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

(Advanced Vehicle Testing Activity)

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AVTA Presentation Outline

• Arizona Public Service’s Alternative Fuel (Hydrogen) Pilot Plant Design and Operations
• Hydrogen internal combustion engine vehicle testing
• Oil bypass filter system evaluation
• Diesel engine idling testing
• INL alternative fuel infrastructure
• INL alternative fuel fleet
• WWW information
APS Alternative Fuel (Alt-Fuel) Pilot Plant - Partners

- Arizona Public Service (APS)
- Electric Transportation Applications (ETA)
- Idaho National Laboratory (INL)

- Started operations - 2002
Alt-Fuel Pilot Plant & Vehicle 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 costs
• Quantify hydrogen & H/CNG ICE vehicle costs, performance, & emissions
Alt-Fuel Pilot Plant - Hydrogen Subsystem

Oxygen

Water → Electricity → H₂ Generator → Dryer → Low Pressure Storage → Compressor → Filter → High Pressure Storage → H₂ Out
Alt-Fuel Pilot Plant – Hydrogen Subsystem

- Proton Energy Systems’ HOGEN PEM stationary fuel cell operating in reverse
  - 300 scfh hydrogen output @ 150 psi
  - 17 kWh per 100 scf hydrogen

- Hydrogen Lectrodryer
  - 300 scfh
  - -80°F dew point
Alt-Fuel 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 filter locations
  – High- & low-pressure storage outlets
  – Dryer inlet & outlet
  – Compressor outlets

• Hydrogen - 99.9997% purity
Alt-Fuel 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 @ 125°F
- Carbon steel, 6 ft. 11 in. inside diameter, 19 ft. long
- Water volume of 6,565 gal.
- Manufactured by Trinity Industries under ASME Pressure Vessel Code
- ASME safety relief valve rated @ 165 psi piped to vent stack
High Pressure Hydrogen Storage Tanks

- 17,386 scf @ 6,000 psi (total both tanks)
- Rated for 6,667 psi @ 200°F
- Seamless horizontal carbon steel, 16 in. outside diameter, 28 ft. long
- Water volume of 405 gal. (total both tanks)
- Manufactured by CP Industries under 1998 ASME Pressure Vessel Code
- ASME safety relief valve rated @ 6,667 psi piped to vent stack
Alt-Fuel Pilot Plant - Auxiliary Systems

- Water Purification - 215 gal/day, 1.0 micron exit filter
- Control Air - 100 cfm compressor, 90 psi
- 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
Alt-Fuel Pilot Plant - Emergency Shutdown System (EMS)

- Ultra-fast IR/UV detectors
- Combustible gas detectors
- Manual (5) & remote trips
- Vent stack temperature monitor
- Alarms, horns and strobe lights
- Vent stack fire suppression
Alt-Fuel Pilot Plant - EMS

- 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
Alt-Fuel Pilot Plant - EMS

- 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
Alt-Fuel Pilot Plant - Monitoring System

- Real-time station & component monitoring @ 50 monitoring nodes (100 @ completion)
- Fuel quantities collected and costs calculated for pure hydrogen and H/CNG blended fuels
- Electric powered equipment
  - Voltages & currents
- Select process temperatures
- Major process parameters
  - Pressures & flows
Alt-Fuel Pilot Plant - Monitoring Results

• Better understanding component, subsystems, & plant-level efficiencies & costs

• Monitoring system results to date
  – Hydrogen kg energy costs based on historical (26% to 49%) & projected (70%) plant factors - $3.43 down to $2.39 per kg (DOE 2005 target $2.47)
  – Water cost per kg of hydrogen $0.10
Alt-Fuel Pilot Plant - CNG Subsystem

Boost Compressor

Main Compressor

High Pressure Storage (3 levels)

Street Service Low Pressure Natural Gas

CNG Output
Alt-Fuel 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
Alt-Fuel Pilot Plant – Dispenser System

CNG Sub-System → CNG Dispenser

Delivered Hydrogen

Hydrogen Sub-System → H₂ and H₂/CNG Dispensers
Alt-Fuel Pilot Plant - Fueling Dispensers

- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access
Prototype Dispenser Testing

- Uses proportional flow control valves for hydrogen & CNG gas streams to control gas flow rates from 100 to 40,000 scfh
- Dispenser controller adjusts the control valves to provide real-time ratio control of blended fuels
- Control valves are trimmed by a digital dispenser controller using mass flow signals provided by coriolis mass flow transducers in the hydrogen & CNG gas streams
Prototype Dispenser Testing

• Delivers 100% hydrogen, 100% CNG, & blends of H/CNG using two independent single nozzles to AVTA test vehicles
  – 1 Nozzle - CNG and H/CNG fuels (15, 20, 30, & 50% hydrogen - by volume) at 3,600 psi
  – 1 Nozzle - 100% hydrogen dispensing at 5,000 psig

• Next step – commercial package
Hydrogen & H/CNG ICE Vehicle Testing

- Initial ICE hydrogen & H/CNG vehicle testing
  - Ford F150 up to 30% H/CNG (continues in testing)
  - Ford F150 up to 50% H/CNG (testing complete)
  - 100% hydrogen Mercedes Benz van (operating)
  - Dodge van on 15% H/CNG (continues in testing)
- 300,000+ hydrogen & H/CNG test miles, 4,000+ successful fueling events
H/CNG ICE Vehicle Testing

