ETA-HITP04

Revision 0

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HICE Vehicle Constant Speed Fuel Economy Tests

Prepared by

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TABLE OF CONTENTS

Appendices

1. Objective

The objective of this procedure is to provide methods for the testing of constant speed fuel economy of vehicles participating in HICEV America. Testing is conducted in accordance with procedures similar to SAE-J227a (canceled). These methods are not meant to supersede those of the testing facility, those specifically addressed by SAE Test Standards, nor of any regulatory agency who may have or exercise control over the covered activities.

2. Purpose

The purpose of this procedure is to identify acceptable methods for the implementation of a constant speed fuel economy test, similar to that identified in SAE J227a. The SAE J227a Recommended Practice, although canceled, established uniform procedures for testing battery electric vehicles. For consistency and comparability, this procedure adapts the methods of SAE J227a for use with hydrogen internal combustion engine-powered vehicles to collect and retain test data as specified in the HICEV America Technical Requirements.

3. Documentation

Documentation addressed by this procedure shall be consistent, easy to understand, easy to read and readily reproducible. This documentation shall contain enough information to "stand alone"; that is, be self-contained to the extent that all individuals qualified to review it could be reasonably expected to reach a common conclusion, without the need to review additional documentation. Review and approval of test documentation shall be in accordance with ETA-HAC04, "Review of Test Results." Storage and retention of records during and following testing activities shall be completed as described in Procedure ETA-HAC01, "Control, Close-out and Storage of Documentation."

4. Initial Conditions and Prerequisites

Prior to conduct of any portion of the testing, the following initial conditions and prerequisites shall be met. Satisfactory completion of these items shall be verified as complete and recorded on the Vehicle Test Data Sheet contained in Appendix A.

4.1 Personnel conducting testing under this procedure shall be familiar with the requirements of this procedure, and when applicable the appropriate SAE Test Instructions, Administrative Control Procedures, and be certified by the Program Manager, Test Manager or specific Test Engineer prior to commencing any testing activities.

4.2 All documentation required to complete the testing shall be completed, approved prior to commencing the testing it addresses.

4.3 Test Conditions

4.3.1 The test road must be a closed course consisting of dry, clean and smooth roads not exceeding 1.0% (±0.5%) grade

4.3.2 Ambient temperature during road testing shall be within the range of 32°F to 100°F (0°C to 38°C). **This is a deviation from SAE J227a.**

4.3.3 The average wind speed at the test site during the test shall not exceed 10 mph (16 km/h). Wind gusts shall not exceed 20 mph (32 kph) during the test.

4.4 Test Vehicle Preparation

4.4.1 The vehicle should have accumulated a minimum of 2,000 miles (3,200 km) of operation prior to test. At least 1,000 (1,600 km) of these miles must have been driven at speeds above 40 mph (64 kph).

4.4.2 Tires shall have been operated for at least 100 miles (160 km) prior to test and shall have at least 75% of the tread remaining and in good condition. Tires provided with the vehicle shall be the standard tire offered by the vehicle manufacturer, and shall be inflated to the manufacturer's (placard) recommended cold inflation pressures prior to test. This pressure shall not exceed the maximum allowable pressure imprinted upon the tire's sidewall.

4.4.3 Vehicle shall be tested in its normal configuration with normal appendages (mirrors, bumpers, hubcaps, etc.).

4.4.4 Vehicles shall be tested at curb weight plus 332 pounds. - **This is a deviation from SAE J227a.** Consideration should be given to how adding instrumentation will affect the test weight and balance of the vehicle.

4.4.5 Normal manufacturer's recommended lubricants shall be employed.

4.5 The following data shall be collected during conduct of the test specified by this procedure. Overall error in recording or indicating instruments shall not exceed ±2% of the maximum value of the variable being measured. Periodic calibration shall be performed and documented to ensure compliance with this requirement.

4.5.1 Fuel pressure and fuel temperature prior to testing

4.5.2 Vehicle speed versus time

4.5.3 Distance versus time

4.5.4 Fuel pressure and fuel temperature after testing

Vehicle speed and distance versus time data shall be collected using an onboard Data Acquisition System (DAS).

4.6 Environmental conditions during the testing shall be recorded and include, at a minimum, the following:

4.6.1 Range of ambient temperature during the test;

4.6.2 Range of wind velocity during the test;

4.6.3 Range of wind direction during the test.

Bounding values shall be recorded in Appendix A.

