Idaho National Engineering Laboratory

INEL-96/0090

April 1996

Dynamometer Testing of the U.S. Electricar Geo Prizm Conversion Electric Vehicle

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DISCLAIMER

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Assistance Secretary for Energy Efficiency and Renewable Energy (EE)
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EXECUTIVE SUMMARY

A Geo Prizm electric vehicle conversion by U.S. Electricar was tested in the INEL HEV Laboratory over several standard driving regimes. The vehicle, owned by the Los Angeles Department of Water and Power (LADWP), was loaned to the INEL for performance testing under a Cooperative Research and Development Agreement (CRADA) between the U.S. Department of Energy (DOE) and the California Air Resources Board (CARB). The Prizm conversion is the fourth vehicle in the planned test series. A summary of the test results is presented as Table ES-1.

For the LA-92 and the Highway Fuel Economy Test cycles, the driving cycle ranges were 71 and 95 km, respectively. The net DC energy consumption during these cycles was measured at 199 and 154 W·h/km, respectively.

During the constant-current-discharge test, the vehicle was driven 150 km at an average steady speed of 43 km/h.

Energy consumption at various steady-state speeds, averaged over two tests, was approximately 108 W·h/km at 40 km/hr and 175 W·h/km at 96 km/h at 80T state-of-charge (SOC).

Gradeability-at-speed tests indicated that the vehicle can be driven at 80 km/h up a simulated 5% grade for periods up to 15 minutes beginning at an initial 100% SOC, and 3 minutes beginning at 80% battery depth-of-discharge (DOD).

Maximum-effort vehicle acceleration times were determined at five different battery DODs and speeds from 24 to 104 km/h. The acceleration is approximately linear up to 48 km/h, with no DOD effect; at higher speeds the curve becomes non-linear, and the effect of DOD becomes increasingly evident. Gradeability at each of these speeds was also determined, showing a decrease from the initial 26% at 24 km/h to 4% at 104 km/h.

Evaluation of the SOC meter reveals random deviations from linearity.

Speedometer calibration showed the speedometer to be nearly linear over the range of 42 to 97 km/h, with a positive error of approximately 5.1 km/h.

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

VEHICLE DESCRIPTION

VEHICLE TYPE

Manufacturer:	U. S. Electricar
Model:	1994 Geo Prism (conversion)
VIN:	1Y1SK5363RZ082892
Seating Capacity:	4
Drive configuration:	Front motor, front wheel drive

DIMENSIONS

Wheelbase:	2459 mm
Track F/R:	1461/1440 mm
Length:	1461 mm
Width:	1692 mm
Height:	1402 mm
Ground Clearance:	165 mm
Cargo Volume:	N/A

WEIGHTS

Curb Weight:	1578 kg
Inertia Test Weight:	1714 kg
GVWR:	1822 kg

WHEELS & TIRES

Tire Mfg. & Type:	Firestone
Tire Size:	P175/65R14
Tire Pressure (F/R):	35/35 psi

DRIVE SYSTEM

Type:	3 Phase vector AC
Motor:	Hughes Power Control Systems
Controller Mfg.	Hughes Power Control Systems
Transmission:	Single speed
Gear Ratio:	

BATTERY

Mfg.:	Hawker
Model:	Genesis G12V26AH10C
Type:	Sealed Lead-acid
Rated Capacity:	45 Ah @ C/3
Number of Modules:	50
Nominal Voltage:	300 V
Weight:	approx 500 kg (modules only)

CHARGER

Input Voltage:	110/220
Input Power:	NA

MISCELLANEOUS

Power Steering, Power Brakes (front disk)

Parameters Derived from Coastdown

Aerodynamic drag coefficient:	0.45
Frontal Area (.8 x W x H):	1.90 sq. m.
Drag Area Product:	0.85 sq. m.
Tire rolling resistance:	0.0105

TEST RESULTS

40A (C/3 rate) CONSTANT CURRENT RANGE
(Average of two tests)

Range (km)	150
Net Veh. DC E. C. (Wh/km)	105
Average Speed (km/h)	43
AC E. C. (Wh/km)	166

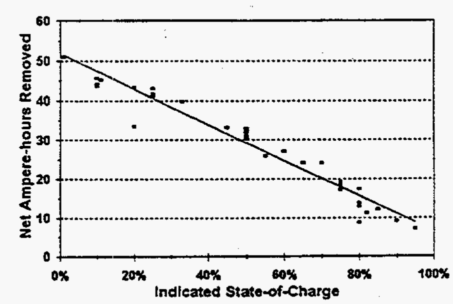
DRIVING CYCLES

(Average of two range tests)	LA92	UDDS	HFEDS
Range (km)	71	82	95
Net DC E. C. (Wh/km)	199	167	154
Gross DC E. C. (Wh/km)	232	195	161
AC E. C. (Wh/km)	331	274	249

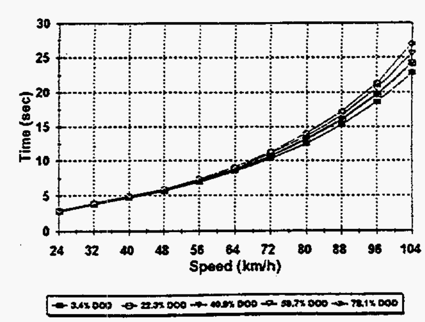
ENERGY ECONOMY @ SPEED (Wh/km)
(Average of two tests)

	Nominal State-of-Charge				
Speed	100%	80%	60%	40%	20%
40 km/h	142	108	107	103	102
48 km/h	136	118	109	106	107
56 km/h	137	120	118	113	113
64 km/h	140	129	125	122	122
72 km/h	146	143	134	130	136
80 km/h	155	149	147	147	145
88 km/h	165	160	155	154	155
96 km/h	180	175	171	173	164

State-of-Charge Meter Evaluation



Acceleration



ABSTRACT

A Geo Prizm vehicle, converted to electric-powered operation by U.S. Electricar, was tested in the Hybrid Electric Vehicle (HEV) Laboratory at the Idaho National Engineering Laboratory (INEL), for the California Air Resources Board. The vehicle is owned and operated by the Los Angeles Department of Water and Power. Results of several dynamometer driving cycles, vehicle acceleration, gradeability tests, and constant-current discharge range evaluations are presented. Results of observations of the vehicle speedometer accuracy are also presented.

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DYNAMOMETER TESTS
OF THE
U. S. ELECTRICAR GEO PRIZM CONVERSION ELECTRIC VEHICLE

INTRODUCTION

A series of electric vehicles have been performance-tested in the HEV Laboratory at the INEL. These vehicles and their performance are of interest to CARB for tracking electric vehicle (EV) technology pursuant to the California Program support the commercialization of the sale of zero-emission. The testing has been done under Task 2 of a CRADA between the DOE and CARB; the testing methodology and techniques have also been transferred to the CARB vehicle testing laboratory. This report presents the results of dynamometer tests performed on a Geo Prizm sedan converted to electric operation by Hughes/U.S. Electricar. This vehicle is owned and operated by the LADWP, and was on temporary loan for the tests at the INEL.

