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Dynamometer Testing of the Ford Ecostar Electric Vehicle #41

Idaho National Engineering Laboratory

U.S. Department of Energy Idaho Field Office

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**Dynamometer Tests
of the
Ford Ecostar Electric Vehicle #41**

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September 1995

**Prepared for the
U. S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy (EE)
Under DOE Idaho Operations Office
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ABSTRACT

A Ford Ecostar vehicle was tested in the Idaho National Engineering Laboratory (INEL) Hybrid Electric Vehicle (HEV) Laboratory over several standard driving regimes. The test vehicle was delivered to the INEL in February 19, 1995 under the DOE sponsored Modular Electric Vehicle Program. This report presents the results of several dynamometer driving cycle tests and a constant current discharge, and presents observations regarding the vehicle state-of-charge indicator and remaining range indicator.

EXECUTIVE SUMMARY

A Ford Ecostar electric vehicle was tested in the INEL HEV Laboratory over several standard driving regimes. The test vehicle was delivered to the INEL in February 19, 1995 under the DOE sponsored Modular Electric Vehicle Program. Summary results of the tests are presented in Table ES-1.

Tests indicated that the driving cycle range for the Ecostar was 143 and 199 km for the LA-92 and Highway Fuel Economy Test (HWFET) cycles, respectively. During the constant current discharge test, the vehicle was driven 244 km at an approximate steady speed of 78 km/h. Net vehicle DC energy consumption was measured at 177 and 236 W·h/km for the HWFET and LA-92 driving cycles, respectively.

Energy consumption at various steady-state speeds was measured. The steady-state energy consumption averaged over two tests was approximately 104 W·h/km at 40 km/h and 221 W·h/km at 104 km/h.

Gradeability-at-speed tests indicated that the vehicle can be driven at 88 km/h up an approximate 4% grade for periods up to 15 minutes without difficulty. This performance was achieved throughout a state-of-charge of the battery from 87 to 58%.

Table ES-1. Ecostar test results summary sheet (INEL Hybrid/Electric Vehicle Laboratory).

VEHICLE DESCRIPTION	TEST RESULTS																																																																		
VEHICLE TYPE Manufacturer: Ford Motor Company Model: Ecostar VIN: IFTCV10E7P3S11041 Seating Capacity: 2 Drive configuration: Front motor, front wheel drive	40A (C/3 rate) CONSTANT CURRENT RANGE <table><tr><td>Range (km)</td><td>243</td></tr><tr><td>Net DC E. C. (Wh/km)</td><td>153</td></tr><tr><td>Average Speed (km/h)</td><td>78</td></tr><tr><td>AC E. C. (Wh/km)</td><td>NA</td></tr></table>	Range (km)	243	Net DC E. C. (Wh/km)	153	Average Speed (km/h)	78	AC E. C. (Wh/km)	NA																																																										
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DIMENSIONS Wheelbase: 2605 mm Track F/R: 1440/1448 mm Length: 4300 mm Width: 1676 mm Height: 1619 mm Ground Clearance: n/a Cargo Volume: n/a	DRIVING CYCLES <table><tr><td></td><td>LA92</td><td>FUDS</td><td>HWFET</td></tr><tr><td>Range (km)</td><td>143.1</td><td>182.4</td><td>199.0</td></tr><tr><td>Net DC E. C. (Wh/km)</td><td>236</td><td>197</td><td>177</td></tr><tr><td>Gross DC E. C. (Wh/km)</td><td>254</td><td>212</td><td>181</td></tr><tr><td>AC E. C. (Wh/km)</td><td>NA</td><td>NA</td><td>NA</td></tr></table> FUDS - average of two tests.		LA92	FUDS	HWFET	Range (km)	143.1	182.4	199.0	Net DC E. C. (Wh/km)	236	197	177	Gross DC E. C. (Wh/km)	254	212	181	AC E. C. (Wh/km)	NA	NA	NA																																														
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WEIGHTS Curb Weight: 1433 kg Inertia Test Weight: 1569 kg Payload: 463 kg	ENERGY ECONOMY @ SPEED (Wh/km) (average of two tests) <table><tr><td></td><td colspan="5">State-of-Charge</td></tr><tr><td>Speed</td><td>100%</td><td>80%</td><td>60%</td><td>40%</td><td>20%</td></tr><tr><td>40 km/h</td><td>126</td><td>114</td><td>110</td><td>111</td><td>104</td></tr><tr><td>48 km/h</td><td>126</td><td>115</td><td>115</td><td>112</td><td>109</td></tr><tr><td>56 km/h</td><td>130</td><td>124</td><td>127</td><td>123</td><td>120</td></tr><tr><td>64 km/h</td><td>137</td><td>135</td><td>132</td><td>131</td><td>127</td></tr><tr><td>72 km/h</td><td>150</td><td>147</td><td>146</td><td>144</td><td>141</td></tr><tr><td>80 km/h</td><td>165</td><td>161</td><td>159</td><td>156</td><td>154</td></tr><tr><td>88 km/h</td><td>180</td><td>176</td><td>176</td><td>175</td><td>172</td></tr><tr><td>96 km/h</td><td>205</td><td>195</td><td>197</td><td>192</td><td>189</td></tr><tr><td>104 km/h</td><td>221</td><td>218</td><td>219</td><td>212</td><td>208</td></tr></table>		State-of-Charge					Speed	100%	80%	60%	40%	20%	40 km/h	126	114	110	111	104	48 km/h	126	115	115	112	109	56 km/h	130	124	127	123	120	64 km/h	137	135	132	131	127	72 km/h	150	147	146	144	141	80 km/h	165	161	159	156	154	88 km/h	180	176	176	175	172	96 km/h	205	195	197	192	189	104 km/h	221	218	219	212	208
	State-of-Charge																																																																		
Speed	100%	80%	60%	40%	20%																																																														
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88 km/h	180	176	176	175	172																																																														
96 km/h	205	195	197	192	189																																																														
104 km/h	221	218	219	212	208																																																														
WHEELS & TIRES Tire Mfg. & Type: Firestone Tire Size: P195/70R14 Tire Pressure (F/R): 50/50 psig	Remaining Range Indicator Evaluation
DRIVE SYSTEM Type: Liquid cooled, AC Motor: 75 HP, 3 phase AC Controller Mfg. Ford/GE Transmission: Single speed Gear Ratio: 12:18	State-of-Charge Meter Evaluation
BATTERY Mfg.: ABB Type: Sodium-sulfur Rated Capacity: 120 Ah Number of Modules: n/a Nominal Voltage: 330V Weight: ~350 kg																																																																			
CHARGER Input Voltage: 240/120 AC Input Power: 30A@240V, 15A@120V																																																																			
MISCELLANEOUS Solar assisted ventilation, regenerative braking AC/heater, cellular phone, power brakes Parameters Derived from Coastdown Aerodynamic drag coefficient: 0.421 Frontal Area (.8 x W x H): 2.17 sq. m. Drag Area Product: .913 sq. m. Tire rolling resistance: 0.0065																																																																			

