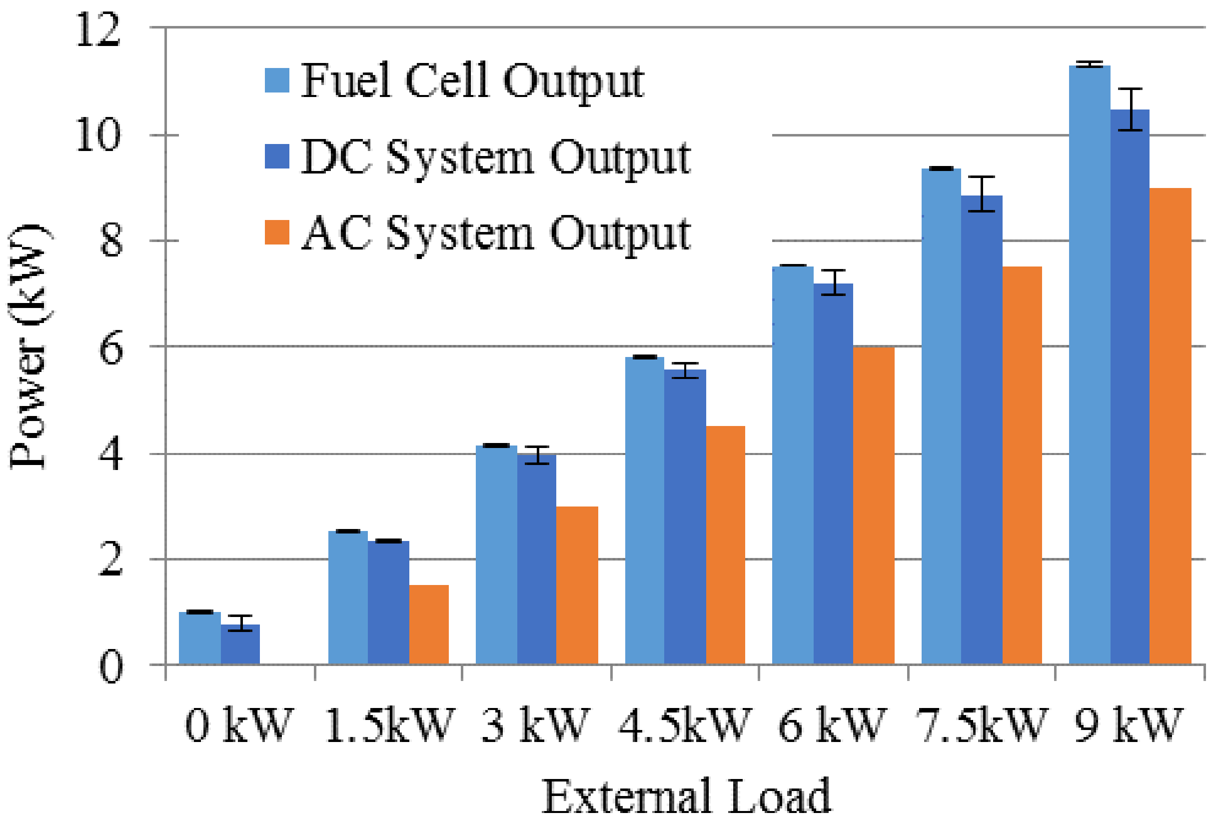
Hot start

Microsoft STARK Concept



Savings:
(1) energy conversion losses
(2) AC/DC converter elimination
(3) reduced cooling

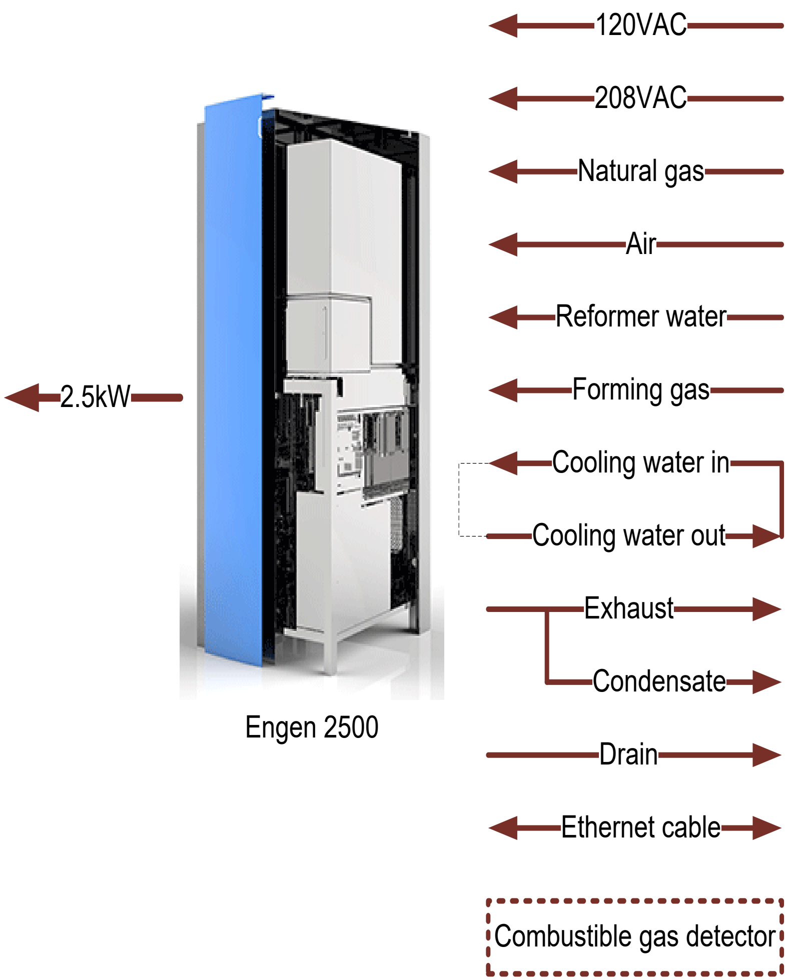
PEMFC Stack and System System Losses



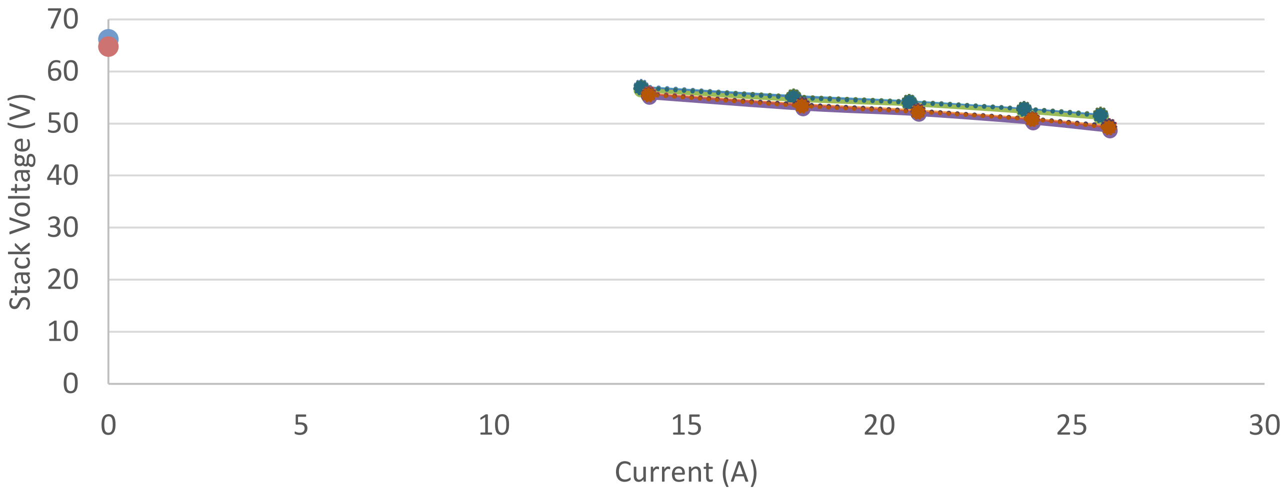
The power outputs of the 12kW in-rack PEMFC system under various external loads. Error bars in the data indicate + one standard deviation from 5 different measurements.

