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U.S. Department of Energy
FreedomCAR & Vehicle Technologies
Advanced Vehicle Testing Activity

HIGH-PERCENTAGE HYDROGEN/CNG BLEND FORD F-150 OPERATING SUMMARY

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January 2003

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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ABSTRACT

Over the past two years, Arizona Public Service, a subsidiary of Pinnacle West Capital Corporation, in cooperation with the U.S. Department of Energy's Advanced Vehicle Testing Activity, tested four gaseous fuel vehicles as part of its alternative fueled vehicle fleet. One vehicle operated initially using compressed natural gas (CNG) and later a blend of CNG and hydrogen. Of the other three vehicles, one was fueled with pure hydrogen and two were fueled with a blend of CNG and hydrogen. The three blended-fuel vehicles were originally equipped with either factory CNG engines or factory gasoline engines that were converted to run CNG fuel. The vehicles were variously modified to operate on blended fuel and were tested using 15 to 50% blends of hydrogen (by volume). The pure-hydrogen-fueled vehicle was converted from gasoline fuel to operate on 100% hydrogen. All vehicles were fueled from the Arizona Public Service's Alternative Fuel Pilot Plant, which was developed to dispense gaseous fuels, including CNG, blends of CNG and hydrogen, and pure hydrogen with up to 99.9999% purity.

The primary objective of the test was to evaluate the safety and reliability of operating vehicles on hydrogen and blended hydrogen fuel, and the interface between the vehicles and the hydrogen fueling infrastructure. A secondary objective was to quantify vehicle emissions, cost, and performance. Over a total of 40,000 fleet test miles, no safety issues were found. Also, significant reductions in emissions were achieved by adding hydrogen to the fuel.

This report presents the results of 4,695 miles of testing for one of the blended fuel vehicles, a Ford F-150 pickup truck, operating on up to 50% hydrogen–50% CNG fuel.

ACRONYMS

APS	Arizona Public Service
CAVTC	Clean Air Vehicle Technology Center
CNG	compressed natural gas
CO	carbon monoxide
DOE	U.S. Department of Energy
ETA	Electric Transportation Applications
FTP-75	Federal Emissions Test Procedure
HCNG	hydrogen blended with natural gas
IM-240	Inspection and Maintenance Driving Cycle
NMOG	non-methane organic gases
NOx	oxides of nitrogen
SULEV	super-low-emission vehicle

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BACKGROUND

Arizona Public Service Program

Federal regulation requires that energy companies and government entities utilize alternative fuels in their vehicle fleets. As a result, several automobile manufacturers are now producing compressed natural gas (CNG) fueled vehicles. Additionally, several converters are modifying gasoline-fueled vehicles to operate on both gasoline and CNG. Because of the availability of CNG vehicles, many energy company and government fleets have adopted CNG as their primary transportation alternative fuel. Meanwhile, recent research has shown that blending hydrogen with CNG (HCNG) can dramatically reduce emissions from CNG vehicles. This research, combined with the large fleet of CNG vehicles in operation nationwide, raises the question, "Can factory CNG vehicles run on a blend of hydrogen and CNG?"

Over the past 23 months, Arizona Public Service Company (APS), in conjunction with Electric Transportation Applications (ETA) and the U.S. Department of Energy's Advanced Vehicle Testing Activity, tested three vehicles fueled by HCNG. The test fleet included two Ford F-150s and one Dodge Ram Wagon Van. This report distinguishes the two F-150s by the names *low-percentage-blend F-150* and *high-percentage-blend F-150*. The low-percentage-blend F-150 was originally equipped with a factory CNG engine. It was modified by NRG Technologies, Inc., in Reno, Nevada to burn blended fuel. APS operated this vehicle on a 30% blend of hydrogen (by volume). The high-percentage-blend F-150 was originally equipped with a factory gasoline engine. NRG Technologies modified it to burn up to a 50% blend of hydrogen and 50% CNG (by volume). APS tested the vehicle at 30% hydrogen for several months. The vehicle was then transitioned to 50% hydrogen (by volume). The Dodge Ram Wagon Van is a dedicated factory CNG vehicle. APS operated this vehicle primarily on CNG. However, some operation and testing was performed using a 15% blend of hydrogen and CNG. A fourth vehicle (Mercedes Sprinter Van) that operated on 100% hydrogen was also tested. All four vehicles were fueled from the APS Alternative Fuel Pilot Plant, which was developed to dispense gaseous fuels, including CNG, blends of CNG and hydrogen, and pure hydrogen with up to 99.9999% purity.