CONTENTS

Abstract	iii
Executive Summary	v
Introduction	1
Test Program and Results	5
Measurements and Data Acquisition	5
Test Set-Up	5
Test Termination Criterion	10
Battery Capacity Verification	12
Energy Economy Tests	12
Federal Urban Driving Schedule (FUDS)	19
Highway Fuel Economy Driving Schedule	19
LA-92 Driving Schedule	29
Gradeability	29
State-of-Charge Meter and Remaining-Range Indicator Evaluation	29
Observations	37
Recommendations	39

FIGURES

1. Photograph of Ford Ecostar in the INEL HEV Laboratory	3
2. Schematic diagram of instrumentation placed on the Ecostar vehicle	7
3. Road load at various speeds calculated from vehicle coastdowns	9
4. Resultant coastdown curve representing dynamometer calibration	11
5. Speed, traction battery power and auxiliary power during energy economy test	14
6. DC energy consumption at various speeds averaged over two tests	15
7. Speed, traction battery power and auxiliary power during FUDS Test No. LECOF608	20-22

8.	Speed, traction battery power and auxiliary power measured during HWFET No. LECOH606	27
9.	Speed, traction battery power and auxiliary power measured during LA-92 driving cycles (Test No. LECOL607)	31-32
10.	State-of-charge readings as measured against net ampere-hours for various driving cycles	34
11.	Miles-to-discharge compared to actual distance remaining to LOS	35

TABLES

ES-1	Ecostar test results summary sheet	vi
1.	Summary results of tests conducted in the INEL HEV Laboratory for Ecostar #41 ...	4
2.	List of measurements recorded on the Laboratory Data Acquisition System	6
3.	Summary data sheet	8
4.	Results of C/3 constant-current discharge using chassis dynamometer	13
5.	Detailed results of Energy Economy Test No. LECOES530	16
6.	Detailed results of Energy Economy Test No. LECOES601	17
7.	Cycle-by-cycle results of FUDS Test No. LECOF605	23-24
8.	Cycle-by-cycle results of FUDS Test No. LECOF608	25-26
9.	Cycle-by-cycle results of HWFET No. LECOH606	28
10.	Cycle-by-cycle results of LA-92 driving cycles	33

DYNAMOMETER TESTS OF THE FORD ECOSTAR ELECTRIC VEHICLE #41

INTRODUCTION

This report presents the results of dynamometer tests performed in the INEL Hybrid/Electric Vehicle Laboratory on a Ford Ecostar van. The intent of these tests was to determine the performance of the vehicle under various standard driving regimes. By measuring significant parameters under these driving regimes, information was obtained by which the vehicle subsystems performance may be judged.

The Ecostar (see Figure 1) vehicle was received at the INEL on February 19, 1995 and tests were performed during the period between May 30 and June 12, 1995. Table 1 shows the summary results of measurements taken for these tests.

Figure 1. Photograph of Ford Ecostar in the INEL HEV Laboratory (95-337-3-1 or 2).

Table 1. Summary results of tests conducted in the INEL HEV Laboratory for Ecostar #41.

