Electrolytic Hydrogen Production Workshop
NREL, Golden, Colorado
February 27-28th, 2014

High Pressure PEM Electrolysis

Status, Key Issues, and Challenges

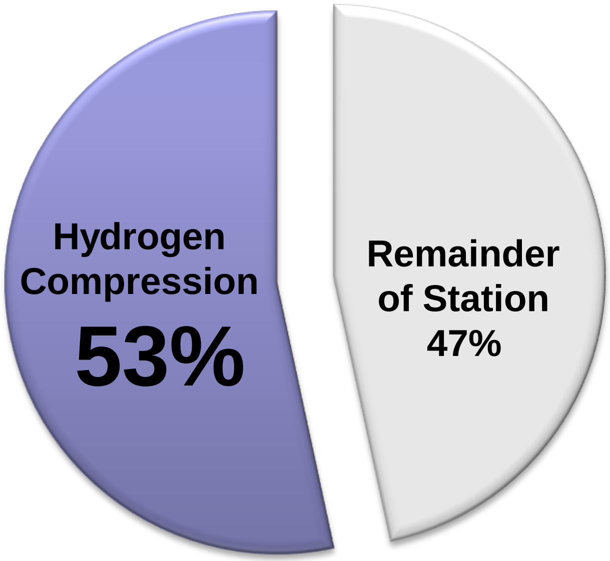
Monjid Hamdan
Director of Engineering

Giner, Inc.
89 Rumford Ave,
Newton, Ma. 02466

High Pressure PEM Electrolysis

High cost of compression is making it difficult for all hydrogen production pathways to match the energy cost of gasoline…

Hydrogen compression dominates refueling costs



CSD Costs
Refueling Station (2011 Technology)[1]

[1]http://www.hydrogen.energy.gov/pdfs/12021_csd_cost_projections.pdf, May 14th, 2012

Advantages of High Pressure PEM Electrolysis

- Eliminates one or more stages of mechanical compression
- Reduces system complexity
  - Lower drying requirements
- Low maintenance
  - No moving parts
  - No contaminants
- Permits hydrogen generation at user end-site
- Cross-cutting technology, applicable to Electrochemical Hydrogen Compressors

Advancements in
<u>Membrane</u>, <u>Stack</u>, & <u>System</u>
required for commercial viability

Membrane Challenges: High Pressure Operation

Mechanical Strength

- Membrane creep
  - Loss of Stack Seals
  - Membrane extrusion into fluid ports
  - Hardware leakage (internal & external)
  - There is a need to improved strength without adversely impacting conductivity

Chemical Durability

- Membrane degradation increases with operating pressure
  - Significant increase in chemical degradation rate under high pressure operation

