Idaho National Laboratory

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

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

Jim Francfort
Idaho State University

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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)

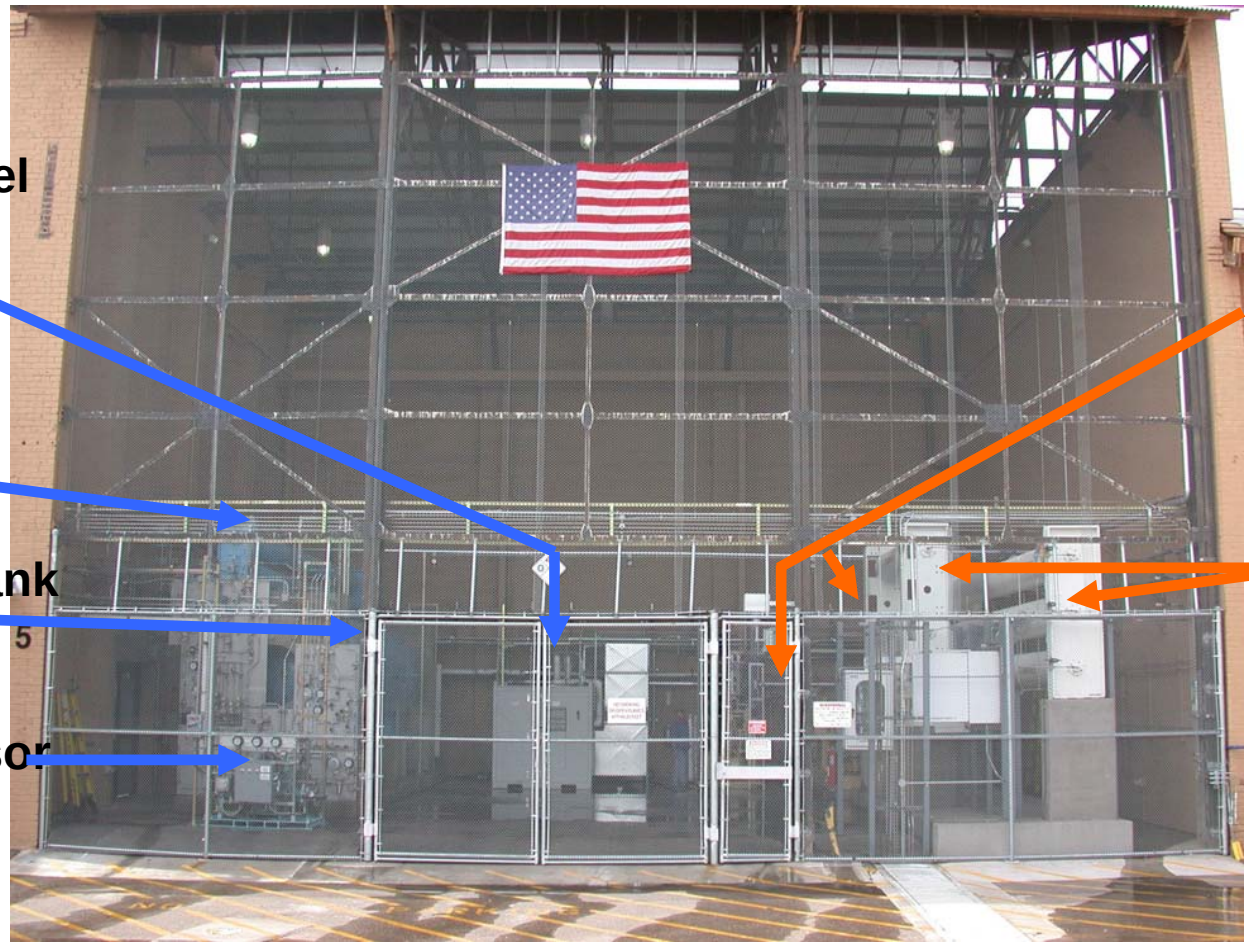
APS Alternative Fuel (Hydrogen) Pilot Plant

