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Evaluation of Renewable Hydrogen Power-to-Gas in California

Renewable Hydrogen Production Workshop

California Energy Commission – Sacramento

Advanced Power & Energy Program
University of California · Irvine

National Fuel Cell Research Center
University of California · Irvine

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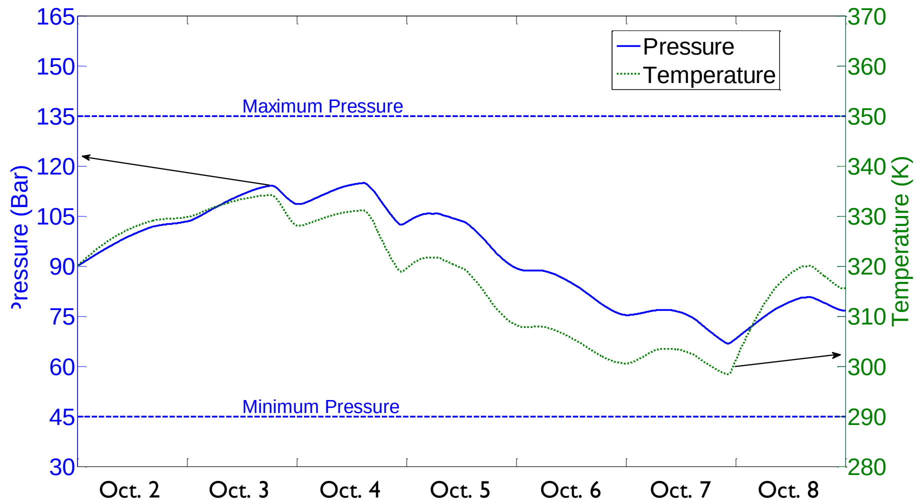
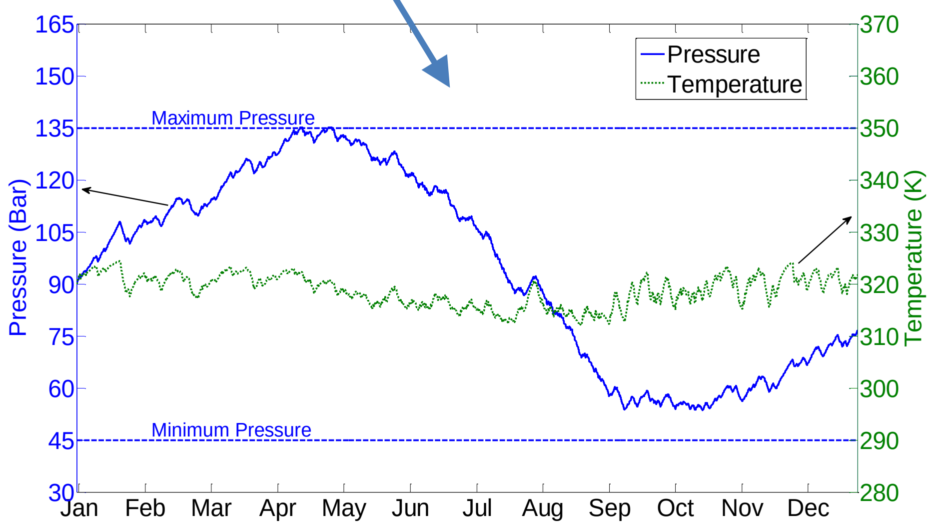
January 30, 2017

Hydrogen Energy Storage Dynamics

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



- Seasonal energy storage possible

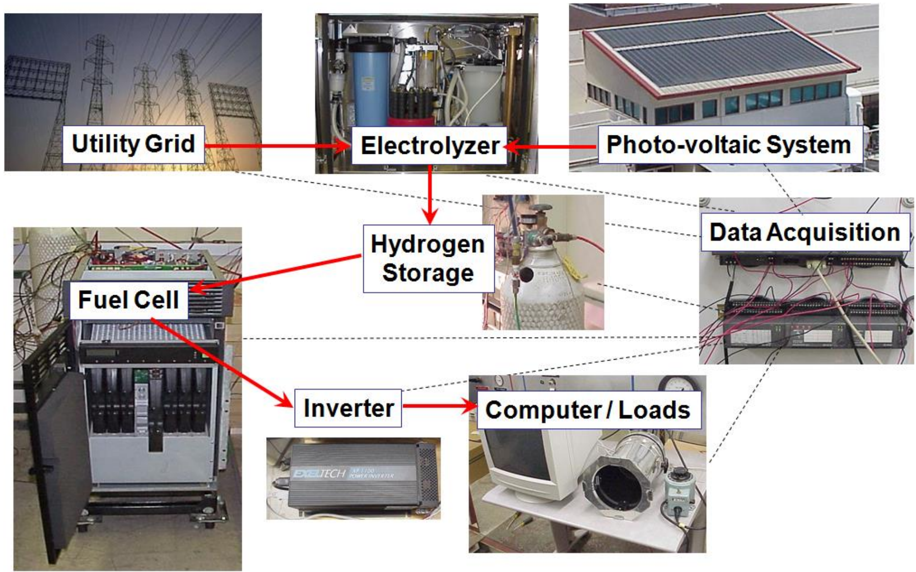


Maton, J.P., Zhao, L., Brouwer, J., Int'l Journal of Hydrogen Energy, Vol. 38, pp. 7867-7880, 2013

SoCalGas P2G Support & Collaboration @ UC Irvine

Major Actions and Accomplishments in 2015-16

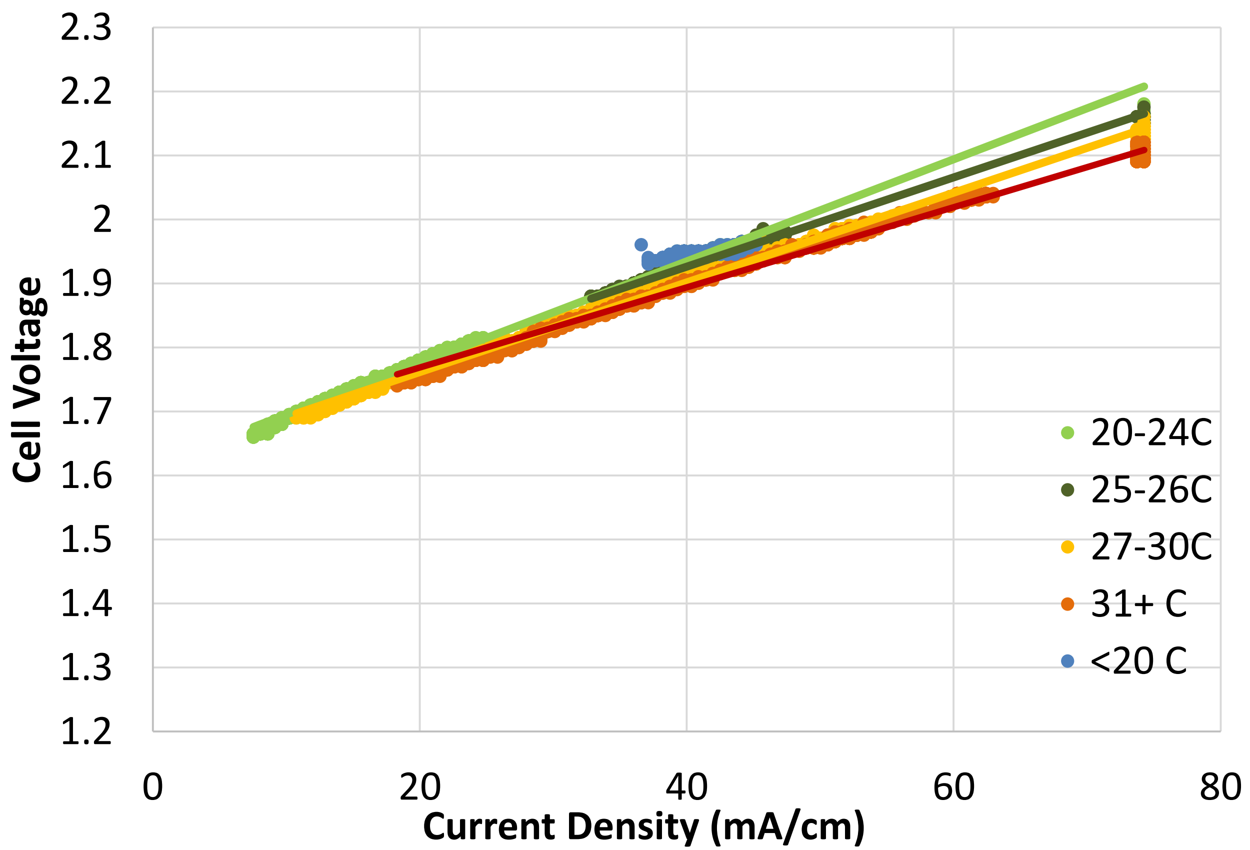
1. Lab-scale H_2 production dynamics by direct-DC & AC PV electrolysis
2. Hydrogen injection into existing natural gas distribution system infrastructure – leakage assessment
3. Evaluation of one customer-side leakage mitigation strategy
4. Evaluated alternative electrolysis technologies (PEME, SOE, REP)
5. Collaboration with SoCalGas to evaluate hydrogen and hydrogen blend leakage rates
6. Simulation of pipeline materials impacts (embrittlement, fatigue)
7. Simulation of P2G impacts in grid and microgrid
8. Full-scale hydrogen production & injection into 400 psi line
9. Combustion of P2G gas in NGCC
10. Economic analyses



