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

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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, a Dodge Ram Wagon Van, 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 22,816 miles of testing for the Dodge Ram Wagon Van, operating on CNG fuel, and a blended fuel of 15% hydrogen–85% CNG.

ACRONYMS

APS	Arizona Public Service
ATL	Automotive Testing Labs
CAVTC	Clean Air Vehicle Technology Center
CNG	compressed natural gas
CO	carbon monoxide
DOE	U.S. Department of Energy
ETA	Electric Transportation Applications
FTP75	Federal Emissions Test Procedure
HCNG	hydrogen blended with natural gas
IM240	Inspection and Maintenance Driving Cycle
NMOG	non-methane organic gas
NOx	oxide 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 Dodge Ram Wagon Van 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 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 (grams per mile).

	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 is the class of MDVs with a test weight of 5751 to 8500 lb. Test weight by the California definition is analogous to the federal definition of adjusted loaded vehicle weight (ALVW); test weight = (curb weight + gross vehicle weight)/2.

OPERATING RESULTS

Conversion Technique/History

The Dodge Ram Wagon Van, shown in Figure 1, is a model year 1999 vehicle equipped from the factory for operation on CNG. The vehicle was not modified. APS began testing the van in September 2000. It was fueled with CNG from that time until July 16, 2002 (odometer reading 30,734). After July 16, APS operated the vehicle on a 15% hydrogen–85% CNG (by volume) fuel. Table 2 shows the factory specifications. The Dodge Ram Wagon Van fuel tank is rated at 3600 psig.

Figure 1. CNG- and HCNG-fueled Dodge Ram Wagon Van.

Table 2. Dodge Ram Wagon Van factory specifications.

Engine	5.2 L V8
Factory HP	150
Curb weight	5529 lb
GVWR	7700 lb

Emissions Summary

The Dodge Ram Wagon Van was tested at ATL, operating on both CNG and on a blend of 15% hydrogen–85% CNG. Both IM-240 and FTP-75 tests were performed for each fuel. Table 3 presents emissions results for the van while operating using CNG. Table 4 presents the emissions results for the van while operating using the 15% hydrogen blend. Note that the Dodge Ram Wagon Van was operated on the blended hydrogen fuel for this test only. In actual service, the van was operated on CNG until July 16, 2002. At that time, it was switched to the blended fuel for in-service operation

Table 3. Emission test results: vehicle operating using CNG (gm/mi).

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	CO_2
FTP-75							
10/11/2000	5647	0.063	0.333	0.454	2.177	0.083	568.197
10/13/2000	5679	0.041	0.243	0.327	2.206	0.108	562.405
Average		0.052	0.288	0.391	2.192	0.096	565.301
IM 240							
10/11/2000	5662	0.011	0.087	0.113	0.637	0.027	542.381
10/13/2000	5709	0.007	0.071	0.089	0.649	0.024	539.220
Average		0.009	0.079	0.101	0.643	0.026	540.801

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

Table 4. Emissions test results: vehicle operating using 15% H_2 (gm/mi).

Test Date	Mileage	NMHC	CH_4	HC	CO	NO_X	CO_2
FTP-75							
10/16/2000	5713	0.029	0.193	0.255	1.006	0.176	507.868
10/18/2000	5724	0.032	0.19	0.255	0.951	0.191	495.138
Average		0.0305	0.1915	0.255	0.9785	0.1835	501.503

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

CNG versus HCNG

By blending CNG with 15% hydrogen, emission levels were generally reduced, as shown in Table 5. Nitrogen oxide emissions, however, increased substantially. Review of the original test data reveals that the rise in NOx levels from the HCNG-fueled van occurred in phases 1 and 3 of the FTP-75 test (cold start and hot start phases, respectively). Emissions during each phase of the FTP-75 test are shown in Table 6. Phase 1 NOx emissions increased by 70%, and phase 3 NOx emissions increased by 142%. During phase 2, the transient phase, NOx emissions were actually reduced by 40% from the HCNG-fueled van compared to the pure-CNG-fueled van. The rise in NOx levels with the addition of hydrogen to the fuel can be attributed to the fact that the vehicle had no engine modifications and was not optimized to burn HCNG.

Table 5. Percent change in emissions: vehicle operating using CNG versus HCNG.

Total hydrocarbons	-34.7
Carbon monoxide	-55.4
Oxides of nitrogen	+92.1
Carbon dioxide	-11.3

Table 6. FTP-75 NOx emissions by phase (gm/mi).

FTP-75	CNG			HCNG			Percent
Phase	Test 1	Test 2	Avg	Test 1	Test 2	Avg	Change
1	0.254	0.337	0.2955	0.482	0.527	0.5045	+70
2	0.008	0.002	0.005	0.004	0.002	0.003	-40
3	0.096	0.136	0.116	0.268	0.294	0.281	+142

Fuel Efficiency

During 2001, the Dodge Ram Wagon Van was refueled from commercial CNG dispensers located at Sky Harbor International Airport. Over the course of the year, the vehicle tallied 13,160 miles and used 994.7 gge (gasoline gallon equivalent) of CNG, resulting in a fuel economy of 13.2 mi/gge (see Appendix B for a monthly mileage and fuel summary). In early 2002, vehicle fueling was transferred to the APS Alternative Fuel Pilot Plant. Fueling logs were not kept during the transition period (first quarter of 2002). Fueling records were kept from April 1, 2002 through July 11, 2002, while the vehicle was fueled from dispensers manufactured by Fueling Technologies Inc. (FTI) and located at APS. The FTI dispensers, shown in Figure 2, dispense fuel in gge's (one gge is equal to 5.66 pounds of CNG). During April 1, 2002 through July 11, 2002, the vehicle logged 4,534 miles and used 262.8 gge of CNG. This translates to a fuel economy of 17.3 mi/gge, well above the fuel economy achieved in 2001. However, subsequent testing of the FTI dispenser for CNG revealed a calibration error, which makes the fuel-use data for the April 1, 2002 to July 11, 2002 period unreliable.

