# 2013 Ram 1500 HFE Bi-Fuel CNG Conversion

## Advanced Vehicle Testing – Accelerated Reliability Testing Results


## VEHICLE SPECIFICATIONS[1]

### Vehicle Features

EPA Class: Standard Pickup Truck 2WD

Seatbelt Positions: 3

Type: Gasoline ICE with Stop/Start; Converted to Gasoline with CNG Bi-Fuel Capability[2]

### Engine

Model: Pentastar, 3.6 L, V6, 24-Valve VVT

Peak Power: 227 kW @ 6,400 rpm

Peak Torque: 365 Nm @ 4,175 rpm

### Weights

Design Pre-Conversion Curb Weight: 4,572 lb

Delivered Pre-Conversion Curb Weight: 4,621 lb

Delivered Post-Conversion Curb Weight: 4,918 lb

GVWR: 6,010 lb

### Gasoline Fuel Tank

Fuel Tank Capacity: 26 gal

Fuel Type: Regular Unleaded

### CNG Fuel Tank

Fuel Tank Capacity: 20.4 GGE (NIST)[3]

Fuel Type: CNG

Tank Type: Type IV Composite

Pressure Rating: 3,600 psi

### 12 V Battery

Manufacturer: East Penn Manufacturing Company, Inc.

Model: Synergy Group Size H8

Capacity: 92 Ah @ $C_{20}$

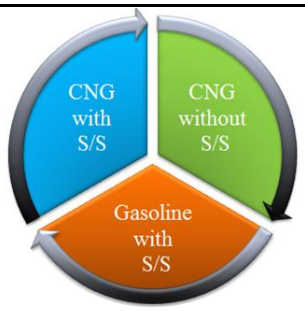
## TESTING BACKGROUND AND DESCRIPTION

As part of the Advanced Vehicle Testing and Evaluation (AVTE) program, a 2013 Ram 1500 High Fuel Efficiency (HFE) model pickup truck, featuring Stop/Start (S/S) Technology[4], was converted from a gasoline only vehicle to a bi-fuel vehicle capable of being fueled by compressed natural gas (CNG) or conventional gasoline. The S/S system remained operational post-conversion.

A fundamental benefit of bi-fuel conversions permits the operator to select the fuel to consume, which can be advantageous when a price differential exists between gasoline and CNG. For example, according to the Clean Cities Alternative Fuel Price Report from April 2015[5], published by the U.S. Department of Energy, the national averages for CNG and and gasoline were $2.09 per GGE[6] and $2.42 per gallon, respectively.

As part of a separate initiative, during the CNG conversion process, the factory 12 V battery was substituted with an advanced, lead-carbon, 12 V battery. Evaluation of the battery included its capability to accommodate

loads when the engine is not powering the 12 V system while in S/S mode, as well as overall battery durability.




After baseline testing, which included closed-track and dynamometer testing of both the pre- and post-conversion vehicle, the Ram truck underwent Accelerated Reliability testing in the Phoenix, Arizona metropolitan area from February 2015 through May 2015. The baseline report presenting the results from both the pre-conversion and post-conversion testing of the vehicle can be found here: http://avt.inl.gov/pdf/ice/fact2013dodgeram.pdf.

The Accelerated Reliability test utilized professional drivers operating the truck through a predetermined, 8.8 mile urban-city loop, 14 times a day. In order to evaluate the factory S/S system and the CNG conversion, the truck was tested in the following fuel usage and drive modes: (1) CNG with S/S, (2) CNG without S/S, and (3) gasoline with S/S.

**TABLE 1**: Eight-Day Driving Schedule

| | | |
|---|---|---|
| Day 1 | 14 Laps | CNG with S/S |
| Day 2 | 14 Laps | CNG without S/S |
| Day 3 | 14 Laps | CNG with S/S |
| Day 4 | 14 Laps | CNG without S/S |
| Day 5 | 14 Laps | CNG with S/S |
| Day 6 | 14 Laps | CNG without S/S |
| Day 7 | 14 Laps | CNG with S/S |
| Day 8 | 14 Laps | Gasoline with S/S |

To maximize the number of S/S activations, the urban drive loops were performed during rush-hour driving conditions throughout the day. As shown in Table 1, a repeating eight-day driving schedule was followed to ensure that daily mileage accruals within each drive mode were at the following target percentages: CNG with S/S, 50%; CNG without S/S, 40%; and gasoline with S/S, 10%. Each day of testing was completed in a single drive mode.

At the completion of a driving day in either of the CNG modes, the CNG tank was refilled. At the beginning of a gasoline usage day, the stock gasoline tank was filled to replenish the gasoline used during the prior CNG test modes. The design of this CNG conversion required that cold-engine startups utilize gasoline, regardless of the fuel type selected by the driver. If the fuel selection was gasoline, then no further changes took place. However, if the fuel selection upon initial startup was CNG, gasoline was consumed until engine temperature and engine speed thresholds were achieved. Once these required parameters were met, the fuel type was then automatically switched from gasoline to CNG and any subsequent engine starts that occurred were fueled with CNG (including those during S/S activations). Any instance in which the vehicle was turned off, such as during driver breaks or shift changes, and the required engine parameters were not met upon startup, the vehicle would revert back to the initial engine startup process using gasoline.