	Test Number						
	LECOC3R1 (Constant Current)	LECOE530* (Energy Economy)	LECOE601 (Energy Economy)	LECOF605 (FUDS)	LECOH606 (HWFET)	LECOL607 (LA-92)	LECOF608 (FUDS)
General:							
Number of completed cycles	-	-	-	15	12	9	15
Distance (km)	242.6	193.5	232.2	183.1	199.0	143.1	181.7
Vehicle DC Energy Consumption (Wh/km)	152.9	159.3	154.5	195.6	176.8	235.9	197.9
Gross Ampere-hours (Ah)	126.3	107.6	126.9	135.5	130.6	134.4	136.1
Regen Ampere-hours (Ah)	0.1	0.9	1.1	9.2	3.1	8.4	9.0
Net Ampere-hours (Ah)	126.3	106.9	125.8	126.4	127.5	126.0	127.2
Gross DC Energy (kWh)	37.1	31.1	36.2	38.6	36.1	36.4	38.7
Regen DC Energy (kWh)	0.0	0.3	0.3	2.8	1.0	2.6	2.8
Net DC Energy (kWh)	37.1	30.9	35.9	35.8	35.2	33.7	36.0
Duration of Test (HH:MM:SS)	03:06:56	02:38:51	03:08:17	08:16:49	02:35:39	04:55:45	08:05:46
Driving Cycle Discharge Information:							
Minimum Battery Voltage (V)	255.3	221.3	228.9	226.1	227.0	210.8	226.8
Maximum Battery Current (A)	159.2	235.9	220.0	242.9	183.2	265.9	226.1
Maximum Battery Power (kW)	40.6	52.6	51.0	54.4	43.9	56.0	51.5
Average Speed (km/h)	77.9	73.1	74.0	22.1	76.7	29.0	22.5
Average Battery Power (kW)	11.9	11.6	11.4	4.3	13.6	6.8	4.5
Average Battery Current (A)	40.5	40.3	40.1	15.3	49.2	25.3	15.7
Driving Cycle Regen Information:							
Maximum Battery Voltage (V)	320.0	325.8	325.5	319.9	325.0	329.8	320.3
Maximum Battery Current (A)	26.0	51.1	41.7	32.6	50.2	73.7	32.3
Maximum Battery Power (kW)	7.8	14.8	14.4	10.3	15.8	22.7	10.3
Auxiliary (non-traction) System Information:							
Average Auxilliary Power (kW)	0.1	0.2	0.3	0.1	0.2	0.1	0.1
Auxilliary Energy Consumption (kWh)	0.4	0.4	0.9	0.6	0.5	0.6	0.6

* Vehicle was not discharged to 100% DOD.

TEST PROGRAM AND RESULTS

Measurements and Data Acquisition

Measurements were made with the Laboratory Data Acquisition System (LDAS). A total of 35 actual and calculated parameters were recorded during all tests. All data channels were recorded at 1 second intervals. A list of these parameters is given in Table 2. The schematic diagram of Figure 2 shows the location of the current and electrical power instrumentation placed on the vehicle. The nomenclature for the measurements derived from this instrumentation is referenced to the data field names listed in Table 2.

Test numbers coincide with filenames of the INEL standard format data files for each test. The Vehicle Test Data Summary Sheet shown in Table 3 provides a summary of these data files archived at the INEL.

Test Set-up

The road loads programmed into the dynamometer were determined from coastdown data supplied by Ford. Ford performed the coastdown runs with the drive axles in place and at a different test weight than specified for these tests. Therefore, the dynamometer loads were mathematically corrected to arrive at the proper load curve for dynamometer calibration. The additional losses during Ford's coastdown runs due to the drive shafts were measured by performing coastdown runs on the dynamometer with and without the drive shafts connected. The difference between these two conditions (representing the losses due to the drive shafts) was then subtracted from the curve derived from the Ford coastdown and adjusted for the difference in the vehicle test weight and standard temperature and air pressure. This process resulted in the theoretical force-speed curve to be applied by the dynamometer which correctly represents the vehicle loads while driving on a level roadway. Figure 3 graphically shows the

Table 2. List of measurements recorded on the Laboratory Data Acquisition System.

<u>Measurement</u>	<u>Units</u>	<u>Explanation</u>
ELAP_TIME	SEC	Elapsed time from beginning of test.
SPEED	KMH	Dynamometer roll speed
DYNO_RPM	RPM	Dynamometer roll speed
DYNO_FORCE	NEWT	Force at roll surface
AMB_TEMP	DEGC	Ambient temperature
SPEED_MPH	MPH	Dynamometer roll speed
NOM_SPEED	KMH	Target driving cycle speed
AH/KM	AH/KM	Cumulative ampere hours per kilometer
WH/KM	WH/KM	Cumulative Watt hours per kilometer
BAT_VOLT	VOLT	Traction battery voltage
BAT_CURR	AMPS	Traction battery current
BAT_PWR	KW	Traction battery power
BAT_ENR_O	KWH	Cumulative gross vehicle DC energy
BAT_ENR_I	KWH	Cumulative regen DC energy
BAT_ENR_N	KWH	Cumulative net DC energy
BAT_AH_O	AH	Cumulative gross ampere hours
BAT_AH_I	AH	Cumulative regen ampere hours
BAT_AH_N	AH	Cumulative net ampere hours
MAIN_CURR	AMPS	Current to traction motor
MAIN_PWR	KW	Power to traction motor
AUX_CURR	AMPS	Auxiliary systems current
AUX_PWR	KW	Auxiliary systems power
CYCLE_NO	#	Driving cycle count
DISTANCE	KM	Cumulative distance
DYNO_HP	KW	Dynamometer power
DYNO_TRQ	NM	Dynamometer torque
TB_BAK_PWR	KW	Traction battery backup power measurement
XBAT_VOLT	VOLT	SLI (12 v) battery voltage
XBAT_CURR	AMPS	SLI (12 v) battery current
XBAT_PWR	KW	SLI (12 v) battery power
DCO_CURR	AMPS	DC/DC converter output current
DCO_PWR	KW	DC/DC converter output power
HTR_CURR	AMPS	Current through battery heaters
HTR_PWR	KW	Power through battery heaters
TEMP_1_REF	DEGC	Thermocouple reference temperature

∞ Page 1 of 1

Figure 3. Road load at various speeds calculated from vehicle coastdowns.

results of this process. The resulting corrected road load force equation used to represent the Ecostar during these tests is given by:

$$\text{Road Load Force} = 99.338 + .04263 v^2$$

where road load force is in newtons and velocity (v) is in km/h.