4.7 Verify that Procedures ETA-HIAC006, "Receipt Inspection," and ETA-HITP11, "Vehicle Verification," have been completed.

4.8 A description of the test route, road surface type and condition (SAE J688, "Truck Ability Prediction Procedure"), and lengths and grades of test route, shall be recorded in Appendix A.

4.9 The date and starting and ending times shall be recorded in Appendix A

4.10 The starting and ending vehicle odometer readings shall be recorded in Appendix A.

4.11 All instrumentation used in the test shall be listed on Appendix B, attached to the test data sheets/results, and shall include the following information:

4.11.1 Manufacturer

4.11.2 Model Number

4.11.3 Serial Number

4.11.4 Last Calibration date

4.11.5 Next Calibration date

4.12 The speed-time measuring device and other necessary equipment shall be installed so that they do not hinder vehicle operation or alter the operating characteristics of the vehicle. Mounting will nominally be at the rear of the vehicle.

4.13 Any deviation from the test procedure, and the reason for the deviation, shall be recorded in accordance with ETA-YAC002.

4.14 All documentation required to complete the testing shall be completed, approved and issued prior to commencing the testing it addresses.

4.15 During data reduction, the actual distance traveled and the corresponding fuel consumption shall be determined. The volume of hydrogen consumed when testing vehicles shall be determined by measuring the pressure change in the fuel storage tank during testing. The test vehicle fuel storage tank shall be instrumented with a calibrated pressure gauge having an accuracy in the range of measurement of at least 2%.

4.17 Each Range Test shall be terminated when the specific requirements of the procedure have been reached. However, if the Supplier's instructions provide guidance concerning when to stop driving the vehicle, the vehicle's range will be the range achieved when the conditions meeting that guidance have occurred. [Example: If the owner's manual/driver's instructions provided with the vehicle provide direction to stop driving upon receipt of a specific telltale or other indication normally available to the driver, the vehicle will be stopped and the test terminated when that telltale/indication has occurred.]

5.0 Testing Activities Requirements

5.1 Fuel Economy at 45 mph Constant Speed

The purpose of this section is to determine fuel economy with the vehicle loaded at curb weight plus 332 pounds, and operated at a constant 45 mph.

This testing shall be completed subject to the initial conditions and prerequisites stated in Section 4 of this procedure.

NOTE

All steps shall be completed in the order written. Deviations from any step or requirement shall have the approval of the Program Manager or Test Manager in accordance with Procedure ETA-HIAC002, "Control of Test Conduct."

5.1 Record information concerning the vehicle being tested in Appendix A.

5.2 Instrument the vehicle to obtain, at a minimum, the data identified in Section 4.5. Calibrate the fifth wheel, as necessary.

5.3 Record fuel pressure and temperature of the fuel tank to be used for constant speed fuel economy testing after soaking the vehicle for 4 hours in a constant temperature area. Tank temperature shall be measured by a thermocouple attached to the tank exterior approximately mid tank (long dimension). The temperature of the tank shall be within 1˚C of the air temperature in the immediate vicinity of the tank and the air temperature approximately four (4) feet from the tank. Isolate the fuel tank to be used for constant speed fuel economy testing until commencement of step 5.7.

5.4 Adjust the vehicle's cold tire pressures to match the manufacturer's placard value, or the maximum cold inflation pressure imprinted upon the tire's sidewall, whichever is less.

5.5 Operate the vehicle for a minimum of 10 miles to allow the engine and fluids to reach operating temperature.

5.6 Switch the vehicle fuel supply to the tank isolated in step 5.3. Record time of test commencement and the vehicle's odometer reading on Appendix A and start the onboard DAS. Accessories shall not be used during testing activities.

5.7 From a standing start, accelerate the vehicle under its own power to a speed of 45 mph ±1 mph (72 km/h ±1.6 km/h).

5.8 Each time the vehicle passes the lap marker, record the odometer reading. Each reading shall be recorded in the smallest increment displayed by its respective indicator.

NOTE

All vehicle's tested will be operated in accordance with the requirements of the Manufacturer's operating manuals/instruction cards/placards. Should the manufacturer's requirements for stopping the vehicle be met prior to reaching the criteria in Step 5.9, the test shall be terminated.

5.9 Maintain this speed without interruption until the vehicle travels at least 60 miles (100km).

5.10 Pull the vehicle off to the side of the test track Record the final odometer reading and time on Appendix A. (This may be recorded via a DAS).

