Idaho National Laboratory

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

Advanced Vehicle Testing Activity

Hydrogen Station & ICE Vehicle Operations and Testing

Jim Francfort for Lee Slezak

WestStart CALSTART Hydrogen Internal Combustion Engine Symposium – February 2006

INL/CON-06-01109

Presentation Outline

- **Background and Goal**
- **Arizona Public Service (APS) Alternative Fuel (Hydrogen) Pilot Plant - design and operations**
- **Fuel Dispensing**
- **Prototype Dispenser Testing**
- **Hydrogen and HCNG Internal Combustion Engine (ICE) Vehicle Testing Activities**
- **WWW Information**

AVTA Background and Goal

- **AVTA is part of the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program**

- **These activities are conducted by the Idaho National Laboratory (INL) and the AVTA testing partner Electric Transportation Applications**

- **AVTA Goal - Provide benchmark data for technology modeling, 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 test miles)
- Neighborhood EVs (15 models)
- Urban EVs (3 models, 1.75 million test miles)
- Hybrid EVs (9 models, 28 HEVs, 1.75 million miles)
- Hydrogen ICE vehicles (several models, 300k miles)
- Oil bypass filter testing (17 vehicles, 1.2 million miles)

APS Alternative Fuel (Hydrogen) Pilot Plant - Partners

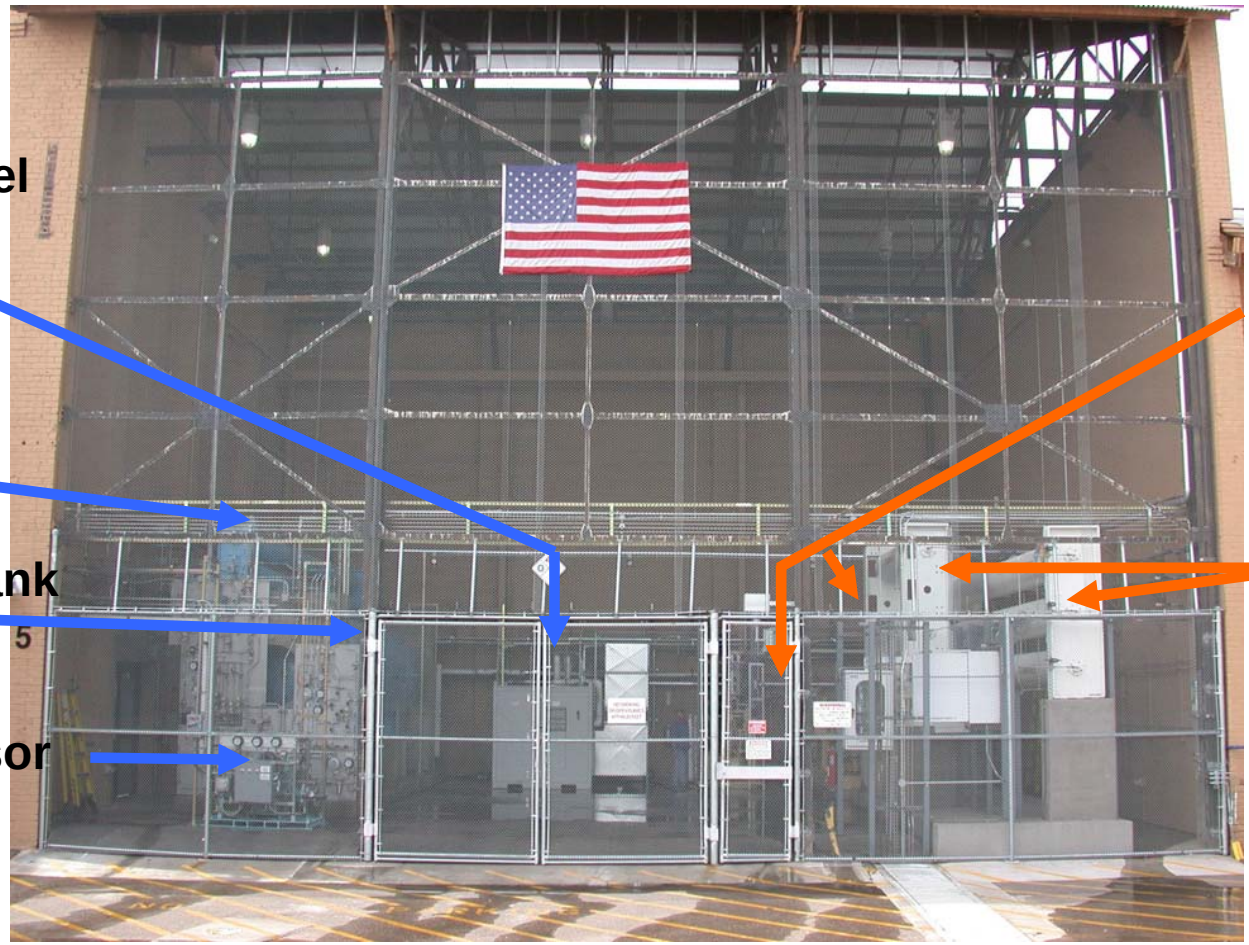
- Arizona Public Service (APS)
- Electric Transportation Applications (ETA)
- U.S. Department of Energy (DOE)
- Idaho National Laboratory (INL)