- **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**

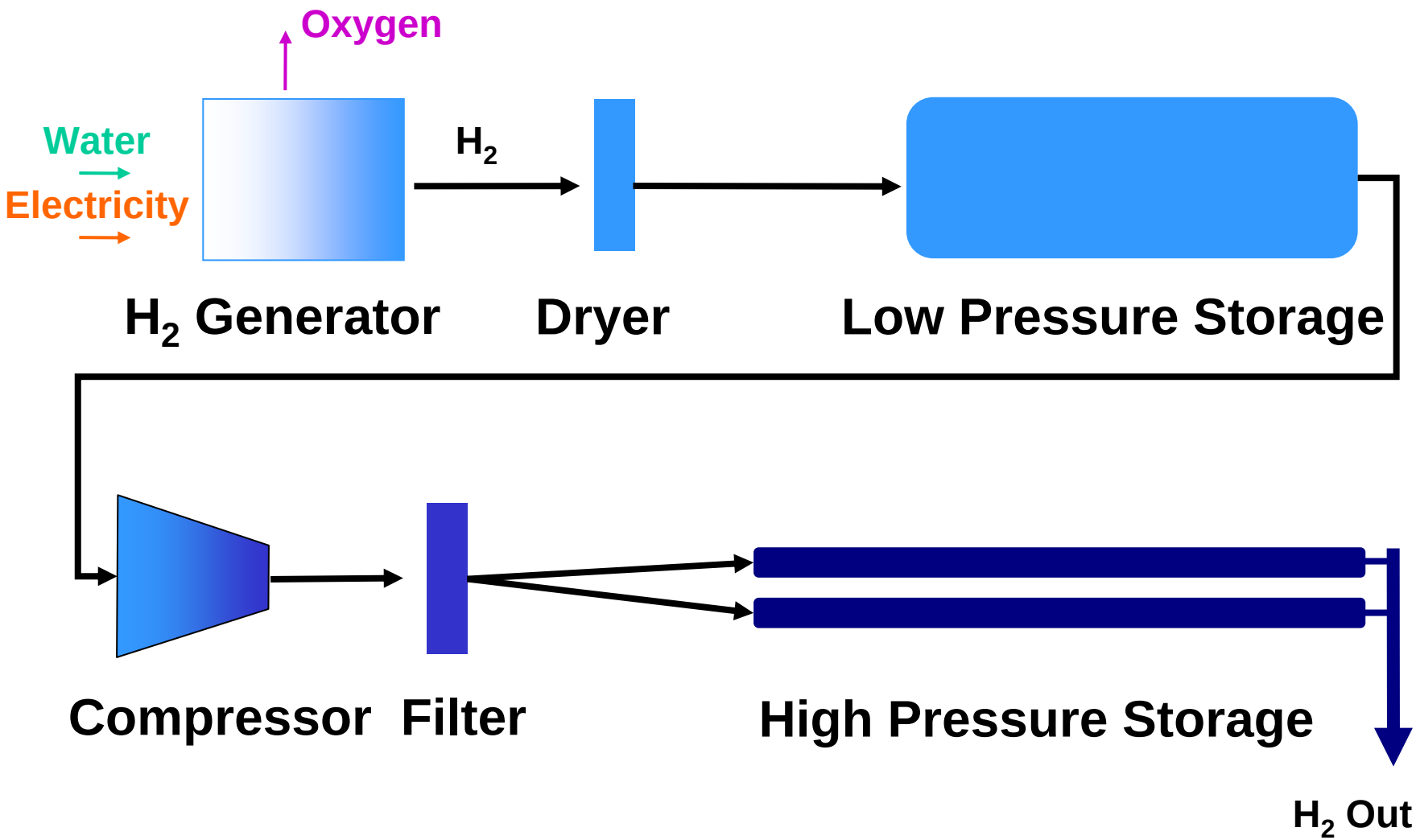
Hydrogen Testing Objectives

- **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



Pilot Plant - Hydrogen Subsystem

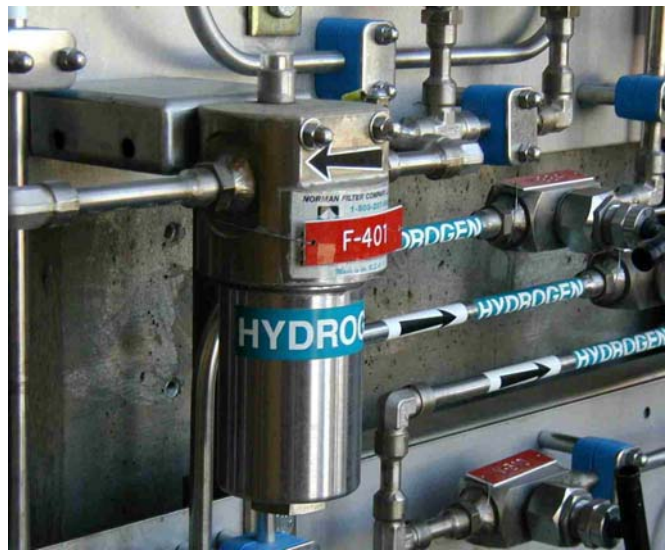