The speed-time coastdown curve determined by the above described process is shown in Figure 4.

Test Termination Criterion

All tests were terminated according to the criteria specified by SAE J1634, "Electric Vehicle Energy Consumption and Range Test Procedure", which is generally defined as the inability of the vehicle to attain some minimum level of performance, or some alternative point which may be specified by the manufacturer. The Ecostar has a Limited Operating Strategy (LOS) indicator on the driver's display panel which indicates to the driver that the vehicle has reached the end of range in which full vehicle performance is available. Ford states that when this indicator is first displayed, approximately 10 more miles remain (with reduced performance) before the traction battery is completely depleted and must be recharged. For the purposes of these tests, the alternative termination criterion employed was to terminate the test after completing the driving cycle if possible (subject to minimum performance limits) after the LOS indicator was displayed. In most cases, this resulted in the completion of the cycle being performed when LOS was indicated. In only one instance (test number LECOF605) was the test terminated prior to completing the driving cycle. In this instance, the LOS indicator came on after the start of the 16th FUDS cycle, and the test was terminated because the vehicle could not meet the minimum speed for the cycle in the LOS mode.

Figure 4. Resultant coastdown curve representing dynamometer calibration.

Battery Capacity Verification

A battery capacity verification was performed by driving the vehicle on the chassis dynamometer, manually controlling the vehicle speed such that the traction battery was discharged at a constant 40 A constant current. During this discharge, the traction battery delivered 40 A for 3 hours and seven minutes (126.3 Ah), exceeding the battery manufacturer's rated battery capacity of 120 Ah. Table 4 provides the other significant results of this test.

Energy Economy Tests

Two energy-economy-at-speed tests were performed to verify the repeatability of the data and validate consistent dynamometer operation. In this test, the vehicle is driven at selected constant speeds for approximately 1-minute durations starting from traction battery depths-of-discharge of 0%, 20%, 40%, 60%, and 80% respectively. The traction battery is discharged to these levels between the energy economy test segments by driving the vehicle on the dynamometer at the C/3 (40 A) rate. A plot of vehicle speed, traction battery and auxiliary power as a function of the battery depth-of-discharge (DOD) is shown in Figure 5 for a typical energy economy test. The results of the data analysis (averaged for the two tests) giving the vehicle DC energy consumption at various speeds and DODs is shown in Figure 6. Detailed results of each test are presented in Tables 5 and 6. During these tests, the battery cooling system was activated toward the end of discharge as exemplified by the increase in auxiliary power (see AUX_PWR in Figure 5). The energy consumption values reported in Figure 5 are corrected for this effect.

Table 4. Results of C/3 constant current discharge using chassis dynamometer.

Constant Current Test Results	
Test Number LECOC3R1	
Vehicle DC Ampere-hours	126.3 Ah
Average Speed	77.9 km/h
Distance	242.7 km
Average Traction Battery Current	40.5 A
Average Traction Battery Power	11.9 kW
Net Vehicle DC Energy	37.14 kWh

Figure 5. Speed, traction battery power and auxiliary power during energy economy test.

Figure 6. DC energy consumption at various speeds averaged over two tests.

Table 5. Detailed results of Energy Economy Test No. LECO530.

	Nominal Speed (km/h)								
	40	48	56	64	72	80	88	96	104
0% DOD									
Vehicle DC Energy Consumption (Wh/km)	124	126	129	136	149	162	181	202	220
Average Battery Voltage (V)	309	308	307	305	301	298	293	288	282
Average Battery Current (A)	16.4	20.0	22.1	27.1	35.2	44.2	55.0	68.5	82.6
Average Battery Power (kW)	5.1	6.1	6.8	8.3	10.6	13.2	16.4	19.7	23.2
20% DOD									
Vehicle DC Energy Consumption (Wh/km)	112	115	124	132	147	158	175	194	216
Average Battery Voltage (V)	307	306	304	303	299	294	290	285	277
Average Battery Current (A)	16.6	18.6	23.2	26.2	35.7	46.6	54.1	64.9	83.0
Average Battery Power (kW)	5.1	5.7	6.8	8.1	10.7	13.7	15.4	18.5	23.0
40% DOD									
Vehicle DC Energy Consumption (Wh/km)	113	117	135	136	149	160	177	200	219
Average Battery Voltage (V)	306	305	303	300	296	293	287	282	274
Average Battery Current (A)	14.8	16.9	22.7	30.4	39.2	45.3	55.4	68.6	82.6
Average Battery Power (kW)	4.7	5.3	6.7	9.1	11.6	13.3	15.9	19.3	22.6
60% DOD									
Vehicle DC Energy Consumption (Wh/km)	118	114	132	135	147	159	177	194	215
Average Battery Voltage (V)	303	302	299	297	294	290	286	278	270
Average Battery Current (A)	14.9	19.6	26.7	29.0	35.4	44.9	50.1	67.8	83.6
Average Battery Power (kW)	4.6	5.9	7.8	8.6	10.4	13.0	14.3	18.8	22.5
80% DOD									
Vehicle DC Energy Consumption (Wh/km)	107	110	122	129 *	143 *	156 *	175	193	213
Average Battery Voltage (V)	298	298	296	292	289	285	279	272	264
Average Battery Current (A)	13.2	18.1	23.2	29.7	37.8	45.9	48.7	69.3	86.2
Average Battery Power (kW)	3.9	5.4	6.9	8.6 *	10.7 *	13.0 *	13.7	18.8	22.8

* Does not include battery cooling

Table 6. Detailed results of Energy Economy Test No. LECO601.