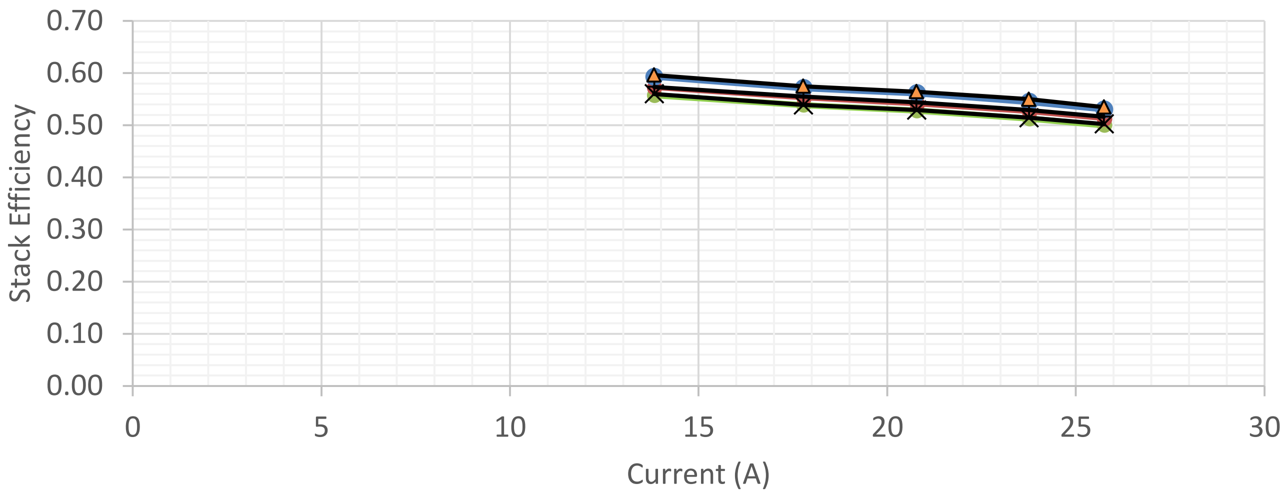
Direct DC Power Dynamics

- **What do we do before ubiquitous hydrogen infrastructure?**
  - **Solid Oxide Fuel Cells – natural gas operation (three systems evaluated)**



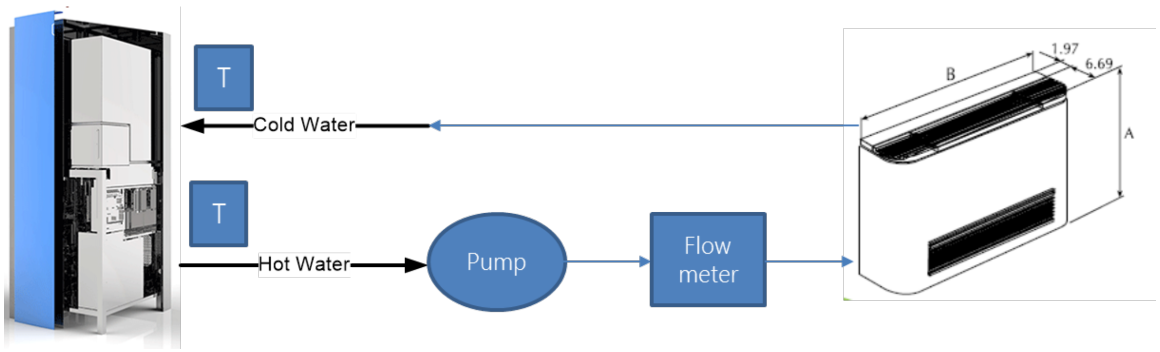
SOFC Stack and System Steady-State Performance

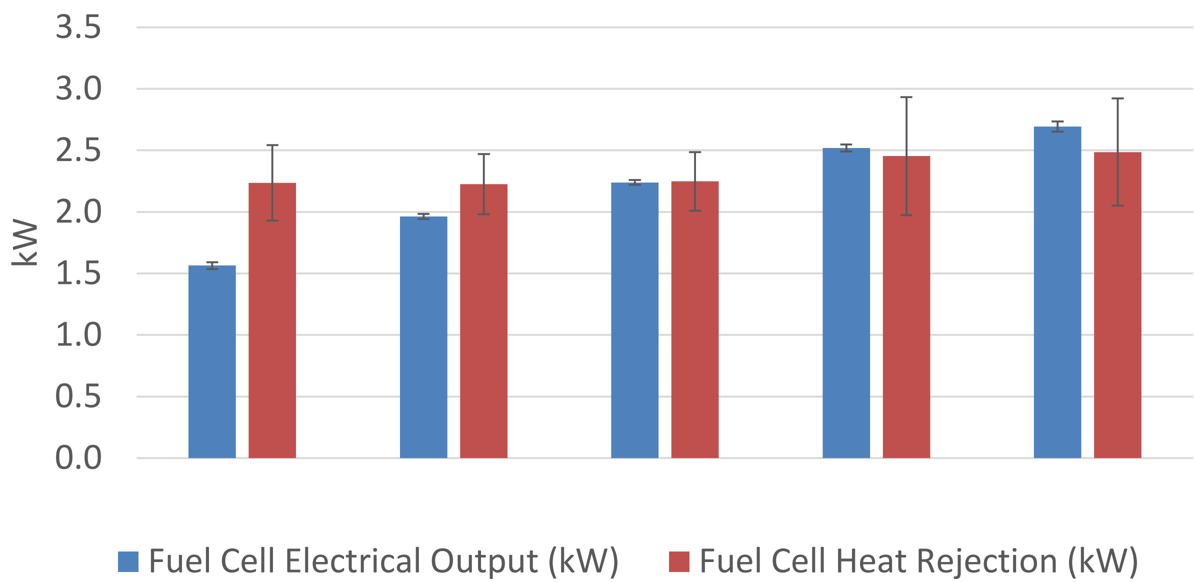




- Characterized I-V relation within the operating range.
- Provide information on overall data center design: bus, power supply, DC/DC.
- Electrical efficiency **>52%** under standard operating conditions.

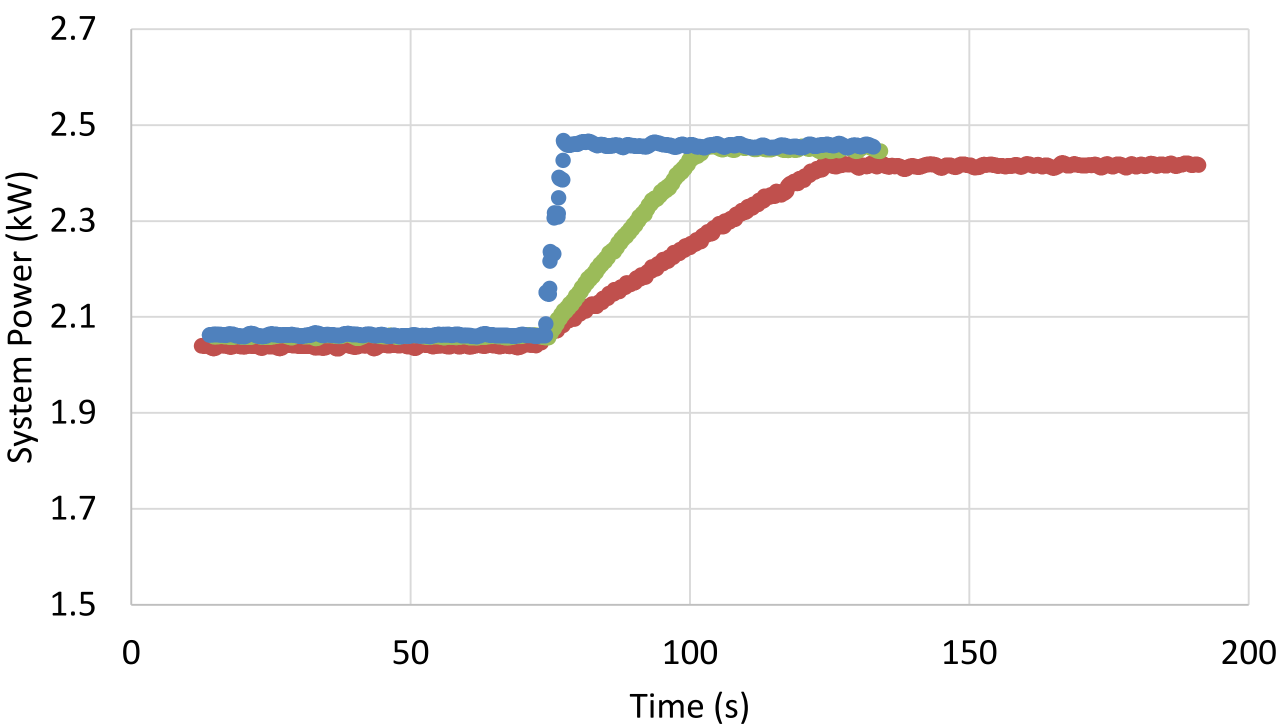
SOFC Stack and System Steady-State Performance





