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

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

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January 2003

Idaho National Engineering and Environmental Laboratory
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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 results of 16,942 miles of testing for one of the blended fuel vehicles, a Ford F-150 pickup truck, operating on up to 30% hydrogen/70% 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 comprised two Ford F-150s and one Dodge Ram Wagon Van. The Dodge 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.

The primary objective of the test program was to evaluate the safety and reliability of operating the vehicles on hydrogen and HCNG fuels, and the interface between the vehicles and the hydrogen-fueling infrastructure. A secondary objective was to quantify vehicle emissions, cost, and performance. An additional goal was to test the speculation that using HCNG fuel could extend oil change intervals (thus reducing operating cost and reducing waste products) and, if true, to determine an acceptable oil change interval using the hydrogen fuel.

This report covers the up to 30% hydrogen blend F-150 Ford pickup 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 Dodge Ram Wagon Van: 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 internal combustion engine vehicle 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 has an average 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 reported here were gathered at 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 IM-240 and 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, California 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 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 three 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 NOx = oxides of nitrogen
CO = carbon monoxide

[3] MDV-Medium Duty Vehicle; MDV3 is the class of MDV's with test weight between 5751-8500 lbs. Test Weight by the 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

This low percentage blend HCNG test vehicle is a model year 2000 F-150 originally equipped with a factory CNG engine, specifications listed in Table 2. It was modified by NRG Technologies in Reno, Nevada to run on a blend of CNG and 28% hydrogen (by volume). NRG Technologies modifications include adding a supercharger, making ignition modifications, and adding an exhaust gas re-circulator. The vehicle utilizes the factory installed carbon steel CNG fuel tank. The tank operates at 3600 psig. APS began testing this vehicle in June of 2001.

Figure 1. Low-percentage-blend F-150.

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

Table 2. Factory specifications.

Engine	5.4 L V8
Factory HP	230
Curb weight	5,170 lb
GVWR	7650 lb

Emissions Summary

Emissions from the low-percentage-blend F-150 were measured at Automotive Testing Labs. Both IM-240 and FTP-75 tests were performed, the results of which are presented in Table 3.

The vehicle was tested several times to validate the results. Carbon monoxide emissions from the low-percentage-blend F-150 averaged 0.26 g/mi over the FTP-75 tests, well under the California SULEV standard of 1 g/mi. Nitrogen oxide emissions averaged 0.078 g/mi, near the California ULEV standard of 0.07. Non-methane organic gases (NMOG) were not measured.

Arizona Public Service also randomly selected a Ford F-150 equipped with a factory gasoline engine and tested its emissions at Automotive Testing Labs. Results from the gasoline F-150 are shown in Table 4.

Table 3. Emissions Test Results (g/mi).

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	**CO_2**
FTP							
5/2/2001	1592	0.011	0.075	0.094	0.237	0.063	440.606
5/3/2001	1613	0.019	0.084	0.118	0.249	0.094	441.442
5/4/2001	1636	0.024	0.082	0.121	0.267	0.094	437.370
5/8/2001	1657	0.017	0.099	0.133	0.257	0.084	439.940
6/14/2001	2148	0.028	0.091	0.136	0.223	0.104	435.899
8/30/2001	3890	0.028	0.074	0.116	0.348	0.051	442.515
8/31/2001	3915	0.028	0.067	0.107	0.210	0.053	437.009
Average		0.022	0.081	0.117	0.255	0.077	439.254
IM240							
5/2/2001	1592	0.062	0.05	0.124	0.135	0.040	392.720
5/3/2001	1625	0.008	0.042	0.057	0.118	0.025	402.205
5/4/2001	1647	0.014	0.054	0.078	0.146	0.023	410.147
5/8/2001	1670	0.016	0.069	0.098	0.101	0.022	411.302
8/30/2001	3901	0.014	0.054	0.078	0.077	0.089	397.635
8/30/2001	3903	0.016	0.028	0.049	0.125	0.051	402.614
8/31/2001	3928	0.013	0.045	0.066	0.101	0.019	397.634
8/31/2001	3931	0.013	0.026	0.045	0.095	0.033	396.020
Average		**0.019**	**0.046**	**0.074**	**0.112**	**0.037**	**401.285**

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

Table 4. Gasoline-fueled F-150 emission test results.

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	CO_2
FTP							
6/20/2001	23497	0.122	0.013	0.136	1.644	0.17	620.709
6/21/2001	23519	0.107	0.011	0.119	1.457	0.163	623.015
Average		0.1145	0.012	0.1275	1.5505	0.1665	621.862
IM240							
6/10/2001	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	0.44	578.728
Average		0.0105	0.0095	0.02	0.0865	0.5025	581.95

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

Table 5 and Figure 3 illustrate the emission comparison between the HCNG low-percentage-blend F-150 and the random-gasoline-fueled F-150. Reductions were achieved in all major emission categories. Carbon monoxide emissions from the low-percentage-blend F-150 were the most impressive compared to the gasoline-fueled F-150, dropping 83%. Likewise, nitrogen oxides were reduced by more than half. Total hydrocarbon emissions showed a 7.5% drop, and greenhouse gas, carbon dioxide, was cut by nearly 30%.

Table 5. Percent reduction in emissions (HCNG versus gasoline-fueled F-150).

