US Department of Energy Hybrid Electric Vehicle Battery and Fuel Economy Testing

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Abstract

The Advanced Vehicle Testing Activity (AVTA), part of the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program, has conducted testing of advanced technology vehicles since August, 1995 in support of the AVTA goal to provide benchmark data for technology modeling, and research and development programs. The AVTA has tested over 200 advanced technology vehicles including full size electric vehicles, urban electric vehicles, neighborhood electric vehicles, and hydrogen internal combustion engine powered vehicles. Currently, the AVTA is conducting significant tests of hybrid electric vehicles (HEV). This testing has included all HEVs produced by major automotive manufacturers and spans over 1.3 million miles. The results of all testing are posted on the AVTA web page maintained by the Idaho National Laboratory. Through the course of this testing, the fuel economy of HEV fleets has been monitored and analyzed to determine the "real world" performance of their hybrid energy systems, particularly the battery. While the initial "real world" fuel economy of these vehicles has typically been less than that evaluated by the manufacturer and varies significantly with environmental conditions, the fuel economy and, therefore, battery performance, has remained stable over vehicle life (160,000 miles).

Key Words

Hybrid Electric Vehicle; Fuel Economy Testing

1. Introduction

The Advanced Vehicle Testing Activity (AVTA), part of the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program, has conducted testing of advanced technology vehicles since August, 1995 in support of the AVTA goal to provide benchmark data for technology modeling, and research and development programs. The AVTA has tested over 200 advanced technology vehicles including full size electric vehicles, urban electric vehicles, neighborhood electric vehicles, and hydrogen internal combustion engine powered vehicles. Currently, the AVTA is conducting significant tests of hybrid electric vehicles (HEV). This testing has included all HEVs produced by major automotive manufacturers and spans over 1.3 million miles. Through the course of this testing, the fuel economy of HEV fleets has been monitored and analyzed to determine the "real world" performance of their hybrid energy systems, particularly the battery. The results of all testing are posted on the AVTA web page maintained by the Idaho National Laboratory [1].

2. Testing

The AVTA uses two HEV testing methods. Baseline Performance Testing evaluates vehicles using a series of detailed test procedures [2] on a closed-track and dynamometer. Testing typically occurs over a six-weeks period, using new vehicles. Accelerated Reliability Testing places new HEVs in operating fleets using procedural guidance [3] to establish their operating mission and collect data. Vehicles are operated for as much as 8,000 miles per month and data is collected from vehicle operation over the vehicles operating life, which in most cases is 160,000 miles. Typically, two vehicles of a given model are tested, with one vehicle subjected to Baseline Performance Testing and both vehicles subjected to Accelerated Reliability Testing.

Baseline Performance Testing includes acceleration, range, braking and handling tests. Two fuel economy tests are also conducted as part of Baseline Performance Testing. These tests are conducted in accordance with a detailed test procedure [4] implementing the requirements of Society of Automotive Engineers Surface Vehicle Recommended Practice J-1634 [5]. One test is conducted with air conditioning operating and the other test is conducted without the air conditioning operating. After completion of the initial Baseline Performance Testing, vehicles are placed in Accelerated Reliability Testing using fleets in the Phoenix, Arizona metropolitan area. Two vehicles of a model type are typically tested for up to 160,000 miles of combined city and highway driving. At the end of Accelerated Reliability Testing (typically 160,000 miles), each vehicle is again subjected to fuel economy testing, as well as battery capacity and power testing. As of April 2005, the first generation Toyota Prius (model years 2002 and 2003), Honda Insight, and Honda Civic HEVs have completed initial Baseline Performance Testing, Accelerated Reliability Testing and end-of-life Baseline Performance Testing. The second generation Toyota Prius (model year 2004+), Honda Accord, Ford Escape, and Chevrolet Silverado HEVs have completed initial Baseline Performance Testing. These later HEV models have also entered Accelerated Reliability Testing.

3. Baseline Performance Testing Results

Comparison of Baseline Performance Testing results for fuel economy with and without air conditioning operational has revealed a significant decrease in fuel economy with the use of air conditioning. Figure 1 presents fuel economy for selected HEVs both with and without air conditioning operational. Figure 2 shows the percentage decrease in fuel economy for these same HEVs.