This report covers the high-percentage-blend F-150 testing activities. The testing results for the other HCNG and 100% hydrogen-fueled vehicles are reported separately. The APS Alternative Fuel Pilot Plant and the vehicle fueling interface operations will also be reported separately. The Idaho National Engineering and Environmental Laboratory manages the hydrogen and HCNG light duty internal combustion engine vehicle testing for the U.S. Department of Energy's Advanced Vehicle Testing Activity.

Emission Test Procedures

Two emission test procedures were performed on the F-150: IM-240 and FTP-75.

IM-240

Several states use *The Inspection and Maintenance Driving Cycle* (IM-240) for the emissions testing of light duty vehicles. The test consists of a single phase; it spans 240 seconds, which represents 1.96 miles of travel, and it reaches a top speed of 56.7 mph and an average speed of 29.4 mph. The test is limited by the fact that it fails to account for cold starts, when automobile emissions are typically highest.

FTP-75

Federal Test Procedure 75 (FTP-75) is a more thorough emissions test than IM-240. The test consists of three phases; it spans 1,874 seconds, which represents 11.04 miles of travel; and it averages a speed of 21.2 mph. The three phases are a cold-start phase, a transient phase, and a hot-start phase that occurs 10 minutes after completion of the transient phase. This research acknowledges the FTP-75 results as the true emissions values. The IM-240 results are reported only for completeness.

Emissions Test Facilities

The emissions data assembled in this report were gathered at two testing facilities: Automotive Testing Labs and the Clean Air Vehicle Technology Center.

Automotive Testing Labs

Automotive testing Labs (ATL) is located in Mesa, Arizona. Most of the emissions testing conducted by APS was performed at ATL. The laboratory is capable of performing a variety of standard emissions tests, including the IM-240 and the FTP-75.

Clean Air Vehicle Technology Center

The Clean Air Vehicle Technology Center (CAVTC) is located in Hayward, California. CAVTC is the only commercial testing center in the United States believed capable of performing the FTP-75 test while eliminating the effects of ambient pollution. This feature of CAVTC makes it particularly well-suited to measure emissions from very-low-emission vehicles.

California Emission Standard

Throughout this report, reference is made to the California emission standards. Currently, LEV I emission standards are in effect. However, a more stringent set of emission standards, LEV II, will come into effect in 2004. The California LEV II emission standards categorize emissions into the following groups: low-emission vehicles (LEV), ultra-low-emission vehicles (ULEV), and super-ultra-low-emission vehicles (SULEV). The standards are based on weight class and are measured over the FTP-75 test. All vehicles in this report are classified by California emission standards as MDV3[3]. A portion of the California emission standards for MDV3 is shown below in Table 1.

Table 1. California LEV II emission standards (g/mi).

	NMOG	CO	NOx
LEV	0.09	4.2	0.07
ULEV	0.055	2.1	0.07
SULEV	0.01	1	0.02

NMOG = non-methane organic gases.
CO = carbon monoxide.
NOx = oxides of nitrogen.

[3] MDV= medium duty vehicle; MDV3 = MDVs with test weight between 5751 and 8500 lb. *Test weight* by California definition is analogous to the federal definition of adjusted loaded vehicle weight (ALVW); test weight = (curb weight + GVWR)/2

OPERATING RESULTS

Conversion Technique/History

The high-percentage-blend HCNG test vehicle is a model year 2001 Ford F-150 (see Figures 1 and 2) originally equipped with a factory gasoline engine (specified in Table 2). It was modified to run on a blend of CNG and hydrogen by NRG Technologies, Inc. Table 3 shows the modifications. The vehicle arrived for testing at Arizona Public Service (APS) on January 6, 2002. They subsequently operated the vehicle on a 30% hydrogen blend (by volume) for 5 months. On June 1, 2002, NRG Technologies retuned the engine to operate on a 50% hydrogen blend (by volume). APS tested the vehicle on the 50% blend for the balance of the test period.

Figure 1. High-percentage-blend Ford F-150.

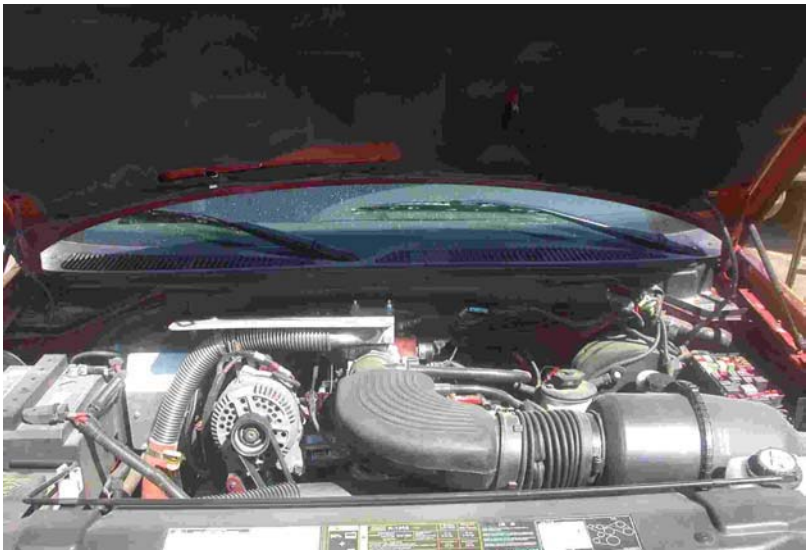

Figure 2. High-percentage-blend F-150 engine compartment.