5.11 The vehicle shall not be driven more than 0.3 miles or 0.5% of the test distance, whichever is greater, prior to completing step 5.12. As an alternative, the fuel tank used for the constant speed range test may be isolated and the vehicle driven using a supplemental fuel supply.

5.12 Record fuel pressure and temperature of the fuel tank to be used for constant speed fuel economy testing after soaking the vehicle for 4 hours in a constant temperature area. Tank temperature shall be measured by a thermocouple attached to the tank exterior approximately mid tank (long dimension). The temperature of the tank shall be within 1°C of the air temperature in the immediate vicinity of the tank and the air temperature approximately four (4) feet from the tank.

5.13 Calculate the quantity (moles) of fuel consumed using the following formula.

$$\Delta n = \left(P_{initial} * V_{initial}\right) / (\zeta * R * T_{initial}) - \left(P_{final} * V_{final} / \zeta * R * T_{final}\right)$$

where;

R = Universal Gas Constant

ζ = Compressability Factor

5.14 Calculate the quantity (gge) of fuel consumed using the following formula.

$$Q = \Delta n * EMW / ACC$$

where;

EMW = Effective Molecular Weight of the fuel

ACC = Average Conversion Constant for the fuel

select the appropriate EMW as follows;

5.15 Calculate the constant speed fuel economy (miles/gge)using the following formula.

$$FE = (ODOMETER_{initial} - ODOMETER_{final}) / Q$$

5.16 For convenience and accuracy, the equations used in Sections 5.13 through 5.15 have been incorporated into a MicroSoft Excel® speadsheet. The file name for this spreadsheet is "ETA-HITP02 (Fuel Use Calculator)" and is marked as Revision 0. A sample print from this spreadsheet is attached as Appendix C.

5.2 Calibration of the Vehicle Speedometer

This section should be completed concurrent with completion of ETA-HITP11, "Vehicle Verification," as well as in conjunction with Sections 5.1 and 5.2 of this procedure. It may also be implemented any time the speedometer is suspected of mis-operation. If the calibration is being completed independent of range testing, do not complete steps 5.3.1, 5.3.2 or 5.3.3.

5.2.1 When accelerating the vehicle to a predetermined speed of 65 mph, or maximum vehicle speed, record the vehicle speedometer reading compared to the installed Data Acquisition System (DAS) speed reading, in 10 mph increments, up to and including the final speed achieved. [To promote safety, this may be done verbally by speaking to a tape recorder, and then later transcribed into Appendix C.]

5.2.2 The error between the speedometer and the DAS readout shall be calculated and the results posted in the vehicle for the driver to use.

5.2.3 If the driver notices a difference between the indicated value and the calculated correction factor, this test should be run again.

5.2.4 If the vehicle is being operated for the sole purpose of calibrating the speedometer, calibration should be as follows:

5.2.4.1 Ensure the vehicle is instrumented with a DAS.

5.2.4.2 With the vehicle stopped, record the speedometer reading.

5.2.4.3 Accelerate the vehicle to 20 mph; record the speedometer reading and the DAS heads-up display speed readout.

5.2.4.4 Increase vehicle speed in 5 mph increments, recording the speedometer and heads-up display speed read-out at each speed. Continue this until the vehicle has achieved 65 mph, or maximum achievable speed, whichever is less.

5.2.4.5 Develop a calibration reference table, Appendix C, for the speedometer.

5.2.4.6 Mount the calibration reference table in the subject vehicle adjacent to the speedometer.

6. GLOSSARY

6.1 Curb Weight - The total weight of the vehicle including batteries, lubricants, and other expendable supplies but excluding the driver, passengers, and other payloads.

6.2 Effective Date - The date, after which a procedure has been reviewed and approved, that the procedure can be utilized in the field for official testing.

6.3 Fifth Wheel - A calibrated instrument used to measure a vehicle's speed and distance independent of the vehicles on-board systems.

6.4 Gross Vehicle Weight Rating (GVWR) - The maximum design loaded weight of the vehicle specified by the Supplier.

6.5 HICEV America – Hydrogen Internal Combustion Engine Vehicle America Performance Test Program, the DOE sponsored test program for independently assessing the performance of vehicles submitted for testing.

6.7 Initial Conditions - Conditions that shall exist prior to an event occurring.

6.8 Prerequisites - Requirements that must be met or resolved prior to an event occurring.

6.9 Program Manager - As used in this procedure, the individual within Electric Transportation Applications responsible for oversight of HEV America.