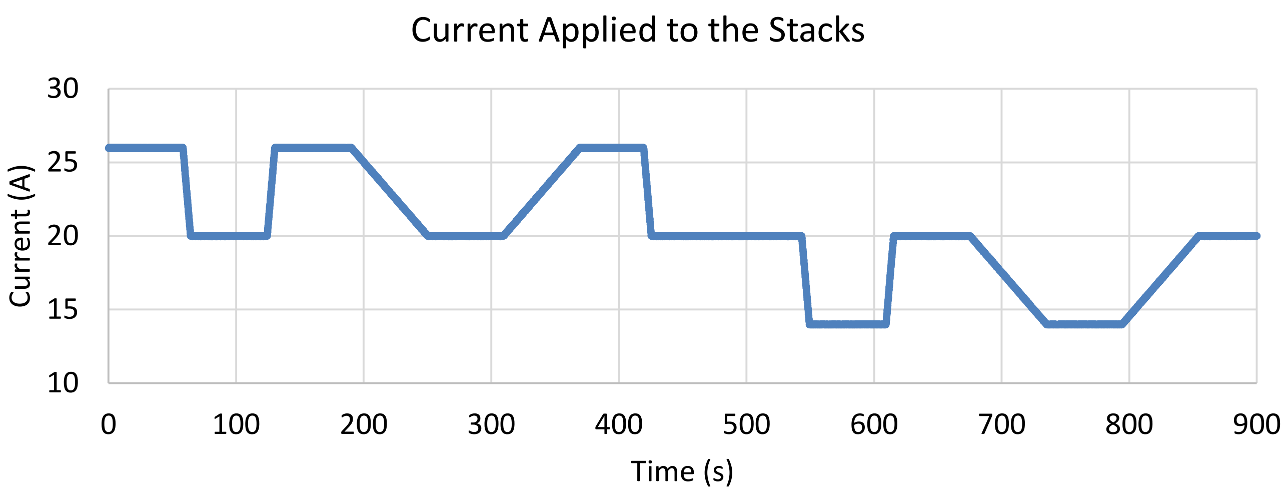
- Characterized the heat rejected at various power outputs.
- Provide information on sizing of the cooling system for data centers.
- Power to Heat Ratio over 1 at full load.

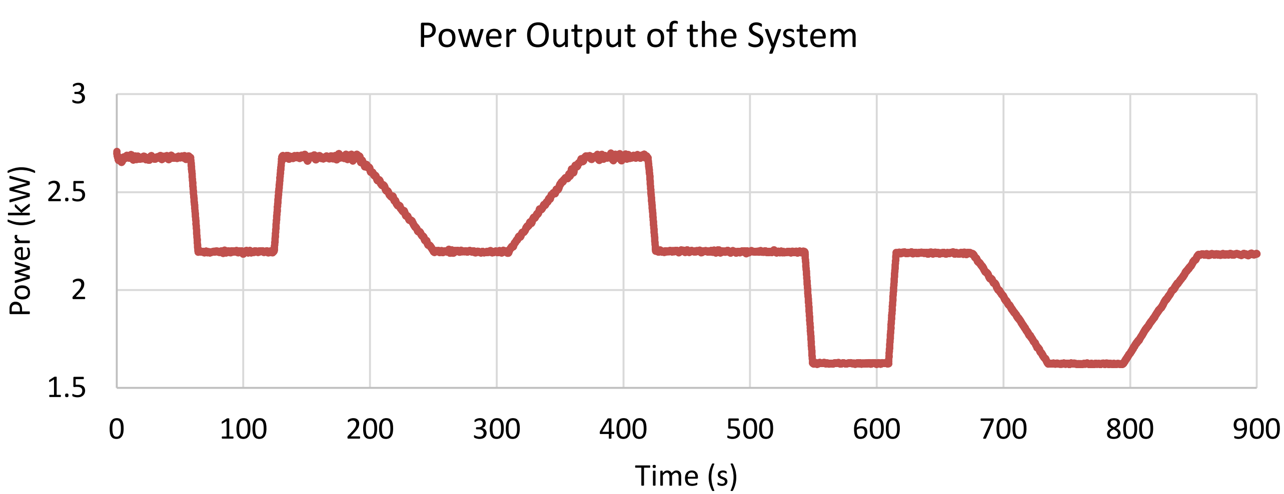
SOFC Stack and System Transient Performance



- Characterized ramping behavior of the fuel cell system with controlled ramp loads.
- Ramp rate of 1 A/s achieved.
- No significant power overshoot observed.
- With proper system design the SOFC system could ramp fast.

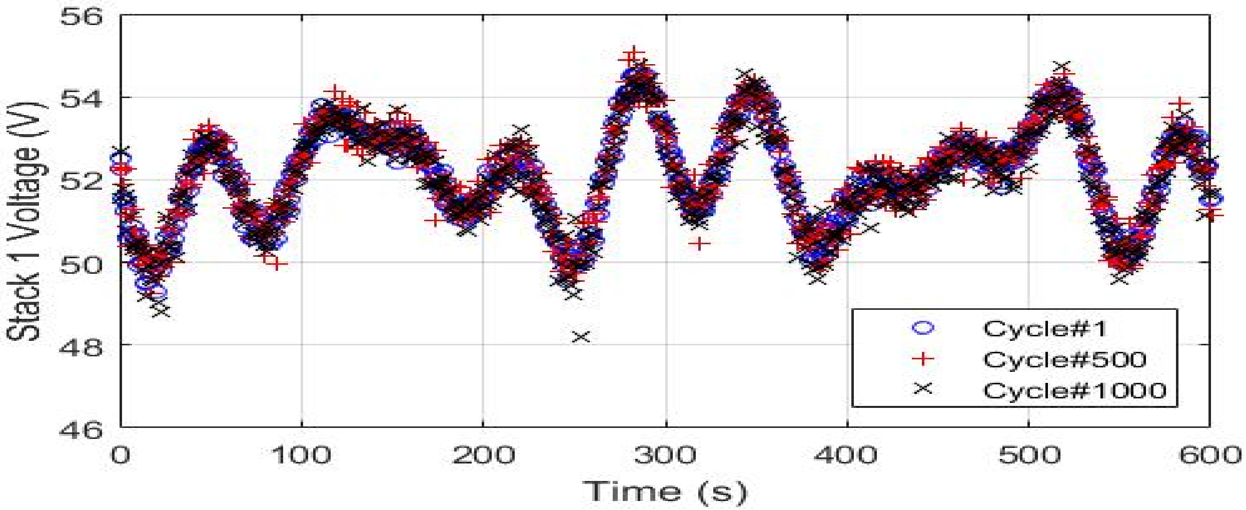
SOFC Stack and System Transient Performance

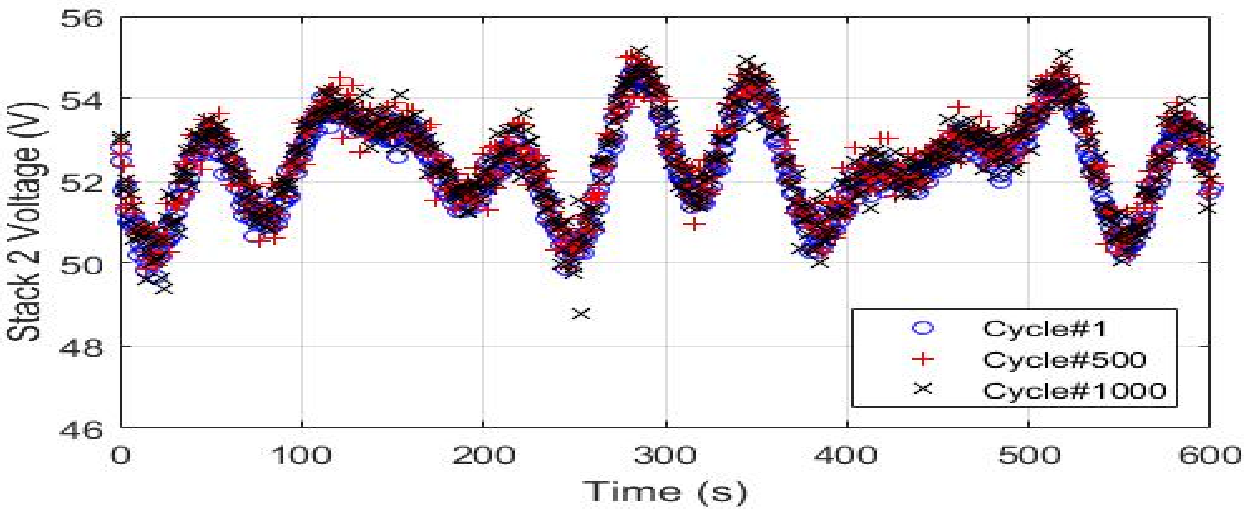




- Ramp up and down with various ramp rates were tested.
- System responds immediately to the transient demand perturbation.
- The SOFC system could follow fast load transients.