Operating since June 2002

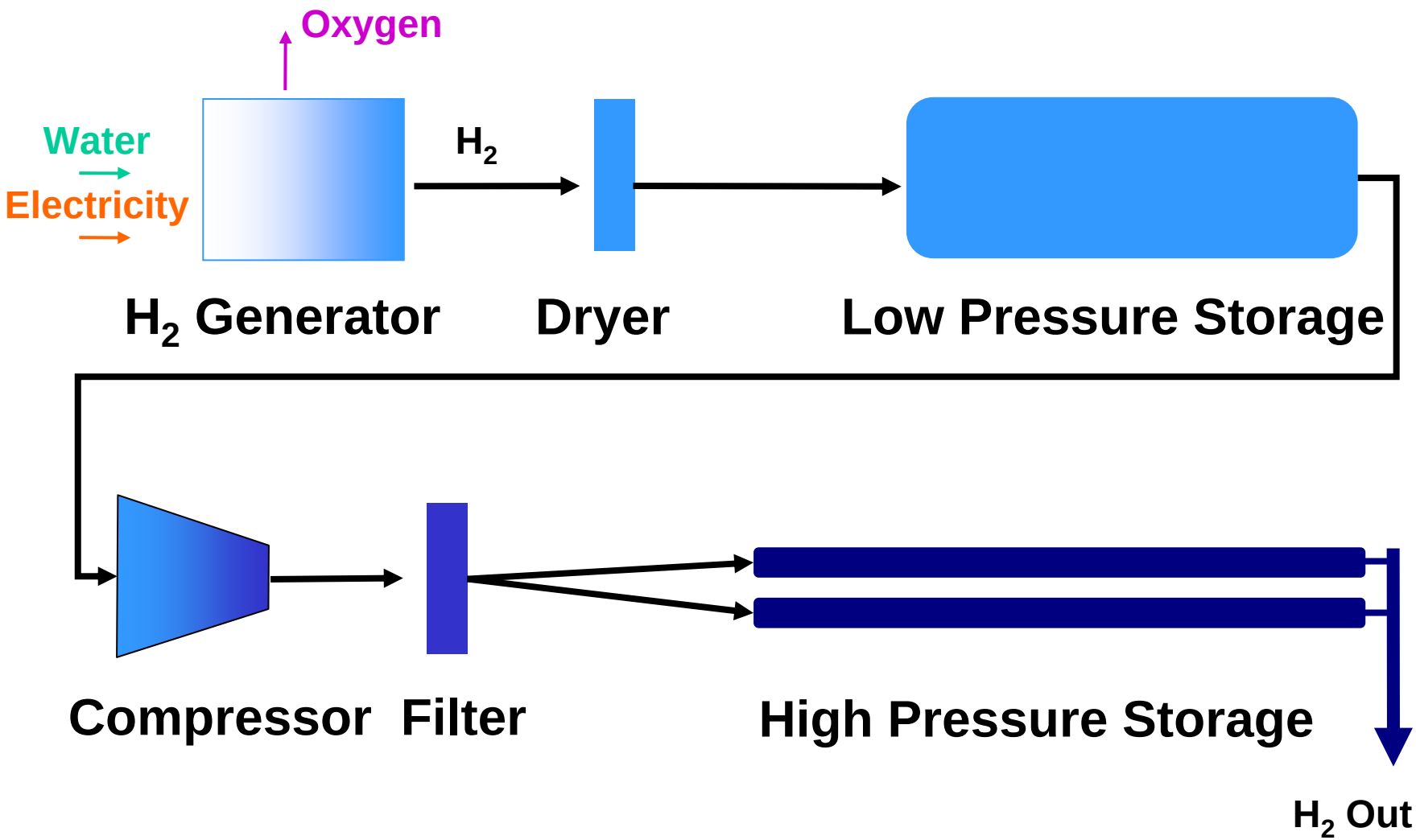
Pilot Plant & Hydrogen ICE Vehicle Testing Objectives