6.10 Shall - This word is used to indicate an item which requires adherence without deviation. Shall statements identify binding requirements. A go, no-go criterion.

6.11 Should - This word is used to identify an item which requires adherence if at all possible. Should statements identify preferred conditions.

6.12 Test Director - The individual within Electric Transportation Applications responsible for all testing activities associated with HEV America.

6.13 Test Director's Log - A daily diary kept by the Test Director, Program Manager, Test Manager or Test Engineer to document major activities and decisions that occur during the conduct of a Performance Test Evaluation Program. This log is normally a running commentary, utilizing timed and dated entries to document the day's activities. This log is edited to develop the Daily Test Log published with the final report for each vehicle.

6.14 Test Engineer - The individual(s) assigned responsibility for the conduct of any given test. [Each contractor/subcontractor should have at least one individual filling this position. If so, they shall be responsible for adhering to the requirements of this procedure.]

6.15 Test Manager - The individual within Electric Transportation Applications responsible for the implementation of the test program for any given vehicle(s) being evaluated to the requirements of HEV America. [Subcontract organizations may have similarly titled individuals, but they are not addressed by this procedure.]

7. REFERENCES

7.1 HICEV America Vehicle Specification

7.2 ETA-HIAC01 - "Control, Close-out and Storage of Documentation"

7.3 ETA-HIAC02 - "Control of Test Conduct"

7.4 ETA-HIAC04 - "Review of Test Results"

7.5 ETA-HIAC06 - "Receipt Inspection"

7.6 ETA-HITP02 - "Implementation of SAE Standard J1666 May93, Electric Vehicle Acceleration, Gradeability and Deceleration Test Procedure"

7.7 ETA-HITP11 - "Vehicle Verification"

7.8 SAE Standard J227a, Electric Vehicle Test Procedure, FEB 1976.

APPENDIX-A
45 mph Constant Speed Fuel Economy Test Data Sheet
(Page 1 of 2)

VIN Number: _____

Project No.:	Test Date(s):
Root File No.:	
Test Driver: (Initials) (Date)	
Test Engineer: (Initials) (Date)	

Vehicle Setup

VEHICLE WEIGHTS AS TESTED WITH DRIVER & INSTRUMENTATION (Test Weight is Curb Weight plus 332 pounds)			
Left Front: (lbs or kg)	Right Front: (lbs or kg)	Total Front: (lbs or kg)	Percent Front: %
Left Rear: (lbs or kg)	Right Rear: (lbs or kg)	Total Rear: (lbs or kg)	Percent Rear: %
		Total Weight: (lbs or kg)	

INSTALLED TIRES (Placard or sidewall whichever is less)			
Preparation Area Temperature: (℉ or ℃)			
Left Front		Right Front	
Pressure: (psi or kPa)		Pressure: (psi or kPa)	
Left Rear		Right Rear	
Pressure: (psi or kPa)		Pressure: (psi or kPa)	

Track/Weather Conditions

Test Track Location:	Track Grade: %
Ambient Temperature (initial): (40-100°F or 5-38°C)	Ambient Temperature (final): (40-100°F or 5-38°C)
Track Temperature (initial): (°F or °C)	Track Temperature (final): (°F or °C)
Wind Velocity (initial): (<10 mph or 16 km/h)	Wind Velocity (final): (<10 mph or 16 km/h)
Wind Direction (initial): °	Wind Direction (completion): °

APPENDIX-A
45 mph Constant Speed Fuel Economy Test Data Sheet
(Page 2 of 2)

VIN Number _____

Sequence No:	File No.:	Direction of Travel:
Time (initial):	Time (final):	
Odometer (initial): (miles or kilometers)	Odometer (final): (miles or kilometers)	
Fuel Storage Tank Pressure (initial): (psi)	Fuel Storage Tank Pressure (final): (psi)	
Fuel Storage Tank Temperature (initial): (°F or °C)	Fuel Storage Tank Temperature (final): (°F or °C)	
Comments (initials/date):		
Completed By: (Printed Name)	(Signature)	(Date)
Reviewed By: (Printed Name)	(Signature)	(Date)
Approved By: (Printed Name)	(Signature)	(Date)

APPENDIX B
Calibration of Vehicle Speedometer Test Data Sheet
(Page 1 of 1)

VIN Number: _____

Sequence No:	File No.:	Direction of Travel:
Time (initial):	Time (final):	
Odometer (initial): (miles or kilometers)	Odometer (final): (miles or kilometers)	