	Nominal Speed (km/h)								
	40	48	56	64	72	80	88	96	104
0% DOD									
Vehicle DC Energy Consumption (Wh/km)	128	126	131	137	150	167	179	207	221
Average Battery Voltage (V)	309	308	306	304	301	297	294	287	281
Average Battery Current (A)	16.7	19.8	24.0	28.9	36.4	45.1	54.2	69.6	82.3
Average Battery Power (kW)	5.1	6.1	7.3	8.8	10.9	13.5	15.9	20.0	23.2
20% DOD									
Vehicle DC Energy Consumption (Wh/km)	116	115	124	137	149	164	177	195	219
Average Battery Voltage (V)	307	306	304	301	298	294	290	284	277
Average Battery Current (A)	15.3	18.2	23.0	29.6	36.2	44.8	54.1	66.3	82.2
Average Battery Power (kW)	4.7	5.6	7.0	8.9	10.7	13.2	15.6	18.8	22.9
40% DOD									
Vehicle DC Energy Consumption (Wh/km)	107	113	119	128	142	157	174	194	218
Average Battery Voltage (V)	306	305	303	301	297	293	288	280	270
Average Battery Current (A)	14.0	18.1	22.0	27.6	34.6	43.2	54.1	66.6	84.8
Average Battery Power (kW)	4.3	5.5	6.7	8.3	10.3	12.6	15.4	18.7	22.8
60% DOD									
Vehicle DC Energy Consumption (Wh/km)	104	109	114	127	141	153	172	190	209
Average Battery Voltage (V)	299	299	297	294	291	287	281	275	267
Average Battery Current (A)	13.9	17.6	21.4	28.0	35.1	42.9	54.4	66.0	81.9
Average Battery Power (kW)	4.2	5.3	6.4	8.3	10.2	12.3	15.3	18.3	21.8
80% DOD									
Vehicle DC Energy Consumption (Wh/km)	110 *	108	118	125	138	152	168	185	203
Average Battery Voltage (V)	294	294	292	290	286	281	274	268.6	261
Average Battery Current (A)	16.1	17.8	22.7	27.9	35.1	43.5	54.5	66.3	80.4
Average Battery Power (kW)	4.5	5.2	6.6	8.1	10.0	12.2	14.9	17.84	21.0

* Does not include battery cooling

Federal Urban Driving Schedule (FUDS)

Two Federal Urban Driving Schedule (FUDS) tests were performed. These tests involved driving the vehicle on the dynamometer while following the FUDS speed-time profile until either the vehicle LOS was displayed, and the sub-cycle was completed, or until the vehicle could not meet the minimum performance requirements. A graph showing vehicle speed, traction battery power and auxiliary battery power for one of these tests is shown in Figure 7. Note in Figure 7 the auxiliary power increases for a period of time in response to the battery heating on discharge.

A cycle-by-cycle analysis of the data for each of the two FUDS tests are shown in Tables 7 and 8. Energy consumption values reported in this table are not corrected for the energy required for traction battery heating and cooling.

Highway Fuel Economy Driving Schedule

One Highway Fuel Economy Test driving profile test was performed (test number LECO606). This profile was driven repeatedly without rest periods until the LOS indicator was displayed. Figure 8 shows the vehicle speed, traction battery power and auxiliary power during this test. The increase in the auxiliary power (AUX_PWR) over the apparent baseline at the beginning of the test is due to the battery heaters being energized. The increases noted during cycles 8 to 9 and 11 to 12 are due to the battery cooling system turning on. Cycle-by-cycle results are given in Table 9. Energy consumption values reported in this table are not corrected for the energy required for traction battery heating and cooling.

Figure 7. Speed, traction battery power and auxiliary power during FUDS Test No. LECOF608.

Figure 7. (Continued)

Figure 7. (Continued)

Table 7. Cycle-by-cycle results of FUDS Test No. LECOF605.

	Cycle Number											
	1	2	3	4	5	6	7	8	9	10	11	12
General:												
Distance (km)	12.2	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.2
Vehicle DC Energy Consumption (Wh/km)	203.9	196.1	195.0	194.6	198.0	195.2	196.3	195.2	193.5	194.2	194.4	193.6
Gross Ampere-hours (Ah)	8.9	8.9	8.9	8.9	9.0	8.8	8.9	8.9	8.8	8.9	8.9	9.0
Regen Ampere-hours (Ah)	0.3	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6
Net Ampere-hours (Ah)	8.6	8.3	8.2	8.2	8.4	8.3	8.3	8.3	8.2	8.3	8.3	8.4
Gross DC Energy (kWh)	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5	2.6
Regen DC Energy (kWh)	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Net DC Energy (kWh)	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.3	2.4
Driving Cycle Discharge Information:												
Minimum Battery Voltage (V)	233.7	255.3	248.7	243.8	242.4	228.5	236.0	227.3	226.1	246.0	234.6	255.0
Maximum Battery Current (A)	203.6	150.4	167.0	181.4	187.4	230.0	215.9	242.9	237.2	166.9	202.8	155.0
Maximum Battery Power (kW)	47.6	38.4	41.5	44.2	45.4	52.5	49.1	54.4	53.8	41.7	48.4	39.2
Average Speed (km/h)	31.9	31.8	31.8	31.7	31.7	31.8	31.7	31.7	31.7	31.7	31.7	31.9
Average Battery Power (kW)	6.5	6.2	6.2	6.2	6.3	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Average Battery Current (A)	22.5	21.7	21.6	21.6	21.9	21.7	21.7	21.7	21.6	21.8	21.7	21.9
Driving Cycle Regen Information:												
Maximum Battery Voltage (V)	317.6	319.9	319.9	318.2	318.5	317.5	317.1	317.6	317.1	316.1	315.7	313.8
Maximum Battery Current (A)	19.2	27.8	28.5	29.1	28.7	28.3	32.1	28.3	26.4	27.4	29.9	32.6
Maximum Battery Power (kW)	5.8	8.7	9.1	9.3	8.9	8.8	10.3	9.0	7.8	8.6	8.2	10.2
Auxiliary (non-traction) System Information:												
Average Auxilliary Power (kW)	0.12	0.11	0.07	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Auxilliary Energy Consumption (kWh)	0.05	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 7. (Continued).