Table 2. Factory specifications.

Engine	5.4 L V8
Factory HP	260 hp
Curb weight	5600 lb
GVWR	6300 lb

Table 3. Engine Modifications.

SVO heads
Exhaust Intercooler
Supercharger
Exhaust gas recirculator
Ignition modification
Equipped with three hydrogen tanks

Quantum Technologies in Irvine, California manufactured the hydrogen-rated fuel storage tanks shown in Figure 3. The tanks have an inner polymer liner that is not prone to hydrogen embrittlement, a carbon fiber reinforced shell, and a tough external shell that enhances damage protection. The tanks have a maximum actual working pressure of 4400 psi and a service pressure of 3600 psi (see Table 4).

Figure 3. Quantum hydrogen fuel tanks.

Table 4. Quantum nominal tank specifications.

Diameter (in.)	15.5
Length (in.)	72
Empty weight (lb)	120
Service pressure (psi)	3600
Hydrogen fuel capacity @ 15˚C	3 (kg)
Certification	NGV2-2000 modified for H_2

Emissions Summary

The high-percentage-blend F-150 was converted by NRG Technologies to be a super-low-emission vehicle (SULEV). Because of the low emissions level, the vehicle exhaust can be cleaner than the ambient air. Therefore, it was necessary to perform emission testing at CAVTC, as they are able to eliminate the effects of ambient pollution. The F-150 was operating using a 30% hydrogen blend at the time of emissions testing. Emission test results are shown in Table 5.

Table 5. Emissions test results (gm/mi).

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	CO_2
FTP-75							
10/24/2001	87	0.0014	0.108	0.123	0.879	0.005	518.1

NMHC = non-methane hydrocarbons. CO = carbon monoxide.
CH_4 = methane. NOx = oxides of nitrogen.
HC = total hydrocarbons. CO_2 = carbon dioxide.

Arizona Public Service also randomly selected a Ford F-150 equipped with a factory gasoline engine and tested its emissions at Automotive testing Labs. The results from the gasoline F-150 are shown in Table 6.

Table 6. Gasoline-fueled F-150 emission test results.

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	CO_2
FTP-75							
6/20/2001	23497	0.122	0.013	0.136	1.644	0.170	620.709
6/21/2001	23519	0.107	0.011	0.119	1.457	0.163	623.015
Average		0.114	0.012	0.127	1.551	0.166	621.862
IM240							
6/20/2001	23509	0.015	0.008	0.023	0.127	0.565	585.172
6/21/2001	23531	0.006	0.011	0.017	0.046	0.440	578.728
Average		0.011	0.009	0.020	0.087	0.503	581.950

NMHC = non-methane hydrocarbons. CO = carbon monoxide.
CH_4 = methane. NOx = oxides of nitrogen.
HC = total hydrocarbons. CO_2 = carbon dioxide.

Table 7 and Figure 4 compare the high-percentage-blend F-150 and the gasoline-fueled F-150. The results show a considerable decrease in all measured emission levels (excluding methane) when compared to gasoline. Total hydrocarbon emissions decreased slightly. Carbon monoxide emissions measured 0.879 g/mi, well under the 1 g/mi California SULEV standard. The most noteworthy achievement of this vehicle, however, is its virtually zero nitrogen oxide emissions.

Table 7. 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 NOx = oxides of nitrogen.
CO = carbon monoxide. CO_2 = carbon dioxide.

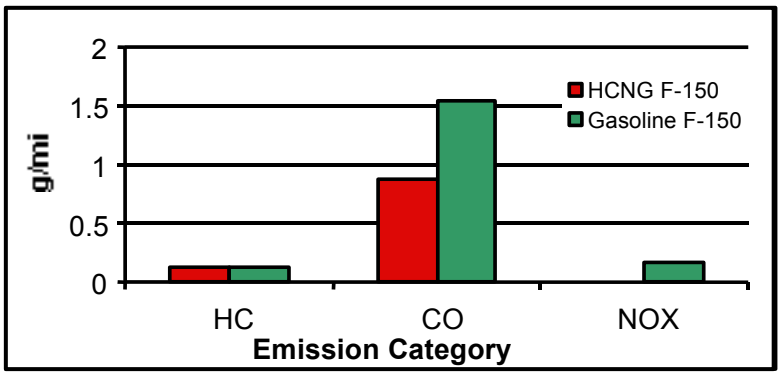

Figure 4. HCNG F-150 versus gasoline-fueled F-150.