P2G Accomplishment: Lab-Scale Electrolyzer Dynamics

HOGEN-RE proton exchange membrane electrolyzer

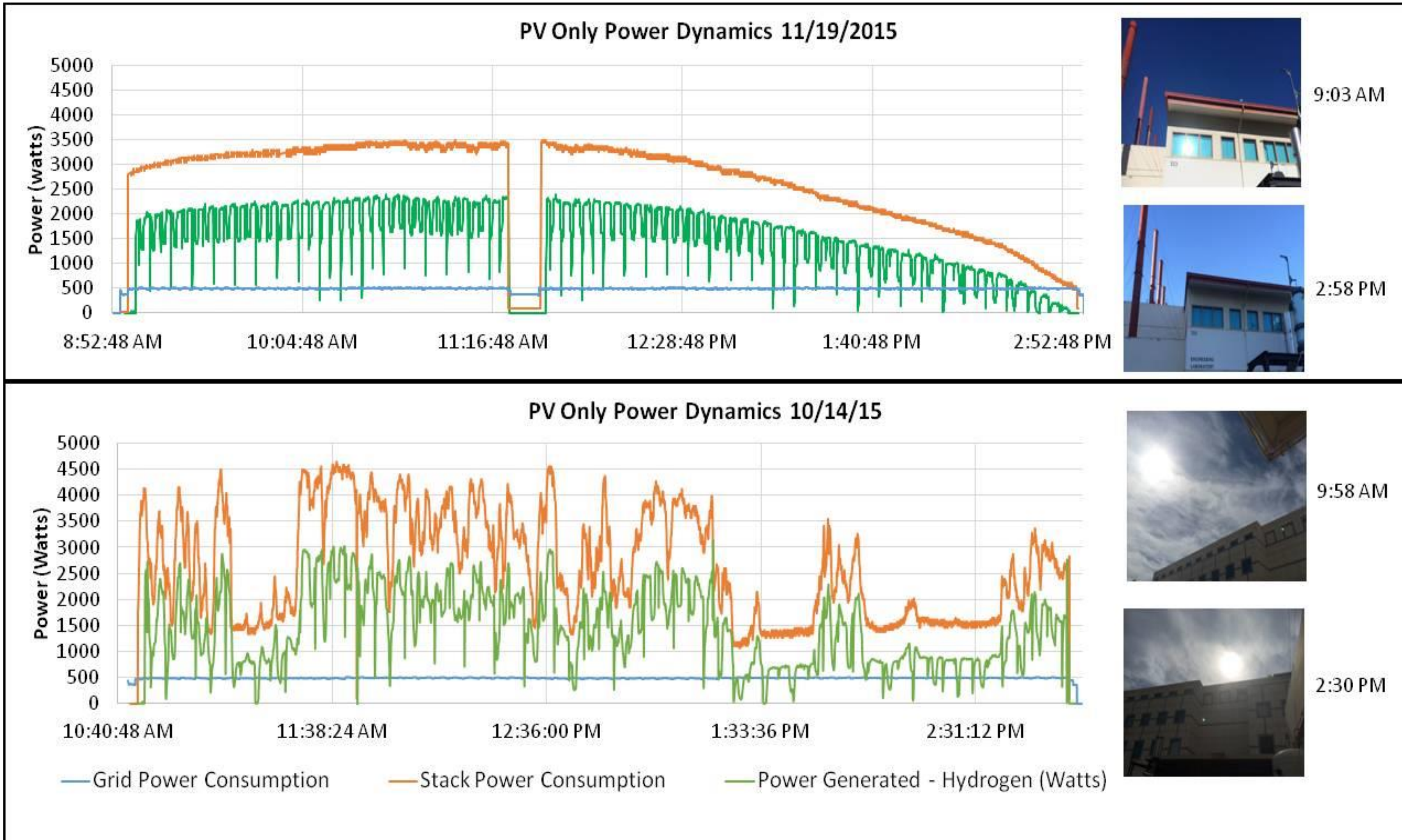
- Performs best when hot (summer vs. winter)



P2G Accomplishment: Lab-Scale Electrolyzer Dynamics

HOGEN-RE proton exchange membrane electrolyzer

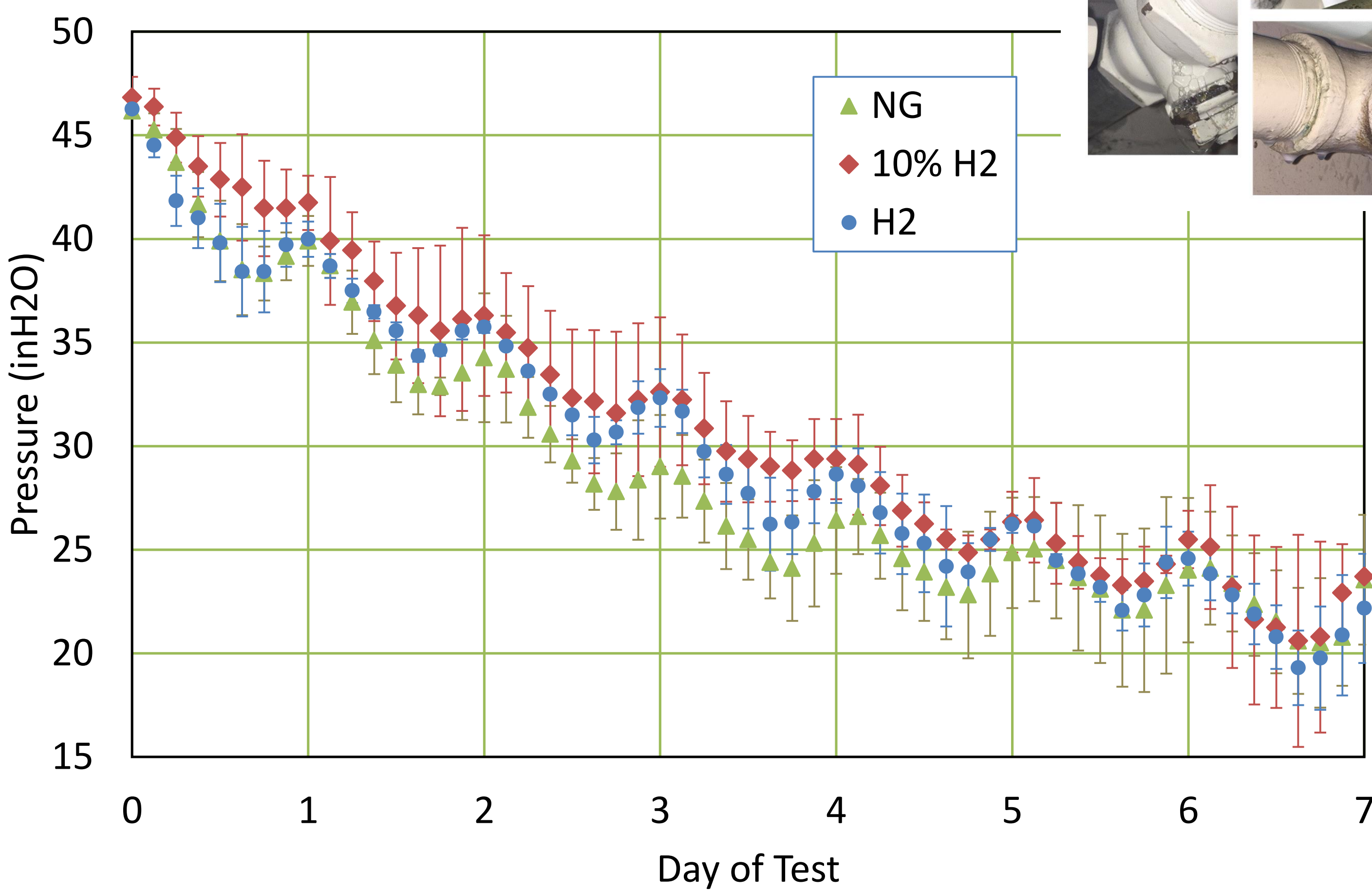
- Hydrogen production dynamics (with and without clouds)



P2G Accomplishment: Hydrogen Pipeline Injection

H2 injection into existing natural gas infrastructure (low pressure)