4. Accelerated Reliability Testing Results

As of August 1, 2005, the 24 HEVs in AVTA Accelerated Reliability Testing (Table 1) have accumulated 1.35 million test miles (Figure 3) with cumulative fuel economies ranging from 18.1 mpg for the Chevrolet Silverado HEV to 45.2 mpg for both the second generation Toyota Prius and the Honda Insight HEVs (Table 1). When viewed on a monthly basis (Figure 4), the three HEV models (Civic, Insight and Gen I Prius) with the most test miles show seasonal variations in fuel economies of greater than 10% (Figure 5) and as high as 11.6% for the Civic. The "Hot 3 Months" shown in Figure 5 are June, July and August with average high temperatures of 103 ^{o}F and lows of 77 ^{o}F. The "Cool 3 Months" shown in Figure 5 are December, January and February with average high temperatures of 66 ^{o}F and lows of 45 ^{o}F.

An objective of AVTA testing is to determine the degree of HEV traction battery degradation over the vehicle life. To date, only one traction battery pack has failed in the AVTA's hybrid electric test vehicles (1.35 million total test miles). A Honda Insight with 72,000 miles had both the battery control module and traction battery pack fail. Both were replaced by the dealer under warranty. The cause of the pack failure is not known. However, it is speculated that the battery pack failure was caused by the battery control module failure. To obtain a more precise measure of battery degradation, and its impact on vehicle performance, HEVs completing Accelerated Reliability Testing receive end-of-life Baseline Performance fuel economy testing and battery testing including capacity testing and hybrid pulse power characterization testing in accordance with the FreedomCar Hybrid Battery Test Manual [6]. Results of fuel economy testing completed through July, 2005 are shown in Table 2, along with the results, for each vehicle, of the initial Baseline Performance fuel economy testing. Battery testing is currently scheduled for September, 2005.

5. Discussion and Conclusions

Fuel economy for HEVs operating in "real world" conditions is less than that predicted by the US Environmental Protection Agency in their fuel economy rating for new vehicles [7]. Combining the Baseline Performance fuel economy testing results with the Environmental Protection Agency (EPA) testing results (Figure 6) shows that the AVTA's fuel economy test results are very similar to the EPA results when fuel economy testing is conducted with the air conditioning off. However, with air conditioning on during conduct of the test, fuel economy decreases significantly. This decrease is also seen in Accelerated Reliability Testing fuel economy results.

Although HEV fuel economy is initially less than that reported by the EPA, the fuel economy remains stable over the vehicle life as shown in Table 2. To maintain fuel economy stable over the life of an HEV, either battery performance must remain stable or any decrease in performance must be less than the performance margin designed into the hybrid energy system. Additional testing will be conducted, including battery capacity and power to determine the degree, if any, of battery degradation in vehicles completing Accelerated Reliability Testing. However, it is clear from data collected to date, that battery performance is sufficient to provide stable vehicle fuel economy over a 160,000 mile HEV life.