The vehicle was manufactured in 1994 and then converted by U.S. Electricar to a 50 kW 3-phase AC induction electric drive. The traction battery pack consists of 50 Hawker Genesis G12V26AH10C sealed lead-acid battery modules arranged in two parallel banks with 25 modules in each bank. The battery packs are located below the passenger compartment. An on-board charger operates from either 110 or 220 VAC. The vehicle was delivered to the INEL on July 14, 1995. The tests were conducted in conformance with a formal Test Plan, "EHV-TP-33, Test Plan for the Prototype Electric Vehicle From U.S. Electricar," from July 20, 1995 to September 7, 1995. At the start of the testing, the vehicle odometer reading was 3,832 miles.

TEST PROGRAM AND RESULTS

Measurements and Data Acquisition

Measurements were made with the Laboratory Data Acquisition System (LDAS). A total of 30 actual and calculated parameters were recorded during all tests. All data channels were recorded at 1-second intervals. The nomenclature for the measurements derived from this instrumentation is referenced to the data field names listed in Table 1. Test numbers coincide with filenames of the Idaho National Engineering Laboratory (INEL) standard format data files for each test. The Vehicle Test Data Summary Sheet shown in Table 2 provides a summary of the test files archived at the INEL.

The test program comprised, in sequence, road coastdown tests which supplied road-load input to dynamometer calibration set-up, and a series of dynamometer tests:

- Constant-current range determination
- Urban Dynamometer Driving Schedule (UDDS)
- Highway Fuel Economy Driving Schedule (HFEDS)
- LA-92 Driving Schedule
- Energy economy at speed
- Maximum-effort acceleration versus speed for specified battery DOD and fixed grade
- Gradeability operation for specified DODs, vehicle speed, and grade.

The road coastdown test data measured in Idaho Falls (4800 ft/1462 m elevation) were corrected to sea level before use. Separate battery tests were not conducted. The vehicle test weight was 3,778 lb (1714 kg).

Additional features to be checked during the test series were the SOC meter and the vehicle speedometer.

Table 1. List of measurements recorded on the Laboratory Data Acquisition System (LDAS)

Measurement	Units	Explanation
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
PACK_VOLT	VOLT	Backup traction battery voltage reading
PACK_CURR	AMPS	Backup traction battery current reading
PACK_PWR	KW	Backup traction battery power reading
AUX_VOLT	VOLT	Auxiliary systems voltage
AUX_CURR	AMPS	Auxiliary systems current
AUX_PWR	KW	Auxiliary systems power
DISTANCE	KM	Cumulative distance
DYNO_HP	KW	Dynamometer power
DYNO_TRQ	NM	Dynamometer torque
TEMP_1-REF	DEGC	Thermocouple reference temperature
BAT_TEMP_1	DEGC	Traction battery temperature (1 module)

Table 2. Vehicle test data summary sheet.

U. S. Electricar Geo Prism (loaned by Los Angeles Dept. of Water and Power)

DISCHARGE													CHARGE								
TEST NUMBER	DATE	TEST TYPE	AHout	AHin	AHnet	kWout	kWin	kWnet	Distance (km)	DC Wh/km (gross)	DC Wh/km (net)	TTT HH:MM:SS	TEST NUMBER	DATE	AH	kWh (Battery)	kWh (wall)	Charge % Return	AC Wh/km	TTC HH:MM:SS	COMMENTS
LAN1C720	7/20/95	CD							3.0			00:03:45									Coastdown tests on road, drive axles in place.
LAS1C720	7/20/95	CD							3.3			00:03:30									"
LAN2C720	7/20/95	CD							3.0			00:03:46									"
LAS2C720	7/20/95	CD							3.4			00:04:16									"
LAN3C720	7/20/95	CD							3.0			00:04:09									"
LAS3C720	7/20/95	CD							3.3			00:04:23									"
LAN4C720	7/20/95	CD							2.9			00:05:11									"
LAS4C720	7/20/95	CD							3.3			00:03:35									"
LAN1C801	8/1/95	CD							2.8			00:03:20									Coastdown tests on road, drive axles removed.
LAS1C801	8/1/95	CD							3.2			00:04:23									"
LAN2C801	8/1/95	CD							3.0			00:03:54									"
LAS2C801	8/1/95	CD							3.3			00:04:02									"
LAN3C801	8/1/95	CD							3.1			00:03:45									"
LAS3C801	8/1/95	CD							3.3			00:04:06									"
LAN4C801	8/1/95	CD							3.2			00:04:00									"
LAS4C801	8/1/95	CD							3.3			00:04:21									"
LAN5C801	8/1/95	CD							3.4			00:03:55									"
LAS5C801	8/1/95	CD							3.7			00:04:43									"
LAN6C801	8/1/95	CD							3.6			00:04:47									"
LAS6C801	8/1/95	CD							3.8			00:04:53									"
LLAAOC01	8/7/95	CD							1.8			00:03:32									Dynamometer coastdowns, drive axles removed.
LLAAOC02	8/7/95	CD							2.0			00:03:04									"
LLAAOC03	8/7/95	CD							2.0			00:02:55									"
LLAAOC04	8/7/95	CD							2.0			00:03:43									"
LLAAOC05	8/7/95	CD							2.0			00:03:11									"
LLADAOC1	8/7/95	CD							4.3			00:05:04									"
LLADAOC2	8/7/95	CD							4.4			00:05:44									"
LLADAOC3	8/7/95	CD							4.4			00:05:00									"
LLADAOC4	8/7/95	CD							4.3			00:04:50									"
LLADAI01	8/8/95	CD							0.0			00:00:03									Test invalid - False start
LLADAIC2	8/9/95	CD							2.0			00:02:28									Dynamometer coastdowns, drive axles in place.
LLADAIC3	8/9/95	CD							2.0			00:03:06									"
LLADC001	8/9/95	CD							4.8			00:03:06									"
LLADC002	8/9/95	CD							3.9			00:02:29									"
LADWPC01	8/15/95	CD							5.3			00:04:08									Dyno coastdowns, axles in, A=0, B=0, C=0
LADWPC02	8/15/95	CD							5.2			00:04:31									"
LLADI817	8/17/95	CC	54.8	0.1	54.8	16.1	0.0	16.1	155.4	104	104	03:40:22					24.8		160	NA	
LLADF821	8/21/95	UDDS	51.0	6.6	44.4	15.2	2.1	13.1	77.4	196	169	02:53:55					21.4		276	NA	
LLADE821	8/22/95	EE	11.8	0.2	11.6	3.6	0.1	3.5	24.7	146	143	00:27:35					NA		NA	NA	Test invalid
LLADH823	8/23/95	HFEDS	53.6	2.2	51.4	15.6	0.7	14.9	96.4	162	155	01:35:40					24.1		250	NA	
LLADL824	8/24/95	LA-92	58.9	7.7	51.1	16.9	2.4	14.5	72.7	232	200	02:31:25	LLADX824	8/24/95	64.2	20.5	24.0	126%	330	15:27:44	
LLADB825	8/25/95	ACCEL	39.9	3.3	36.7	11.8	1.1	10.7	72.2	163	148	01:40:21	LLADX825	8/25/95	47.2	14.8	18.0	129%	250	17:51:34	
LLADG826	8/26/95	5% GRAD	42.0	0.2	41.8	12.1	0.1	12.0	29.3	411	409	00:50:12	LLADX826	8/26/95	65.0	16.5	20.3	132%	691	27:28:04	
LLADE827	8/27/95	EE	45.6	0.9	44.6	13.4	0.3	13.1	92.2	145	142	01:27:27	LLADX827	8/27/94	53.3	17.4	21.5	119%	233	11:09:37	
LLADF828	8/28/95	UDDS	57.2	7.8	49.4	16.6	2.4	14.2	86.0	194	165	03:12:20	LLADX828	8/28/95	59.3	19.3	23.3	120%	271	12:13:20	
LLADH829	8/29/95	HFEDS	51.2	2.4	48.8	14.9	0.8	14.1	92.6	161	153	01:32:35	LLADX829	8/29/95	58.2	19.0	23.0	119%	248	10:17:39	
LLADL830	8/30/95	LA-92			Test invalid - Driver Aid Failure								LLADX830	8/30/95	8.6	26.3	10.2	NA	NA	NA	Test invalid - Driver Aid Failed
LLADL831	8/31/95	LA-92	55.1	7.4	48.0	15.9	2.3	13.7	68.7	231	199	02:24:29	LLADX831	8/31/95	59.1	18.8	22.8	123%	331	16:31:54	
LLADB901	9/1/95	ACCEL	39.9	3.1	37.0	11.8	1.0	10.8	71.2	165	152	01:41:29	LLADX901	9/1/95	49.5	14.7	18.7	134%	263	27:20:56	
LLADG905	9/5/95	5% GRAD	39.9	0.1	39.9	11.4	0.0	11.4	28.4	401	401	00:40:46	LLADX905	9/5/95	50.6	15.9	19.4	127%	684	17:44:41	
LLADE906	9/6/95	EE	44.6	1.3	43.5	13.1	0.4	12.7	93.0	141	137	01:28:07	LLADX906	9/6/95	54.1	17.2	20.9	124%	225	15:57:00	
LLADI907	9/7/95	CC	52.1	0.1	52.1	15.4	0.0	15.4	144.3	106	106	03:22:54	LLADX907	9/7/95	64.7	20.4	24.8	124%	172	17:25:33	

