and

H₂ Refuel H-Prize Competition Experience
Ivys’ Role in the Hydrogen Industry

- Ivys’ members led the development of a compact, on-site SMR appliance (Nuvera PowerTap™)
- Responsible for the safe deployment of 8 Nuvera H2 forklift stations (24/7 mission critical operations)
- Helped establish 1st H2 FCEV refueling station in Massachusetts (2009)
- Developing state-of-art H70-T40 dispenser systems (DOE Award #DE-EE0007273)
- Active Hydrogen Codes & Standards Participation

Team Leader of SimpleFuel™, winner of DOE’s $1M H2Refuel H-Prize competition

Development Location:
Consumer Use Profiles

- **Highway Connector Stations**
  - ‘Fast Fills’
  - High-Capacity Refueling Stations
  - 100-200+ kg/day

- **Public Metro**

- **Fleets**
  - ‘Opportunity Dispenses’
  - Return-to-base
  - Lower-Capacity Refueling Appliances
  - Forklift Fleets
  - 1-50kg kg/day

- **Multi-Family Community**

- **Single Family Home**

- **Simple.fuel.™**

- **H2refuel**
  - U.S. Department of Energy
New class of *Refueling Appliance*
- 5 kg/day, 700 bar H2 delivery solution
- ‘Drop-in’ installation, small footprint
- Modular & scalable for evolving market
- ‘Opportunity Dispense’ in 5-15 minutes
- Cost competitive to gas & liquid delivered
- Uses water & electricity ⇒ renewable H2 option
- Serves both automotive and forklift markets
Role of H-Prize Competition

H-Prize created as part of the Energy Independence & Security Act of 2007

- Goal is “to advance the research, development, demonstration, and commercial application of hydrogen energy technologies.” (PLAW 110-140, Sec. 654)
- Initiative of DOE EERE Fuel Cell Technology Office
- Administered by the Hydrogen Educational Foundation, a 501(c)(3) non-profit organization
- Hydrogen infrastructure was focus of 2014-2016 round of H-Prize, titled “H2Refuel” targeting innovative solutions for home & community-based hydrogen refuelers for FCEVs
- Competition-based…promotes American Innovation!
Tenets of SimpleFuel™ Design Approach:
- Safety First, Beyond Compliance
- Compact; Simple to Permit and Install
- Cost Effective
- Easy to Use, Friendly & Approachable
- Networkable; Enable Distributed Solutions
- Customer excitors!

<table>
<thead>
<tr>
<th>H-PRIZE CRITERIA (HOME)</th>
<th>WEIGHT</th>
<th>MINIMUM SCORE</th>
<th>MAXIMUM SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispensing Pressure</td>
<td>3</td>
<td>350 bar or higher</td>
<td>700 bar or higher</td>
</tr>
<tr>
<td>Tested Availability</td>
<td>2</td>
<td>80% or higher</td>
<td>98% or higher</td>
</tr>
<tr>
<td>Installed System Cost</td>
<td>2</td>
<td>$25k/kg or less*</td>
<td>$5k/kg or less</td>
</tr>
<tr>
<td>Dispensing Time (1 kg)</td>
<td>1</td>
<td>10 hours or less</td>
<td>30 mins or less</td>
</tr>
<tr>
<td>Standard Fills per Day (1 kg)</td>
<td>1</td>
<td>1 or more</td>
<td>5 or more</td>
</tr>
<tr>
<td>Direct User Cost per kg</td>
<td>1</td>
<td>$20 or less</td>
<td>$8 or less</td>
</tr>
</tbody>
</table>

*Home category allowed a maximum installed system cost of $35k/kg if no team satisfied minimum score target
Target Entry Market Applications

Captive Fleets – Industrial Trucks
- >13,000 H2-powered forklifts in US today!
- ~60% market is less than 50kg/day H2
- Saves valuable real estate, enables incremental DC expansion & retail stores

Tethered Fleets – On-Road Vehicles
- Up to 10-20 FCEVs per refueler
- Affords incremental, managed conversion
- State/Municipal, Workplace, Ride Share & University Programs
- 100 tonnes GHG/year savings possible with renewable grid-tie options
### Automotive Appliance Key Specifications

#### 700 bar Automotive H2 Appliance

*Product suite can support a managed fleet of 10 to 20 FCEVs with 5-15 minute opportunity fills*

<table>
<thead>
<tr>
<th>Dispense Pressure</th>
<th>Daily Capacity</th>
<th>Fueling Rate (typ.)</th>
<th>Hydrogen Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 bar</td>
<td>5 (or 10) kg H2/day</td>
<td>5 – 30 min/kg H2</td>
<td>Meets SAE J2719 / ISO 14687-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Consumption</th>
<th>RO Water Consumption</th>
<th>Noise</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 (or 29) kWe max</td>
<td>3 (or 6) L/h</td>
<td>&lt; 70 dBA at 1m</td>
<td>2.03m W x 1.07m D x 2.08m H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Installed System Cost</th>
<th>Direct User Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; $35,000/kg</td>
<td>&lt; $15/kg</td>
</tr>
</tbody>
</table>

