U.S. Department of Energy
FreedomCAR & Vehicle
Technologies Program

Advanced Vehicle Testing
Activity – Hydrogen Pilot Plant
and H2-ICE Vehicle Activities

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Presentation Outline

• Background & Goal
• Arizona Public Service (APS) Alternative Fuel (Hydrogen) Pilot Plant - design & operations
  – Hydrogen subsystem
  – CNG subsystem
  – Auxiliary & Safety systems
• Fuel Dispensing
• Hydrogen & HCNG Internal Combustion Engine (ICE) Vehicle Testing Activities
• Gen II station
• Barriers & Applications
• WWW Information
AVTA Background & Goal

- Advanced Vehicle Testing Activity (AVTA) is part of the U.S. Department of Energy’s FreedomCAR and Vehicle Technologies Program

- These activities are managed by the Idaho National Laboratory (INL also performs data analysis and reporting activities)

- AVTA Goal - Provide benchmark data for technology modeling, and research and development programs, and help fleet managers and other vehicle purchasers make informed purchase and operations decisions
AVTA Background

- Full-size pure EVs (40 models, 5 million miles)
- Neighborhood EVs (15 models)
- Urban EVs (3 models, 1.75 million test miles)
- Hybrid EVs (12 models, 35 HEVs, 2.2 million miles)
- Plugin HEVs (starting with 3 models)
- Hydrogen ICE vehicles (several models, 300k miles)
- Electric ground support (aircraft) equipment
- Oil bypass filter testing (17 INL units, 1.3 million miles)
APS Alternative Fuel (Hydrogen) Pilot Plant

- Partners - Arizona Public Service (APS), Electric Transportation Applications (ETA), INL, & DOE
- First & longest operating hydrogen station in the U.S. – since June 2002
- Hydrogen produced onsite
- Hydrogen & CNG fueling
Hydrogen Testing Objectives

- Evaluate the safety & reliability of operating ICE vehicles on 100% hydrogen & hydrogen/compressed natural gas (H/CNG) blended fuels (15 to 50% H/CNG)
- Evaluate hydrogen fueling infrastructure & operations costs
- Quantify hydrogen & H/CNG ICE vehicle costs, performance, & emissions
Pilot Plant - Layout

Hydrogen Fuel Cell

2 H2 High psi tanks

H2 Low psi tank

H2 Compressor

2 CNG Compressors

6 CNG Tanks (3 psi levels)
Pilot Plant - Hydrogen Subsystem

- Oxygen
- Water
- Electricity

H₂ Generator → Dryer → Low Pressure Storage

Compressor → Filter → High Pressure Storage

H₂ Out
Pilot Plant – Hydrogen Subsystem

• Proton Energy Systems’ HOGEN PEM stationary fuel cell operating in reverse
  – PEM fuel cell, 57 kW, 20 cells
  – 300 scfh hydrogen output @ 150 psi
  – 17 kWh per 100 scf hydrogen

• Hydrogen Lectrodryer
  – 300 scfh
  – -80°F dew point
Pilot Plant – Hydrogen Subsystem

- Hydrogen compressor
  - Pressure Dynamic Consultants (Pdc Machines)
  - Oil-free triple diaphragm
  - Two-stage compression
  - 300 scfh @ 6,000 psi

- Norman hydrogen filters
  - High- & low-pressure storage outlets
  - Dryer inlet & outlet
  - Compressor outlets

- Hydrogen - 99.9997% purity
Pilot Plant - Hydrogen Subsystem

- Low pressure hydrogen storage (lower tank)
- High pressure hydrogen storage (upper 2 tanks)
Low Pressure Hydrogen Storage Tank

- 8,955 SCF @ 150 psi
- Rated for 250 psi at 125°F
- Carbon steel, 6 ft. 11 in. inside diameter, 19 ft. long
- Water volume of 6,565 gallons
- Manufactured under ASME Pressure Vessel Code, Section VIII, Division 22
- ASME safety relief valve rated at 165°F piped to vent stack
High Pressure Hydrogen Storage Tanks