Figures and Tables

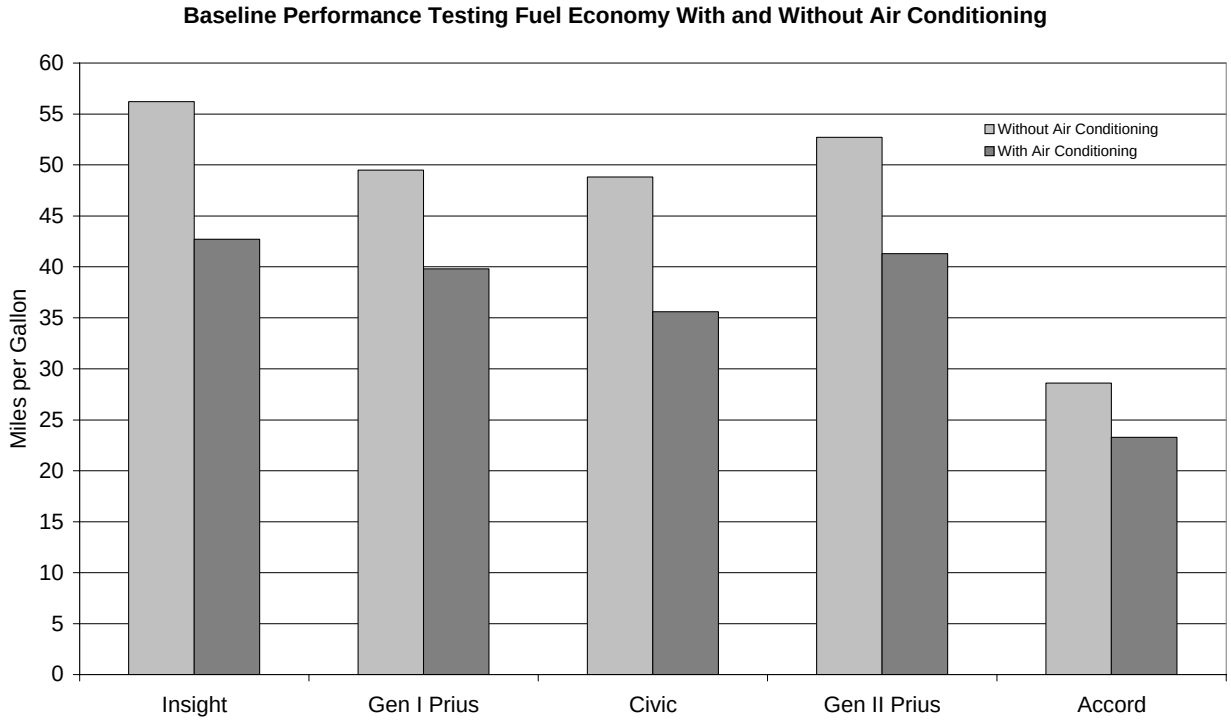

Figure 1. Baseline Performance Testing fuel economy with and without air conditioning operational

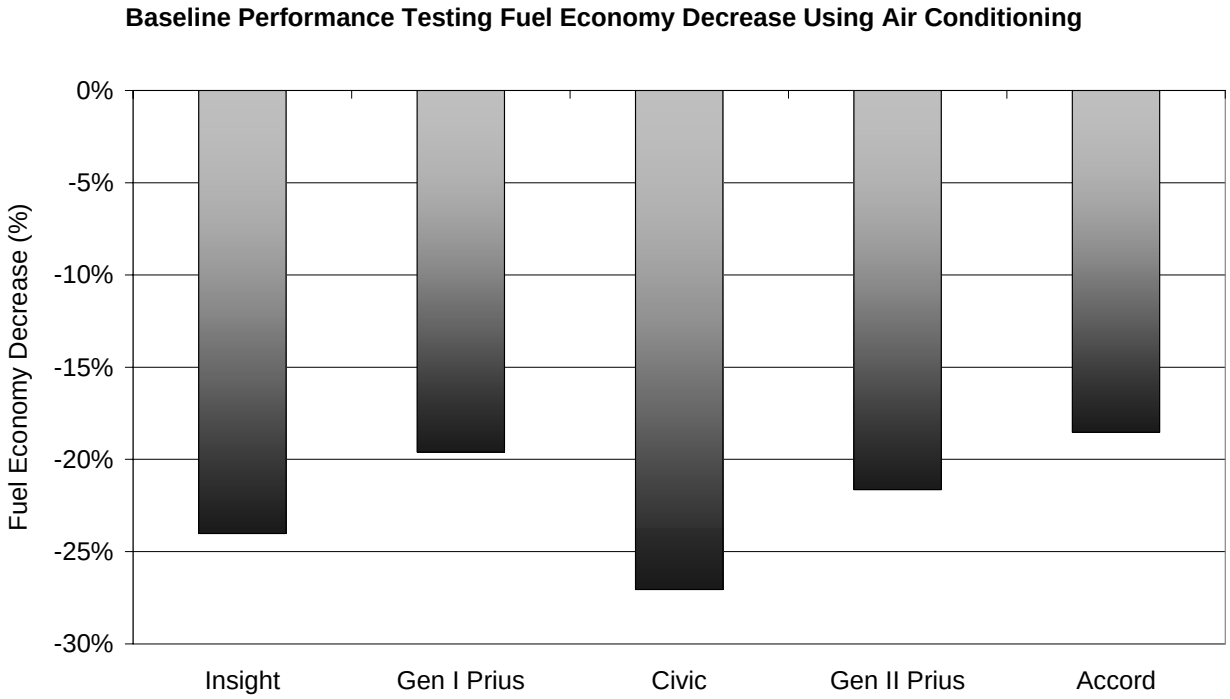

Figure 2. Percentage decrease in Baseline Performance Testing fuel economy when testing is conducted with air conditioning operational