IDENTIFICATION		
VIN:		1Y1SK5363RZ082892
Curb Weight:		1578 kg (3480 lb)
Payload:		136 kg (300 lb)
GVWR:		1822 kg (4018 lb)
Inertia Test Weight:		1714 kg (3780 lb)
Battery:	Hawker Genesis	G12V26AH10C
	Weight:	approx. 500 kg (1150 lb)
	Type:	sealed lead-acid
	Nominal Voltage:	300 v

TEST TYPE LEGEND	
CD	Coastdown Test
CC	Constant Current Discharge
UDDS	Urban Dynamometer Driving Schedule (SAE J1634)
EE	Energy Economy Test (SAE J227a draft)
HFEDS	Highway Fuel Economy Driving Schedule (SAE J1634)
LA-92	LA-92 Driving Schedule
ACCEL	Maximum Effort Acceleration Tests (SAE J1666)
5% GRAD	Sustained 80 km/h on 5% grade

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Test Set-up

Vehicle Road Loads

The load-versus-speed characteristics representing test vehicles, and used to program the chassis dynamometer, is typically derived from vehicle coastdowns. The process involves driving the vehicle to a speed of 96 kmm/h, disengaging the drive system by either disengaging the clutch and/or placing the transmission into "neutral," and measuring the resultant speed and time while the vehicle coasts to a speed of <16 km/h. The measured speed-time data are then mathematically manipulated to determine the representative load at speed corrected to standard atmospheric conditions (temperature and pressure). This method has been used with good accuracy for many years on conventional vehicles where the drive system can be decoupled from the vehicle wheels. However, for vehicles whose drives cannot be decoupled from the wheels (i.e., in the case of the Geo Prizm test vehicle), the effect of the connected drive system on resulting road-load calculations can be significant. Furthermore, if the conventional method of determining the vehicle road loads is employed, the resultant load programmed into the dynamometer will include the contribution of the engaged drive system. Therefore, during a dynamometer test, the vehicle traction motor will be working against the normal transmission and other driveline loads, and the loads programmed into the dynamometer which also include these loads. In effect, the load on the vehicle driveline will include twice the losses of the engaged driveline components. It is necessary to either determine the contribution of the engaged driveline components and adjust the dynamometer load settings for these losses, or eliminate these losses by disconnecting the driveline during the coastdown trials.

A series of on-the-road coastdown trials were performed to determine the driveline components' losses. The process involved performing coastdown trials with the entire driveline intact, and then repeating these trials with the vehicle drive axles removed. The latter trials necessitated towing the vehicle up to > 96 km/h and then releasing the tow cable to allow the vehicle to coast down. Coastdown trials (under the two conditions of drive axles installed and removed) were also conducted on the chassis dynamometer with no programmed loads.

Theoretically, the retarding force at speed (i.e., the contribution of the connected driveline components) can be calculated by subtracting the calculated forces of the axles-in case from those of the axles-out case.

Each coastdown speed-time data set was analyzed according to SAE J1263, "Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques," May 1984. This document presents the methodology for deriving the road-load force-speed characteristics of a vehicle from coastdown data. The results of these analysis presents the road loads as a function of vehicle speed in the mathematical form:

$$F = f'_0 + f'_2 V^2$$

Where V is vehicle speed, and the coefficients f'_0 and f'_2 are determined from the data.

Table 3 gives the coefficients derived from the coastdown trials performed on the Geo Prizm. The force-speed curves from these coefficients are shown graphically in Figure 1.

Table 3. Road load coefficients derived from Geo Prizm coastdown trials.

Test condition	f'_0 (N)	f'_2 (N/(km/h)^2)
On-road, axles-in	199.5	0.03323
On-road, axles-out	175.7	0.03838
Dynamometer, axles-in	149.9	0.00591
Dynamometer, axles out	129.4	0.00519

As shown in Figure 1, the calculated component of the connected driveline derived from both on-road coastdown data or dynamometer data are in good agreement. Based on these observations, the driveline components contribute approximately 25 N retarding force (at all speeds), representing between approximately 25% of the total road load at 20 km/h and 4% of the total road load at 100 km/h.