- **Evaluate the safety & reliability of operating ICE vehicles on 100% hydrogen and hydrogen/compressed natural gas (HCNG) blended fuels (15 to 50% HCNG)**
- **Evaluate hydrogen fueling infrastructure costs**
- **Quantify hydrogen and HCNG ICE vehicle costs, performance, and emissions**

Pilot Plant - Layout



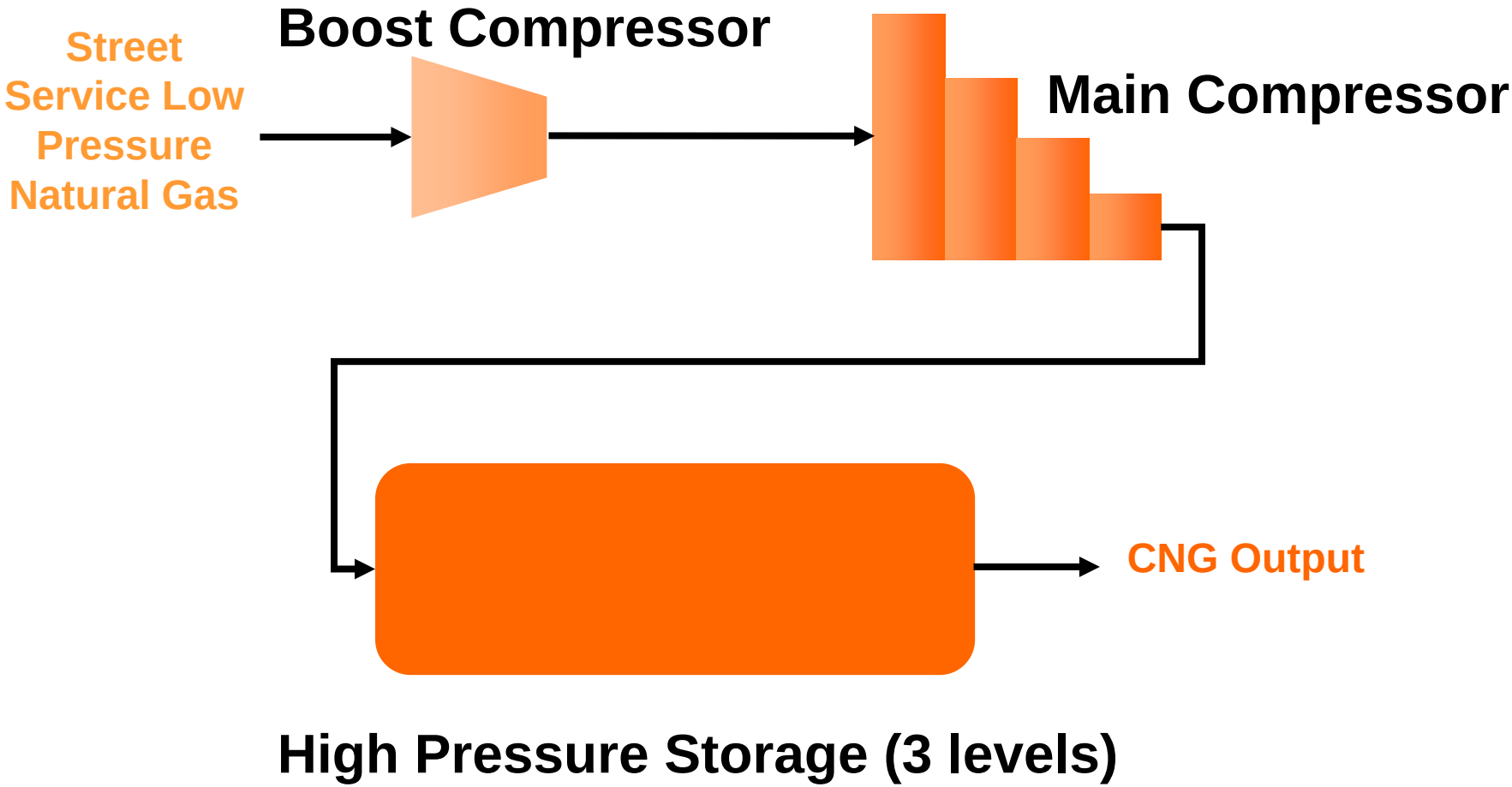
Pilot Plant - Hydrogen Subsystem



Pilot Plant - Hydrogen Storage

- **Low pressure hydrogen storage (lower tank) - 8,955 SCF @ 150 psi**
- **High pressure hydrogen storage (upper 2 tanks) - 17,386 SCF @ 6,000 psi (total both tanks)**

Pilot Plant - CNG Substation



Pilot Plant - Fueling Dispensers

- **Includes metering and electronic billing interface**
- **Fully permitted for motor fuel dispensing**
- **Public access**