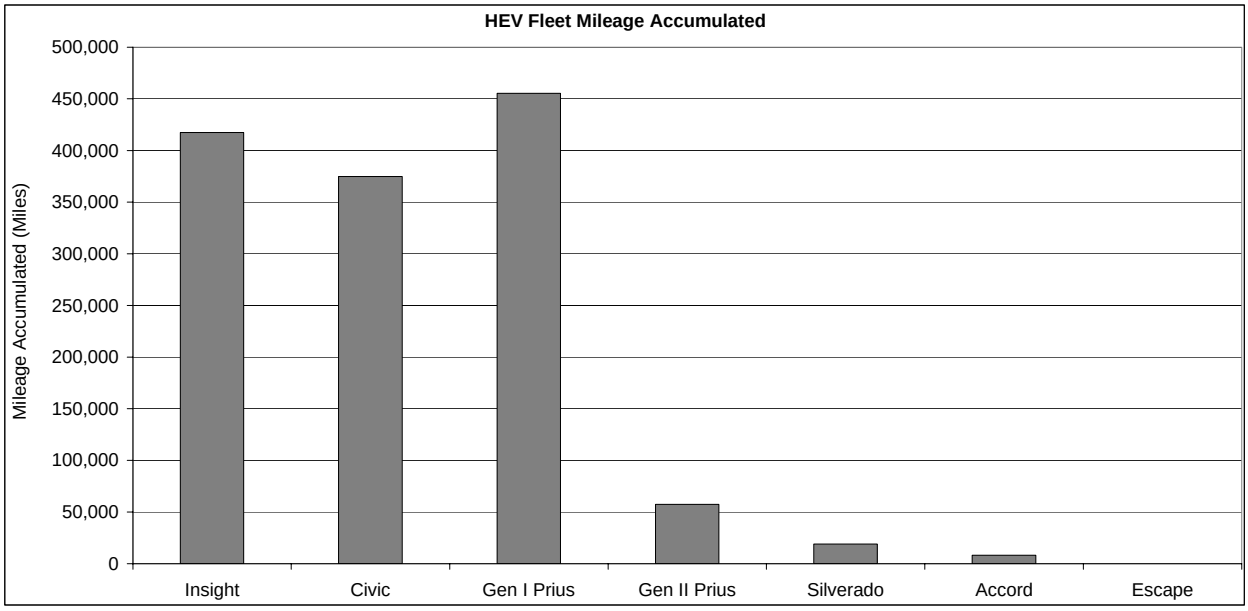

Figure 3. Total Accelerated Reliability Testing miles by HEV model.