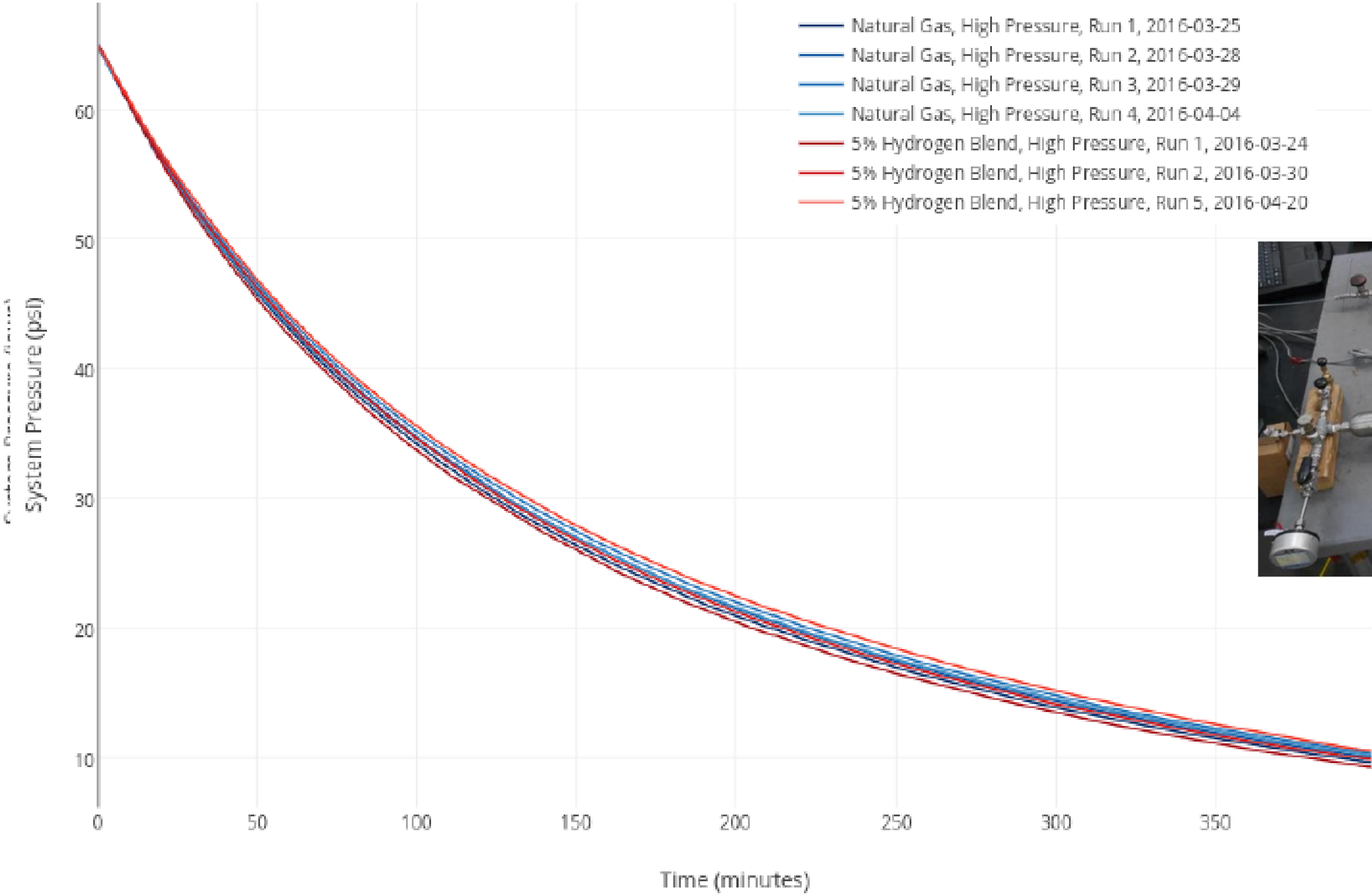
- NG, H2/NG mixtures, H2 leak at same rate

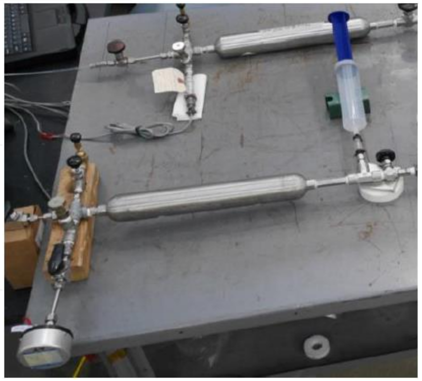


P2G Accomplishment: Hydrogen Leakage Assessment

H2 and H2/NG mixture leakage rates

- Test apparatus with fixed small orifice

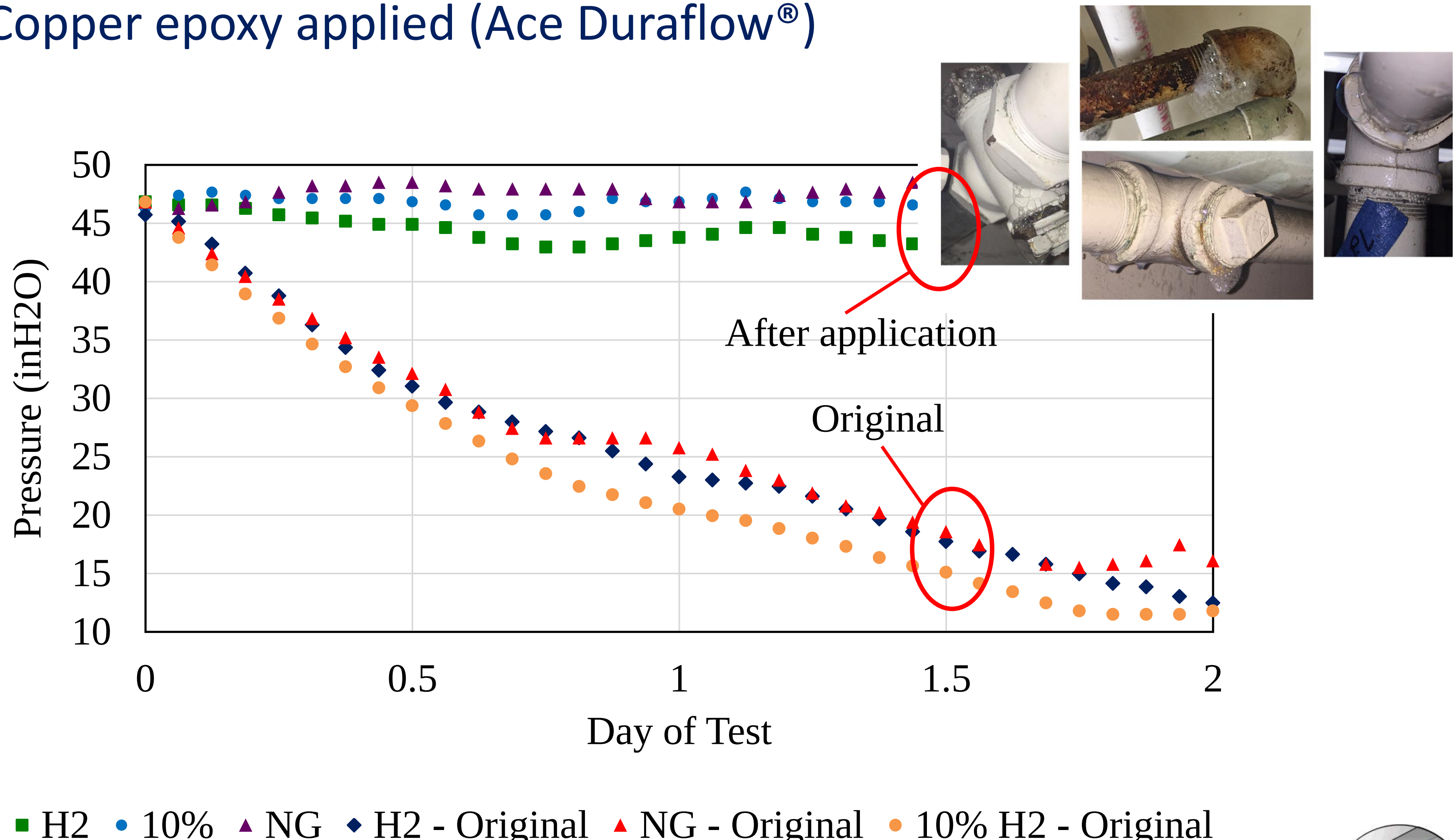




P2G Accomplishment: Leak Mitigation Evaluation

H2 injection into existing natural gas infrastructure (low pressure)