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

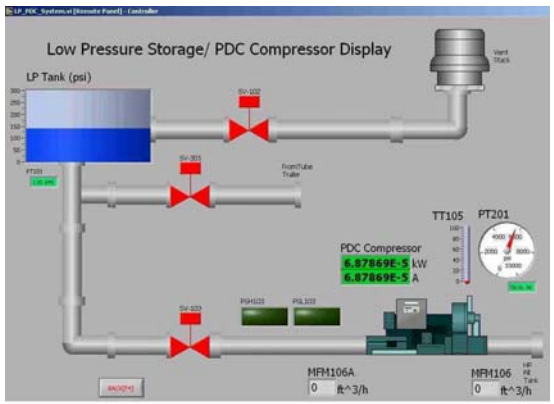
COPY RECEIVED BY DATE 3/22/02

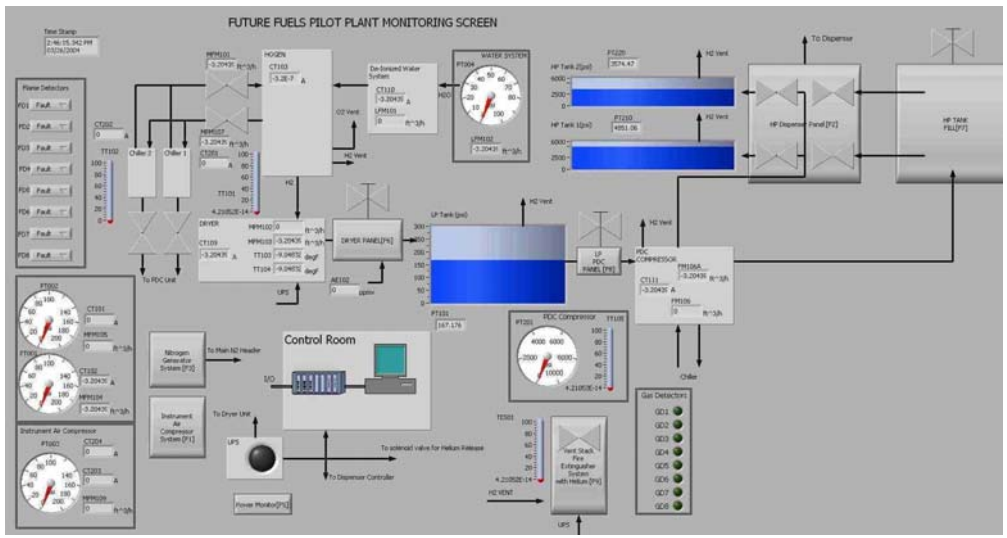
FIRE CAPTAIN DATE 3/29/02

CUSTOMER COPY

Pilot Plant - Monitoring

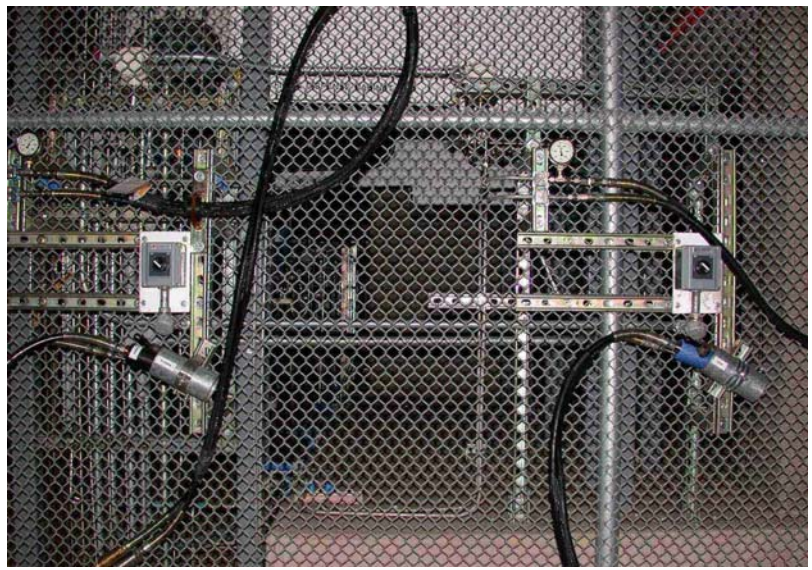
- 6,000 fueling events & 7,200 kg of hydrogen produced
- Hydrogen kg energy costs based on historical (26% to 49%) and projected (70%) plant factors
  - $3.43 down (26% PF) to $2.39 per kg (70% PF)
  - DOE 2005 energy cost target $2.47
- Water cost per kg of hydrogen $0.10





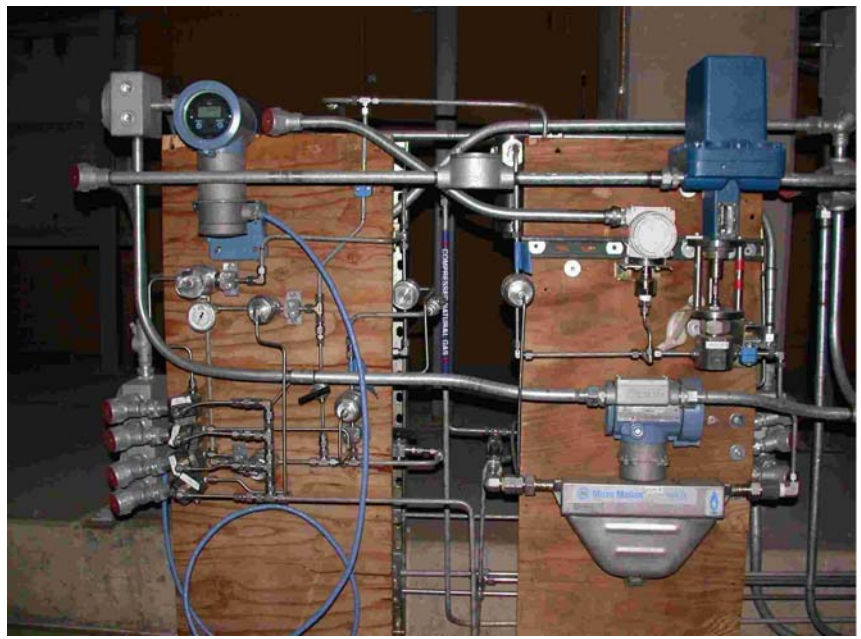
Prototype Dispenser Testing

- **Uses proportional flow control valves for hydrogen and 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 and CNG gas streams**



Prototype Dispenser Testing