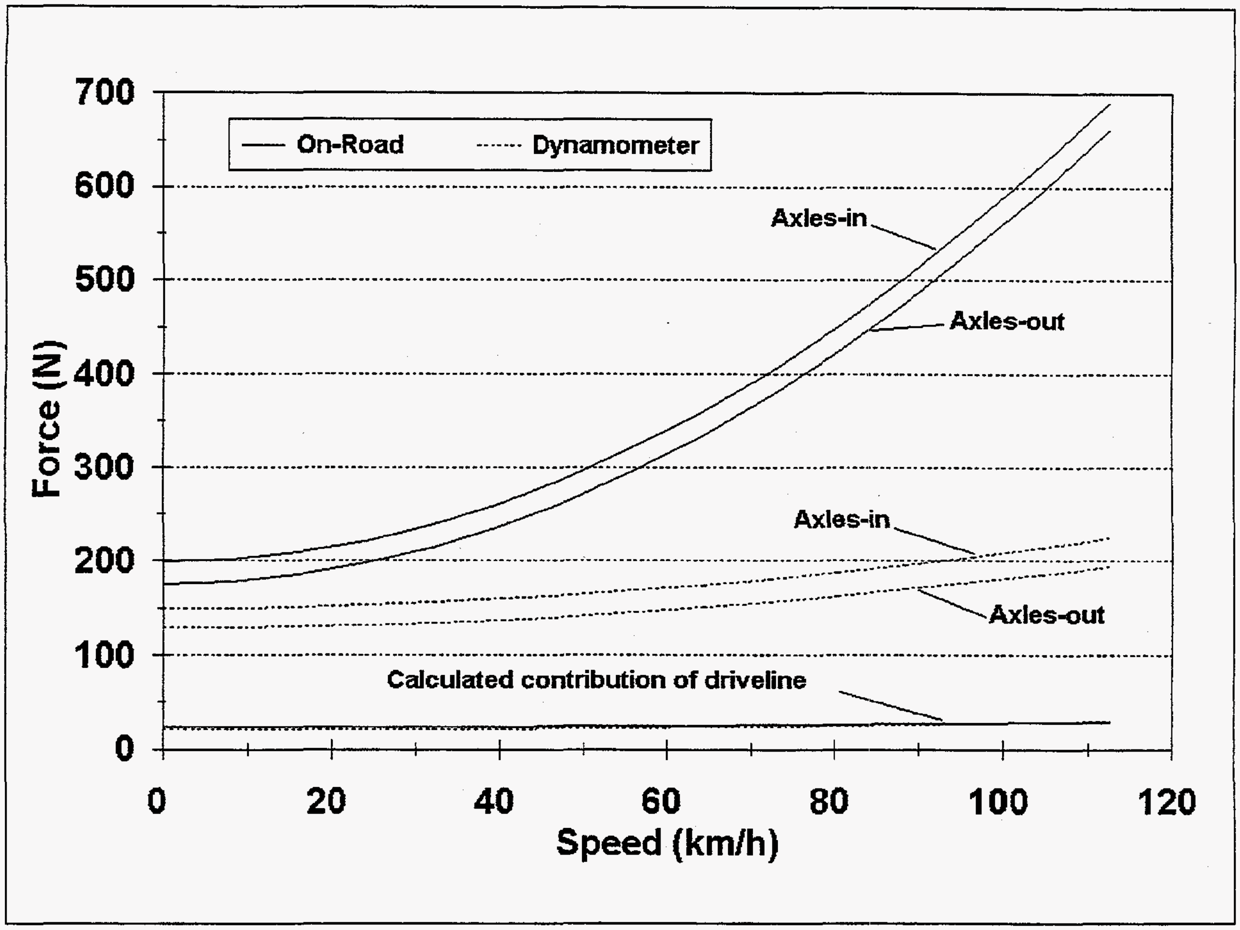

Figure 1. Road loads derived from various vehicle coastdown tests.

Chassis Dynamometer Setup

Based on the above results, it was determined that the contribution of the connected driveline components is significant when compared to the total vehicle road load and should not be included in the chassis dynamometer loads. Therefore, the dynamometer programmed loads were determined based on the on-road coastdown data for the case where the driveline was disconnected from the drive wheels. The process used in setting the dynamometer loads was as follows:

1. Determine the target speed-time coastdown curve derived from the appropriate f'_0 and f'_2 coefficient using the relationship found in SAE J1263.

2. Place the test vehicle on the chassis dynamometer.

3. Warm up the dynamometer and vehicle using the proper inertia weight settings until stabilized (in this case, drive axles were removed from the vehicle).

4. Enter an initial load into the dynamometer controller.

5. Use the dynamometer motor to drive the vehicle and dynamometer up to a speed >96 km/h. Disengage the dynamometer drive motor and allow the vehicle to coast to <16 km/h. Measure speed and time as the vehicle coasts.

6. Compare measured speed-time data to the desired (target) speed time. Calculate a new load from the data measured in Step 5, and the target speed-time of Step 1. Enter these new coefficients into the dynamometer controller.

7. Repeat Steps 5 and 6 until the measured speed-time agrees with the target speed-time within acceptable limits. Acceptable agreement between the measured speed-time and target speed time is defined as follows:

Coastdown Speed Range	Time
88 to 72 km/h	± 1 sec.
32 to 16 km/h	± 0.1 sec
96 to 16 km/h	± 1.0 sec

Figure 2 shows the target speed-time curve and the recorded speed-time points from a series of dynamometer coastdown runs best matching the target curve. Note that the agreement improves with succeeding coastdown runs due to the stabilization of the dynamometer and vehicle operating temperatures.

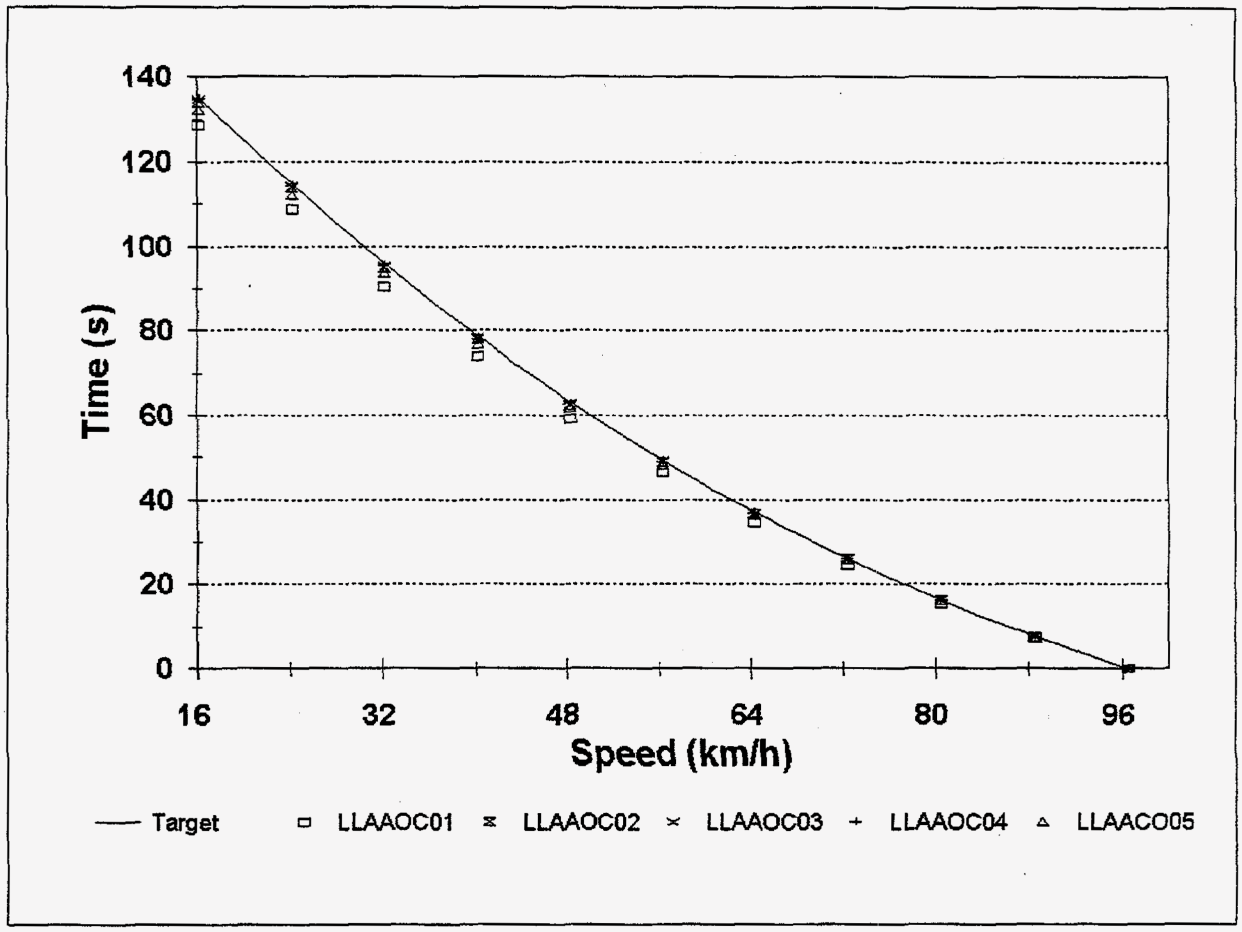

Figure 2. Dynamometer set up coastdown speed-time curve.