- Ongoing hydrogen & H/CNG ICE vehicle testing
  - 8 APS fleet vehicles on 15% H/CNG - S-10s, Sierra pickups, Blazers, Dodge Ram van
  - 16+ City of Phoenix (including Phoenix Fire Department) fleet vehicles on 15% H/CNG
5.4L 16-valve Hydrogen ICE Vehicle Testing

• Ford 16-valve 5.4L SOHC V-8, 100% hydrogen, fuel injected, supercharged, & 1,365 lbs payload
• Converted by Electric Transportation Engineering Corporation (eTec)
• Onboard hydrogen storage
  – 3 Dynetek tanks
  – Aluminum inner vessel, fiberglass wrap
  – 3,000 psi
  – 6.5 kilograms
5.4L 16-valve Hydrogen ICE Vehicle Testing

- Baseline Performance testing results
  - Maximum 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 fuel economy: 27.0 miles/GGE
  - Range 95 to 175 miles (6.5 GGE storage)
- Fleet testing - 2,800 miles: 17.2 miles/GGE
5.4L  32-Valve 100% Hydrogen ICE - Status

• Engine changed to 10.5 to 1 compression, 12 pounds supercharge boost
• To be Baseline Performance and Fleet tested
• Fuel storage
  – 3 Dynetek tanks
  – Aluminum inner vessel, carbon wrap
  – 5,000 psi tanks
  – 15 kilograms
## 30% H/CNG F150 Performance Testing

<table>
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<tr>
<th>Fuel Blend</th>
<th>Acceleration to 60 mph (secs.)</th>
<th>Fuel Economy (miles/gge)</th>
<th>Range (miles)</th>
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<tbody>
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<td>23.3</td>
<td>122</td>
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<tr>
<td>15% H/CNG</td>
<td>10.97</td>
<td>22.6</td>
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<tr>
<td>30% H/CNG</td>
<td>12.68</td>
<td>23.5</td>
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Hydrogen Test Vehicles

- Future (Baseline) Performance testing
  - 100% hydrogen 32-valve Ford/ETEC pickup
  - 100% hydrogen GMC Sierra 6-passenger, 6-liter pickup modified by Roush/Power Tech/ETA

- Future fleet testing
  - 32- & 16-valve 100% hydrogen pickups
  - Eight 100% hydrogen GMC Sierra pickups
  - 18 H/CNG vehicles in 2 Phoenix Fleets
Oil Bypass Filter System Evaluation

• Goal: Examine oil bypass filter effectiveness, & demonstrate & quantify engine oil use reductions
  – Demonstrate oil bypass filtration systems from puraDYN & Refined Global Solutions
  – Demonstrate oil reduction benefits
  – Economic benefits analysis by vehicle & fleets
  – Analysis and dissemination of DOE complex-wide economic and oil-use benefits
Oil Bypass Filter System Evaluation

• Filters clean partial flow of oil down to 1 micron, have evaporative units, & some with additive packages

• Puradyn systems installed on 8 INEEL motor coach buses (Detroit Diesel series 50 & 60 engines, & 1 Caterpillar diesel engines – all 4 stroke)

• Puradyn filter systems installed on 6 Tahoes

• Refined Global Solutions (RGS) filters on 3 INL buses (Detroit Diesel series 60 engines – all 4 strokes)
Oil Bypass Filter System Evaluation

• Test oil quality for 28 variables - total base number, oxidation & nitration levels, contaminants (metals, water, soot, & fuel), & track makeup oil use

• Status – 1.1 million test miles (July 30, 2005) with 860,000 bus miles & 270,000 Tahoe miles

• Oil change avoidance: 90% buses (~35 quarts) & 60% Tahoes (~5 quarts)

• Economics good on buses
Diesel Engine Idling Testing

• Reduce use of 850 million gallons of diesel during idling periods

• Help develop accurate idling-reduction lifecycle cost analysis & system payback expectations

• Historical data indicates the relative composition of wear metals generated during the period directly following extended idling may be significantly different than those generated during normal engine operations
Diesel Engine Idling Testing

- Two INL buses (DD series 50 engines) with historical oil testing data from the Oil Bypass Study were idled 1,000 hours each.
- Used chemical & ferrographic analysis of engine oils & oil filters to evaluate relative magnitude & differences in diesel engine wear during normal over-the-road operations & extended engine idling periods.
- Driver logs, fueling records, & onboard data loggers used to collect: makeup oil & fuel use, idling times & percents, rpm, vehicle speeds, & overall engine profiles during operating periods & idling phases.
- Preliminary finding: after a period of high idling, aluminum & chromium increased significantly.
INL Alternative Fuel Infrastructure

- Liquid natural gas (LNG) / compressed natural gas (CNG) station at “site”
- CNG station in Idaho Falls
- E85 (85% ethanol / 15% gasoline) station at “site”
- Adding E85 fueling in Idaho Falls
- B20 (20% biodiesel / 80% diesel) station at “site”
- Added 2nd 7.2 gge 3,600 psi CNG tanks to 36 pickups & replaced 4 gge 3,000 psi tanks on 13 Contours with 7.2 gge 3,600 psi CNG tanks
INL Alternative Fuel Fleet (318 vehicles)

- 79 B20 motor coach buses
- 7 Dedicated LNG motor coach buses
- 154 Bi-fuel light-duty CNG vehicles
- 52 Bi-fuel E85 (85% ethanol) pickups/SUVs
- 22 Bi-fuel LNG pickups
- 2 Dedicated CNG vans (injector tests Ford & Bosch)
- 2 Dedicated propane light-duty vehicles
http://avt.inl.gov

AVTA Questions?