- 17,386 SCF @ 6,000 psi (total both tanks)
- Rated for 6,667 psi at 200°F
- Seamless horizontal carbon steel, 16 in. outside diameter, 28 ft. long
- Water volume of 405 gal. (total both tanks)
- Manufactured under 1998 ASME Pressure Vessel Code, Section VIII, Division 1, Addendum 1999, Appendix 22 (SF3)
- ASME safety relief valve rated at 6,667°F piped to vent stack
Pilot Plant - CNG Subsystem

- **CNG Boost Compressor**
  - 300 scfm @ 60 psi

- **CNG Main Compressor**
  - 350 scfm @ 5,000 psi

- **CNG Storage/Pressure – 6 tanks**
  - 3 Low: 11,079 scf @ 3,600 psi
  - 2 Medium: 5,711 scf @ 4,500 psi
  - 1 High: 5,711 scf @ 5,000 psi

- Manufacturer: CP Industries
Pilot Plant - Auxiliary Systems

- Water Purification - 215 gal/day, 1.0 micron exit filter
- Control Air - 100 cfm compressor, 90 psi
- Water Chiller - 293,000 Btu/h,
- Nitrogen - Air/hydrogen buffer gas - production, piping, compression & 600 scf storage. 97% purity @ 100 psi
- Helium - vent stack purging
- Vents - fabricated from 0.5 in. 304 stainless steel tubing, 3 in. schedule 40 stainless steel pipe
Pilot Plant - Emergency Shutdown System

- Combustible gas detectors
- Ultra-fast IR/UV flame detectors
- Manual (5) & remote trips
- Vent stack temperature monitor
- Alarms, horns & strobe lights
- Vent stack fire suppression
Pilot Plant – Hydrogen Gas Detectors

- Six combustible gas detectors (Det-Tronics RS 8471)
- Monitors hydrogen & natural gas in 1% increments of lower flammability limits (LFL)
- Alarm condition at 25% of LFL reached
- Emergency shutdown when 50% of LFL reached
Pilot Plant – Flame Detectors

• Two mid-level (35 feet) & four corner IR/UV flame detectors (Spectrex 20/20LB units)
• One detector at fuel dispenser unit
• If flame detected, emergency shutdown initiated within 3 milliseconds
Pilot Plant - Monitoring

- Real-time station & component monitoring at 100 nodes
- Fuel quantities & costs collected for pure hydrogen and HCNG blended fuels
- Electric power equipment
  - Voltages & currents
- Select process temperatures
- Major process parameters
  - Pressures & flows
Pilot Plant - Monitoring

- Hydrogen kilogram (kg) energy costs based on historical (26% to 49%) & projected (70%) plant factors
  - $3.43 down (26% PF) to $2.39 per kg (70% PF)
  - DOE 2005 energy cost target $2.47
- Water cost per kg of hydrogen $0.10
- 8,600 kg of hydrogen produced (6/30/06)
Pilot Plant – Dispenser System

- CNG Sub-System
- Delivered Hydrogen
- Hydrogen Sub-System
- H₂ and H₂/CNG Dispensers
Pilot Plant - Fueling Dispensers

- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access
- 11,295 fueling events (6/30/06)
  - 545 @ 100% Hydrogen
  - 3,940 @ 15 to 50% HCNG blends
  - 6,810 @ 100% CNG
Prototype Dispenser Testing

- Uses proportional flow control valves for hydrogen & CNG gas streams from 100 to 40,000 scfh
- Real-time ratio control of blended fuels - uses coriolis mass flow transducers in hydrogen & CNG gas streams
- 1 Nozzle - CNG & HCNG fuels (15, 20, 30, & 50% hydrogen by volume) at 3,600 psi
- 1 Nozzle - 100% hydrogen at 5,000 psi
- Being commercialized by Clean Energy
Hydrogen & HCNG ICE Vehicle Testing

- Initial ICE hydrogen & HCNG vehicle testing
  - Dodge van on 15% HCNG (operating)
  - Ford F150 up to 30% HCNG (operating)
  - Ford F150 up to 50% HCNG (testing complete)
  - 100% hydrogen Mercedes Benz van (operating)
- Total of 300,000 hydrogen & HCNG miles
15% HCNG Dodge Van Emissions Testing