- **Delivers 100% hydrogen, 100% CNG, and blends of HCNG using two independent single nozzles to fuel AVTA test vehicles**
  - **1 Nozzle - CNG and HCNG fuels (15, 20, 30, and 50% hydrogen - by volume) at 3,600 psi**
  - **1 Nozzle - 100% hydrogen dispensing at 5,000 psig**
- **Next step - commercial package**



Hydrogen and HCNG ICE Vehicle Testing

- **Initial ICE hydrogen and HCNG vehicle testing**
  - **Dodge van on 15% HCNG (continues in testing)**
  - **Ford F150 up to 30% HCNG (continues in testing)**
  - **Ford F150 up to 50% HCNG (testing complete)**
  - **100% hydrogen Mercedes Benz van (operating)**

15% HCNG Dodge Van Emissions Testing

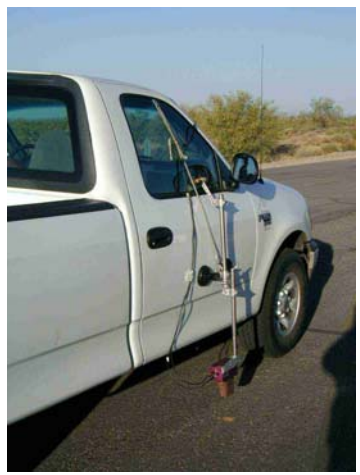
- **5.2 L CNG V8 (no modifications) with 71,000 HCNG test miles - no problems**
- **27,000 miles of 15% HCNG fuel data - 15.5 miles/GGE**