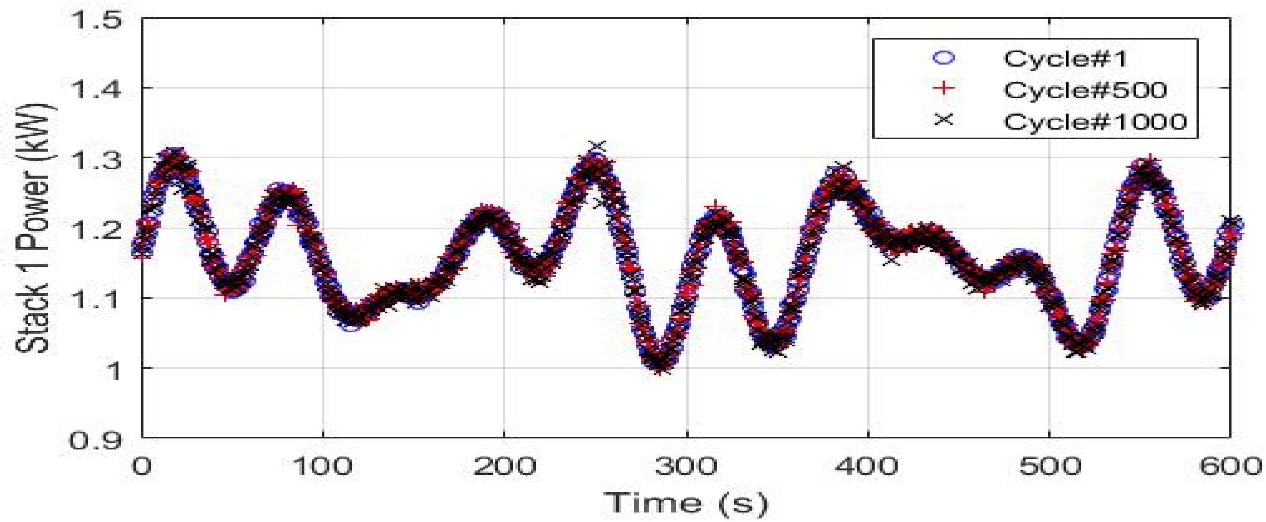
SOFC Stack and System Cycling Performance

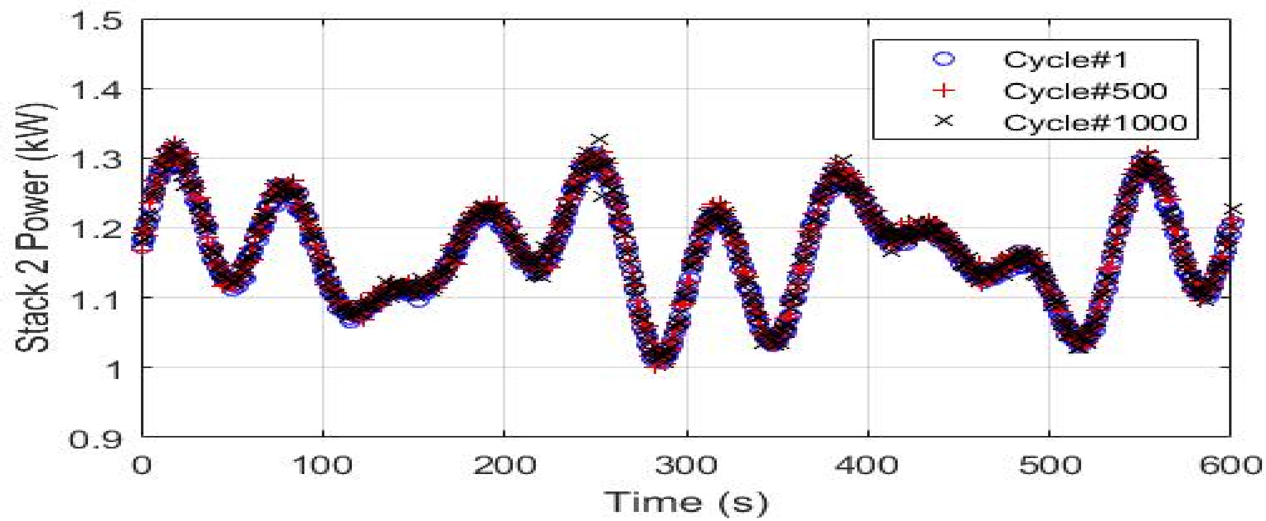




- After over 1000 hours of dynamic operation, slight voltage deviations were observed.

SOFC Stack and System Cycling Performance





- After over 1000 hours of dynamic operation, Negligible power output degradation observed.

Goal Must Be: 100% Zero Emissions

Envision this future, invest in its evolution

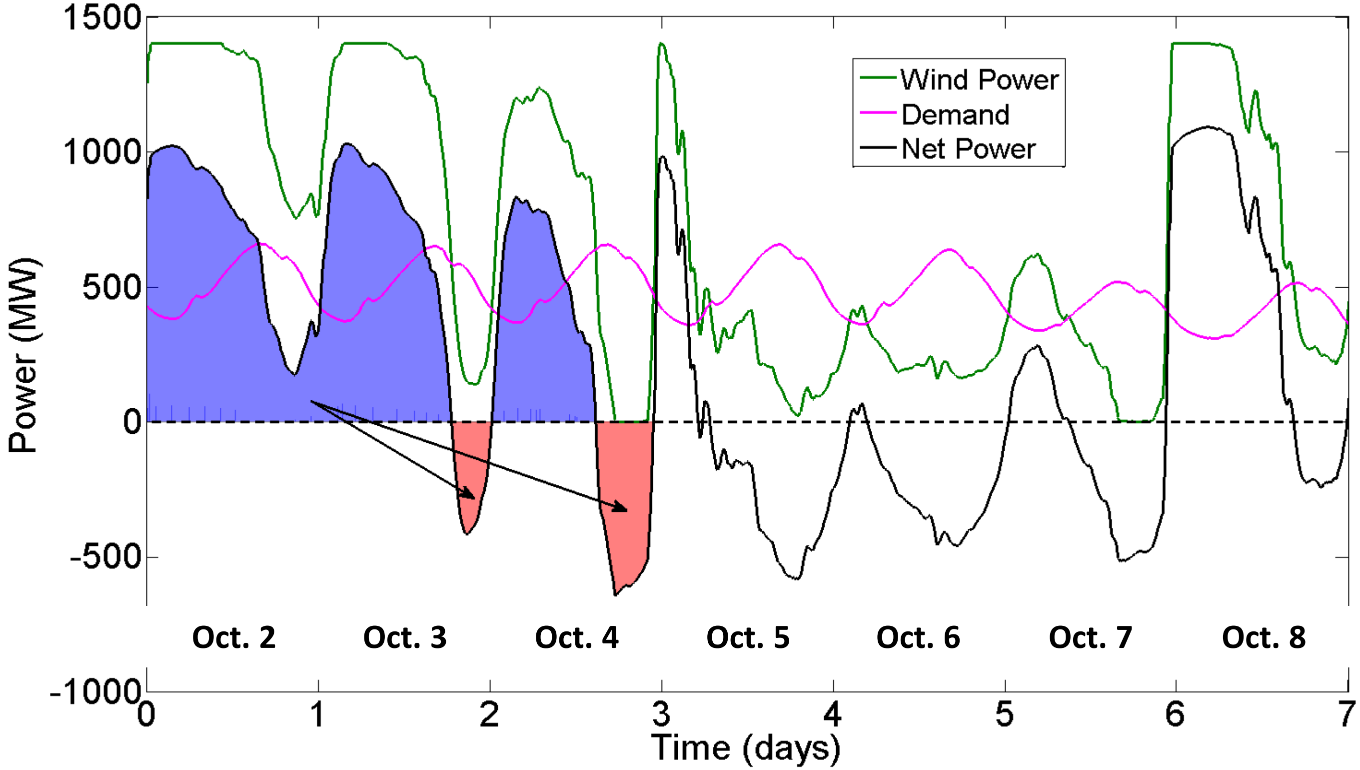
- ALL primary energy from sun, wind, wave, …