Pilot Plant – Hydrogen Subsystem

- **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**

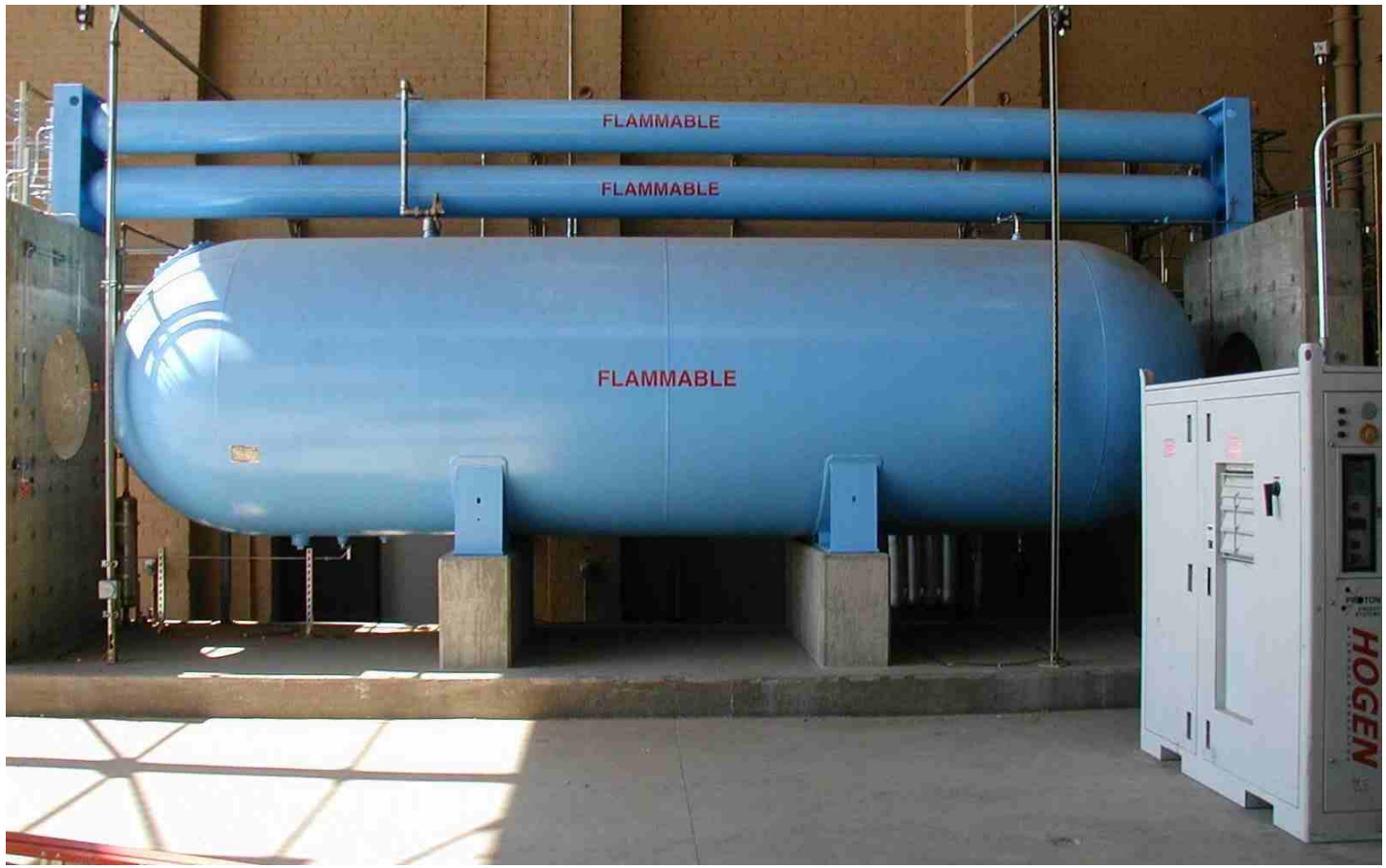
Pilot Plant – Hydrogen Subsystem

- 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)