## TEST RESULTS

Over the 75 days of Accelerated Reliability testing, the truck was driven an average of 123 miles per day. Total distance driven in all three modes combined was 8,739 miles. The breakdown of mileage accrued in each mode is as follows: CNG with S/S, 4,613 miles; CNG without S/S, 3,397 miles; and gasoline with S/S, 729 miles.

Factors such as the duration of the vehicle-off time period, the ambient temperature, and the drive cycle determined how much time was needed for the engine to reach the thresholds required to switch from gasoline to CNG fuel. This system design makes the amount of gasoline used in CNG mode highly variable; thus, an overall average during driving with CNG mode selected was determined. Over the course of testing, the vehicle used an average of 0.0038 gallons of gasoline per mile driven with CNG mode selected. Including this additional fuel energy with the CNG modes resulted in a fuel economy for CNG with S/S of 21.6 MPGe and a

fuel economy for CNG without S/S of 20.8 MPGe. The fuel economy of the gasoline with S/S mode was 22.0 mpg.


The fuel economy improved by 3.8% when operated in CNG with S/S mode activated versus CNG without S/S mode. The difference in fuel economy between gasoline with S/S and CNG mode with S/S was 1.9%. With similar fuel economy values between gasoline and CNG, the price of fuel would likely be the largest factor in driving costs for this vehicle.

Over the test period of February to May 2015, the average fuel price for the Phoenix metro area was $2.09/GGE for CNG and $2.43/gallon for regular unleaded gasoline. Based on these fuel prices, the resulting fuel cost per mile was 9.8¢ for CNG with S/S, 10.2¢ for CNG without S/S, and 11.0¢ for gasoline with S/S.

Data captured over the test period showed the daily average S/S activations at 154 times in CNG mode and 161 times in gasoline mode. Average daily time spent in CNG with S/S mode active was 42.4 minutes and 42.8 minutes in gasoline with S/S mode active. The percentage of time that the S/S mode activated at potential activation points (i.e., the vehicle speed was 0 mph) was 64.7% in CNG mode and 69.2% in gasoline mode. In all other instances, the engine continued to idle while the vehicle was stopped.

NOTES:

1. Vehicle specifications were supplied by the manufacturer, measured, or derived from a literature review.
2. The vehicle was converted to a bi-fuel (gasoline and compressed natural gas (CNG)) vehicle by NatGasCar, LLC.
3. The National Institute of Standards and Technology (NIST) has established a value of 5.66 lb of CNG/GGE at 3,600 psi and 21 °C, where 'GGE' is the acronym for gasoline gallons equivalent. Another method for calculating GGE is the "Industry Average", where the value is 4.82 lb of CNG/GGE. The NIST method is used for the fuel economy calculations in this report.
4. The factory S/S system operated automatically and did not require any input from the driver, although it can be disabled when desired. The 12 V battery voltage was continually monitored by the factory system which utilizes pulse-width modulation for the fuel pump, cooling fans and Heating, Ventilating, and Air Conditioning (HVAC) blower controls. Modulating electrical energy for specific needs, rather than running at a constant rate, reduces energy demands, fuel consumption, and emissions. The S/S system shuts off fuel flow to the engine under certain conditions, such as coasting, decelerating, or at a stop, in order to reduce fuel consumption and emissions. However, the 12 V electric loads such as the radio, gauges and climate controls remain on. Once the driver releases the brake pedal, the engine restarts automatically.
5. The Clean Cities Alternative Fuel Price Report summarizes prices that were submitted between April 1, 2015 and April 15, 2015 by Clean Cities coordinators, fuel providers, and other Clean Cities stakeholders in their local regions. (http://www.afdc.energy.gov/fuels/prices.html)
6. When CNG is sold to consumers at a dispensing station, it is priced in dollars per gallons of gasoline equivalent (GGE). One GGE of CNG is the amount of the gas it takes to equal the energy content of one liquid gallon of gasoline. The conventional metric for fuel economy when using gasoline is miles per gallon (mpg). For energy sources other than gasoline, the U.S. Environmental Protection Agency (EPA) has established the metric of miles per gallon of gasoline equivalent (MPGe). The MPGe rating expresses the number of miles a vehicle travels under a certain energy source (CNG, Hydrogen, electricity, etc.) which is equal in energy content to one gallon of gasoline.

**As a production vehicle, this vehicle is assumed to meet all Federal Motor Vehicle Safety Standards (FMVSS) for Internal Combustion Engine Vehicles prior to conversion.**

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