Fuel Cells and Hydrogen Solutions for Portable Power Applications

March 2, 2017

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Submit your questions at any time by typing in the Question Box and hitting Send.

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About NEESC

The Northeast Electrochemical Energy Storage Cluster (NEESC) is a network of industry, academic, government and non-governmental leaders working together to help businesses provide energy storage solutions. The cluster is focused on businesses that provide the innovative development, production, promotion and deployment of hydrogen fuels and fuel cells to meet the pressing demand for energy storage solutions.

The cluster spans an area in the northeastern United States from New Jersey to Maine. Its formal organization is funded by the US Small Business Administration’s Regional Cluster Initiative. NEESC is administered by the Connecticut Center for Advanced Technology, Inc. (CCAT) and its local state partners:

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Today’s Moderator

Bob Rose, Executive Director, Breakthrough Technologies Institute

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Today’s Guest Speakers

DeLisa Leighton, Director – Hydrogen Services, Luxfer-GTM Technologies

Steve Szymanski, Director of Government Business, Proton OnSite

Roy Bant, Hydrogen Energy Business Development Manager, Northeast, Air Liquide

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Hydrogen Solutions

DeLisa Leighton, Director of Strategic Accounts, Hydrogen
“I find out what the world needs, then I go ahead and try to invent it.”

-Thomas Edison
Times of Energy Transition
Modern Energy

Job Creation

Energy Independence

H2/fuel Cell

Energy Sustainable

Environment
H2 Solutions

Luxfer-GTM Technologies

H2 Fueling Services™
Current Fueling Activities

Current Service Areas
- Western States, Gulf States, the South, North East
- 2017 expansion Great Lake Area and Midwest
Fueling Equipment

GTM1350-H2 Refueler

- The highest capacity, lightest weight transports on the market today
- The only DOT/TC approved, mobile, H2 refueler
- Electric booster pump to maximize output
- Towable behind a standard ¾ ton pickup NGV1 fill connections standard
- Highest safety standards: 8G frames
- Complete dispenser package with hose and WEH dispenser nozzle

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tr>
<td># of Cylinders:</td>
<td>16</td>
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<tr>
<td>Working Pressure:</td>
<td>3,600psig</td>
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<tr>
<td>Total Water Vol.:</td>
<td>155.5scf</td>
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<tr>
<td>Trailer Dimensions:</td>
<td>8’W x 17’L x 6.5’H</td>
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<tr>
<td>H2 Capacity:</td>
<td>78kgs</td>
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<tr>
<td>Compression:</td>
<td>Electric booster</td>
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<tr>
<td>Min. inlet pressure:</td>
<td>500psig</td>
</tr>
<tr>
<td>Max. outlet pressure:</td>
<td>5,000psig</td>
</tr>
<tr>
<td>Power:</td>
<td>230V/3ph</td>
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<tr>
<td>Fuel cell consumption:</td>
<td>150 grams/hour</td>
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<tr>
<td>Gross Weight:</td>
<td>6,400lbs</td>
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</table>
Fueling Equipment

G-PAK Series

- DOT Approved
- Designed to fit in back of standard pickup truck
- Lightweight - requiring no hazmat or placarding for up to three packs

<table>
<thead>
<tr>
<th></th>
<th>G-PAK 1</th>
<th>G-PAK 3</th>
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</thead>
<tbody>
<tr>
<td># of Cylinders</td>
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<td>3</td>
</tr>
<tr>
<td>Max. Working Pressure</td>
<td></td>
<td>5,000 psig</td>
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<tr>
<td>Water Capacity (scf)</td>
<td>3.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Tare Wt.</td>
<td>175lbs</td>
<td>520lbs</td>
</tr>
<tr>
<td>Dimensions</td>
<td>46-3/4&quot;W x 29-1/16&quot;L x 22-1/8&quot;H</td>
<td>46-3/4&quot;W x 62-1/3&quot;L x 22-1/8&quot;H</td>
</tr>
</tbody>
</table>
Zero-Sets - Super Bowl 50

Zero Set Gen 3

- ZERO EMISSIONS
- “Whisper Quiet”
- 5.5 Day, 24x7 Run time (50% duty cycle)
- Provides DC and AC power, with 48amp-hours of battery storage
- Towable behind most vehicles/no hazmat or placard
Zero-Set Light Towers

- ZERO EMISSIONS
- “Whisper Quiet”
- 36 Hour run time (fills at H2 stations)
- High output, adjustable 4x 220 Led Flood Lights
- Light sense technology auto on/off feature
- Towable behind most vehicles/no hazmat or placard required
Whatever you can do or dream you can, begin it.

Boldness has genius, power, and magic in it.

Knowing is not enough; we must apply.

Willing is not enough; we must do.