HC	CO	NO_X	CO_2
7.6%	83.5%	53.4%	29.4%

CO = Carbon Monoxide
NOx = Oxides of Nitrogen
CO_2 = Carbon Dioxide

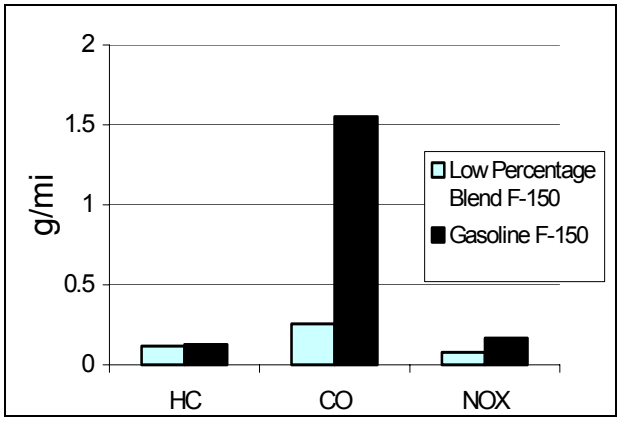

Figure 3. HCNG F-150 versus gasoline-fueled F-150.

Fuel Efficiency

The low-percentage-blend F-150 was fueled using a FuelMaker Model FMQ-2-36 dispenser from the time that it arrived at APS until July 5, 2002. The FuelMaker dispenser receives blended CNG and hydrogen from a fuel mixer made by NRG Technologies. Figure 4 shows the FuelMaker and mixer. 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. This dispensing system does not measure the quantity of fuel. Subsequent to July 5, the vehicle was fueled by dispensers manufactured by Fueling Technologies Inc. (FTI). The FTI dispensers depicted in Figure 5 are equipped with an accurate fuel measuring system.

Inasmuch as the FuelMakers are not equipped with a fuel measurement system, fuel efficiency over the time period before July 5, 2002 can only be estimated. From July 5 until August 9, the F-150 logged 1,776 miles and used 282.3 kg of blended fuel. This translates to a fuel efficiency of 15.7 miles per gasoline gallon equivalent (gge) over this time period. See Appendix B for a monthly fuel and mileage summary.

Figure 4. FuelMaker with HCNG mixer.

Figure 5. FTI blended fuel dispenser.

Operating Cost

The low percentage blend F-150 suffered no mechanical problems and, therefore, incurred no repair expense during the test period. One of the goals of the test program was to determine if oil change intervals could possibly be extended by using HCNG fuel. APS changed the oil in this vehicle at 2,713 miles and conducted an oil analysis on the drained oil.[4] They did not change the oil again until the vehicle odometer read 17,408 miles. Mobil 1 Synthetic oil was used in all oil changes. At the second oil change, an oil analysis was conducted on the oil that had been in the engine for almost 15,000 miles.[5] The test showed slightly abnormal silicon levels of 53 ppm. The original Schaeffer analysis showed 53 ppm as well on the oil that had been in the engine only 2,713 miles. Silicon levels are typically high in Ford engines. All other wear metal and additive levels were normal. The oil analysis also revealed 0% water in the oil.

Each oil change cost $90.00, for a total cost of $180.00. The vehicle operated 16,942 miles during the test period, resulting in a maintenance cost of 1 cent per mile.

Operating Results Summary

The primary goal of testing the CNG 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 low percentage blend F-150. The vehicle also demonstrated consistent, reliable behavior and operated without problems. The vehicle demonstrated very low emissions compared to gasoline engines and achieved good fuel economy. Preliminary results indicate that the low-percentage-blend vehicle's oil change interval can be extended to at least 15,000 miles. However, more testing is necessary to validate acceptable oil change intervals.

[4] Oil analysis conducted by Schaeffer Lubricants.
[5] The second oil analysis was conducted by CTC Analytical Services.

CONCLUSIONS

Based on the performance of the low-percentage-blend F-150 and of the high-percentage-blend F-150 (reported separately in the High-Percentage Hydrogen/CNG Blend Ford F-150 report, INEEL/EXT-03-00007), it is apparent that a re-tuned, factory dedicated, CNG vehicle (the low-percentage-blend F-150) can provide operating results comparable to a gasoline vehicle converted for HCNG use (the high-percentage-blend F-150) with far less conversion work required. 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.

Adding hydrogen to the CNG fuel of the low-percentage-blend F-150 did not impact the reliability of the vehicle during this limited test. Emissions from the low-percentage-blend F-150 were extremely low compared to the gasoline F-150, and also when compared to the SULEV standard. In addition, preliminary testing indicates it may be possible to extend oil change intervals with the use of HCNG fuel well beyond the conventional 3,000 miles, thus lowering operating costs and decreasing waste products.

APPENDIX A

FUEL PROPERTIES AND GASOLINE GALLON EQUIVALENTS

The gasoline gallon equivalent (gage) is a simple metric to compare the energy content in any given fuel to the energy in one gallon of gasoline. The gage 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 gage. 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
VIN 1FTPFD7M8YK839272 **LICENSE AF-533E**

Date	9/1/01	10/1/01	11/1/01	12/1/01	1/1/02	2/1/02	3/1/02	4/1/02	5/1/02	6/1/02	7/5/02	8/5/02	Total*
Odometer	1672	4180	6724	8412	9923	12107	13442	14322	14986	15458	16838	18369	18614
Monthly mileage	2508	2544	1688	1511	2184	1335	880	664	472	1380	1531	245	16942
Monthly fuel use (kg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	246.8	35.4	282.2
Fuel economy (mi/gage)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15.5	17.3	15.7

* End of testing 8/9/02.