• 5.2 L CNG V8 (no modifications) with 71,000 HCNG test miles - no problems
• 27,000 miles of 15% HCNG fuel data - 15.5 miles/GGE

<table>
<thead>
<tr>
<th>Percentage change in 15% HCNG emissions compared to 100% CNG emissions</th>
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<tbody>
<tr>
<td>Total hydrocarbons</td>
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<tr>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td>Carbon dioxide</td>
</tr>
</tbody>
</table>
30% HCNG F150 Testing

- 5.4 L V8 CNG engine – added: supercharger, ignition modifications & exhaust gas recirculator

- Fleet testing - 59,000 30% HCNG miles: 17.3 miles/GGE

<table>
<thead>
<tr>
<th>Fuel Blend</th>
<th>0 to 60 mph (secs.)</th>
<th>Miles/GGE</th>
<th>Range (miles)</th>
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<tr>
<td>CNG</td>
<td>10.10</td>
<td>23.3</td>
<td>122</td>
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<tr>
<td>15% HCNG</td>
<td>10.97</td>
<td>22.6</td>
<td>110</td>
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<tr>
<td>30% HCNG</td>
<td>12.68</td>
<td>23.5</td>
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# 30% HCNG F150 Emissions Testing

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Percentage Change in Emissions Testing</th>
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<tbody>
<tr>
<td></td>
<td>NMHC</td>
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<tr>
<td>Gasoline</td>
<td>Base</td>
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<tr>
<td>CNG</td>
<td>-80</td>
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<tr>
<td>15% HCNG</td>
<td>-78</td>
</tr>
<tr>
<td>30% HCNG</td>
<td>-89</td>
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</table>

NMHC = Non-Methane Hydrocarbons  
CH<sub>4</sub> = Methane  
HC = Total Hydrocarbons  
CO = Carbon Monoxide  
NO<sub>x</sub> = Oxides of Nitrogen  
CO<sub>2</sub> = Carbon Dioxide
50% HCNG F150 Emissions Testing

- Modifications
  - SVO heads, exhaust intercooler & supercharger
  - Exhaust gas recirculator & ignition modification
  - Equipped with 3 Quantum hydrogen 3,600 psi tanks with 9 kg total storage

Percent reduction in emissions (HCNG versus gasoline-fueled F-150)

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>CO</th>
<th>NO\textsubscript{x}</th>
<th>CO\textsubscript{2}</th>
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<td>-3.5%</td>
<td>-43.3%</td>
<td>-97.0%</td>
<td>-16.7%</td>
</tr>
</tbody>
</table>

HC = total hydrocarbons
CO = carbon monoxide
CO\textsubscript{2} = carbon dioxide
NO\textsubscript{x} = oxides of nitrogen
HCNG ICE Vehicle Fleet Operations

• APS meter reader fleet 12 Bifuel vehicles (GM)
  – 1,600 fueling events, 190,000 miles using 10,600 GGE of 15% HCNG

• Public Fleet - private party Bifuel conversions
  – 350 fueling events, 36,000 miles (estimated) using 1,800 GGE of HCNG blends (mostly 15%)
5.4L 16-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 16-valve Ford/ETEC pickup
- 5 speed transmission, supercharged (3 psi boost), hydrogen fuel injectors, & air-to-water intercooler
- Hardened valves & seats, & forged pistons with 12:1 compression
- Motec fuel & spark controls, lean-burn mode
- Onboard hydrogen storage 3 Dynetek tanks @ 3,000 psi, 6.5 kg, aluminum vessel & fiberglass wrap
- Converted by ETEC
- 1,365 lbs payload
5.4L 16-valve 100% Hydrogen ICE Vehicle