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 vehicle or battery manufacturer. U.S. Electricar had recommended that we terminate testing when the battery voltage dropped to 250 Vdc under load conditions.

Constant-Speed Energy Economy Tests

Two Constant-Speed Energy Economy Tests were performed (test numbers LLADE827 and LLADE906). 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 (15 A) rate. Figure 3 shows energy consumption at various nominal dynamometer speeds for five different DODs. Figure 4 shows the corresponding average battery power. It is highly probable that the curves for 0% discharge reflects a cold system; subsequent vehicle warm-up is reflected in the points for increasing DOD, until the points for 60 and 80% nearly coincide.

Driving Cycles

The results of the formal driving cycle range tests are presented in Table 4.

- Urban Dynamometer Driving schedule (UDDS)
- Highway fuel economy driving schedule (HFEDS)
- LA-92 driving schedule

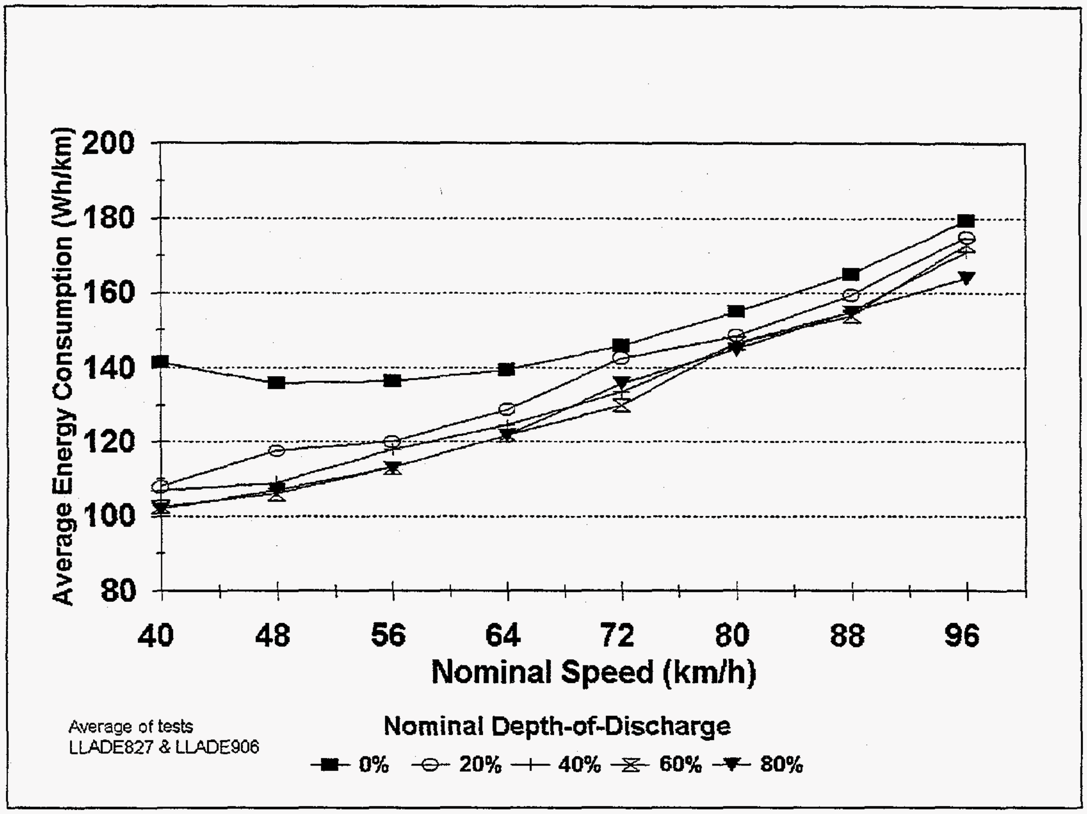

Figure 3. Average energy economy at steady speed-versus-battery depth-of-discharge.

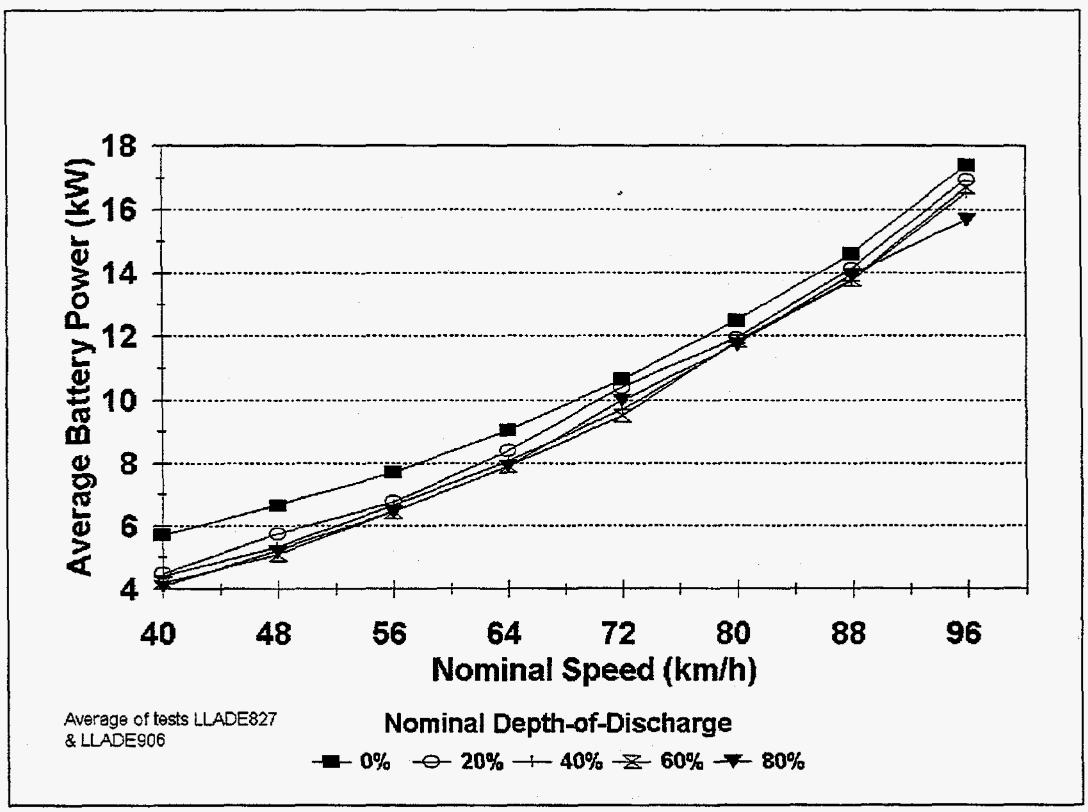

Figure 4. Average battery power at steady speed-versus-battery depth-of-discharge.

Table 4. U.S. Electricar Geo Prizm results of driving cycle range tests.