Cycle Number											
13	14	15	16*								

General:

Distance (km)	12.1	12.1	12.1	1.3							
Vehicle DC Energy Consumption (Wh/km)	194.2	196.4	192.1	197.9							
Gross Ampere-hours (Ah)	9.1	9.3	9.4	1.1							
Regen Ampere-hours (Ah)	0.7	0.6	0.7	0.1							
Net Ampere-hours (Ah)	8.4	8.6	8.7	1.0							
Gross DC Energy (kWh)	2.6	2.6	2.5	0.3							
Regen DC Energy (kWh)	0.2	0.2	0.2	0.0							
Net DC Energy (kWh)	2.4	2.4	2.3	0.3							

Driving Cycle Discharge Information:

Minimum Battery Voltage (V)	233.2	241.2	239.7	262.4							
Maximum Battery Current (A)	218.5	172.9	165.4	86.8							
Maximum Battery Power (kW)	50.5	41.7	39.6	22.7							
Average Speed (km/h)	31.9	31.8	31.8	23.1							
Average Battery Power (kW)	6.2	6.3	6.1	5.1							
Average Battery Current (A)	22.1	22.7	22.8	17.2							

Driving Cycle Regen Information:

Maximum Battery Voltage (V)	312.9	305.7	300.2	294.3							
Maximum Battery Current (A)	32.0	21.1	23.9	16.7							
Maximum Battery Power (kW)	9.9	6.3	7.4	4.9							

Auxiliary (non-traction) System Information:

Average Auxiliary Power (kW)	0.10	0.20	0.11	0.15							
Auxiliary Energy Consumption (kWh)	0.04	0.08	0.04	0.01							

* Partial cycle. Test terminated at 203 seconds of cycle number 16.

Table 8. Cycle-by-cycle results of FUDS test No. LECOF608.

	Cycle Number											
	1	2	3	4	5	6	7	8	9	10	11	12
General:												
Distance (km)	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
Vehicle DC Energy Consumption (Wh/km)	208.8	198.3	197.4	201.2	197.6	197.8	196.2	196.1	195.4	196.3	195.0	195.2
Gross Ampere-hours (Ah)	9.0	9.0	9.0	9.1	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.1
Regen Ampere-hours (Ah)	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
Net Ampere-hours (Ah)	8.8	8.4	8.4	8.5	8.3	8.4	8.3	8.3	8.3	8.4	8.4	8.5
Gross DC Energy (kWh)	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Regen DC Energy (kWh)	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Net DC Energy (kWh)	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Driving Cycle Discharge Information:												
Minimum Battery Voltage (V)	251.1	253.0	235.5	241.4	234.7	244.5	234.9	233.1	233.6	247.2	229.2	242.4
Maximum Battery Current (A)	156.7	163.6	204.8	188.3	202.4	178.2	204.8	216.5	217.4	171.1	226.1	185.1
Maximum Battery Power (kW)	38.8	40.8	45.2	45.5	47.8	43.6	48.3	50.5	50.8	40.6	51.5	44.9
Average Speed (km/h)	31.8	31.8	31.8	31.7	31.7	31.7	31.8	31.7	31.7	31.7	31.8	31.8
Average Battery Power (kW)	6.6	6.3	6.3	6.4	6.3	6.3	6.2	6.2	6.2	6.2	6.2	6.2
Average Battery Current (A)	23.0	21.9	21.9	22.3	21.9	22.0	21.9	21.9	21.9	22.0	22.0	22.2
Driving Cycle Regen Information:												
Maximum Battery Voltage (V)	317.4	320.3	318.5	317.9	318.8	318.0	320.1	318.0	315.8	317.0	313.7	313.9
Maximum Battery Current (A)	18.1	28.2	27.1	27.5	28.9	26.5	32.1	27.0	32.3	27.6	26.9	31.1
Maximum Battery Power (kW)	6.0	9.0	8.6	8.2	9.2	8.4	10.3	8.5	10.2	8.6	8.4	9.6
Auxiliary (non-traction) System Information:												
Average Auxilliary Power (kW)	0.12	0.11	0.12	0.11	0.07	0.06	0.07	0.08	0.08	0.09	0.09	0.09
Auxilliary Energy Consumption (kWh)	0.05	0.04	0.04	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04

Table 8. (Continued).