- Use ONLY zero emissions electrochemical energy conversion to complement
  - Batteries
  - Electrolyzers
  - Fuel cells

- Use ONLY zero emissions energy carriers
  - Hydrogen
  - Renewable gases & liquids

Hydrogen Energy Storage Dynamics

- **Compressed Hydrogen Storage <u>complements</u> Wind & City Power Demand Dynamics in (Texas)**



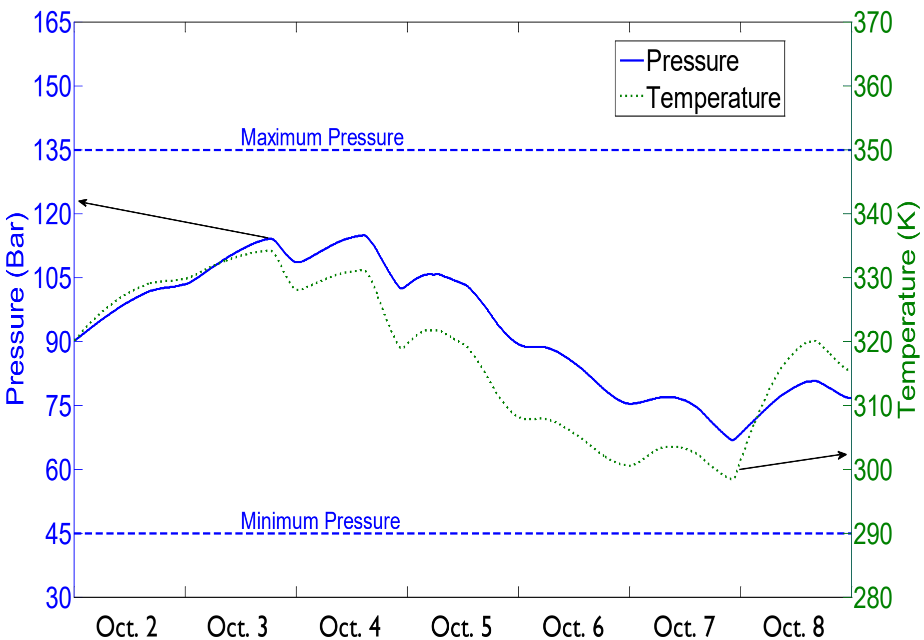
- **Load shifting from high wind days to low wind days**
- **Hydrogen stored in adjacent salt cavern**

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

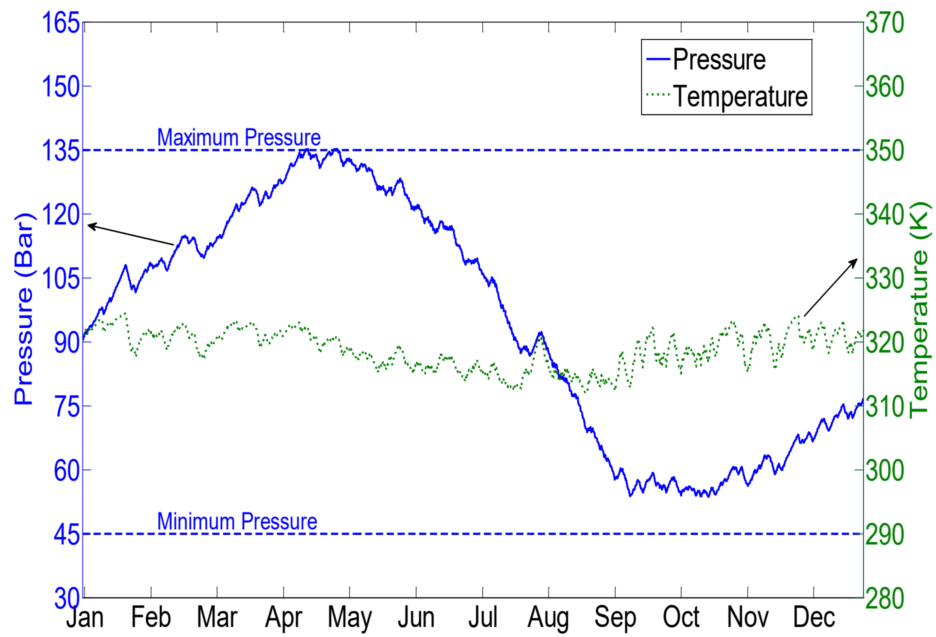
Hydrogen Energy Storage Dynamics

- **Weekly storage and seasonal storage possible with hydrogen and fuel cells/electrolyzers – all zero emissions!**

Weekly



Seasonal

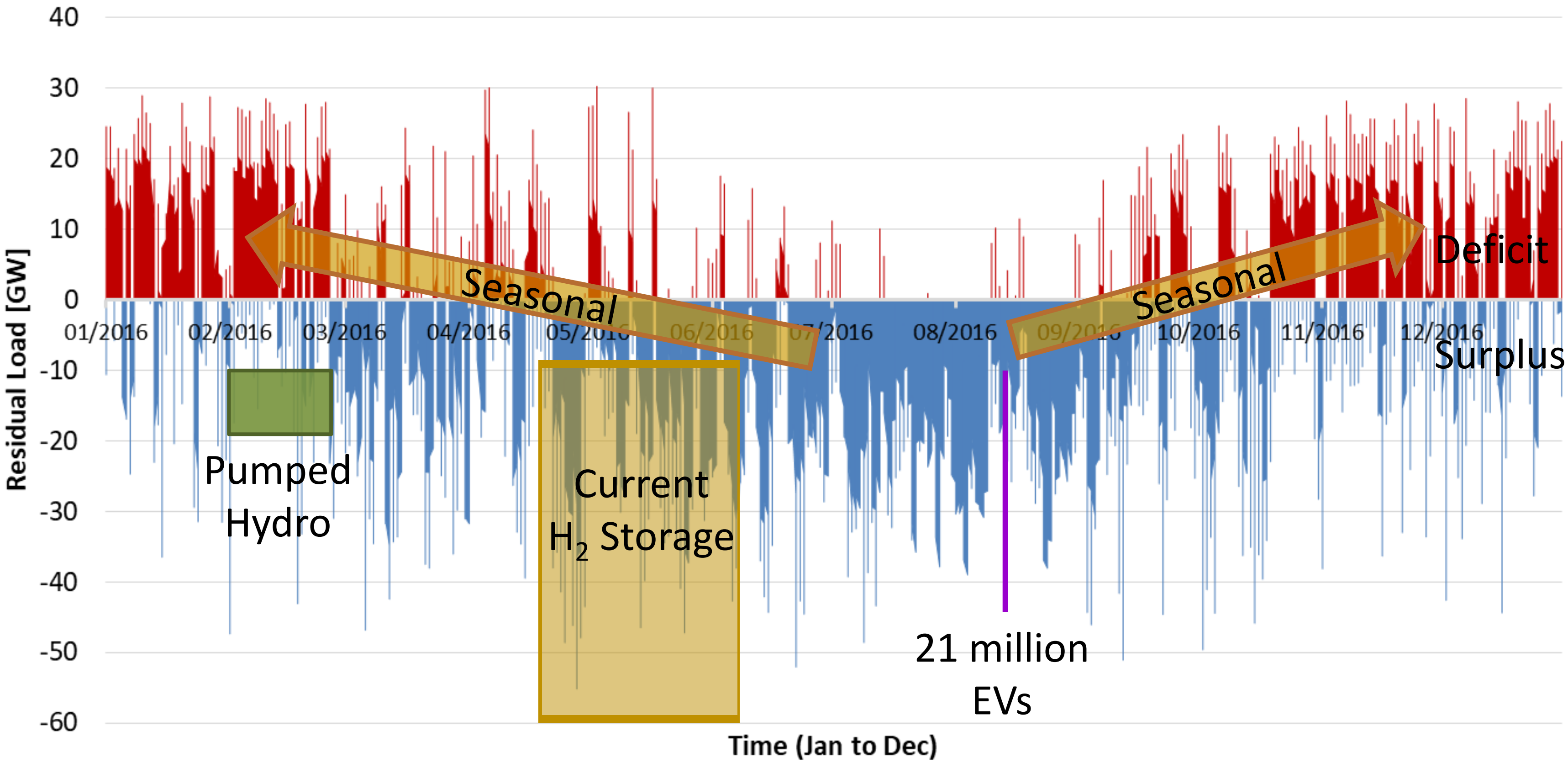


But what can we do if we don't have a salt cavern?