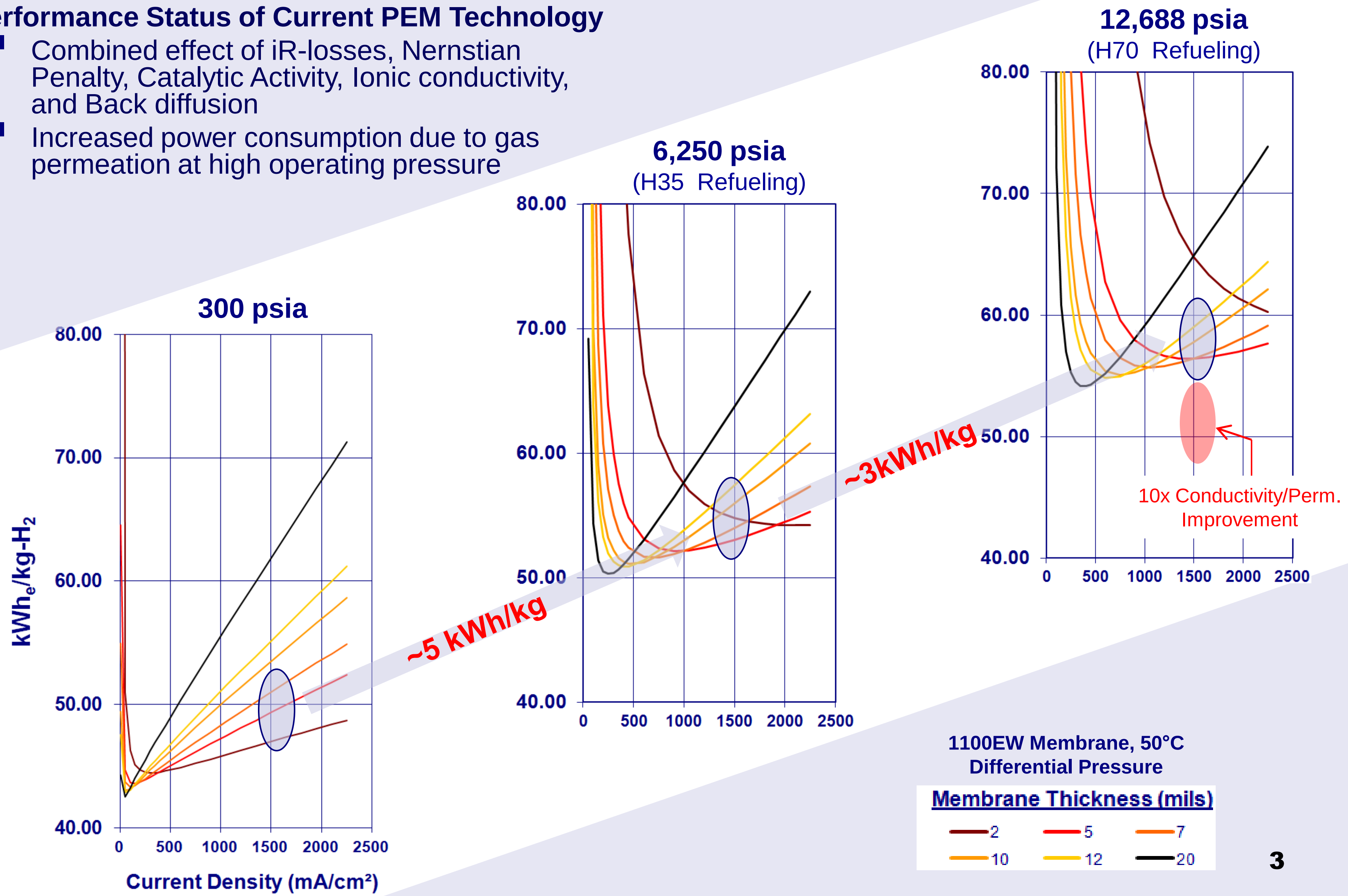
Efficiency

- High back diffusion
  - Thin membranes have low resistance, allowing efficient operation at high current densities. Drawback is high back diffusion.
  - Similar faradaic losses in PEM fuel cells and electrochemical H_2 compressors under same operating conditions & membrane selection
- Need to synthesize new low EW ionomers to meet new performance targets
  - Membranes with high conductivity and low permeability needed