	Test Number							
	LLADI817 (Constant Current)	LLADF821 (UDDS)	LLADH823 (HFEDS)	LLADL824 (LA-92)	LLADF828 (UDDS)	LLADH829 (HFEDS)	LLADL831 (LA-92)	LLADI907 (Constant Current)
General:								
Number of completed cycles	-	6	5	4	7	5	4	-
Distance (km)	155.4	77.4	96.4	72.7	86.0	92.6	68.7	144.3
Net Vehicle DC Energy Cons. (Wh/km)	103.6	169.2	154.8	199.5	165.4	152.7	197.7	106.3
Gross Ampere-hours (Ah)	54.8	51.0	53.6	58.9	57.2	51.2	55.1	52.1
Regen Ampere-hours (Ah)	0.1	6.6	2.2	7.7	7.8	2.4	7.4	0.1
Net Ampere-hours (Ah)	54.8	44.5	51.4	51.1	49.4	48.8	47.7	52.1
Gross DC Energy (kWh)	16.1	15.2	15.6	16.9	16.6	14.9	15.9	15.4
Regen DC Energy (kWh)	0.0	2.1	0.7	2.4	2.4	0.8	2.3	0.0
Net DC Energy (kWh)	16.1	13.1	14.9	14.5	14.2	14.1	13.6	15.4
Duration of Test (HH:MM:SS)	03:38:43	02:53:01	01:34:35	02:30:37	03:11:53	01:32:08	02:23:28	03:21:01
Driving Cycle Discharge Information:								
Minimum Battery Voltage (V)	-	-	-	-	-	-	-	-
Maximum Battery Current (A)	26.1	164.6	138.7	206.8	216.7	122.5	205.4	47.0
Maximum Battery Power (kW)	7.9	47.0	40.0	59.4	50.5	36.5	57.8	14.4
Average Speed (km/h)	42.6	26.9	61.1	29.0	26.9	60.3	28.7	43.1
Average Battery Power (kW)	4.4	4.5	9.5	5.8	4.4	9.2	5.7	4.6
Average Battery Current (A)	15.0	15.4	32.6	20.4	15.4	31.8	20.0	15.5
Driving Cycle Regen Information:								
Maximum Battery Voltage (V)	320.6	345.1	350.7	362.9	348.2	360.9	364.6	326.0
Maximum Battery Current (A)	24.8	77.5	83.9	94.8	73.7	75.0	93.1	32.6
Maximum Battery Power (kW)	7.4	23.9	30.7	37.2	22.8	23.1	31.3	9.1
Recharge Information:								
AC Energy (kWh)	24.8	21.4	24.1	24.0	23.3	23.0	22.8	24.8
DC Energy (kWh)	NA	NA	NA	20.5	19.3	19.0	18.8	20.4
Charger Energy Efficiency (%)	NA	NA	NA	85%	83%	83%	82%	82%
System DC Energy Consumption	NA	NA	NA	282	224	206	273	142
System AC Energy Consumption	159.7	275.9	250.2	330.2	271.2	248.4	331.5	172.1

Table 5 presents summarized results as the average of each of two range tests for each cycle.

Table 5. Summary results of driving cycle tests.

Driving Cycle	FUDS	HFEDS	LA-92
Range (km)	52	95	71
Net DC E.C. (W·h/km)	167	154	199
Gross DC E.C. (W·h/km)	195	161	232
AC E.C. (W·h/km)	274	249	331

Battery Capacity Verification

Two battery capacity verification tests were performed by driving the vehicle on the chassis dynamometer, manually controlling the vehicle speed such that the traction battery was discharged at a constant 15 A current. During this discharge, the traction battery delivered 15 A for 3 hours and thirty-eight minutes (54.8 Ah), exceeding the battery manufacturer's rated battery capacity of 45 Ah. Table 4 provides the other significant results of these tests.

Urban Dynamometer Driving Schedule

Two Urban Dynamometer Driving Schedule (UDDS) tests (test nos. LLADF821 and LLADF828) were performed. These tests involved driving the vehicle on the dynamometer while following the FUDS speed-time profile until either the traction battery voltage dropped below 250 Vdc or until the vehicle could not meet the minimum performance requirements. A graph showing vehicle speed and traction battery data for one of these tests is shown in Figure 5. Summarized data for both tests are included in Table 4.

LA-92 Driving Schedule

Two LA-92 driving schedules were performed (test numbers LLADL824 and LLADL831). Figure 6 shows vehicle speed and traction battery data for one of these tests.

As with the UDDS tests, driving was stopped when either the vehicle could not meet the minimum performance requirements or when the battery voltage under load fell to below 250 Vdc.

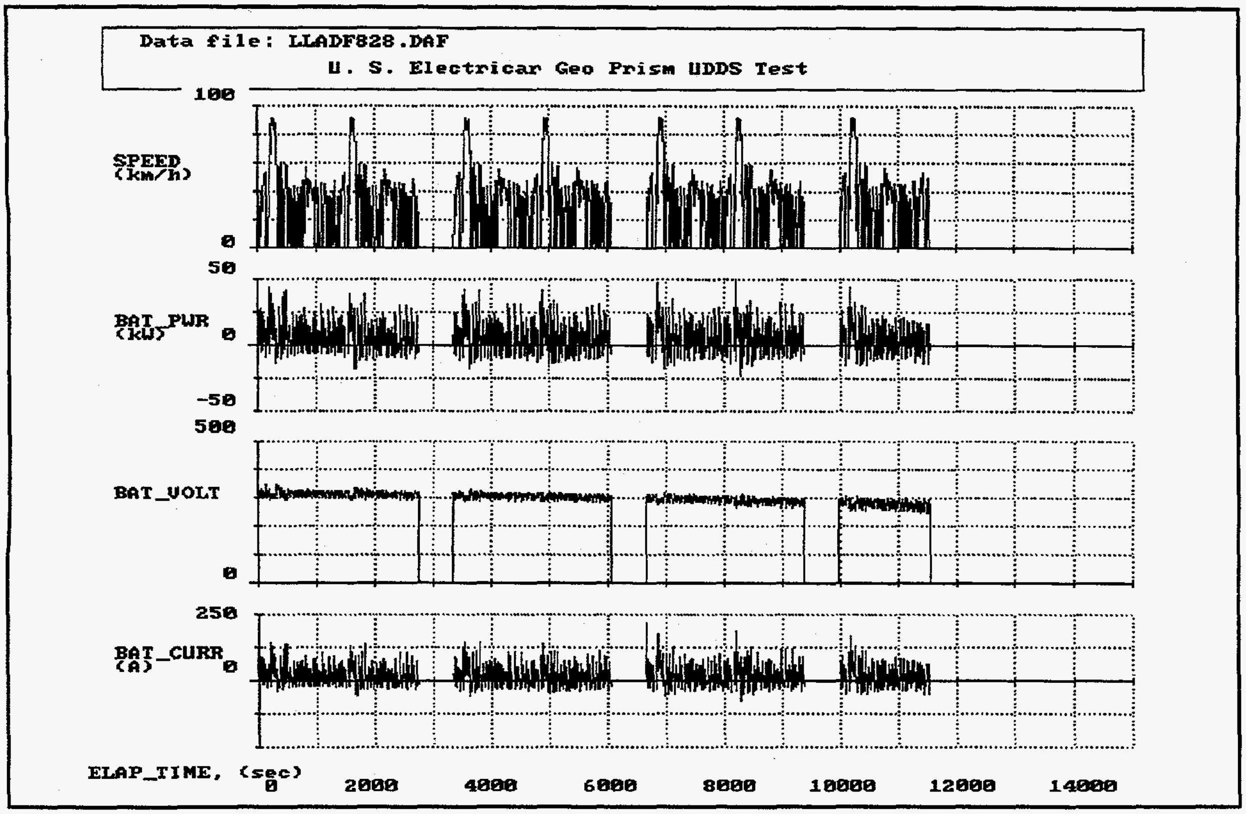

Figure 5. Vehicle speed and traction battery power, voltage, and current for UDDS test number LLAF828.