- Baseline Performance testing results
  - Max speed @ 1 mile: 81 mph & ¼ mile: 58 mph
  - Acceleration (0 to 50 mph): 18.1 seconds
  - SAE J1634 fuel economy (AC on): 14.5 miles/GGE
  - SAE J1634 fuel economy (AC off): 18.0 miles/GGE
  - 45 mph constant speed: 27.0 miles/GGE
  - Range 95 (14.5 miles/GGE) to 175 miles (27 miles/GGE)

- Fleet testing – 5,200 miles: 17.4 miles/GGE (110 miles range)
5.4L 32-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 32-valve Ford/ETEC pickup
- Automatic transmission, hydrogen fuel injectors, 12 pounds supercharger boost & air-to-air intercooler
- Hardened valves & seats, & forged pistons with 11.5:1 compression
- Motec fuel & spark controls, lean-burn mode
- 8,000 fleet testing miles - 14.4 miles/GGE
- Onboard hydrogen storage 3 Dynetek tanks @ 5,000 psi, 15.3 kg (220 miles range)
- Converted by ETEC
6L V-8 100% Hydrogen ICE Vehicle

- Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine
- Converted by ETEC/Roush to 100% hydrogen
- 4-speed automatic transmission, electronic port fuel injection, supercharger, liquid-to-air intercooler
- Integration of powertrain control module & development of hydrogen lean-burn control strategies
- Implementation of J1850 communications to maintain seamless integration with existing OEM equipment
6L V-8 100% Hydrogen ICE Vehicle

- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 200 Horsepower & 260 lb-ft torque
- Preliminary Argonne dynamometer results
  - 14 city & 20 highway miles per GGE
  - Range 140 to 200 miles
  - THC 0.0005 g/mi, NOx 0.0610 g/mi, CO 0.0685 g/mi, & CO₂ 0.0926 g/mi
- Nine vehicles produced
- 8 units in Vancouver B.C.
Generation II Station Design

- Driven by commercial fueling station design requirements
  - Reduced setbacks to allow siting on a commercial corner
  - Reduced operator training to allow operation by service station personnel or vehicle operators
  - Reduced hazards to minimize the maximum potential accident
  - Multiple layers of safety to significantly reduce operating risk
Generation II Station Design

- Coaxial Containment System™
- Expandable modular design
- Envelopes most severe environmental conditions
- Exhaustive safety analysis to support permitting
- Zero setback requirements for flexible siting
- Shop assembled skid design
  - Assembly by ASME shop
  - Field welding minimized
Generation II Station Design - Coaxial Containment System™

- Double wall piping system
  - Shields process piping within a pressure containing pipe
  - Contains pressure waves resulting from any gas ignitions
  - Redirects any detonations to benign location
  - Allows inerting of annulus to prevent gas ignition
  - Eliminates need for blast setback
  - Protects process pipe from vandalism
Status of Fuel Cell Vehicles

• U.S. public use totals 1 FCV (cost between $1 million and $1.5 million)
• About 60 FCVs in DOE/OEM/Oil demo fleets
• Oil companies largest 5 producers of hydrogen – 68% of capacity
Institutional & Economic Barriers

- No intentional institutional barriers (yet) - we’re burning cooking oils in cars
  - Lack of codes & standards
  - Lack of national ICE vehicle certification process
  - Lack of state emissions testing procedures
  - Lack of familiarity (Hindenburg affect?)
Institutional & Economic Barriers

• All economic barriers
  – Hydrogen has to compete economically with gasoline
  – Hydrogen & fuel cell economics very expensive
  – Hogen unit cost more than doubled in 6 years
  – Tube trailer $12.50 kg + transportation & trailer rental
  – Michigan testing ~$80 kg., Chicago testing ~$50 kg., & Phoenix station ~$12 kg.
Hydrogen Needs High Value Applications

- Is hydrogen a chemical (remote production locations) or an energy carrier for transportation (corner “gas” stations)?
- Avoid emissions & greenhouse gas restrictions
- Economic benefits of on-peak electricity production at substations
- Onsite hydrogen generation at power plants for generator cooling - avoid transportation (to remote plant locations) & security issues
- Avoid Katrina shortages
Acknowledgement

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Additional Information
http://avt.inl.gov