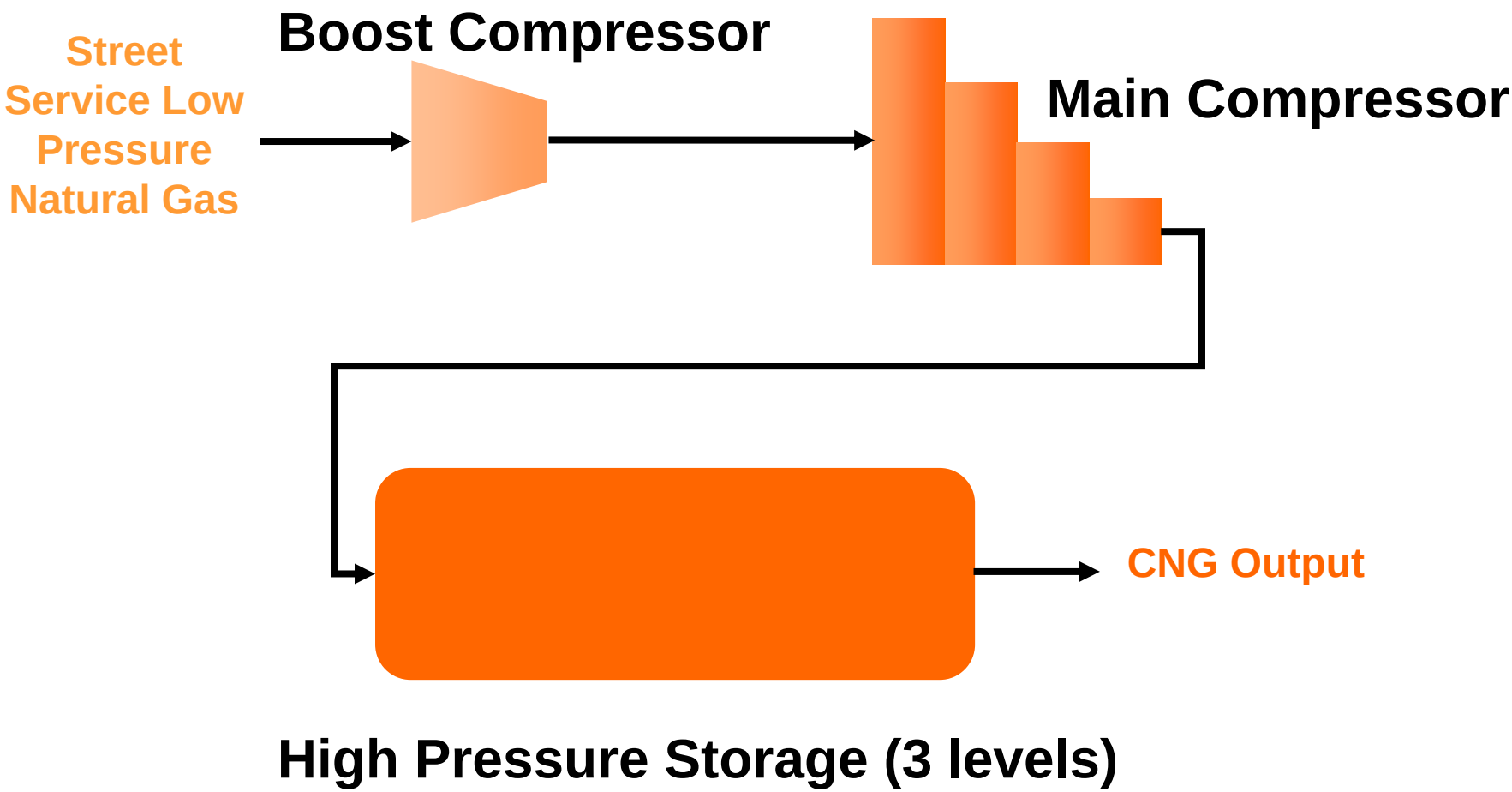
Low Pressure Hydrogen Storage Tank

- **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



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

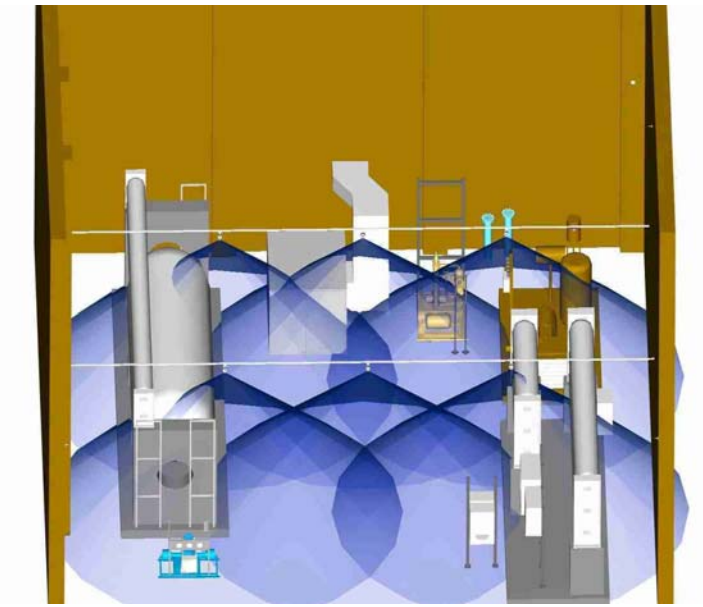
- **Water Purification - 215 gal/day, 1.0 micron exit filter**
- **Control Air - 100 cfm compressor, 90 psi**
- **Water Chiller - 293,000 Btu/h,**
- **Nitrogen - Air/hydrogen buffer gas - production, piping, compression & 600 scf storage. 97% purity @ 100 psi**
- **Helium - vent stack purging**
- **Vents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