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 - 54,000 30% HCNG miles: 17.5 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

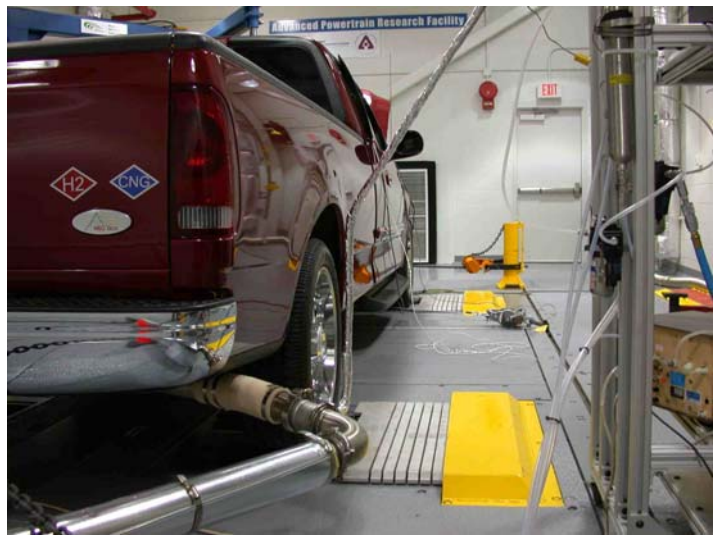
50% HCNG F150 Emissions Testing

- **Modifications**
  - **SVO heads, exhaust intercooler and supercharger**
  - **Exhaust gas recirculator and ignition modification**
  - **Equipped with 3 Quantum hydrogen 3,600 psi tanks with 3 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

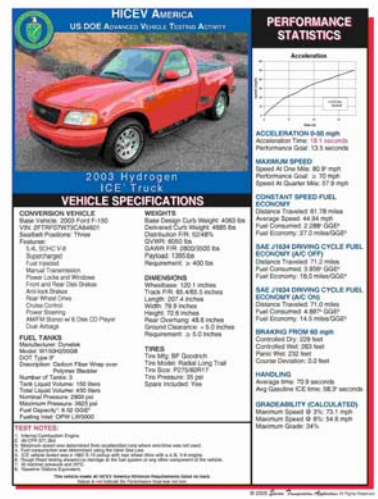


HCNG ICE Vehicle Testing

- **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, and air-to-water intercooler
- Hardened valves and seats, and forged pistons with 12:1 compression
- Motec fuel and spark controls, lean-burn mode
- Onboard hydrogen storage 3 Dynetek tanks @ 3,000 psi, 6.5 kilograms, aluminum vessel and fiberglass wrap
- Converted by ETEC
- 1,365 lbs payload



5.4L 16-valve 100% Hydrogen ICE Vehicle

- **Baseline Performance testing results**
  - **Maximum speed @ 1 mile: 81 mph and 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 (14.5 miles/GGE) to 175 miles (27 miles/GGE)**
- **Fleet testing - 3,500 miles: 17.0 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 and air-to-air intercooler**
- **Hardened valves and seats, and forged pistons with 11.5:1 compression**
- **Motec fuel and spark controls, lean-burn mode**
- **7,500 fleet testing miles - 15.3 miles/GGE**
- **Onboard hydrogen storage 3 Dynetek tanks @ 5,000 psi, 15.3 kilograms (230 miles range)**
- **To be baseline performance tested**
- **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 operate on 100% hydrogen**
- **4-speed automatic transmission, electronic port fuel injection, supercharger, liquid-to-air intercooler**
- **Integration of powertrain control module and 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 – cont'd

- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 180 Horsepower and 260 lb-ft torque
- Anticipated 15 miles per GGE and range 155 miles
- Targeted to meet NOx requirements for 2007 Tier II, Bin 7 standards
- HC < 10 ppm and NOx < 25 ppm on engine dynamometer
- Nine vehicles are being produced in 1st production run
- AVTA to baseline performance test and track 8 unit fleet in Vancouver

Acknowledgement

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FreedomCAR and Vehicle Technologies Program

Vehicle Systems Team Leader, Tien Duong

Project Leader and VSATT Lead, Lee Slezak

http://avt.inl.gov

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