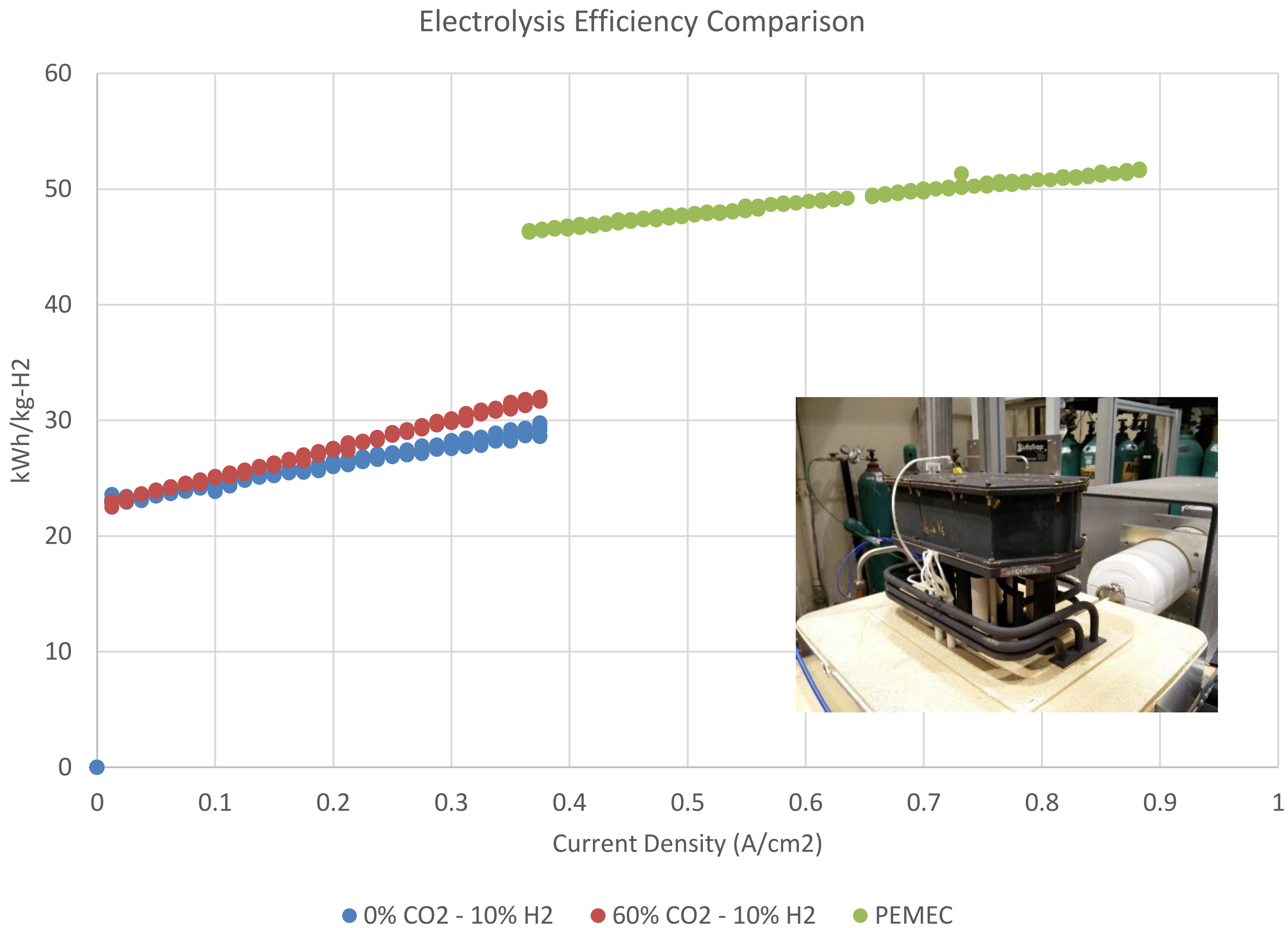
- Copper epoxy applied (Ace Duraflow®)



P2G Accomplishment: Electrolysis Alternatives

Solid Oxide Electrolysis and Co-Electrolysis

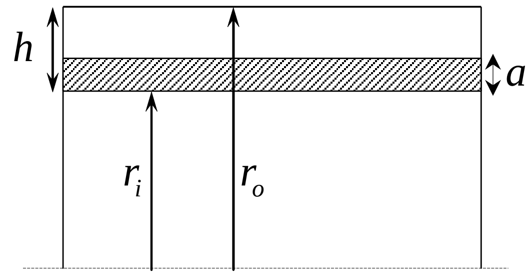
- Comparison to PEMFC (lower activation losses, higher ohmic losses)



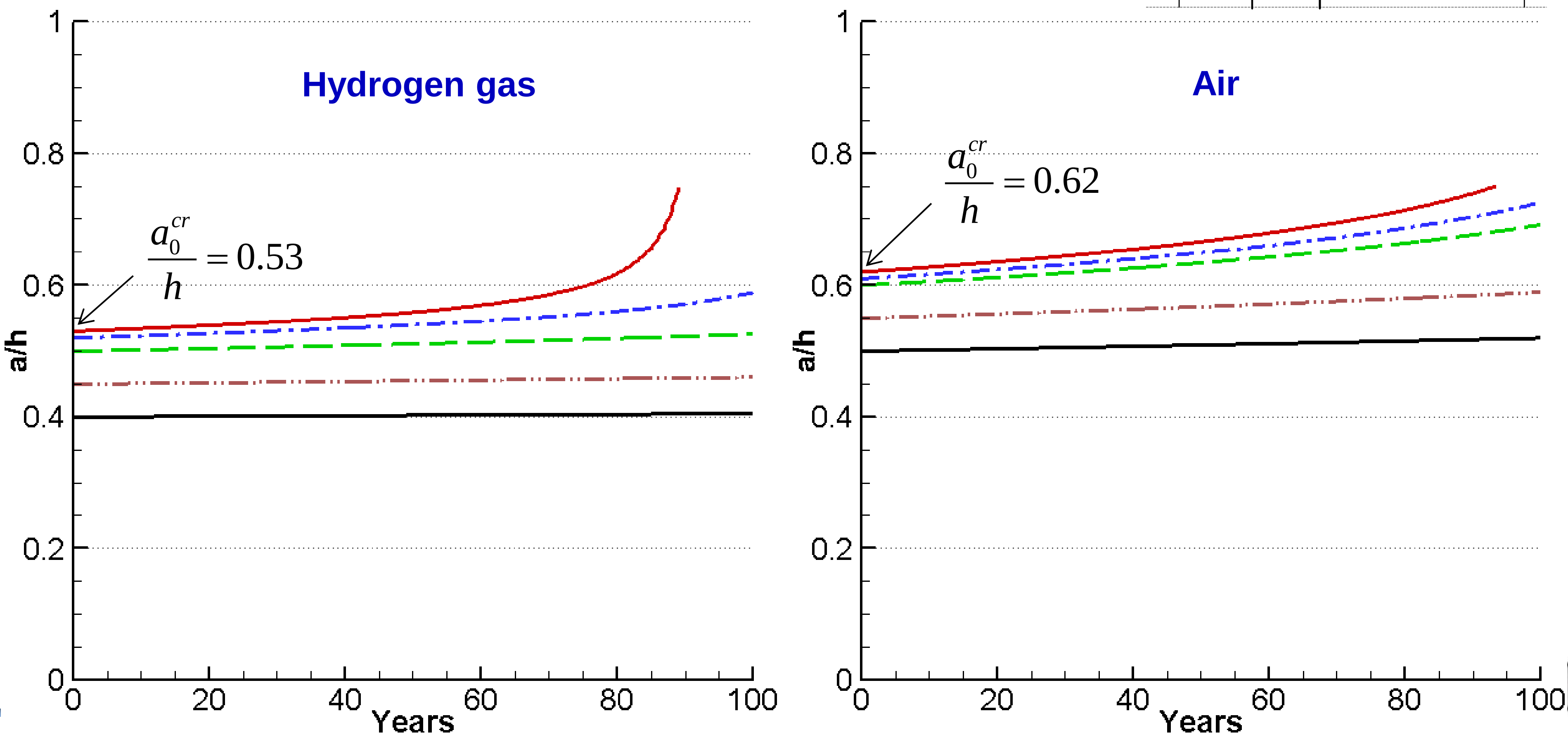
P2G Accomplishment: Pipeline Materials Impacts