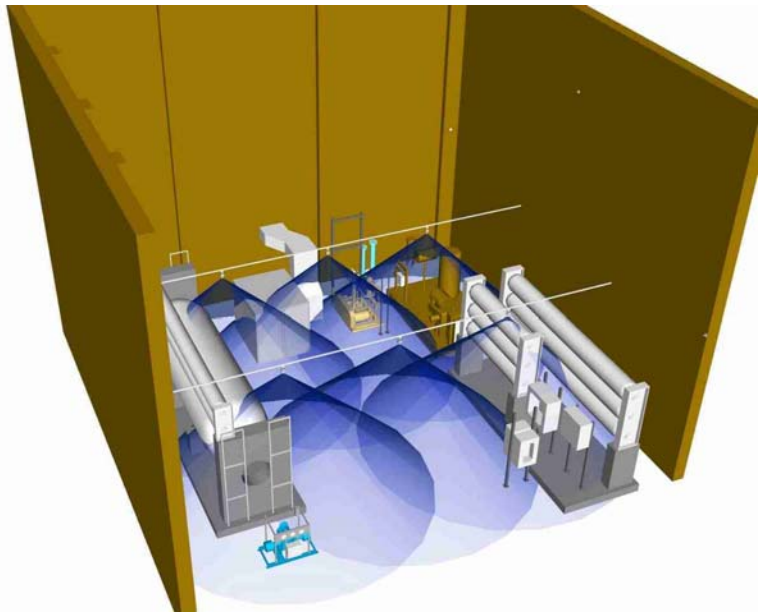
Pilot Plant - Emergency Shutdown System

- 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

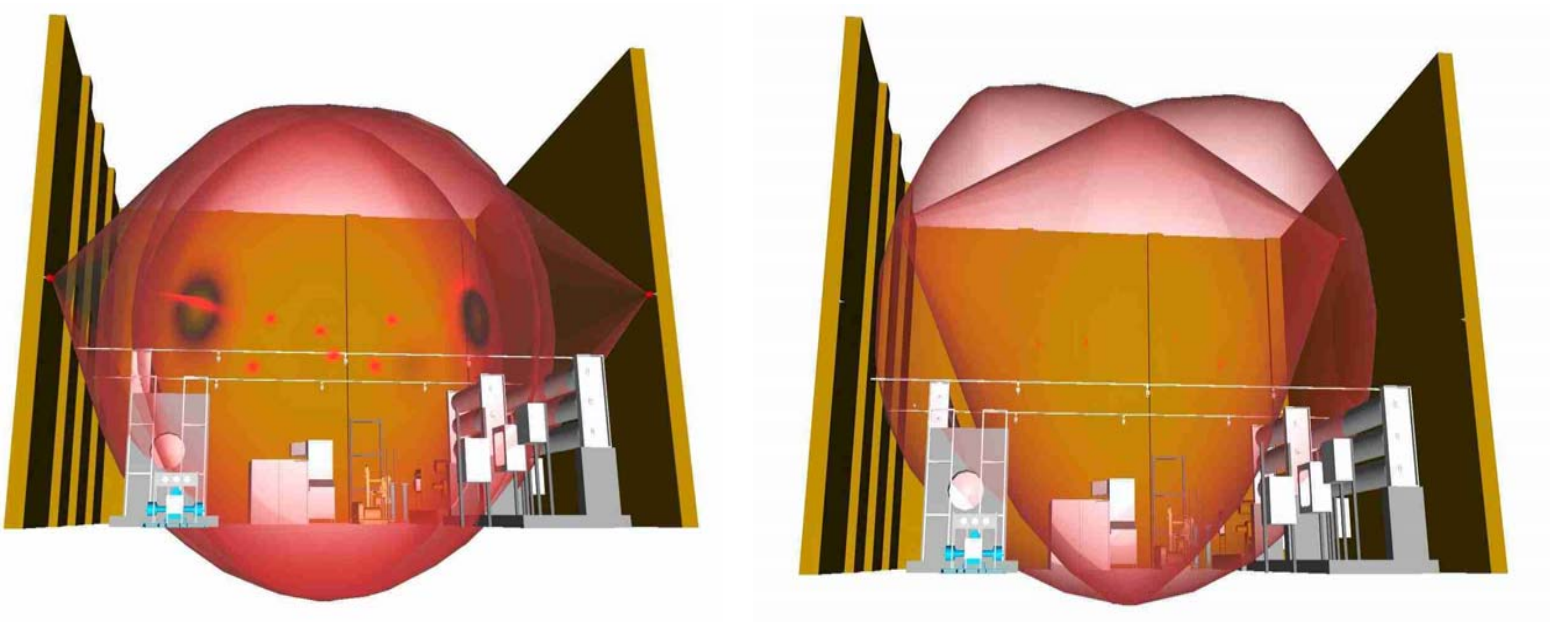
- **Six combustible gas detectors (Det-Tronics RS 8471)**
- **Monitors hydrogen & natural gas in 1% increments of lower flammability limits (LFL)**
- **Alarm condition at 25% of LFL reached**
- **Emergency shutdown when 50% of LFL reached**