	Cycle Number									
	13	14	15							
General:										
Distance (km)	12.1	12.1	12.1							
Vehicle DC Energy Consumption (Wh/km)	195.9	195.9	198.2							
Gross Ampere-hours (Ah)	9.2	9.4	9.6							
Regen Ampere-hours (Ah)	0.7	0.6	0.6							
Net Ampere-hours (Ah)	8.5	8.7	9.0							
Gross DC Energy (kWh)	2.6	2.6	2.6							
Regen DC Energy (kWh)	0.2	0.2	0.2							
Net DC Energy (kWh)	2.4	2.4	2.4							
Driving Cycle Discharge Information:										
Minimum Battery Voltage (V)	197.8	240.5	226.8							
Maximum Battery Current (A)	162.9	177.3	207.0							
Maximum Battery Power (kW)	40.4	43.0	46.6							
Average Speed (km/h)	31.8	31.8	31.9							
Average Battery Power (kW)	6.2	6.3	6.3							
Average Battery Current (A)	22.4	22.9	23.5							
Driving Cycle Regen Information:										
Maximum Battery Voltage (V)	312.5	304.0	298.5							
Maximum Battery Current (A)	30.3	22.8	24.8							
Maximum Battery Power (kW)	9.5	6.3	7.3							
Auxiliary (non-traction) System Information:										
Average Auxilliary Power (kW)	0.09	0.10	0.24							
Auxilliary Energy Consumption (kWh)	0.04	0.04	0.09							

Date: 06-19-1995

Data file: LECOH606.DAF

ECOSIAR HMFET TEST LECOH606

Figure 8. Speed, traction battery power and auxiliary power measured during Highway Fuel Economy Test No. LECOH606.

Table 9. Cycle-by-cycle results of Highway Fuel Economy Test No. LECO606.

	Cycle Number											
	1	2	3	4	5	6	7	8	9	10	11	12
General:												
Distance (km)	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.5	16.6	16.6
Vehicle DC Energy Consumption (Wh/km)	185.9	180.1	177.7	177.8	175.7	176.2	175.1	175.3	175.8	172.1	174.1	176.1
Gross Ampere-hours (Ah)	11.0	10.8	10.8	10.7	10.7	10.7	10.7	10.8	10.9	10.8	11.2	11.5
Regen Ampere-hours (Ah)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3
Net Ampere-hours (Ah)	10.8	10.5	10.5	10.5	10.4	10.5	10.4	10.5	10.7	10.6	10.9	11.2
Gross DC Energy (kWh)	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0	3.0
Regen DC Energy (kWh)	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Net DC Energy (kWh)	3.1	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9	2.8	2.9	2.9
Driving Cycle Discharge Information:												
Minimum Battery Voltage (V)	259.2	256.8	255.5	247.1	255.7	245.9	249.1	242.7	249.2	241.0	243.9	227.0
Maximum Battery Current (A)	140.2	146.3	142.8	163.7	137.6	164.9	162.6	181.1	151.5	160.4	145.1	183.2
Maximum Battery Power (kW)	35.2	37.6	36.5	40.6	36.1	40.6	40.5	43.9	39.3	37.9	33.1	41.5
Average Speed (km/h)	77.1	77.1	77.2	77.1	77.2	77.0	76.9	76.9	76.9	76.9	77.1	77.2
Average Battery Power (kW)	14.3	13.8	13.7	13.7	13.6	13.6	13.5	13.5	13.5	47.8	13.4	13.6
Average Battery Current (A)	50.1	48.9	48.7	48.7	48.4	48.6	48.5	48.8	49.7	49.1	50.6	52.2
Driving Cycle Regen Information:												
Maximum Battery Voltage (V)	323.2	325.0	319.9	316.8	315.3	317.8	312.7	310.0	306.1	303.0	299.8	292.4
Maximum Battery Current (A)	35.3	48.7	36.5	36.3	32.6	50.2	38.2	36.0	33.0	43.3	31.0	27.7
Maximum Battery Power (kW)	11.4	15.8	12.4	11.5	10.3	12.0	11.9	11.1	10.7	13.1	9.9	8.0
Auxiliary (non-traction) System Information:												
Average Auxilliary Power (kW)	0.46	0.20	0.13	0.13	0.13	0.12	0.13	0.23	0.27	0.12	0.19	0.30
Auxilliary Energy Consumption (kWh)	0.10	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.06	0.03	0.04	0.06

LA-92 Driving Schedule

One LA-92 driving schedule was performed (test number LECOL607). Figure 9 shows vehicle speed, traction battery power and auxiliary power measured during this test. Cycle-by-cycle results are given in Table 10. The traction battery cooling system activated during cycles 6 and 8 during this test as indicated by the increase in the auxiliary power (AUX_PWR) measurement. Energy consumption values reported in Table 10 are not corrected for this effect.

Gradeability

A gradeability test was performed to ascertain the vehicle's ability to climb a grade at 88 km/h. However, dynamometer control problems precluded performing a valid test. During a portion of this discharge, while troubleshooting the dynamometer control problem, the vehicle was driven at 88 km/h against a load equivalent to an approximate 4% grade for 15 minutes (DOD from 13% to 42%). No degradation of vehicle performance was experienced during this test and no vehicle malfunctions (such as overheating) occurred.

State-of-Charge Meter and Remaining-Range Indicator Evaluation

The state-of-charge and remaining-range gauges on the vehicle were compared to measured parameters during several tests. The results of these comparisons are shown in Figure 10 for the state-of-charge indicator and in Figure 11 for the remaining-range indicator.