Figure 2. Fueling Technologies Inc. fuel dispensers (CNG and hydrogen/CNG blend fuels).

After July 16, 2002, the vehicle operated on 15% HCNG. The vehicle refueled using an FTI dispenser that dispenses blended fuel in kilograms. During July 16 to August 11, the vehicle logged 835 miles and used 141.5 kg of blended fuel. This translates to a fuel economy of 14.7 mi/gge, which is comparable to the fuel economy achieved using CNG.

Operating Cost

A goal of the test program was to determine if using HCNG fuel could extend oil change intervals. APS changed the oil in the Dodge Ram Wagon Van at an odometer reading of 16,238 miles using Mobil 1 Synthetic oil. The drained oil had operated in the engine for approximately

7,000 miles. An oil analysis conducted on the drained engine oil[4] indicated slightly abnormal silicon levels at 24 ppm, copper levels at 18 ppm, and lead levels at 25 ppm. Tin levels were not monitored in this analysis. The vehicle was then operated on CNG until the next oil change, at odometer reading of 30,993 miles. An oil analysis conducted on the drained oil that had operated in the engine for almost 15,000 miles[5] showed abnormal silicone at 26 ppm, abnormal copper at 27 ppm, abnormal lead at 51 ppm, and abnormal tin at 20 ppm. From these limited data, it appears that operating on CNG for 15,000 miles yields unacceptable results. Additional testing is planned for this vehicle using a blend of 15% hydrogen to determine if this fuel can provide extended oil change intervals.

The Dodge Ram Wagon Van received lubrication and oil change twice during the test, at a total cost of $180.00, and operated for a total of 22,816 miles. This translates to a maintenance cost of 0.7 cents per mile.

The Dodge Ram Wagon Van suffered no mechanical problems during testing at APS and, therefore, incurred no costs for repairs.

Summary of Operating Results

The safety and reliability of the Dodge Ram Wagon Van have been excellent. Emissions while operating on a 15% hydrogen blend were mixed, with an increase in NOx during cold and hot starts but significant decreases in emissions in all other operating modes and with all other pollutants. Extension of the oil change interval while operating on CNG was not achieved. Sufficient data were not obtained during the test period to determine if oil change interval extension is possible using a 15% hydrogen blend fuel.

CONCLUSIONS

The Dodge Ram Wagon Van operated 22,816 miles in the APS fleet. No safety or reliability problems were encountered during its operation. While operating on 15% hydrogen-85% CNG (by volume) fuel, the vehicle exhibited reduction in all measured pollutants, with the exception of NO_x. Further testing of the effects of using 15% hydrogen/85% CNG fuel is required to determine long-term effects of the fuel on vehicle components and performance.

[4] Schaeffer Lubricants conducted the first oil analysis.
[5] CTC Analytical Services conducted the second oil analysis.

Appendix A

Fuel Properties and Gasoline Gallon Equivalent Values

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. Table 7 gives the gge values used for various fuels/fuel mixtures. The value of 5.66 lb CNG was 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 7.

Table 7; 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% H2 blend	13.85	-	5.49	2.49
30% H2 blend	14.32	-	5.31	2.41
50% H2 blend	15.56	-	4.89	2.22

Appendix B

Monthly Mileage

Dodge Ram Wagon Van fuel and mileage summary 2001: operating on CNG.

Date	1/4/01	2/2/01	3/11/01	4/1/01	5/2/01	6/1/01	7/1/01	8/6/01	9/6/01	10/2/01	11/1/01	12/2/01	12/31/02
OD reading (mi)	8753	10024	10152	11104	13070	14539	15828	16821	17680	18632	19917	21371	22906
Month	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	
Monthly mileage (mi)	1271	128	952	1966	1469	1289	993	859	952	1285	1454	1535	
Fuel consumption (gge)	100.18	19.62	66.26	147.78	117.27	94.44	70.96	69.37	75.64	97.00	106.31	112.85	
Fuel economy (mi/gge)	12.69	6.52	14.37	13.30	12.53	13.65	13.99	12.38	12.59	13.25	13.68	13.60	

Dodge Ram Wagon Van fuel and mileage summary 2002: operating on CNG.

Date	1/1/02	4/1/02	5/3/02	6/1/02	7/3/02	7/11/02
OD reading (mi)	22906	26155	27517	29058	30358	30689
Period	1st Qtr	Apr-02	May-02	Jun-02	Jul-02	
Period mileage (mi)	3249	1362	1541	1300	331	
Fuel consumption (gge)	N/A	75.82	92.64	78.77	17.84	
Fuel economy (mi/gge)		17.96	16.64	16.50	18.55	

Dodge Ram Wagon Van fuel and mileage summary 2002: operating on HCNG.

Date	7/16/02	8/1/02	8/11/02
OD reading (mi)	30734	31494	31569
Period	7/16 to 8/11		
Period mileage (mi)	835		
Fuel consumption (kg)	141.55		
Fuel economy (mi/gge)	14.75		

Overall fuel economy.

CNG fuel economy	14.0 mi/gge
HCNG fuel economy	14.75 mi/gge