Simulation of H2 embrittlement and fatigue crack growth with UIUC

- Fatigue crack growth in 6” SoCalGas pipeline

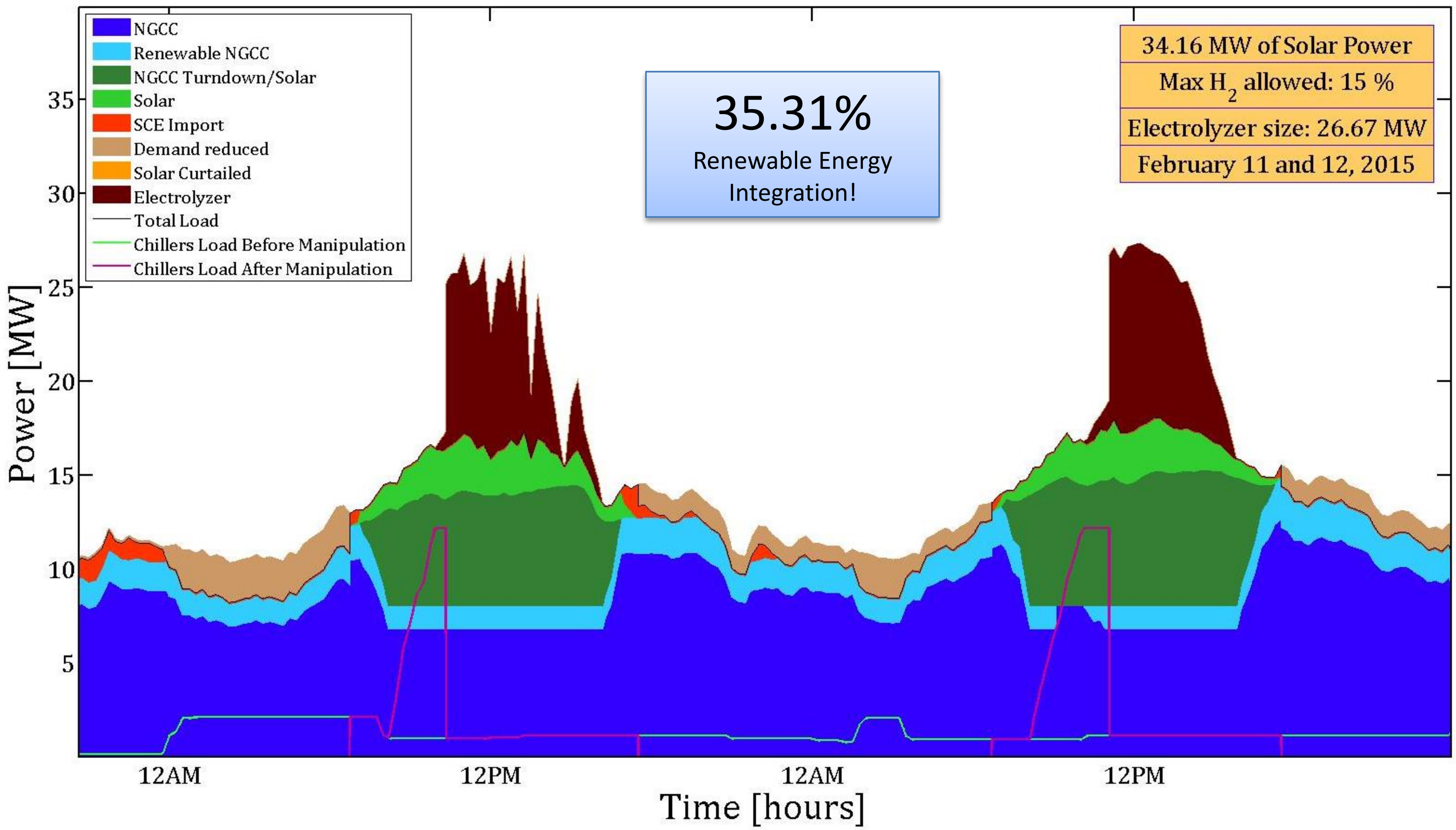


0.188” wall thickness: $(h = 0.188'' = 4.8\text{ mm})$



P2G Accomplishment: UCI Microgrid Simulation

- P2G could significantly increase renewable percentage at UCI



P2G Accomplishment: Large Electrolyzer Deployment

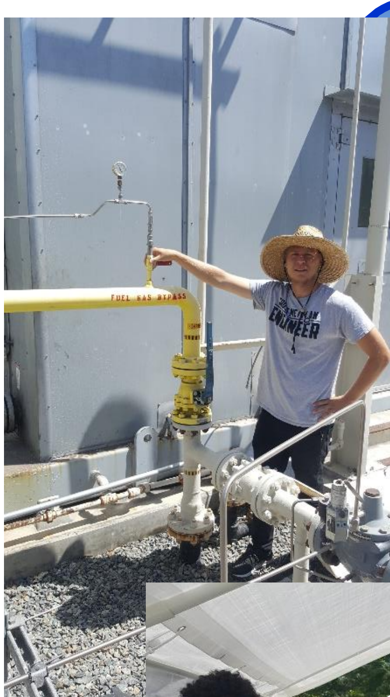
P2G Accomplishment: Large Scale Electrolyzer

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

P2G Accomplishment: Large Scale Electrolyzer

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

- ~0.24 volume % H2 in natural gas

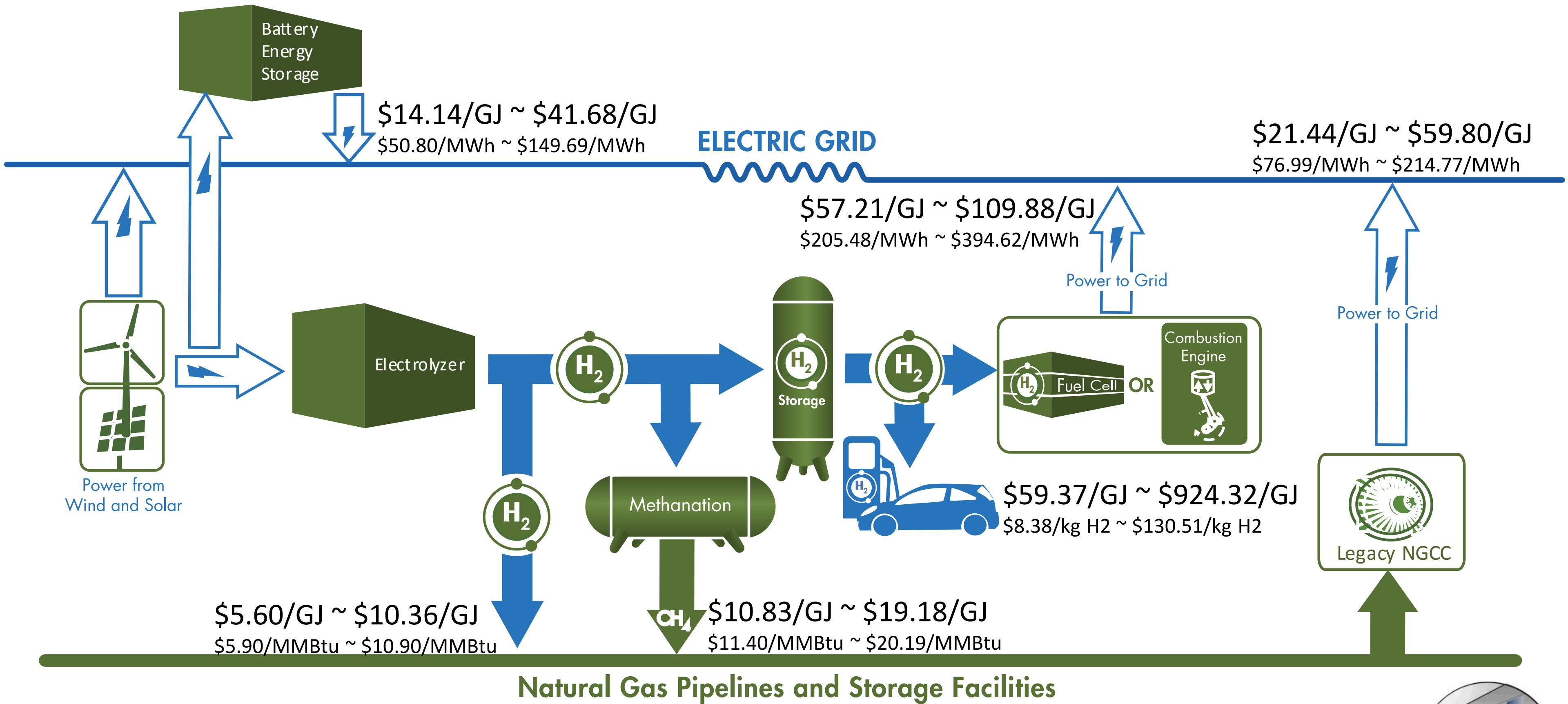


Grand Opening: Friday 7 October

P2G Accomplishment: Detailed Economic Analyses

Levelized Cost of Returned Energy (LCORE)