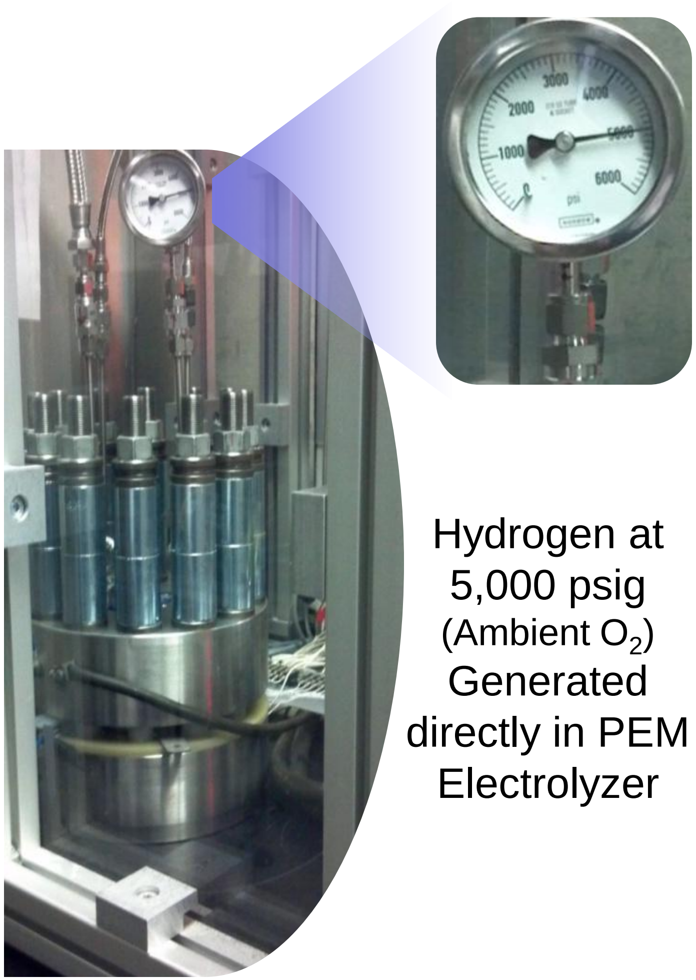
Membrane Efficiency

Performance Status of Current PEM Technology

- Combined effect of iR-losses, Nernstian Penalty, Catalytic Activity, Ionic conductivity, and Back diffusion
- Increased power consumption due to gas permeation at high operating pressure



Stack Hardware



Hydrogen at 5,000 psig (Ambient O_2) Generated directly in PEM Electrolyzer

Future Challenges

- Increase hardware capability for high pressure applications (H35 and H70 refueling)
  - Scale-up: Increased output
    - Increase active area/number of cells
  - Material strength:
    - Conductive anode/cathode membrane support structures with high yield strength
  - Improved sealing:
    - Material creep (vs. time, pressure, & temp cycles)
- Reduce stack cost
  - The repeating cell unit comprises >90% of electrolyzer stack cost
    - Reduce labor/material requirements
    - Anode support structure now dominates cost of the electrolyzer stack
    - High tolerance requirements of cell components increases manufacturing cost
- Improved chemical stability of cell components (H_2 embrittlement)
- Long term endurance testing & validation (5,000+ Hours)

System Challenges

Internal/External Challenges

- Increasing electrolyzer pressure leads to system simplification but requires higher cost BOP components
- Innovative system component development required
  - Hydrogen dryers
  - Gas-phase separators
  - Level sensing
- Extended durability testing/validation
  - Full optimization studies
- Hydrogen safety codes and standards: Collaborators such as NIST or national laboratories, needed to help in standardizing the process

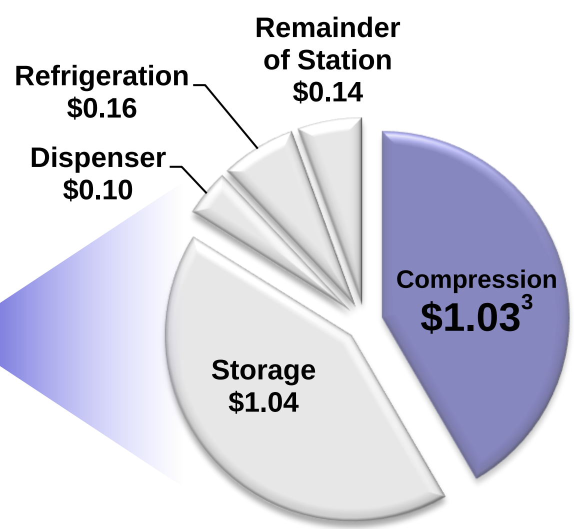
Economic Feasibility: Cost of H_2 Compression in PEM

Forecourt H2A Model (Ver. 3.0)[1]

H_2 Production Cost Contribution ($/kg)	Current Status
Capital Costs	0.70
Fixed O&M	0.30
Feedstock Costs	3.00
Variable Costs	0.10
Total Hydrogen Production Cost	4.10
Delivery (CSD)	**2.50[2]**
Total Hydrogen Production Cost ($/kg)	6.60

[1]2012 DOE Multi-Year Research, Development and Demonstration Plan http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf
[2] 2015-2020 DOE Target is $1.70/kg
[3] 300 psia H_2 feed source
[4]Based on electrical cost of $0.061/kWh

Cost of Compression
$1.03/kg-$H_2$



Truth Table

	Cost of Compression in PEM Electrolyzer ($/kg)		
	Comp.	Increased Feed Stock Costs (Efficiency Losses)[4]	**Total**
300 psia	1.03	0.00	**1.03**
6,250 psia	0.31	+0.31	**0.62**
12,688 psia	0.12	+0.49	**0.61**

- ~$0.40 (40%) cost reduction compared to mechanical compression
- Largest $ contributor is Feedstock
  - Improving membrane efficiency and reducing electric cost are key to future cost reductions
- Higher cost of Stack/BOP may offset gains: Low cost stack/system designs required