Johann Wolfgang von Goethe
Contact Information

DeLisa Leighton
Director of Strategic Accounts, Hydrogen
Mobile: (415) 763-9790
Office: (415) 856-0570
DeLisa@igxgroup.com
Hydrogen Fuel Production for Fuel Cell Power Applications

Stephen Szymanski
203.678.2338
sszymanski@protononsite.com
Proton OnSite Company Overview:

- World leader in PEM water electrolysis
- 2,600+ Systems delivered in 75 countries for:
  - Industrial applications
  - Laboratory markets
  - Military customers
  - Fueling and energy storage
- ISO 9001:2008 certified
- ~ 100 employees
Commercial Electrolysis Technologies:

- Liquid KOH
  - Corrosive electrolyte
  - Complicated BOP and controls
- PEM = solid electrolyte
  - Simple BOP, safer system

Liquid KOH

Proton Exchange Membrane (PEM)
Proton’s PEM Electrolysis
Commercial Status:

- 60,000+ hour stack lifetimes
- 20 year system life
- Scaled to 700 cm² active area and larger
- MW scale capacity
- Manufacturing processes and supply chain very well established
- Still room for commercial cost and efficiency improvements

250 kW stack (above) and 1 MW system (below)
Where our electrolyzers are used:

**Power Plants**
- Cooling electric generators

**Laboratories**
- Carrier gas for analytical instrumentation

**Other Industrial**
- Process gas for semiconductors, heat treatment, and meteorology

**Grid Energy Storage**
- Storing stranded excess renewable energy

**Biogas**
- Turning waste CO₂ into methane

**Transportation**
- Fuel for vehicles/mobile power

**Military**
- Oxygen production and quiet power
How much $\text{H}_2$ can we make?

- 7 kW
  - 1 day: 2.3 kg

- 40 kW
  - 1 day: 13 kg

- 175 kW
  - 1 week: 455 kg

- 1,000 kW
  - 1 day: 432 kg
Advantages of On-site Hydrogen Supply

- Improved process results: ultra high purity $\text{H}_2$
- Improved productivity
- Enhanced gas supply reliability: eliminates runouts
- No personnel required for 24*7 hydrogen supply
- Safer: near zero inventory
- No off-spec product: identified impurities
- Small footprint, more space-efficient
- Stable and reduced costs

Electrolyzers operating on wind power in Idaho
Hydrogen “fuel” does not mean just cars!

Filling a fuel cell paratransit bus left, and producing hydrogen for lift trucks right
On site hydrogen production also supports stationary fuel cell applications:

Fuel cell installations at utility substation (left) and telecom base station (right) to provide energy storage for backup power and peak shaving. Proton has integration expertise in these systems which include electrolyzer, hydrogen storage, PEM fuel cell, and controls. Provides longer run times than batteries, and lower total cost of ownership.
On site production can support mobile and remote fueling requirements:

Mobile fuel cell light tower being fueled at Proton for Connecticut DOT
Remote sites can be supported by electrolysis operating on renewable power:

Remote cell tower site being serviced by fueling trailer

Portable fuel cell genset for remote sites
Containerization makes deployment easy!
SunHydro 2 Project: containerized hydrogen fueling design for ease of installation

- Proton OnSite has developed a new compact “site ready” station design, SunHydro 2.
- In collaboration with DOE and NPS, this equipment design is being demonstrated at the NPS site on Brentwood Ave.
- The station will provide an important fueling capability for FCV’s that will be used for outreach and market development efforts.
Improving the economics of electrolytic H2:

### Graphical Representation

The graph illustrates the cost of hydrogen production and the breakdown into various cost components. It includes the following elements:

- **Intermittent Integration**
- **R&D Advances**

### Cost Breakdown

- **Cost of Hydrogen Production ($/kg)**
  - 3.46
  - 2.24
  - 1.95

### Cost Components

- **Capacity Factor**
- **Cost of Electricity**
- **Capital Cost**
- **Efficiency (LHV)**

<table>
<thead>
<tr>
<th>Component</th>
<th>97% 40%/40%</th>
<th>40% 40%/60%</th>
<th>90% Steam Methane Reforming (SMR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Factor</td>
<td>0.20</td>
<td>0.52</td>
<td>1.56</td>
</tr>
<tr>
<td>Cost of Electricity</td>
<td>0.53</td>
<td>1.22</td>
<td>0.05</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>1.14</td>
<td>0.31</td>
<td>0.26</td>
</tr>
<tr>
<td>Efficiency (LHV)</td>
<td>0.58</td>
<td>0.05</td>
<td>0.62</td>
</tr>
</tbody>
</table>

### Table

- **Other Costs**
- **Feedstock Costs**
- **Fixed O&M**
- **Capital Costs**

DOE H2@Scale webinar, 7/28/16
Conclusions:

• PEM electrolysis is a robust and proven solution for production of hydrogen fuel
• Cost effective hydrogen fueling capability is the enabler for a variety of fuel cell applications
• Remote locations can be difficult to service with traditional delivered hydrogen methods
• On site production helps to fill application gaps for fuel cells and other deployed hydrogen consuming systems
Fuel Cells and Hydrogen Solutions for Portable Power Applications
Hydrogen in the Northeast for Automobiles