Fuel Efficiency

The high-percentage-blend F-150 was fueled using a FuelMaker Model FMQ-2-36 dispenser (see Figure 5) during the entire test period. The FuelMaker dispenser receives blended CNG and hydrogen from a fuel mixer made by NRG Technologies. The mixer receives natural gas at 30 psig from Southwest Gas Company and hydrogen at 30+ psig from a tube trailer. The fuels are mixed and delivered to the FuelMaker, which compresses the fuel blend to 3600 psig and dispenses fuel at a rate of 1.9 scfm. The same system is used to dispense both 50 and 30% hydrogen blends (by volume). This dispensing system does not measure fuel quantity. Therefore, no fuel efficiency data are available for the vehicle.

Figure 5. FuelMaker with HCNG mixer.

Operating Costs

The high-percentage-blend F-150 had no mechanical problems during the test period, therefore, incurred no repair costs. When the vehicle was new (odometer reading 9 miles) the oil was changed to Mobil 1 Synthetic oil at a cost of $90.00. An oil analysis was conducted on the drained oil to serve as a baseline for future oil analysis.[4] The vehicle operated 4,695 miles during the test period. The vehicle maintenance cost during the test period was 1.9 cents per mile.

Operating Results Summary

The primary goal of testing the high-percentage-blend F-150 on HCNG fuel was to evaluate the safety and reliability of operating such a system. No safety problems were encountered with fueling or operating the F-150 using either 30 or 50% hydrogen-blend fuel. The vehicle also demonstrated consistent, reliable behavior; it had no operating problems. The vehicle achieved very low emissions compared to gasoline engines and has near zero NOx levels.

CONCLUSIONS

The addition of hydrogen to the CNG fuel of the high-percentage-blend F-150 did not impact the reliability of the vehicle during this limited test. Emissions from the blend were extremely low compared to the gasoline F-150 and to the SULEV standard. And the vehicle exhibited near-zero nitrogen oxide emissions.

Based on the performance of the high-percentage-blend F-150 and on the low-percentage-blend F-150 (reported separately in the Low-Percentage Hydrogen/CNG Blend Ford F-150 report, INEEL/EXT-03-00008), it is apparent that a re-tuned, factory dedicated, CNG vehicle (the low-percentage-blend base vehicle) can provide operating results comparable to a gasoline vehicle converted for HCNG use (the high-percentage-blend base vehicle) and requires far less conversion work. The dedicated CNG vehicles are already setup for gaseous fuels and comply with the laws and codes governing their use. To convert a gasoline vehicle requires removing the existing tank, adding new tanks, certifying the vehicle as crashworthy, and complying with all laws and standards governing gaseous fuels. The ability to tune a dedicated CNG vehicle for use on blended hydrogen/CNG fuels presents the possibility of dispensing blended fuels without having to modify the vehicles.

[4] Oil analysis was performed by Schaeffer Lubricants.

APPENDIX A

FUEL PROPERTIES AND GASOLINE GALLON EQUIVALENTS

The gasoline gallon equivalent (gge) is a simple metric to compare the energy content in any given fuel to the energy in one gallon of gasoline. The gge values used for various fuels/fuel mixtures are given in Table 8. The value of 5.66 lb CNG is defined by the National Conference on Weights and Measures to be equal to one gge. However, no similar standard exists for hydrogen or various blends of HCNG. The listed gge's were derived from the properties given in Table 8.

Table 8. Fuel properties and gge's.

	Energy Content (kWh/Kg)	Energy Content (kWh/gal)	GGE (lbm)	GGE (kg)
Gasoline	–	34.5	–	–
CNG	13.44	–	5.66	2.57
Hydrogen	33.90	–	2.28	1.04
15% H_2 blend	13.85	–	5.49	2.49
30% H_2 blend	14.32	–	5.31	2.41
50% H_2 blend	15.56	–	4.89	2.22

APPENDIX B

MONTHLY MILEAGE SUMMARY

FORD F150 **LICENSE**

VIN No. 1FTPFD7M8YK839272 **ZEROOUT**

Date	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02*	Jul-02
Odometer	20	114	648	1163	1617	2544	3185	3578	4109	4715
Mileage	94	534	515	454	927	641	393	531	606	203
Total mileage	4695 mi									

*Vehicle operating on 50% hydrogen by volume.