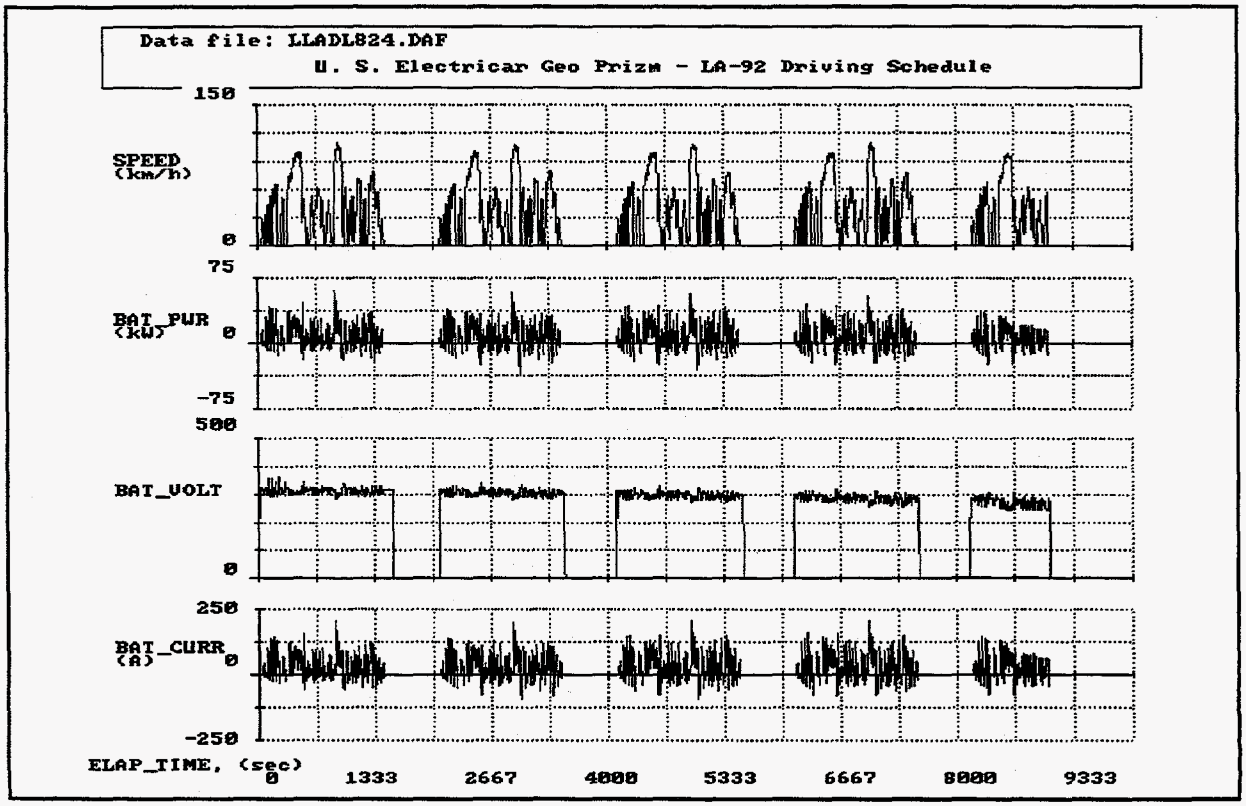

Figure 6. Vehicle speed and traction battery voltage, power, and current for LA-92 test numbers LLADL824 and LLADL831.

Highway Fuel Economy Driving Schedule

Two Highway Fuel Economy Diving Schedule (HFEDS) tests were performed until either the end-of-range criterion were met (inability to follow the speed-time profile or 250 Vdc minimum battery voltage). Figure 7 presents the vehicle speed and traction battery data for one of these tests.

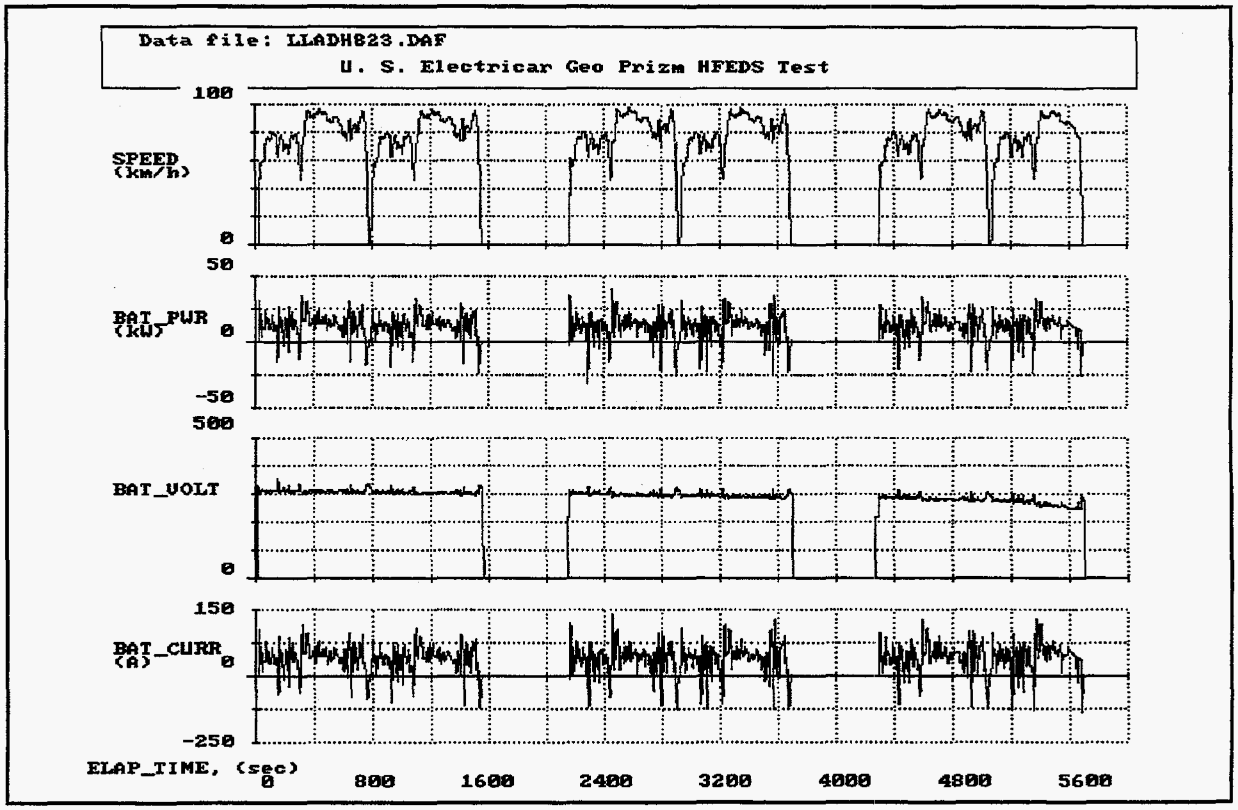

Figure 7. Vehicle speed and traction battery voltage, power, and current for HFEDS test number LLADH823.