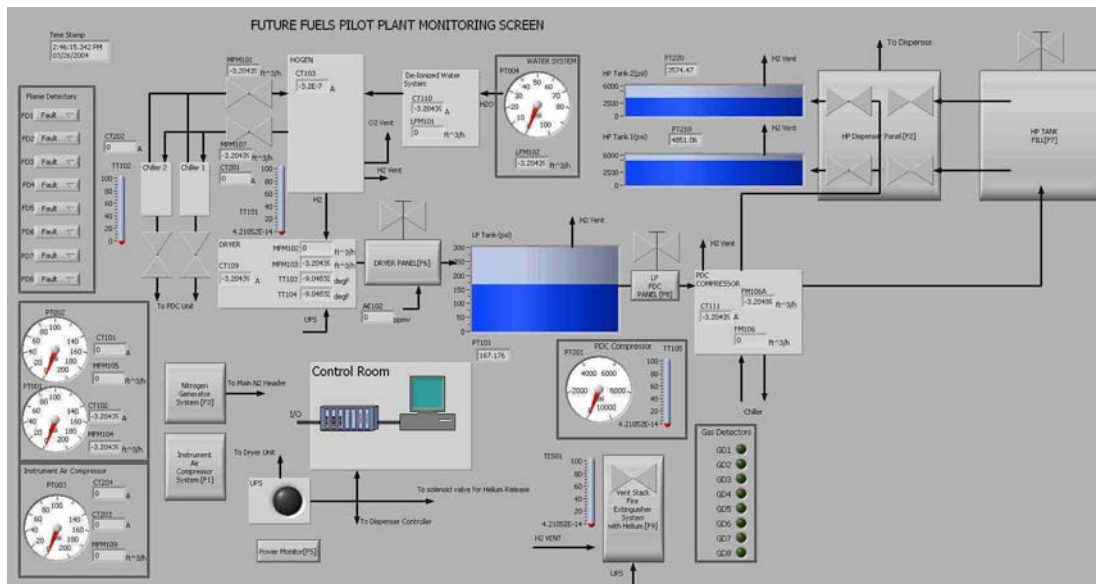
Pilot Plant – Flame Detectors

- **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**



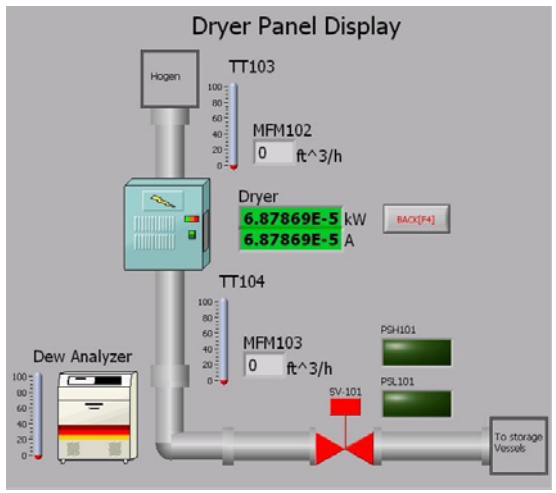
Pilot Plant - Monitoring

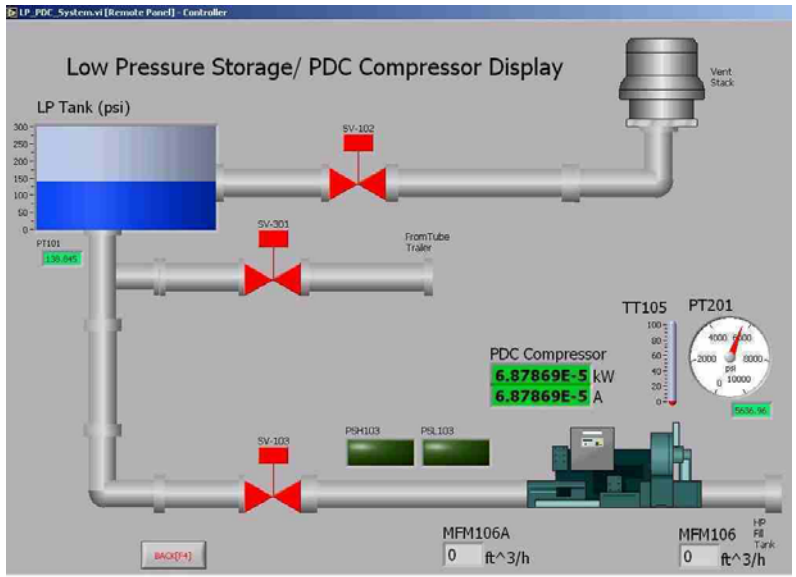
- Real-time station & component monitoring at 100 nodes
- Fuel quantities & costs collected for pure hydrogen and HCNG blended fuels
- Electric power equipment
  - Voltages & currents
- Select process temperatures
- Major process parameters
  - Pressures & flows