- Future Costs & Efficiencies
- 50% capacity factor for all equipment

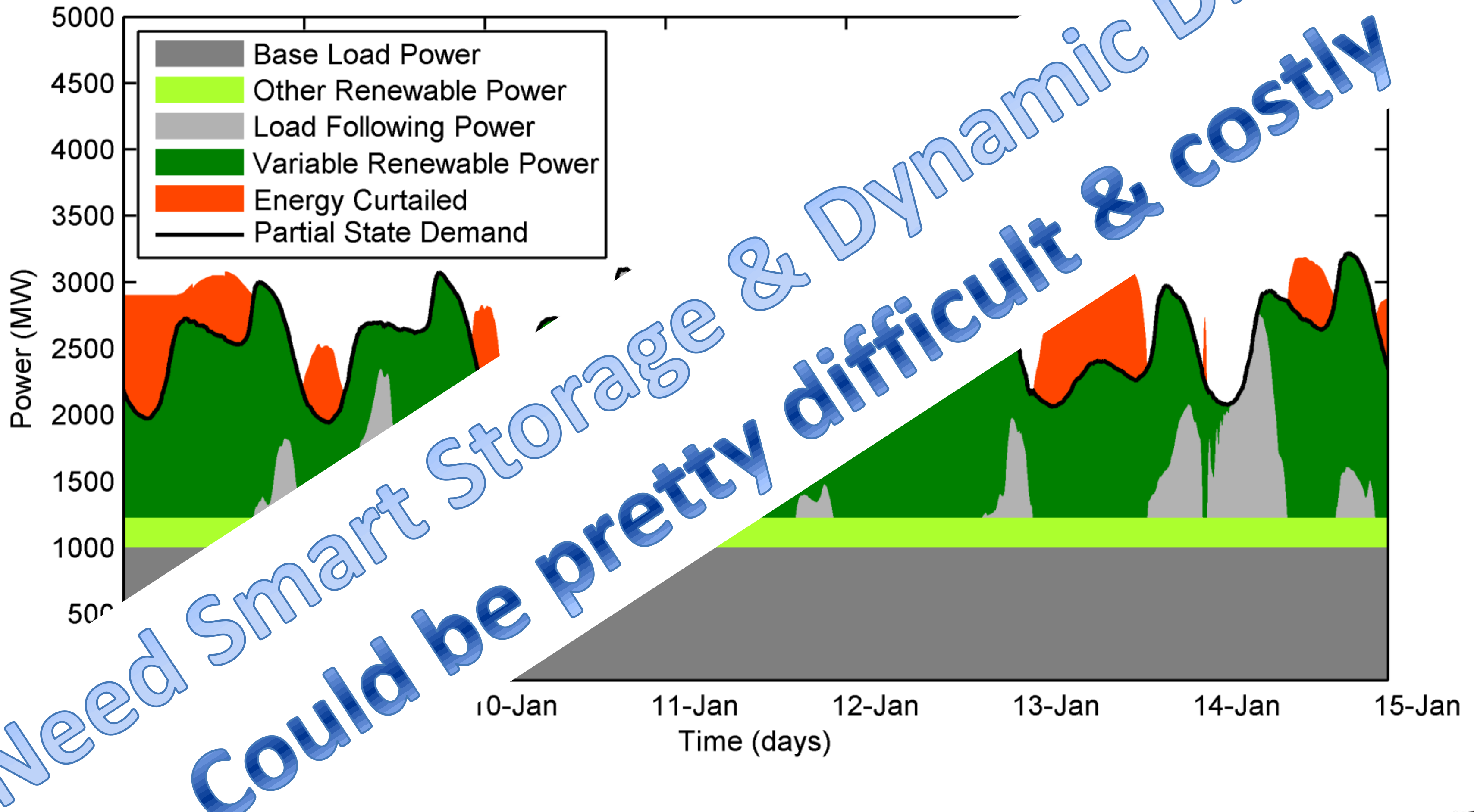


Thanks for your attention!

Backup Slides

Renewable Energy Conversion Backdrop

Ramifications – Increased Renewables



CASE B: 2020, 33% Renewable Wind

Dynamics & Renewable Complementary Technology Need

DYNAMICS are the biggest challenge

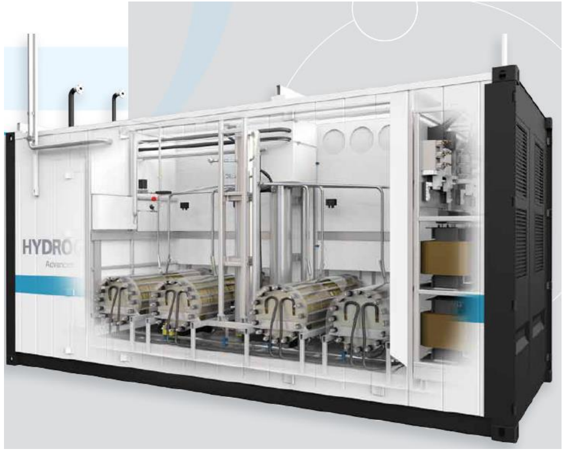
- Both demand and renewable power are highly dynamic
- Local control of load & generation needed (DER & ES)
- Local power production saves T&D losses/costs (DER & flexible ES)
- Complementary dispatchable technology needed (DER & ES)
- Can we handle them all with Battery Energy Storage?

World Total (Mtoe)	kWh/toe	kWh	TWh	
9,301	11,630	1.082E+14	108,171	
Total Storage Needed		80% of energy	86,537	TWh
		(20% capacity factor)		
		Li-ion energy storage cost:	$17,307,300,800,000,000	all
		Li-ion energy storage cost:	$47,417,262,465,753	daily

  - [Key World Statistics, IEA, 2015]
  - Future Li-ion price: $200/kWh [U.S. DOE]

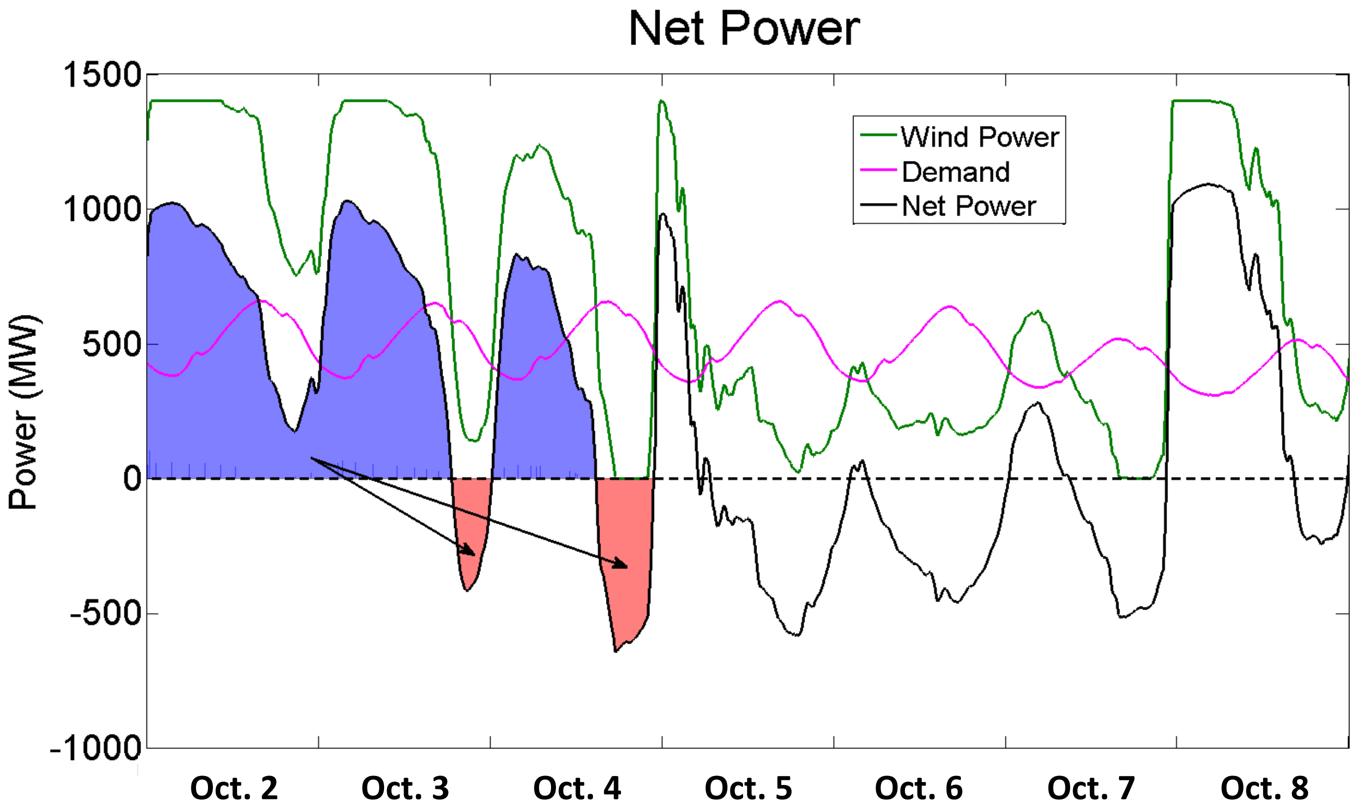
Electrolysis – A Flexible Load

- 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)



Wind & Hydrogen Energy Storage Dynamics

- Compressed Gas Storage & Measured Wind & Demand Dynamics



- 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)