DAS Heads-up Display:	**Vehicle Speedometer:**
20 MPH	
25 MPH	
30 MPH	
35 MPH	
40 MPH	
45 MPH	
50 MPH	
55 MPH	
60 MPH	
70 MPH	
80 MPH	
MPH	
MPH	

Comments (initials/date):

_____

_____

_____

_____

_____

_____

_____

Completed By:	(Printed Name)	(Signature)	(Date)
Reviewed By:	(Printed Name)	(Signature)	(Date)
Approved By:	(Printed Name)	(Signature)	(Date)

APPENDIX C
Vehicle Metrology Setup Sheets
(Page 1 of 1)

VIN Number: _____

Instrument/Device:	Calibration Due Date:	Initials / Date:
Fifth Wheel S/N:		
Fifth Wheel Calibrator S/N:		
DAS S/N:		
DAS Set-up Sheet S/N		
Fuel Pressure Gauge:		
Tire Pressure Gauge S/N:		
Misc:		
Misc:		
Misc:		
Misc:		
Comments (initials/date):		
Completed By: (Printed Name)	(Signature)	(Date)
Reviewed By (QA): (Printed Name)	(Signature)	(Date)
Approved By: (Printed Name)	(Signature)	(Date)

APPENDIX D
Sample Fuel Use Spreadsheet
(Page 1 of 1)

SAMPLE

File Name; ETA-YTP002 (Fuel Use Calculator) **Revision; 0**
Calculations for Fuel Economy

Assumptions		
Assumed LHV for H2	51,608	Btu/lb (LHV)
Assumed LHV for CH4	21,480	Btu/lb (LHV)
Assumed curve fit of Z for H2 (pressure in psi)	Z=2E-12P^3+2E-8P^2+1E-5P+.9974	
Assumed curve fit of Z for CH4 (pressure in psi)	Z=3E-8P^2-1E-4P+.9914	

Test Number	ETA-06-002
Test Date	6/3/03
Test Engineer	B.S.

Input Parameters

Input Gasoline Energy per Gallon	122,000	Btu/gallon (LHV)		
Input Molar Percentage H2	0.3	%		
Input Tank Volume	85	liters	3.00	ft^3
Input Initial Pressure	3220	psig		
Input Initial Temperatue	81.0	˚F	541.0	˚R
Input Final Pressure	1520	psig		
Input Final Temperature	74.1	˚F	534.1	˚R
Input Distance Traveled	60	Miles		

Output Parameters

Initial Gasoline Gallons Equivalent	3.92	GGE
Final Gasoline Gallons Equivalent	1.65	GGE
Gasoline Gallons Equivalent Used	2.27	GGE
Miles Per Gasoline Gallon Equivalent	26.48	Miles per GGE

Claculations

H2 Mass Percentage	0.050847	%			
Initial Pressure	3220	psig	465796.8	psf	
Z for H2	1.021526				
Z for CH4	0.918415				
Molar Ratio (H2/CH4)	0.428571				
Pressure Ratio (H2/CH4)	0.476687				
Partial Pressure of H2	1044.189	psi	150363.2	psf	966 Perfect gas partial pressure (used for calculating Z)
Partial Pressure of CH4	2190.511	psi	315433.6	psf	2254 Perfect gas partial pressure (used for calculating Z)
Total Initial Pound Moles	1.760966				
Initial H2 Weight	1.05658	lbs			
Initial CH4 Weight	19.72282	lbs			
Initial Energy of H2	54527.97	Btu			
Initial Energy of CH4	423646.2	Btu			
Initial Total Energy	478174.2	Btu			
Final Pressure	1520	psig	220996.8	psf	
Z for H2	1.006308				
Z for CH4	0.885032				
Molar Ratio (H2/CH4)	0.428571				
Pressure Ratio (H2/CH4)	0.487299				
Partial Pressure of H2	502.8294	psi	72407.43	psf	456 Perfect gas partial pressure (used for calculating Z)
Partial Pressure of CH4	1031.871	psi	148589.4	psf	1064 Perfect gas partial pressure (used for calculating Z)
Total Final Pound Moles	0.742973				
Initial H2 Weight	0.445784	lbs			
Final CH4 Weight	8.321302	lbs			
Final Energy of H2	23006.02	Btu			
Final Energy of CH4	178741.6	Btu			
Final Total Energy	201747.6	Btu			