- Air Liquide is creating the Northeast’s first hydrogen fueling network
  - November 2014: Air Liquide and Toyota launch collaboration to build the first hydrogen fueling network in the Northeast
  - Air Liquide is investing ~ $2.5 MM per site
  - By 2018, 12 stations from North New Jersey to Boston
    - Two Mobile stations depending on need
    - 2 distribution hubs for delivery to the stations
  - As of the end of 2016, 1186 fuel cell vehicles on the road in California
Anaheim California Hydrogen Station

Commissioned December 2016
Torrance, CA Hydrogen Station

Fueling with Hydrogen is Like Fueling with Gasoline
California currently has 27 hydrogen refueling stations in operation.

- 6 in commissioning.
- 3 under construction.
- 10 in the approval or planning process.
Commercially Available FCEVs

Hyundai Tucson Fuel Cell

Toyota Mirai

Honda Clarity

Mercedes Benz plans to introduce FCEV later this year
Air Liquides Unique expertise and skills

Separating the components of the air to take advantage of their properties

Air Liquide Technologies

Oxygen ($O_2$)
Nitrogen ($N_2$)
Argon ($Ar$)

Producing molecules from the natural resources of the Planet

Air Liquide Technologies

Hydrogen ($H_2$)
Silane ($SiH_4$)
Acetylene ($C_2H_2$)
Carbon Monoxide ($CO$)

Helium ($He$)
How will hydrogen benefit the environment?

Air Liquide has made a commitment to produce at least 50% of the hydrogen necessary for these applications through carbon-free processes by 2020, by combining:

- biogas reforming and the use of renewable energies during water electrolysis,
- carbon capture and storage technologies during the hydrogen production process based on natural gas.
Top 10 Benefits of the Fuel Cell Automobiles

- Extreme Safety and performance testing in all climates AND Hydrogen is actually safer than gasoline
- 3 to 5 minutes fueling time (typically four minutes)
- Range on a full fill (city mileage and highway mileage are the same)
  - Toyota Mirai- 312 miles
  - Hyundai- Tucson- 348 miles
  - Honda Clarity- 366 miles
- 100 miles between stations per the DOE for Northeast traveling
- Some OEM’s have an electrical plug-in to power your house from your vehicle
- Only exhaust is water (You can drink the exhaust)
- Regenerative Braking- puts power into the battery (battery is similarly sized to a standard automobile) and support acceleration
- Has an App to find hydrogen when needed
- OEMs have an attractive offering when owning or leasing a fuel cell vehicle
- Three (3) years of free fuel from most OEM’s
Hydrogen Supply and Distribution

Large Scale Production

H₂ Gaseous Source:
- Steam Methane Reformation
- Waste gas purification
- Electrolysis

Liquefaction

200-450 bar

Onsite Production

SMR

Electrolysis

Air Liquide, the world leader in gases, technologies and services for Industry and Health
Why is all of this important?

- The infrastructure that Air Liquide is building will support other high pressure (450 bar delivery) needs throughout the Northeast.
- Two high pressure hubs will be commissioned:
  - Massachusetts- Commissioned April 2017 (estimated)
  - New Jersey- TBD
  - Others as needed to support the 12 station demand.
- Renewable sources being established for additional high pressure Hubs.
- Air Liquide can offer a turn key solution for fuel cell fork truck and bus depots.
- Opportunity- refrigeration reefers on delivery vehicles to be powered by fuel cells:
  - These trucks currently idle to produce the electricity to power the refrigeration system(s) when making deliveries= noise and diesel exhaust pollution.
  - Problem: High infrastructure costs for each on site hydrogen system.
    - Possible solution- collaboration and use of current hydrogen systems at fork truck accounts.
What’s next for Hydrogen?

Creating an infrastructure to power fuel cell reefers for refrigeration
Air Liquide has built more than 60 hydrogen stations worldwide; 15 additional stations planned to open in the US

Flexible infrastructure products to supply various markets and offer competitive costs

More deployments, helping the societal acceptance

Forklifts
35 MPa
100-300 kg/day

Buses
35 MPa
100-300 kg/day

Cars
70 MPa
50-200 kg/day
Renewable Hydrogen From Waste to Energy
Thank you!

Roy Bant  (roy.bant@airliquide.com)
Hydrogen for Energy Business Development Manager
Questions

DeLisa Leighton  
Director  
Luxfer-GTM Technologies  
delisa@igxgroup.com

Steve Szymanski  
Director  
Proton OnSite  
sszymanski@protononsite.com

Roy Bant  
Manager  
Air Liquide  
roy.bant@airliquide.com

Bob Rose  
Executive Director  
Breakthrough Technologies  
BRose@fuelcells.org

Alexander Barton  
Energy Specialist  
NEESc  
abarton@neesc.org

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