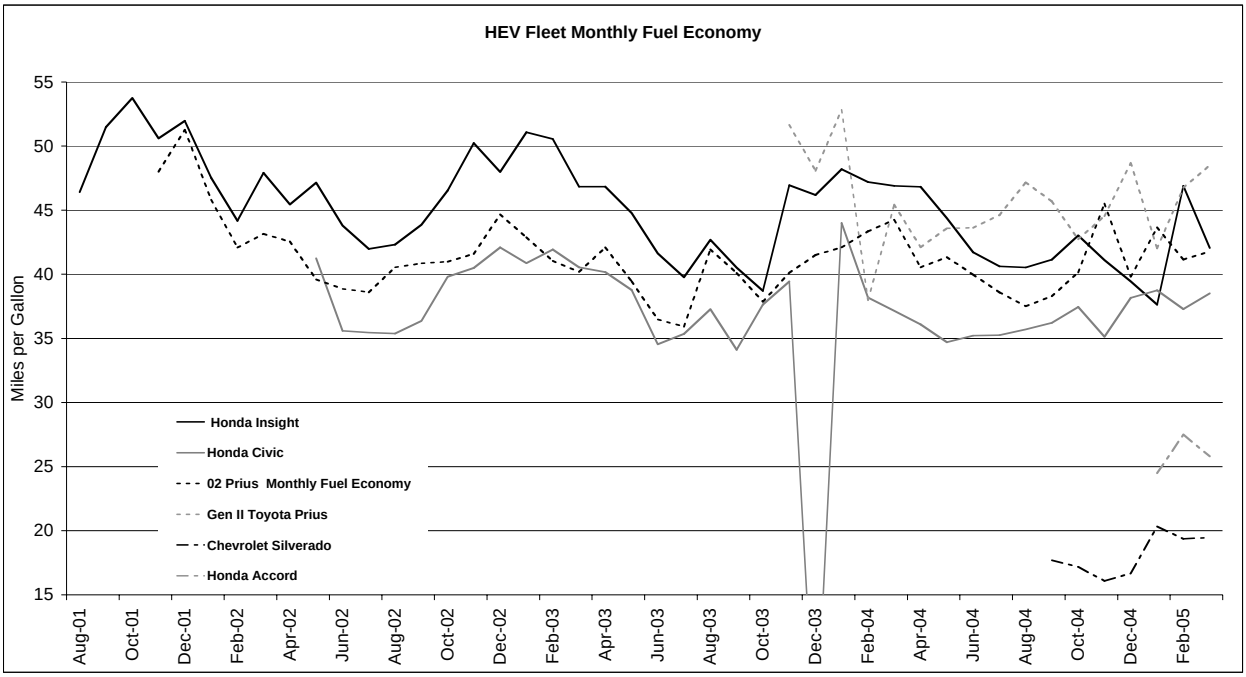

Figure 4. Monthly HEV accelerated reliability testing fuel economy test results

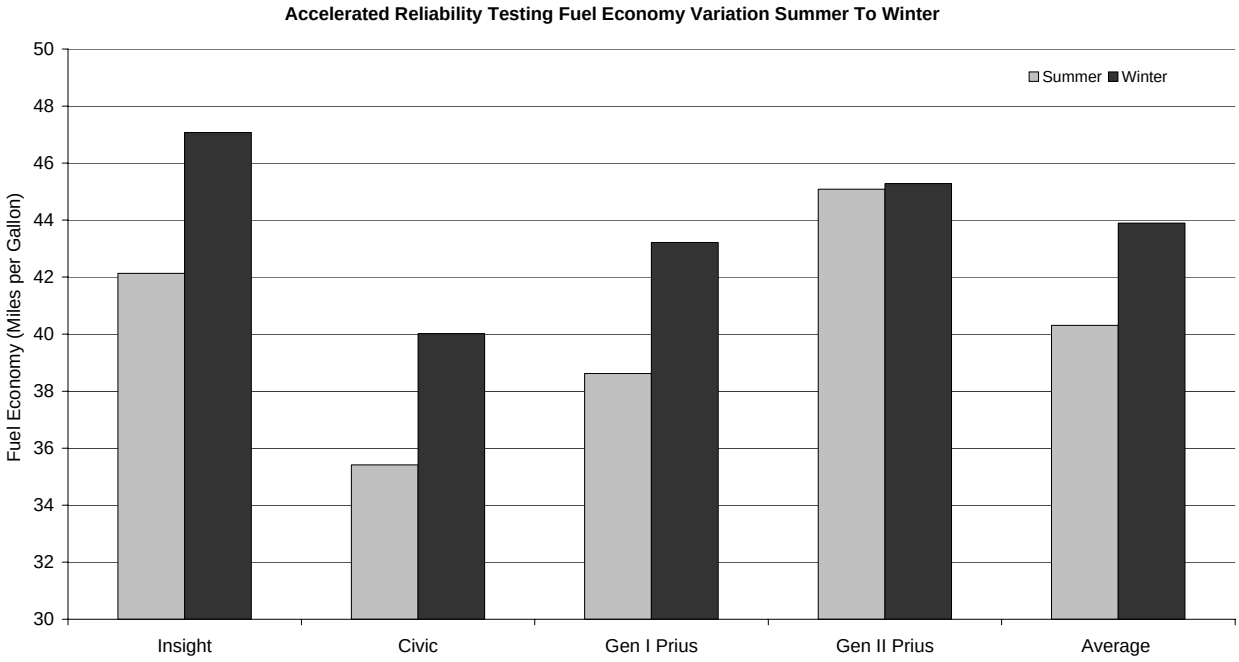

Figure 5. Seasonal variations in fuel economy for HEVs operating in Arizona.