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

Why we need H_2: Amount of Storage Required

- **Recent 1-Year Simulation of 100% Renewable Grid in CA**
  - **Wind dominant case (37 GW solar capacity, 80 GW wind capacity)**



*Using existing natural gas resources for hydrogen storage

§ 21 million = total CA registered light duty vehicles; Nissan Leaf battery

Why We Need H_2: World Grid Energy Storage Need

Simulate meeting of TOTAL world electricity demand w/ Solar & Wind

- How much storage is needed?

	Solar contribution	Wind contribution	Consumption and storage ratio	Consumption (TWh)	Storage (TWh)
Africa	0.70	0.30	8.39	9,123	1,088
America	0.45	0.55	7.83	38,541	4,919
Asia	0.50	0.50	7.95	80,866	10,178
Europe	0.30	0.70	7.50	26,951	3,592
Oceania	0.50	0.50	7.95	1,625	205
TOTAL				157,106	19,981 TWh

[Nuria Tirado, M.S. Thesis, 2018]

- Batteries needed, but, they cannot do it all!
  - Li req'd = 3,144 Mt Co req'd = 25,815 Mt
  - Massive cost (connected power & energy scaling)
  - Self discharge (measured performance in utility applications)

Why We Need H_2: Lithium-ion Batteries

Lithium

- **Resources: 53 Mt (USGS)**

3,144 Mt req'd

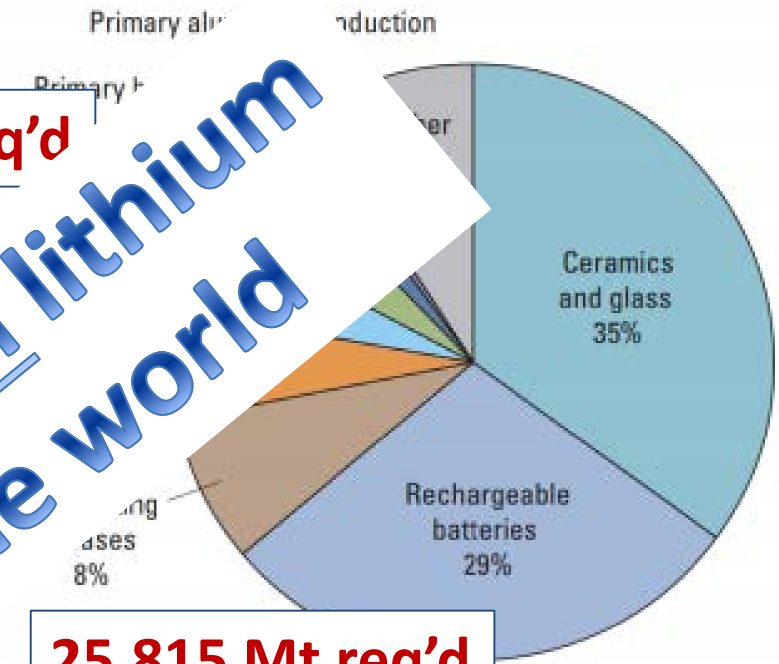
- ○ **Economic feasibility**
  - Size of the deposit
  - Lithium content
  - Content of other elements
  - Processes used for p

Cobalt

- **Terrestrial resourc**
- **Ocean-floor r (USGS)**
- **40% of co ie Democratic Republic of the Congo**

- ○ **Improv ed in cobalt ion**
  - Better geologic models
  - Improved extraction methods
  - Development of recovery processes
  - Technological advances (deep-sea)

There is not enough lithium or cobalt in the world



25,815 Mt req'd

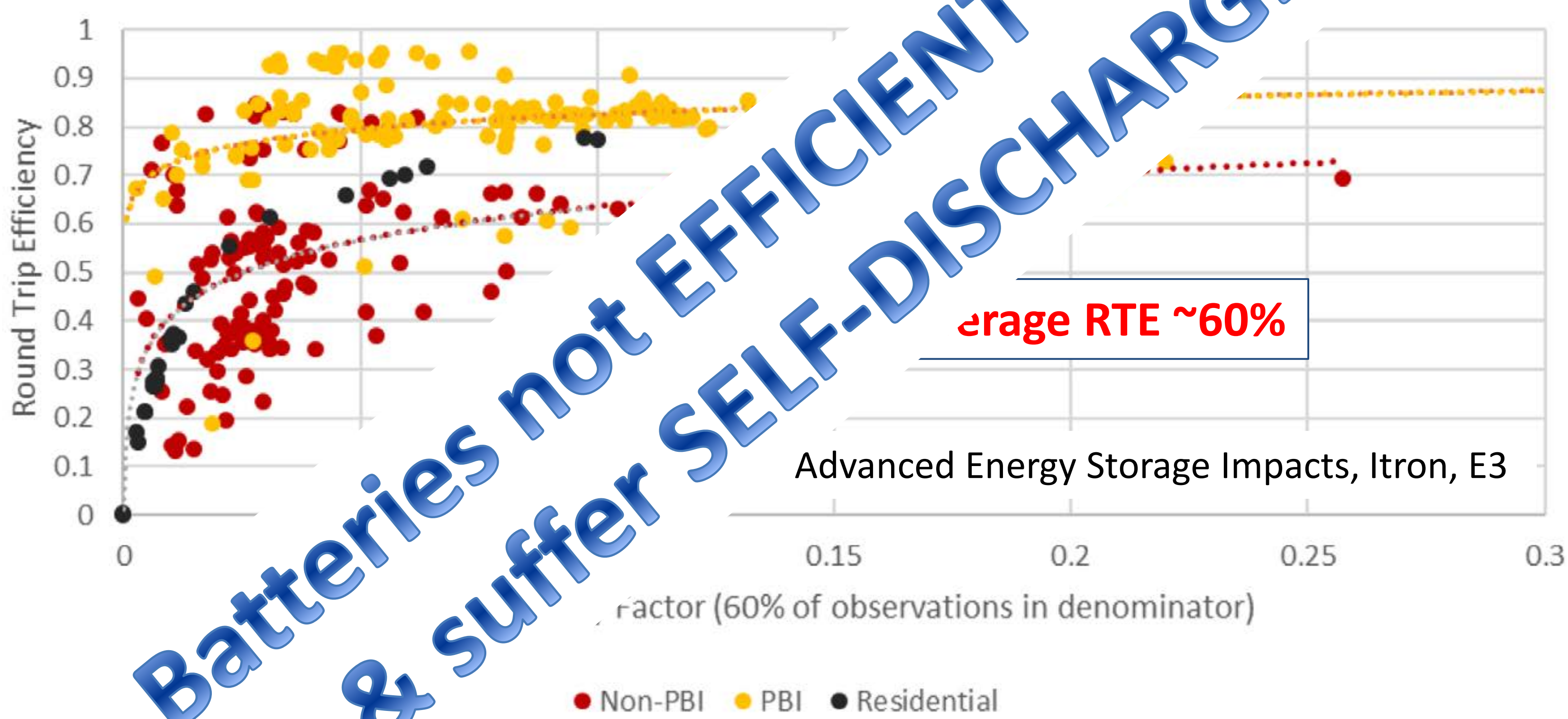
Figure extracted from USGS.