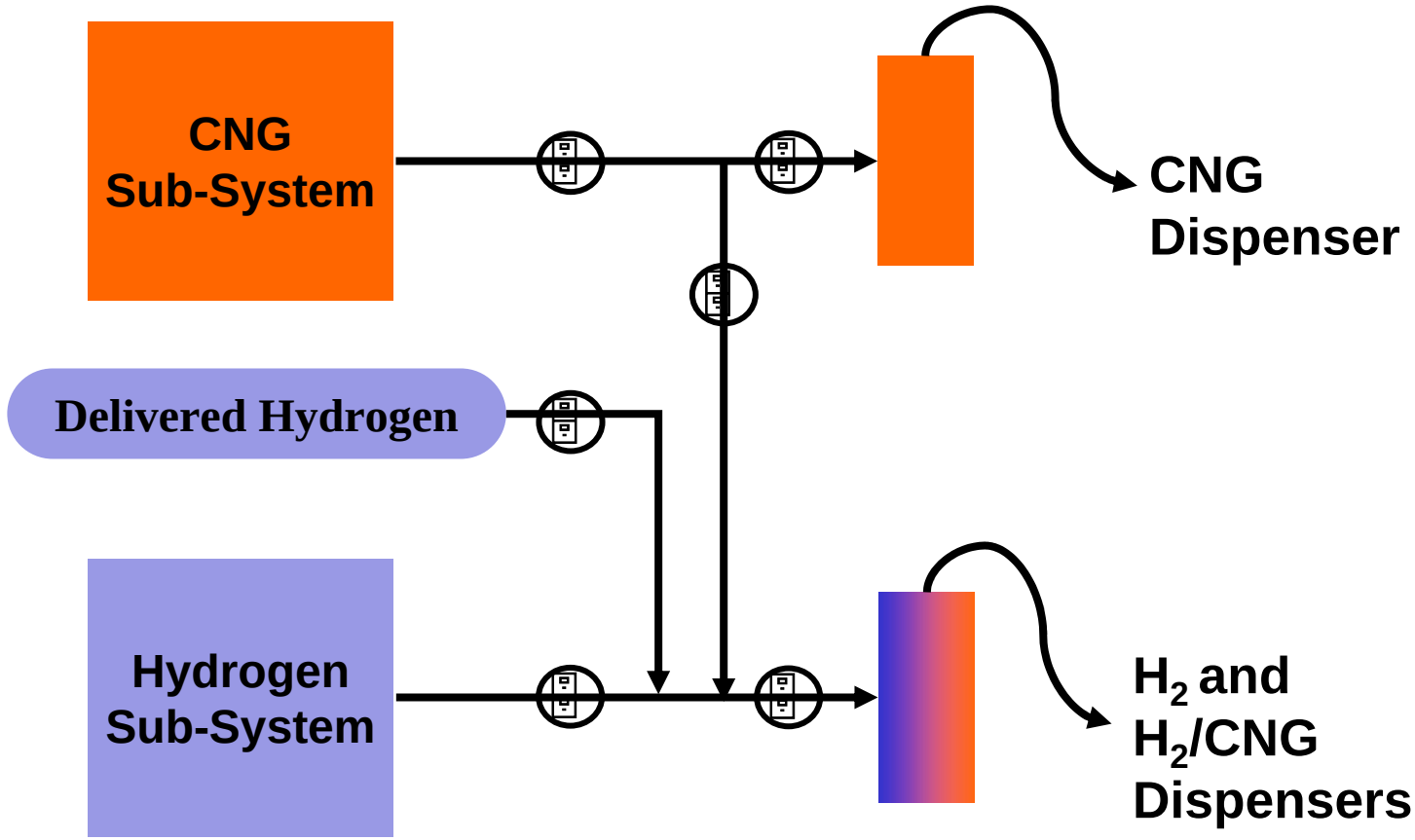
Pilot Plant - Monitoring

- **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



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


City of Phoenix
Fire Department

FIRE PERMIT

150 South 12th Street
Phoenix, Arizona 85034
General Information (602)262-7462

POST THIS PERMIT ON JOB SITE

Permit # F203 0200731 Issue Date 05-MAR-2002 Expires 02-MAR-2012
Permit Description FUEL DISPENSING @ 435 S. 2ND AVE.
Project 99-22738 APS
Address NOT FOUND Zoning
Description/Scope of Work: MOTOR VEHICLE FUEL DISPENSING STATION
MOTOR VEHICLE FUEL-DISPENSING STATIONS:
Operate.
PERMITEE:
APS/Pinnacle West

THIS PERMIT IS NOT TRANSFERRABLE

COPY RECEIVED BY DATE 3/28/12
FIRE CAPTAIN DATE 3/27/12

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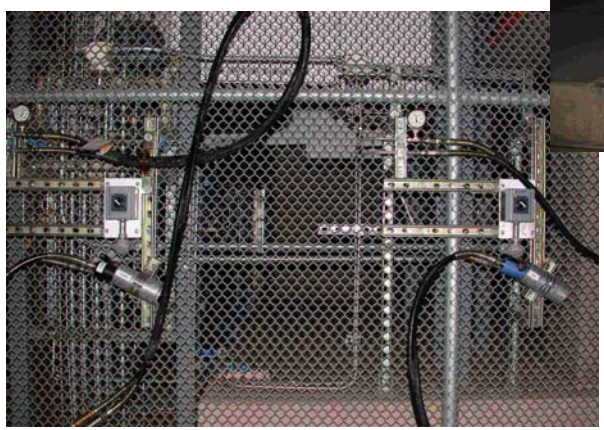
Prototype Dispenser Testing

- **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**

Percentage change in 15% HCNG emissions compared to 100% CNG emissions	
Total hydrocarbons	-34.7%
Carbon monoxide	-55.4%
Oxides of nitrogen	+92.1%
Carbon dioxide	-11.3%

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**

Fuel Blend	0 to 60 mph (secs.)	Miles/GGE	Range (miles)
CNG	10.10	23.3	122
15% HCNG	10.97	22.6	110
30% HCNG	12.68	23.5	102

30% HCNG F150 Emissions Testing

Fuel Type	Percentage Change in Emissions Testing					
	NMHC	CH_4	HC	CO	NO_X	CO_2
Gasoline	Base	Base	Base	Base	Base	Base
CNG	-80	+967	+35	-63	-34	-24
15% HCNG	-78	+1000	+40	-70	-26	-27
30% HCNG	-89	+1050	+37	-73	-25	-28

NMHC=Non-Methane Hydrocarbons

HC=Total Hydrocarbons

NOx=Oxides of Nitrogen

CH_4=Methane

CO=Carbon Monoxide

CO_2=Carbon Dioxide

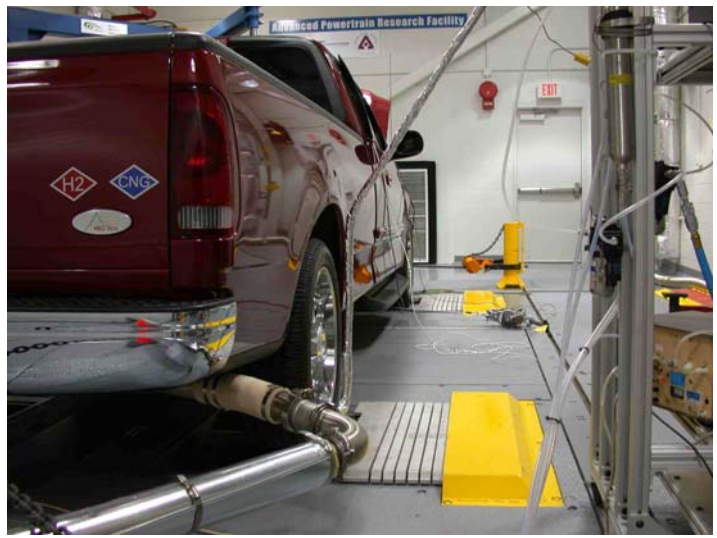
50% HCNG F150 Emissions Testing

- **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)