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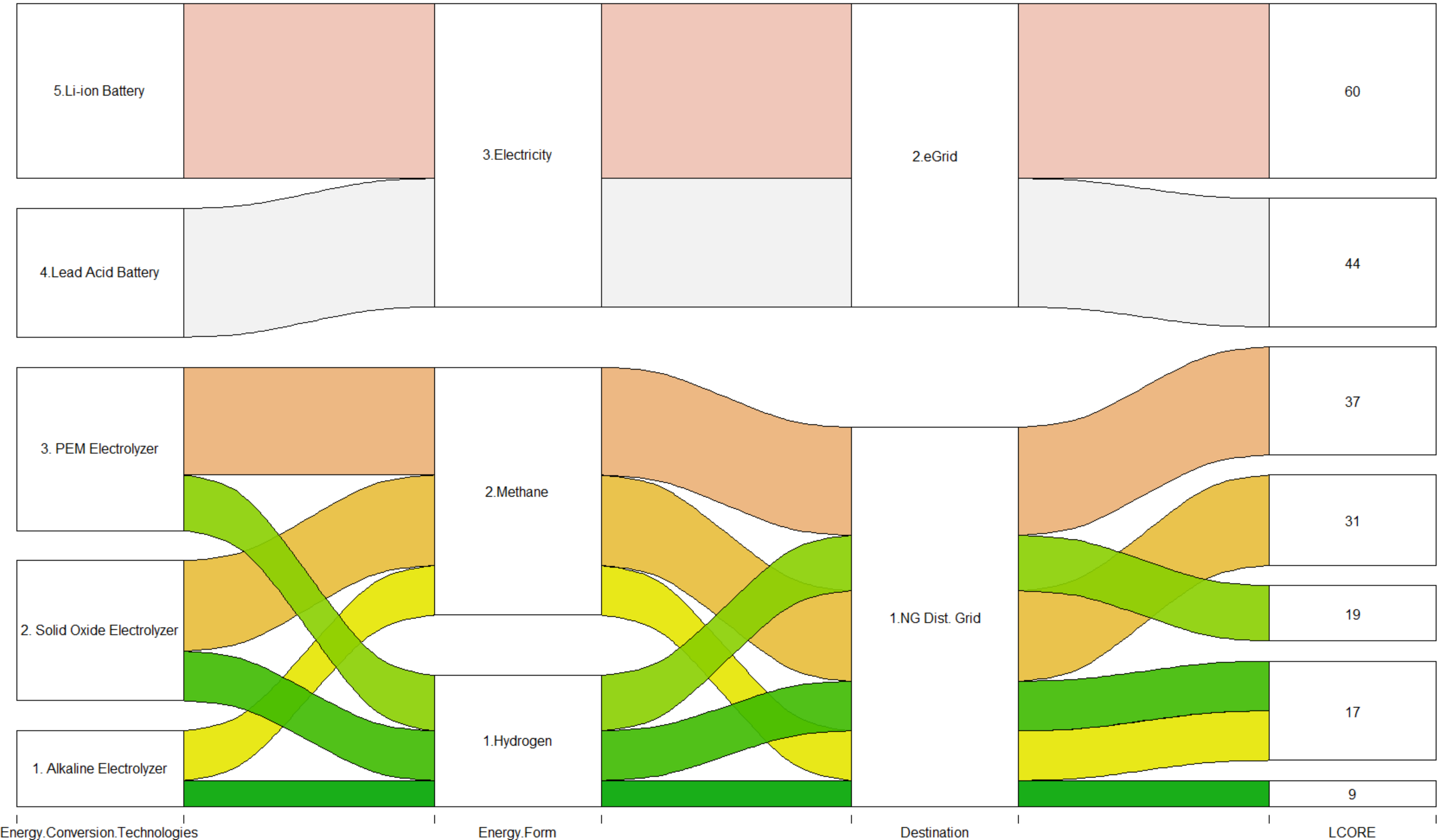
P2G Accomplishment: Detailed Economic Analyses

Levelized Cost of Returned Energy (LCORE)

- Future Costs & Efficiencies

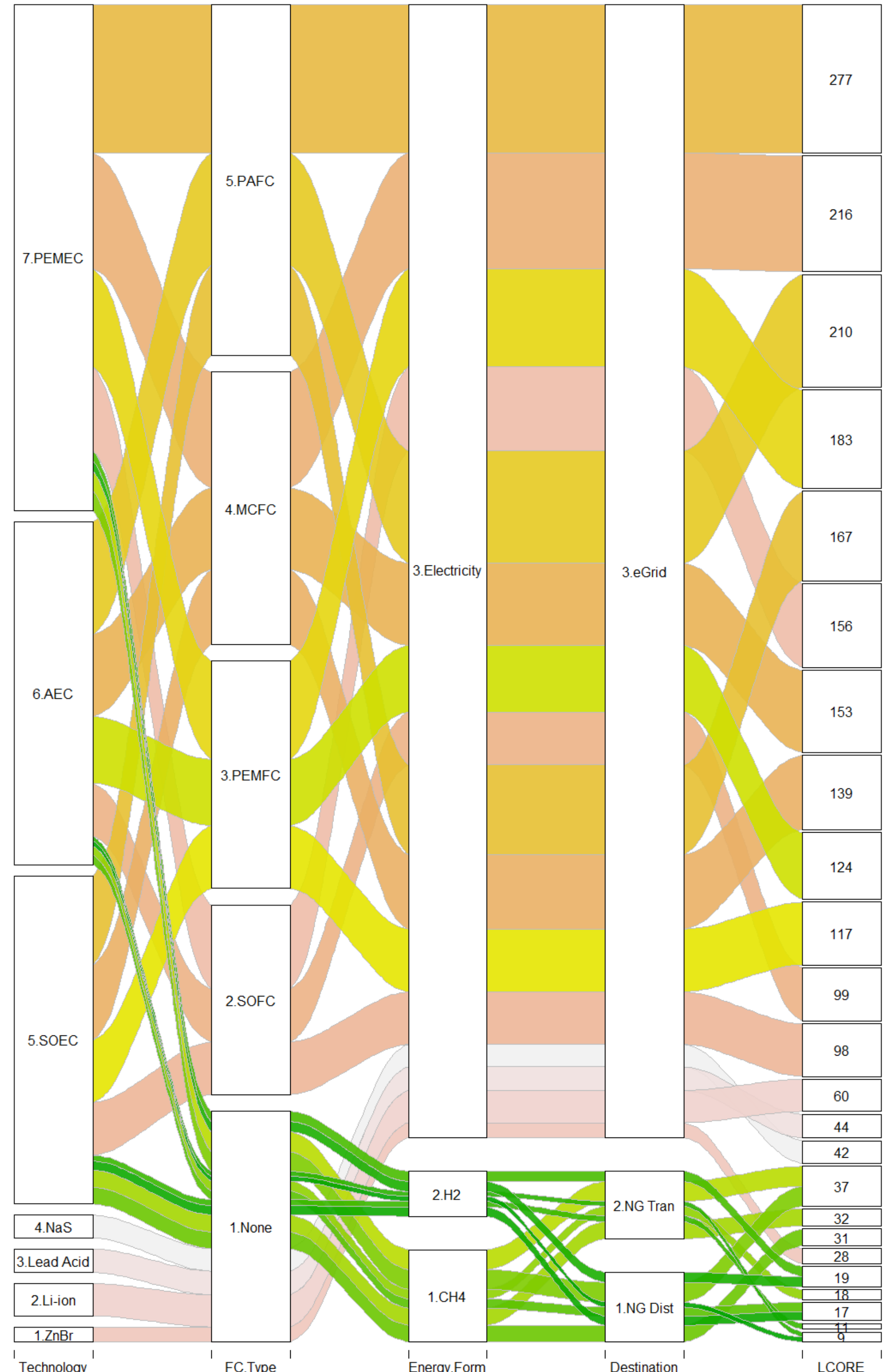


P2G Accomplishment: Detailed Economic Analyses

Levelized Cost of Returned Energy (LCORE)

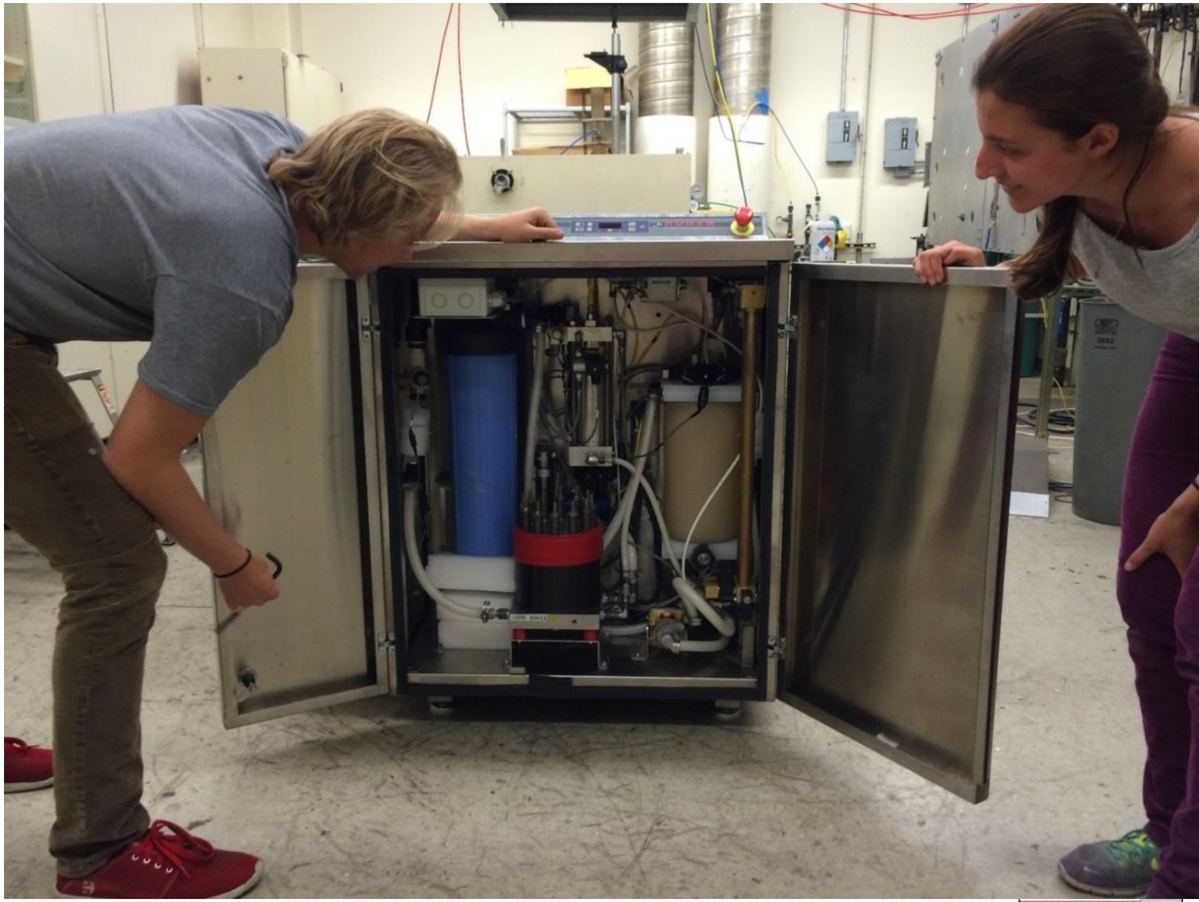
Pathways compared here:

- Electr. + Fuel Cell + Electricity to eGrid
- Electrolyzer + H2 to gas grid
- Electr. + Methanator + NG to gas grid
- Battery ES + Electricity to eGrid



P2G Accomplishment: Lab-Scale Electrolyzer Dynamics

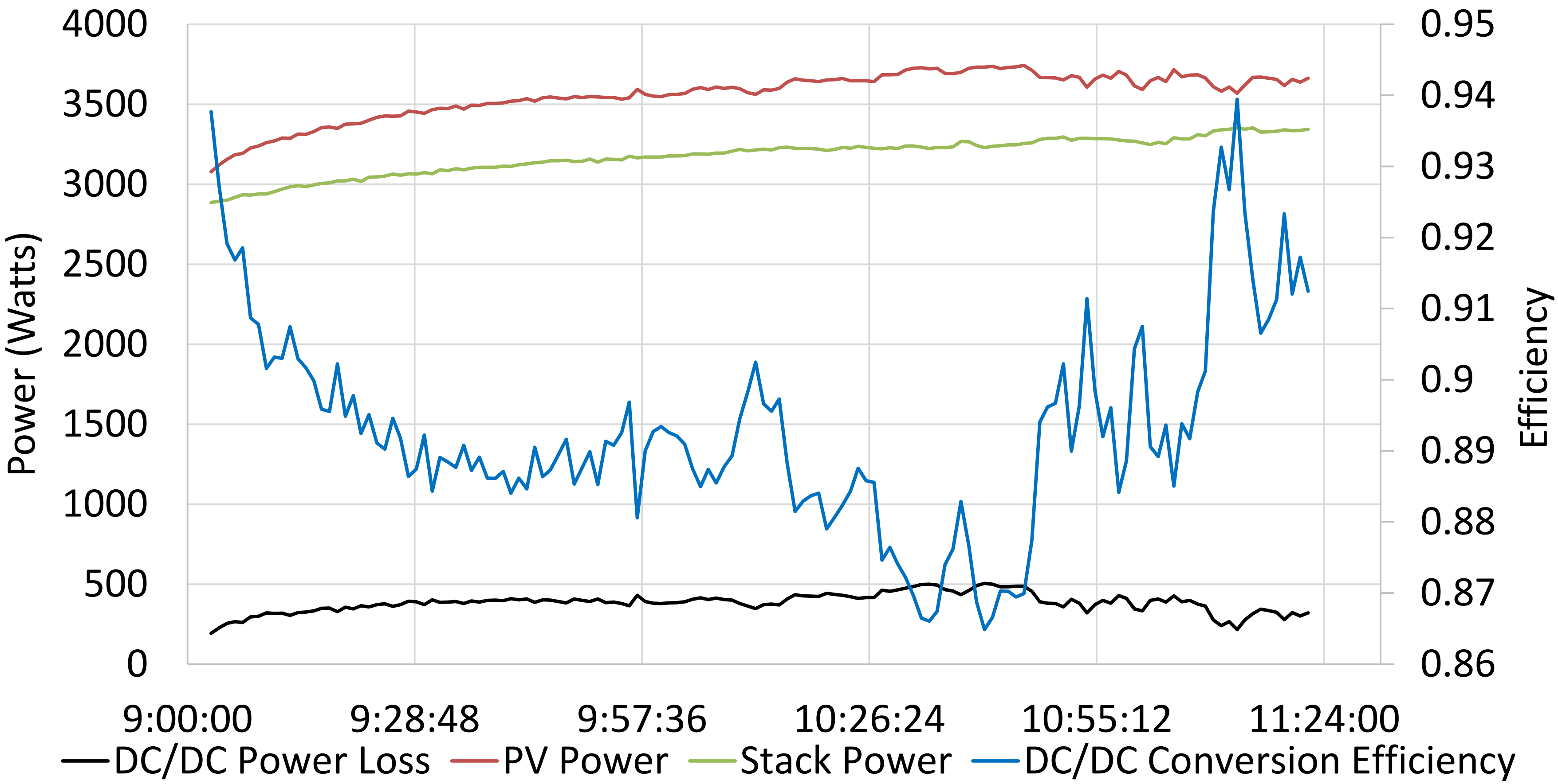
- HOGEN-RE proton exchange membrane electrolyzer
- Installed, connected, evaluated with PV direct-DC and 220V AC
- Sunny and cloudy days
- Overall performance
  - Efficiency in various operating modes
  - BoP losses
  - DC vs. AC
  - Dynamics
- Hydrogen uses
  (1) vented
  (2) stored
  (3) pipeline injected
  (4) end-use consumed



P2G Accomplishment: Lab-Scale Electrolyzer Dynamics

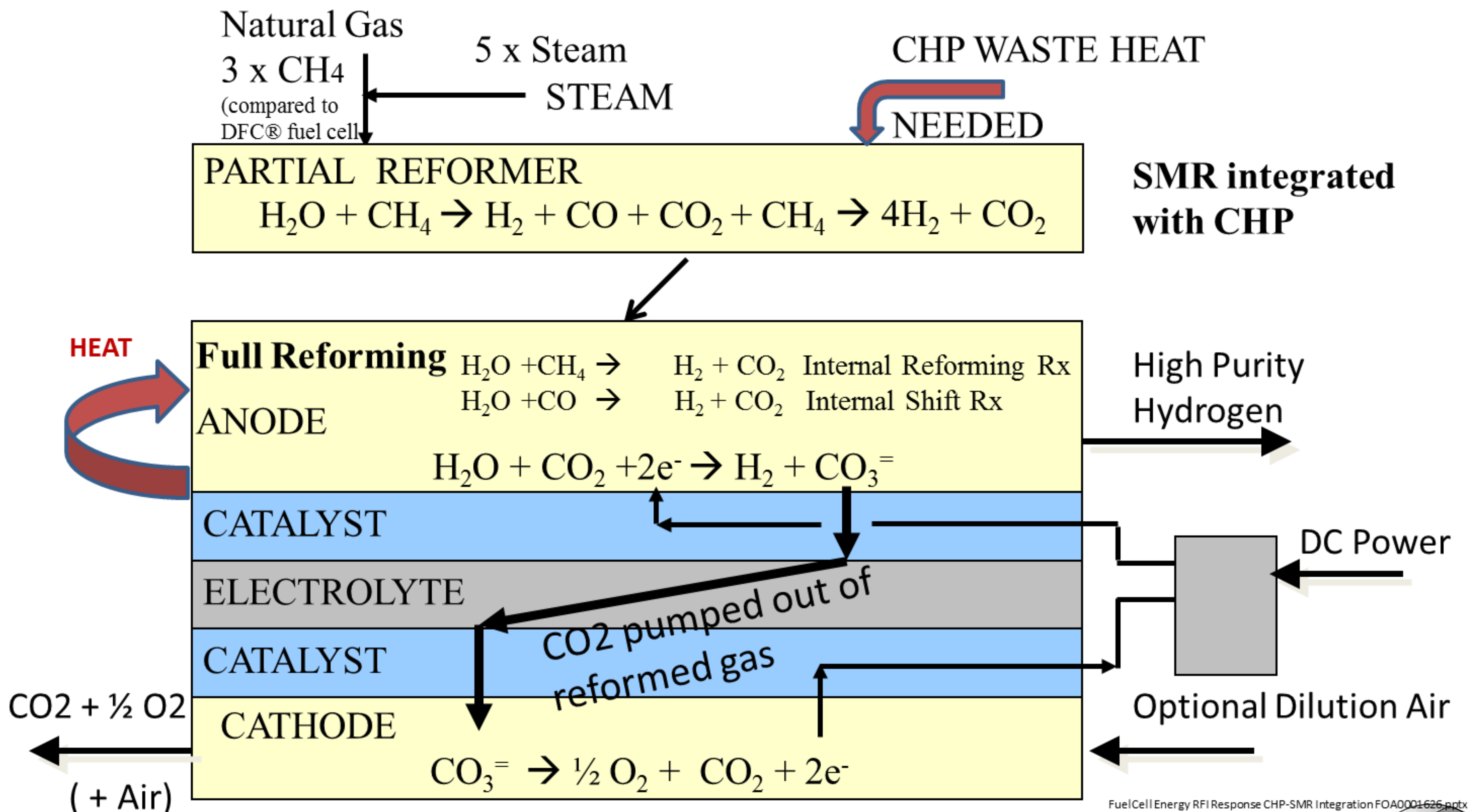
HOGEN-RE proton exchange membrane electrolyzer

- Balance of Plant loss dynamics (direct-PV mode)



P2G Accomplishment: Electrolysis Alternatives

Reformer Electrolyzer Purifier (REP) concept of FuelCell Energy



P2G Accomplishment: Electrolysis Alternatives

Reformer Electrolyzer Purifier (REP) concept of FuelCell Energy