AGENDA

• Hydrogen
  – Introduction
  – Where Does It Come From?

• Hydrogen Fueling Stations
  – Make vs Buy – Sourcing H2
  – Station Technologies

• Point of Fueling
  – The Fueling Process
  – H2, CNG, and Diesel

• Infrastructure Considerations

• Operational Station Examples
  – OSU – Electrolysis Stations
  – SATRA – Liquid H2 Vaporization and Compression
BUCKEYE BULLET II

The Next Generation
In Land Speed Racing

September 25, 2009
303.025 mph
(flying kilometer)

302.877 mph
(flying mile)

Hydrogen Fuel Cell Electric
Land Speed Streamliner

First Fuel cell-powered car over 300 mph
Fastest FIA Record for any Electric Car

www.buckeyebullet.com

THE MIDWEST HYDROGEN CENTER OF EXCELLENCE
A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative
HYDROGEN 101
H2

- Lightest and Simplest Element Known to Man
- 75% of the Mass of the Universe!
- Colorless, Odorless, Tasteless (Undetectable by Humans)
- Highly Flammable, BUT Requires and Ignition Source and Oxidizer
- 1 kg H2 Is Roughly Equal (energy) to 1 Gallon of Gasoline
- 9 Mil. Metric Tons Produced In the USA Annually, 50 Worldwide

1 kg H2

THE MIDWEST HYDROGEN CENTER OF EXCELLENCE
A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative
Hydrogen is one of the most important building blocks in the chemical industry.

- Ammonia Production (Fertilizers)
- Methanol Production
- Polymer Production
- Food Processing
- Oil Refining Oil (Sulfur Reduction),
- Metal Processing and Heat Treating
- Welding
- Powering Fuel Cells
Why H2?

Source: CaFCP analysis using GREET model with support and verification by Argonne National Laboratory and CARB
IS IT SAFE?!
WHERE DOES THE HYDROGEN COME FROM?

Steam Reforming (95%)

Electrolysis (<5%)

Source: Alfa Kaval
Source: US DOE
HYDROGEN FUELING STATIONS
Make vs Buy
WHICH SOURCE IS FOR ME?

Source: [www.airproducts.com](http://www.airproducts.com)
DELIVERY: PRESSURIZED GAS VS CRYO LIQUID

Gaseous Storage

- 350-700 bar (5,000 – 10,000 psi)
- Large heavy tanks
- Can be directly pressure balanced to a vehicle tank
- Can be compressed to intermediate high pressure storage
- Low % utilization of transportation mass

Liquid Storage

- More efficient transport
- Cryogenic temps (-250 C / -420 F)
- Must be vaporized (1:851)
- Must be compressed to vehicle or storage tank
- Leak rate (up to 1% per day)
Steam Reforming

- Most cost effective (today, in large scale)
- Variety of source feed fuels
- Waste heat recovery / co-generation possible
- Greenhouse gas emissions always present
- Requires use fossil fuels
- Technology to efficiently scale down is developing

Electrolysis

- Very simple process
- Equipment is cost effective
- Requires significant electricity
- Can be 100% renewable (solar / wind power)
- Excellent solution to wind curtailment
- No byproducts / emissions
POINT OF FUELING
FUELING STATION
<table>
<thead>
<tr>
<th></th>
<th>DIESEL</th>
<th>H2</th>
<th>CNG</th>
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<tbody>
<tr>
<td>Nozzle</td>
<td>SAE J285</td>
<td>SAE J2600</td>
<td>SAE J1616</td>
</tr>
<tr>
<td>Flow Rate [GPM Eq.]</td>
<td>10 / 40</td>
<td>~ 4</td>
<td>~4</td>
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<tr>
<td>Leak-proof / Spill-proof</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Storage Pressure [bar]</td>
<td>Atmospheric</td>
<td>350 / 700</td>
<td>200 / 250</td>
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<tr>
<td>Breakaway Safety</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

FUELING NOZZLE

17
REFUELING PROCEDURE

1. Open vehicle refueling door and remove the receptacle dust cover.
2. Remove dust cover from nozzle and attach to vehicle receptacle.
3. Rotate lever on nozzle ½ of a turn till locked on.
4. Lightly tug on nozzle to insure connection.
5. Perform leak check; Charge hose, then wait briefly, then check gauge to make sure there isn’t a leak.
6. Press the red lever until storage pressure equals fill pressure.
7. Press the white lever for two seconds.
8. Rotate lever on nozzle and remove.
9. Replace nozzle into holder and replace dust cover.
10. Close access door and confirm it is locked.
11. Replace dust cover on vehicle receptacle and close the fuel door.

Have a Great Day
• SAE J2600 - Compressed Hydrogen Surface Vehicle Fueling Connection Devices
• SAE J2601 – Light Duty Hydrogen Vehicle Fueling Protocol
• SAE J2601/2 - Hydrogen Bus Fueling Technical Information Report
• SAE J2601/3 - Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
• SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety
• SAE J2579 - Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
• SAE J2719 - Hydrogen Fuel Quality for Fuel Cell Vehicles
• SAE J2799 - FCEV to Hydrogen Station Communication
Learning from J2601 AND J2799

- Fast fuel 3-5 minutes
- “Smart” fueling (communication)
- Wireless communication

Source: US DOE / SAE Int.
INFRASTRUCTURE & SITE REQUIREMENTS

- Footprint
- Utilities: Power / Water / Natural Gas
- Permitting
- Safety Measures: Inerrant Design
- Safety Measures: Training and Protocol
- Emergency Response
EXAMPLES OF STATIONS IN OPERATION
MRE Triple Twin System
ELECTROLYSIS STACKS AND H2 PURIFICATION
SARTA LIQUID H2 STATION

- Built in 2016
- Built by Air Products
- Largest H2 Station Outside of California
- ~$1.6 Million Capital Cost
- ~$2.20 per Gallon Eq.
LIQUID H2 STORAGE TANK
HIGH PRESSURE STORAGE
POINT OF FUELING
WHAT QUESTIONS DO YOU HAVE?