HC	CO	NO_X	CO_2
-3.5%	**-43.3%**	**-97.0%**	**-16.7%**

HC = total hydrocarbons
CO = carbon monoxide
CO_2 = carbon dioxide
NOx = oxides of nitrogen

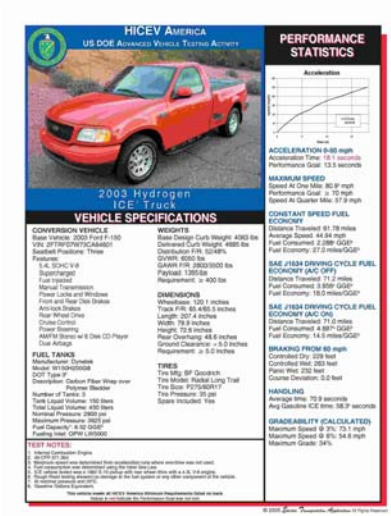


HCNG ICE Vehicle Fleet Operations

- **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

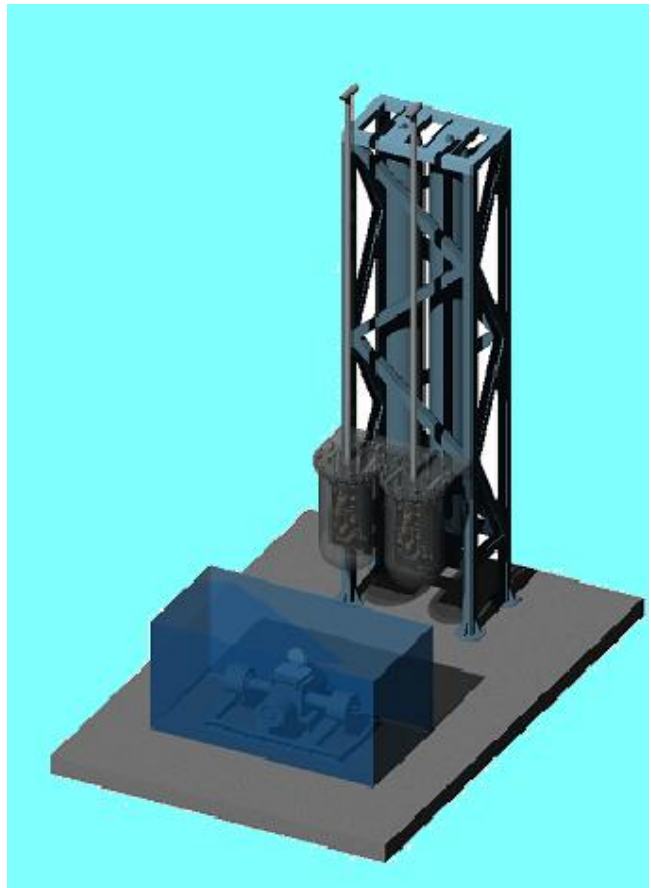
- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 200 Horsepower & 260 lb-ft torque
- Preliminary Argonne dynamometer results
  - 14 city & 20 highway miles per GGE
  - Range 140 to 200 miles
  - THC 0.0005 g/mi, NOx 0.0610 g/mi, CO 0.0685 g/mi, & CO_2 0.0926 g/mi
- Nine vehicles produced
- 8 units 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**

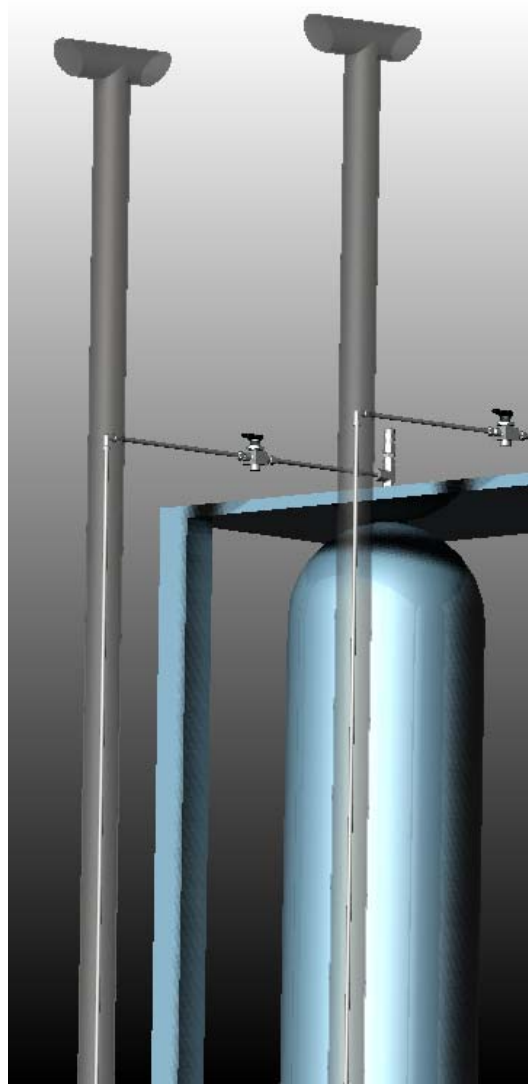
Generation II Station Design

- 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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FreedomCAR and Vehicle Technologies Program

Vehicle Systems Team Leader, Tien Duong

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Additional Information

http://avt.inl.gov

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