Why We Need H_2: Lithium-Ion Batteries

Round-Trip Efficiency (>90% in Laboratory Testir

- **Measured battery system performance ir ions**

FIGURE 1-3: TOTAL ROUNDTRIP EFFICIENCY VERSUS CAPACITY FACT

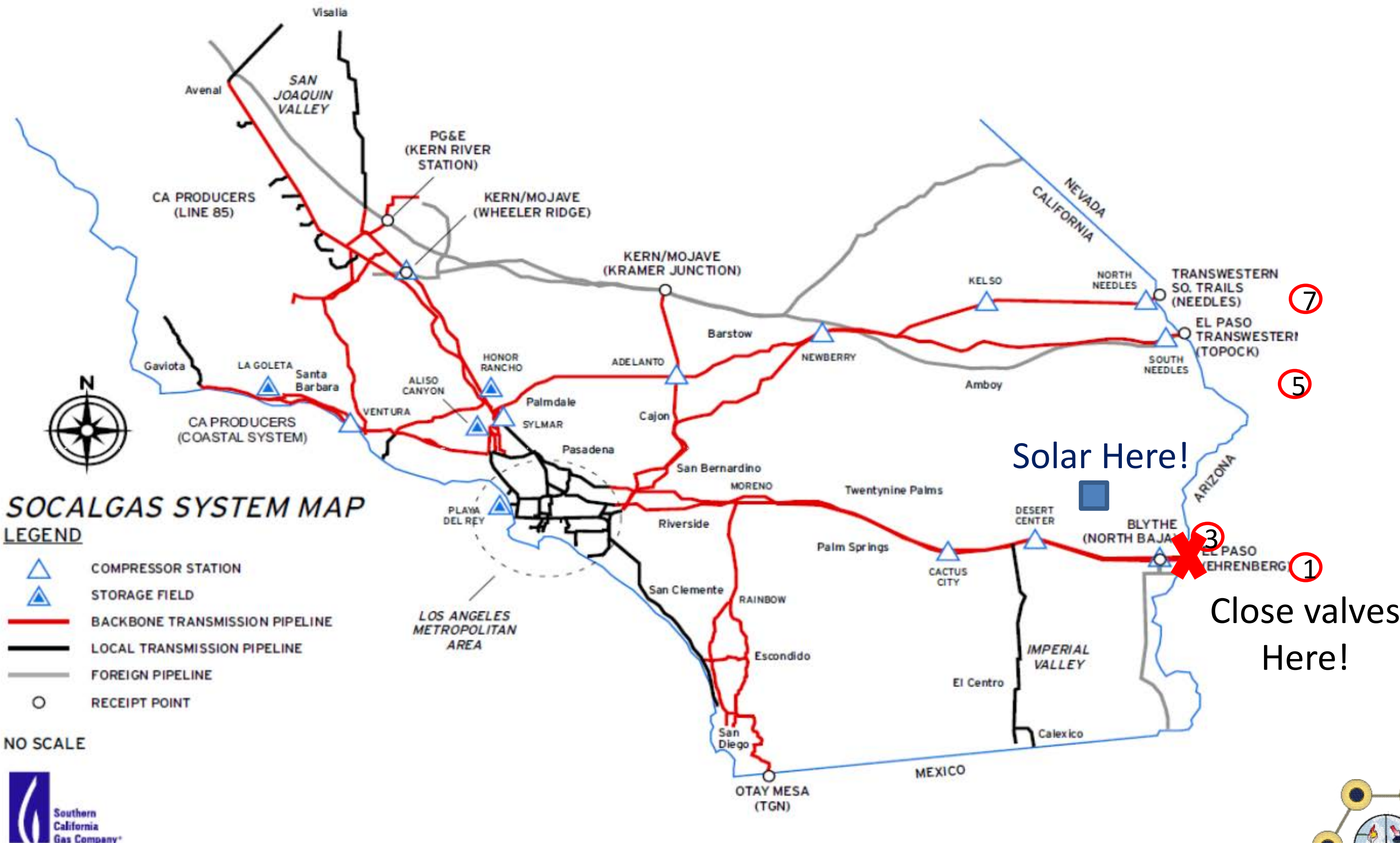


Batteries not EFFICIENT enough & suffer SELF-DISCHARGE

- **Self-D. ne main culprit), plus cooling, transforming, invertin, nverting, and other balance of plant**

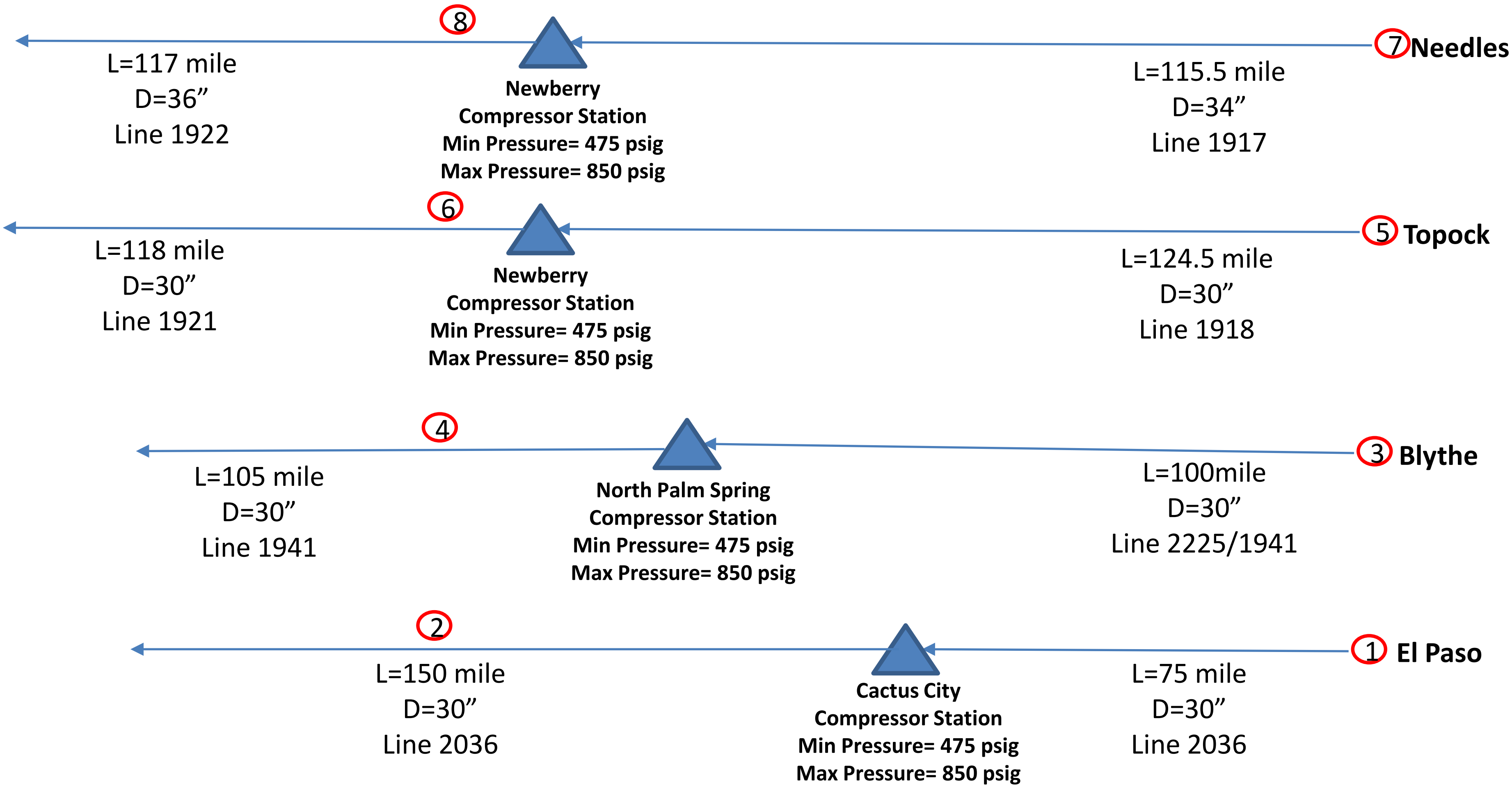
Brief Gedanken experiment

- First mix up to X% – tremendous boon to grid renewables
- Then piecewise conversion to pure hydrogen