Figure 9. Speed, traction battery power and auxiliary power measured during LA-92 driving cycles (Test No. LECOL607).

Figure 9. (Continued).

Table 10 Cycle-by-cycle results of LA-92 driving cycles (Test No. LECOL607.

	Cycle Number											
	1	2	3	4	5	6	7	8	9	10	11	12
General:												
Distance (km)	16.0	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.8			
Vehicle DC Energy Consumption (Wh/km)	237.6	232.6	233.4	233.4	233.8	238.1	235.3	236.3	238.7			
Gross Ampere-hours (Ah)	14.6	14.6	14.6	14.8	14.8	15.0	15.2	15.2	15.6			
Regen Ampere-hours (Ah)	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8			
Net Ampere-hours (Ah)	13.9	13.6	13.6	13.8	13.8	14.0	14.1	14.3	14.8			
Gross DC Energy (kWh)	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.0	4.0			
Regen DC Energy (kWh)	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2			
Net DC Energy (kWh)	3.8	3.7	3.7	3.7	3.7	3.8	3.7	3.8	3.8			
Driving Cycle Discharge Information:												
Minimum Battery Voltage (V)	215.4	217.6	220.2	223.1	224.5	225.9	221.8	223.9	210.8			
Maximum Battery Current (A)	255.7	250.1	246.5	265.9	236.9	233.5	234.3	224.6	237.9			
Maximum Battery Power (kW)	54.9	54.4	54.4	56.0	53.4	52.9	52.1	51.0	50.4			
Average Speed (km/h)	40.1	39.9	39.9	40.0	40.0	39.9	40.0	40.0	39.7			
Average Battery Power (kW)	10.1	10.1	10.1	10.2	10.2	10.3	10.2	10.2	10.1			
Average Battery Current (A)	35.0	34.2	34.3	34.7	34.6	35.3	35.5	35.9	37.2			
Driving Cycle Regen Information:												
Maximum Battery Voltage (V)	325.8	329.8	327.3	323.6	322.1	322.9	320.2	317.3	302.9			
Maximum Battery Current (A)	46.1	60.0	55.8	48.7	54.0	59.9	73.7	52.1	25.1			
Maximum Battery Power (kW)	14.4	19.5	17.6	18.5	17.4	18.4	22.7	17.2	7.7			
Auxiliary (non-traction) System Information:												
Average Auxilliary Power (kW)	0.15	0.11	0.11	0.12	0.12	0.23	0.14	0.28	0.16			
Auxilliary Energy Consumption (kWh)	0.06	0.04	0.04	0.05	0.05	0.09	0.05	0.11	0.06

Figure 10. State-of-charge readings as measured against net ampere-hours for various driving cycles.

Figure 11. Miles-to-discharge compared to actual distance remaining to LOS.

OBSERVATIONS

Several observations are made relative to the Ecostar vehicle as a result to performing the tests:

- This Ecostar vehicle exhibits consistent performance over the entire driving range (up to the point of LOS) with respect to energy consumption measurements between successive driving cycles and driver-observable acceleration performance. During the driving cycle tests, no observable acceleration degradation was noted as the battery state-of-charge decreased.
- The state-of-charge meter appears to accurately track the net DC ampere-hours out of the traction battery, and indicates "empty" at approximately the point that the Limited Operating Strategy (LOS) goes into effect.
- The remaining-range indicator does not provide an accurate prediction of range at the beginning of driving, usually indicating less distance than eventually driven. However, the accuracy of the prediction improves as distance is accumulated and appears to adequately predict the distance remaining on the present battery charge when the remaining range is below 40 miles. This behavior is typical of range prediction devices since they must rely on previous driving history in order to predict into the future the potential distance that can be traveled. Therefore, it should be noted that the results reported in Figure 11 are highly dependent on the order of tests performed.
- Acceleration performance was more than adequate to negotiate the test cycles. However, during the LA-92 driving cycles, it was difficult to follow the driving profile during deceleration because of tire slippage due to insufficient friction between the tires and the dynamometer rolls.
- Instrumenting the vehicle proved difficult in several respects:

1. The electric noise generated by the vehicle subsystems made it difficult to obtain "clean" measurement signals,
2. In some instances, the instrumentation interfered with the vehicle control systems and much care was needed to avoid damage to both the vehicle and the data acquisition system, and
3. The vehicle's built-in ground fault protection causes the traction battery voltage to periodically be applied through a high impedance to the vehicle chassis. This is a safety feature to assure isolation of the traction battery, but causes unpredictable ground loops through the laboratory instrumentation and data acquisition system.

RECOMMENDATIONS

Due to funding constraints, a full complement of measurements and vehicle performance tests could not be obtained. Recommendations for additional tests, measurements that should be obtained to more fully characterize the performance of this vehicle, and suggested areas of additional investigation include the following:

- Perform independent coastdown tests for determining vehicle load-characteristics
- Obtain vehicle DC and AC power/energy measurements during charge to ascertain charger efficiency and to determine the system AC energy consumption for all driving regimes. These measurements should be performed using both available AC input voltages.
- Perform maximum effort acceleration tests on a dry level roadway
- Perform gradeability tests (i.e. 5% grade at 88 km/h) as per the original test plan
- Perform the FUDS/HWFET driving cycle tests as specified by SAE J1634
- Measure energy required for battery heating and other "stand-by" functions
- Perform standard driving cycle tests with major accessories (such as air conditioning, cab heater and headlamps) turned on to ascertain the affect of these accessories on vehicle energy consumption and range.