Values in **bold** represent the tested 5kg H₂/day H-Prize prototype of SimpleFuel™
Industrial Appliance
Key Specifications

350 bar Industrial H2 Appliance
Support a multi-truck fleet with 2 minute fill times

<table>
<thead>
<tr>
<th>Dispense Pressure</th>
<th>Daily Capacity</th>
<th>Fueling Rate</th>
<th>Hydrogen Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 bar</td>
<td>5 or 10 kg H2/day</td>
<td>2.2 – 10 min/kg H2</td>
<td>Meets SAE J2719 / ISO 14687</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Consumption</th>
<th>RO Water Consumption</th>
<th>Noise</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 – 26 kWe max</td>
<td>3 – 6 L/h</td>
<td>&lt; 70 dBa at 1m</td>
<td>2.03m W x 1.07m D x 2.08m H</td>
</tr>
</tbody>
</table>
Rigorous Product Evaluation:
- 700 bar, 5 kg/day SimpleFuel appliance testing with Hyundai Tucson FCEV
- More than 200 fills demonstrated to 4 – 7 kg class automotive tanks
- Furthering collaboration from multiple OEMs to validate product
- Supporting ISO/SAE Ambient-Class Standards Development
Validation Testing

Competition Requirements ensured high utilization and wide range of test conditions.
H2 Refuel H-Prize Winner
Satisfied all technical and cost criteria including 3 month performance test
www.hydrogenprize.org
Automotive Refueling Scenarios

**‘Opportunity’ Dispense**
- Smaller Mass Dispensed
- Lower Final Pressure
- Fastest Fill Rates
- Target application: Quick range addition, managed fleet fueling

**‘Full Fill’ Dispense**
- Large Mass Dispensed
- Full Tank to 700 bar
- Fill Rate Slows During Fueling
- Target application: ‘Slow charge’ complete fill, overnight/shop fueling
The SimpleFuel™ appliance provides a competitive vehicle range fill-time to that of the fastest BEV chargers.
Distributed Fueling Infrastructure Model

Network of 10-20 SimpleFuel™ Refuelers

AND

‘Fast Fill’ Central Hub Station

= Same Investment

- For early markets, reduce total time to fuel (including travel time) by distributing many smaller refueling locations
- Network of SimpleFuel™ refuelers can optimize utilization via direction of vehicles to optimal refueling point
- Fast and simple permitting and installation process is of critical importance to this model
Next Steps

Engagement with Automotive OEMs
• Ivys team helping to develop SAE ambient-class H2 fueling standard, for publication this year
• H-Prize competition drove interest from OEMs in this class of fueling equipment

Initial Customer Deployments
• In discussions with multiple US fleet customers
• Market pull to accelerate OEM adoption of small-scale refueling / standards development
• Cost-effective solution without subsidies

Demonstration and Outreach
• Continuing demonstration with Hyundai FCEV
• MA funded project for fully renewable SimpleFuel™ installation (solar + energy storage) with Hyundai vehicles in late 2017
Thank you

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Supplemental Material
Basic site installation requirements for drop-in install:

- Power per specification
- RO Water Supply – sized for single or multiple systems
- Vents: H2 and O2 per specification
- Vehicle Impact Protection – Bollards
- Detail design review by U.S. Hydrogen Safety Panel Members
- Standard home install/cost provided by expert panel member(s)

Commercialized product is under-going an appliance certification
## Periodic Inspection & Maintenance

<table>
<thead>
<tr>
<th>Service Interval / Service Type</th>
<th>6 Mo. Inspection / Clean / Replace as Needed</th>
<th>1-Year Inspection / Clean / Replace as Needed</th>
<th>1-Year Replacement</th>
<th>5-Year Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrolyzer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet Water Filter</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pressure Equalizers</td>
<td>X</td>
<td>X (Internal Seal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolyte Solution</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cell Stack</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Compressor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil System</td>
<td>X</td>
<td>X (Filter)</td>
<td></td>
<td>X (Oil)</td>
</tr>
<tr>
<td>Diaphragms</td>
<td></td>
<td>X (QTY 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gas Purification &amp; Dispensing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer Guard Filter</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dispenser Filter</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Water Separator Filter</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ventilation Air Filter</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Service cost typically \( \leq 2\%-4\% \) of capital cost per year; year-5 involves stack replacement
Community Outreach
Warwick-Bucks County First Responder Visit (Aug. 23 2016)
The SimpleFuel™ Team would like to thank:

- U.S. Department of Energy
- H₂refuel
- Hydrogen Education Foundation
- H₂ Safety Panel
- Hyundai
- NREL (National Renewable Energy Laboratory)