Pressure and Flow Dynamics

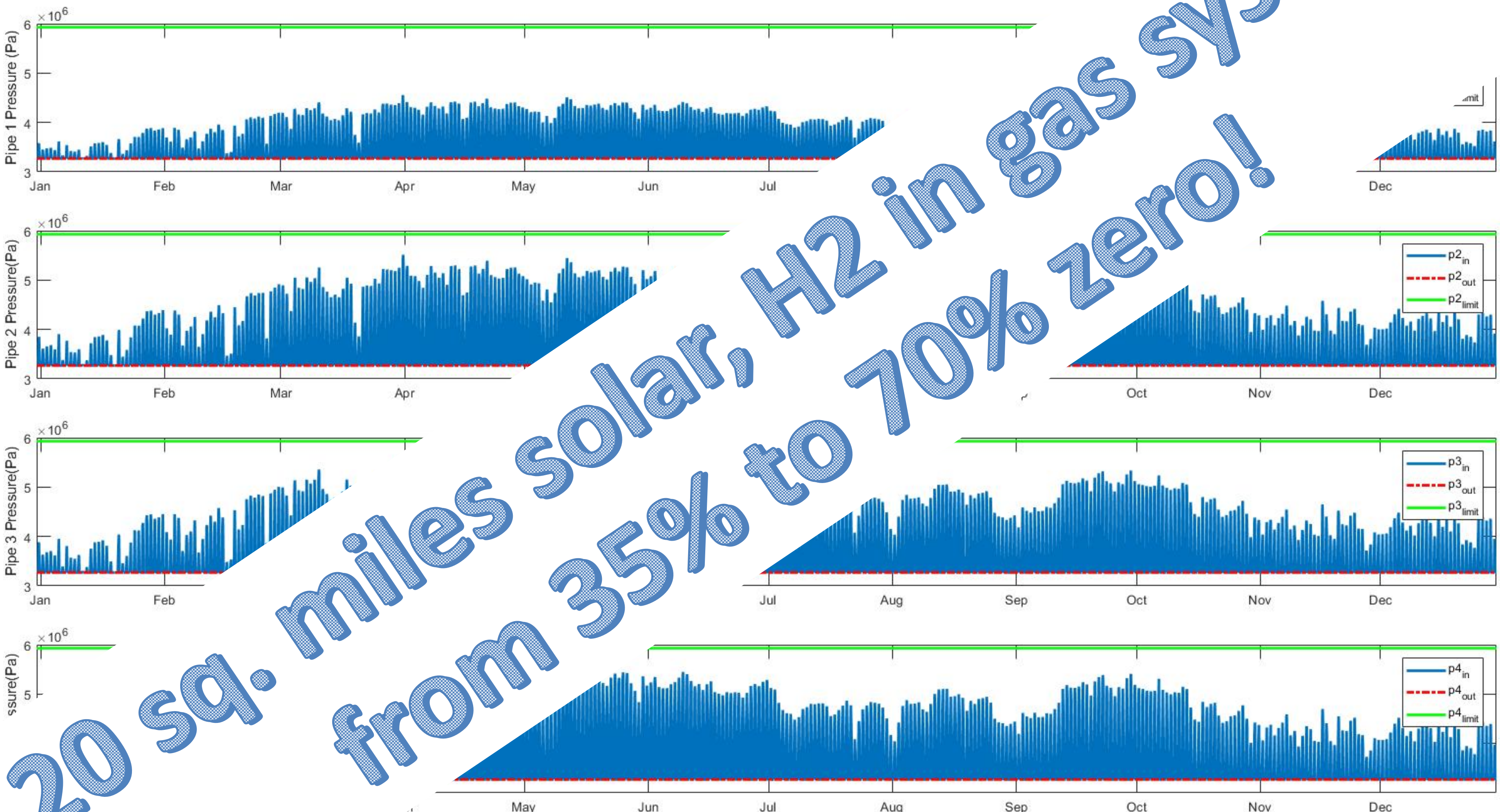
- **With renewable gas injection at border (in desert)**



Reference for pipe and compressor: stationhttps://www.arcgis.com/home/webmap/viewer.html?webmap=f8b54b821642463b8dc0becb2711093a

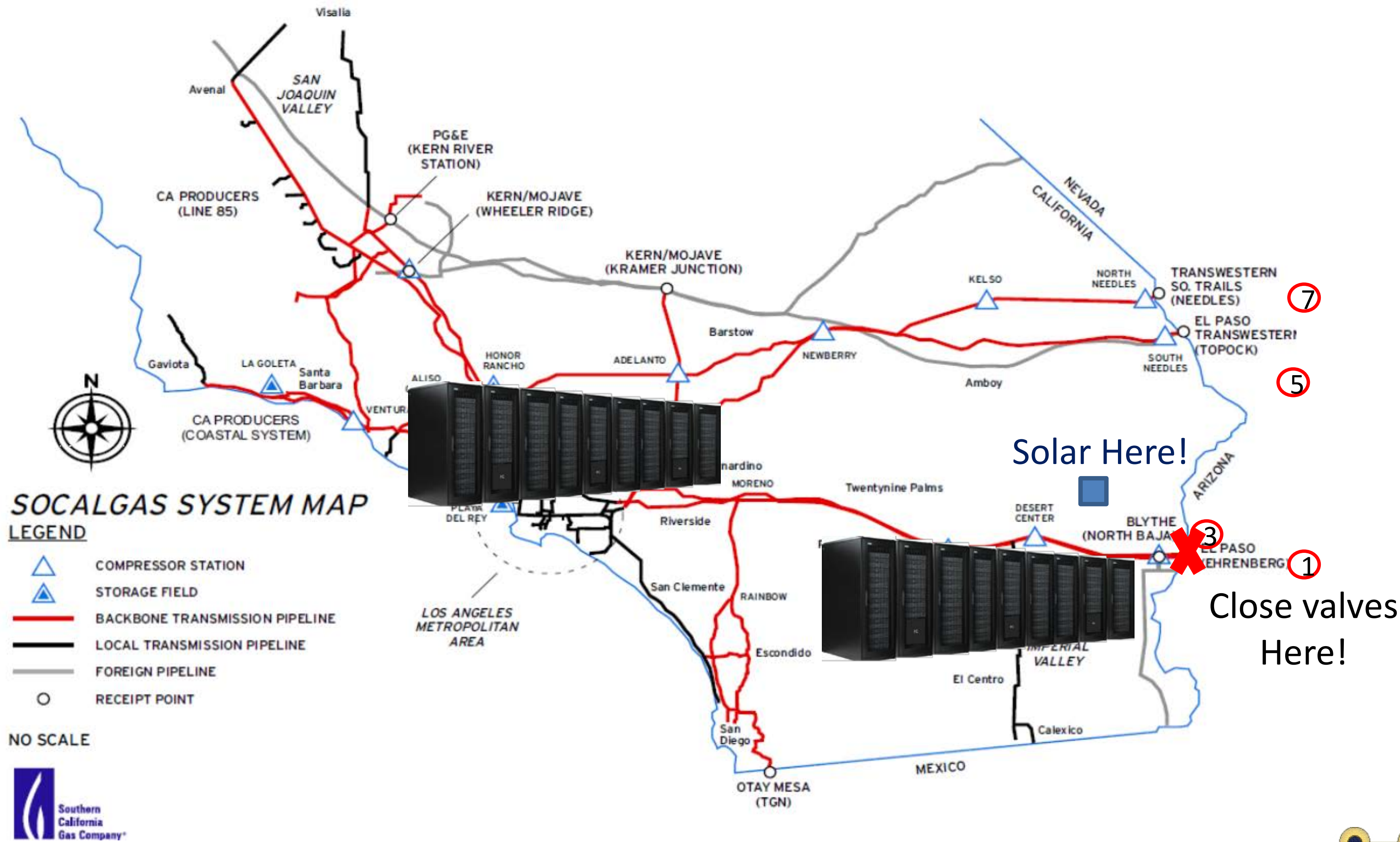
Pressure and Flow Dynamics

- 40% of all electric demand – 20 sq. miles of solar, only use for H_2 storage and T&D



Brief Gedanken experiment

- **Piecewise conversion of gas system to pure hydrogen**



Thank You!

ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

National Fuel Cell Research Center
UCIrvine | UNIVERSITY OF CALIFORNIA