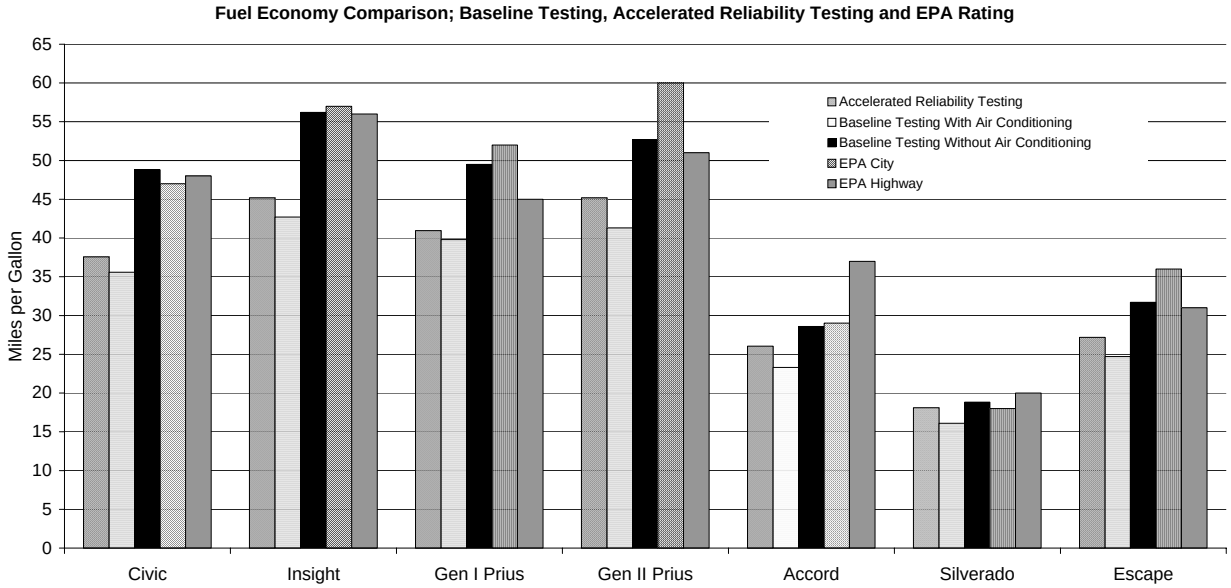

Figure 6. Fleet and baseline performance fuel economy test results compared to EPA results

Table 1. Cumulative fuel economy for vehicles in Accelerated Reliability Testing

Vehicles In Test	Model and Year	Testing Status	Cumulative Fuel Economy (mpg)
6	2001 Honda Insight	Aug 2001 – March 2005	45.2
6	2002 Toyota Prius	Nov 2001 – March 2005	40.9
4	2003 Honda Civics	May 2002 – March 2005	37.6
2	2004 Toyota Prius	Nov 2003 - ongoing	45.2
2	2004 Chevrolet Silverado	Sept 2004 - ongoing	18.1
2	2005 Honda Accord	Jan 2005 - ongoing	26.0
2	2005 Ford Escape	March 2005 - ongoing	NA

Table 2. HEV end-of-life fuel economy test results

HEV Vehicle Model	Fuel Economy			
	New Vehicle		After 160,000 miles	
	With A/C	Without A/C	With A/C	Without A/C
Civic	35.6	48.8	36.6	50.1
Gen I Prius	69.8	49.5	40.3	51.7
Insight	42.7	56.2	44.5	55.9

References

[1] http://avt.inl.gov
[2] http://avt.inl.gov/hev.shtml#testproc
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[7] 2005 Fuel Economy Guide, DOE/EE 0302, United States Department of Energy, Office of Energy Efficiency and Renewable Energy, www.fueleconomy.gov/feg/feg2000.htm.