Maximum-Effort Acceleration

Figures 8 and 9 show maximum-effort acceleration to various speeds at five different DOD, and a constant (0%) grade. Each test is an average of three runs at each DOD, and the data for the two tests are in excellent agreement. It should be noted that only the initial DODs were identical; all others showed nominal variations of 0.1 to 0.5%.

The percent grade that the vehicle can ascend at a given speed can be derived from this test data. Figures 10 and 11 show the results of this analysis as specified by SAE J1666, "*Electric Vehicle Acceleration, Gradeability, and Deceleration Test Procedure*".

Gradeability

Two gradeability tests were conducted on a fixed (5%) simulated grade, at 80 km/h, and starting at two DODs for each test. Figure 12 plots the raw data for one of these tests. Vehicle speed was maintained for 15 minutes starting from 0% DOD. The battery was then discharged to 80% for the second portion of the test, which could be maintained for only three minutes prior to encountering the 250 Vdc traction battery limit specified by U.S. Electricar.

Vehicle Meter Calibrations
State-of-Charge

The state-of-charge (SOC) meter showed general agreement with the Laboratory Data Acquisition Systems (LDAS)-measured current drain from the battery. Figure 13 shows the non-systematic point-to-point variations versus a straight-line function representing a "perfect" SOC meter reading.

Vehicle Speedometer

Calibration of the vehicle speedometer against the dynamometer is shown in Figure 14. Eight calibration points are read consistently higher than the corresponding dynamometer speed, by approximately 5.1 km/h (3.2 mph) over the range 42 to 97 km/h.

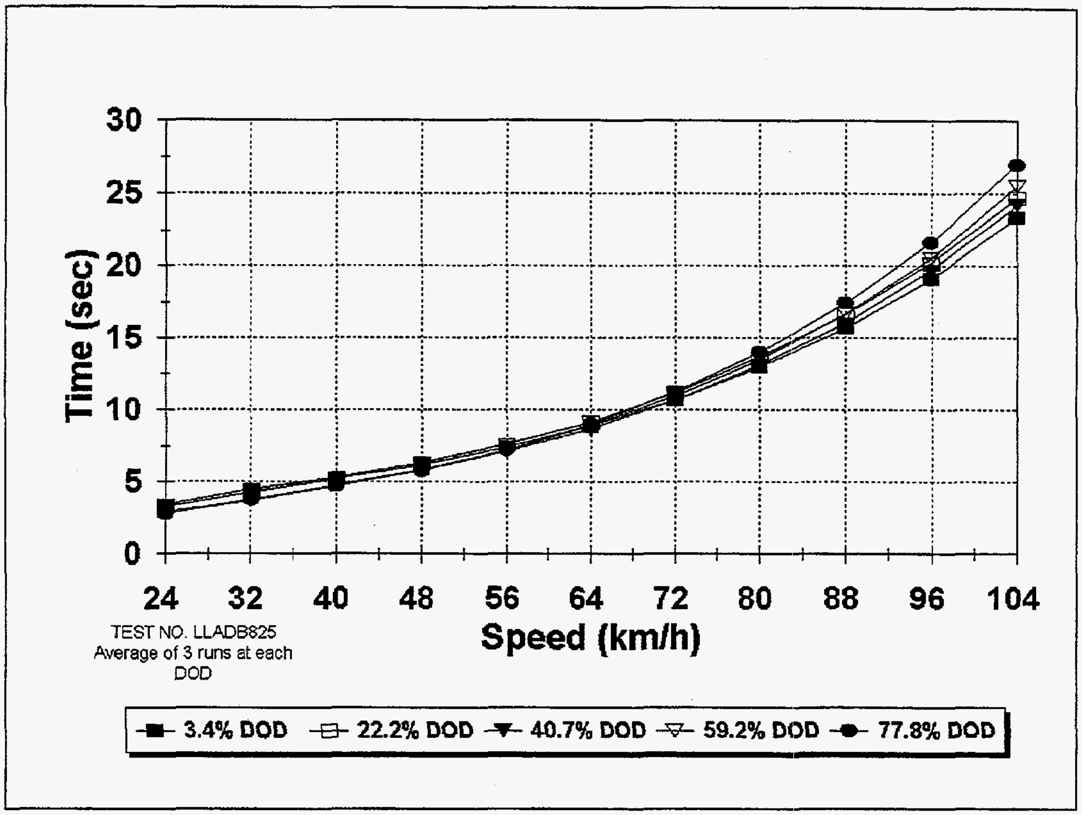

Figure 8. Maximum effort acceleration at various battery DODs for test number LLADB825.

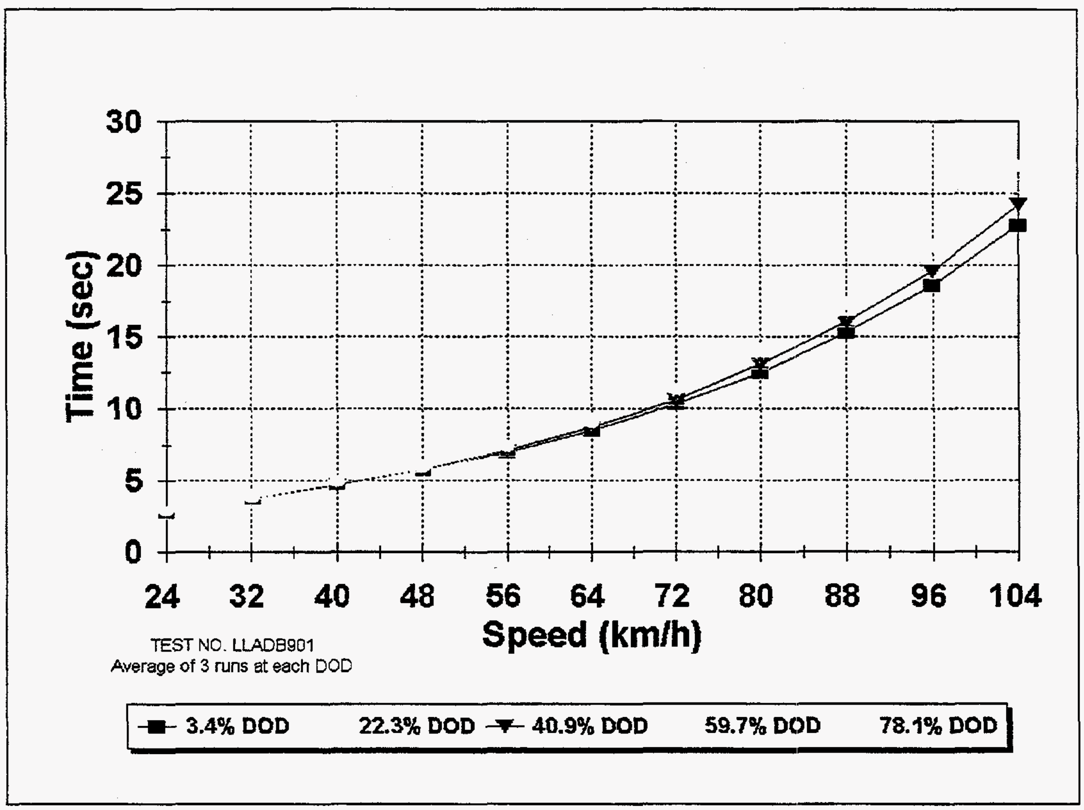

Figure 9. Maximum effort acceleration at various battery DODs for test number LLADB901.

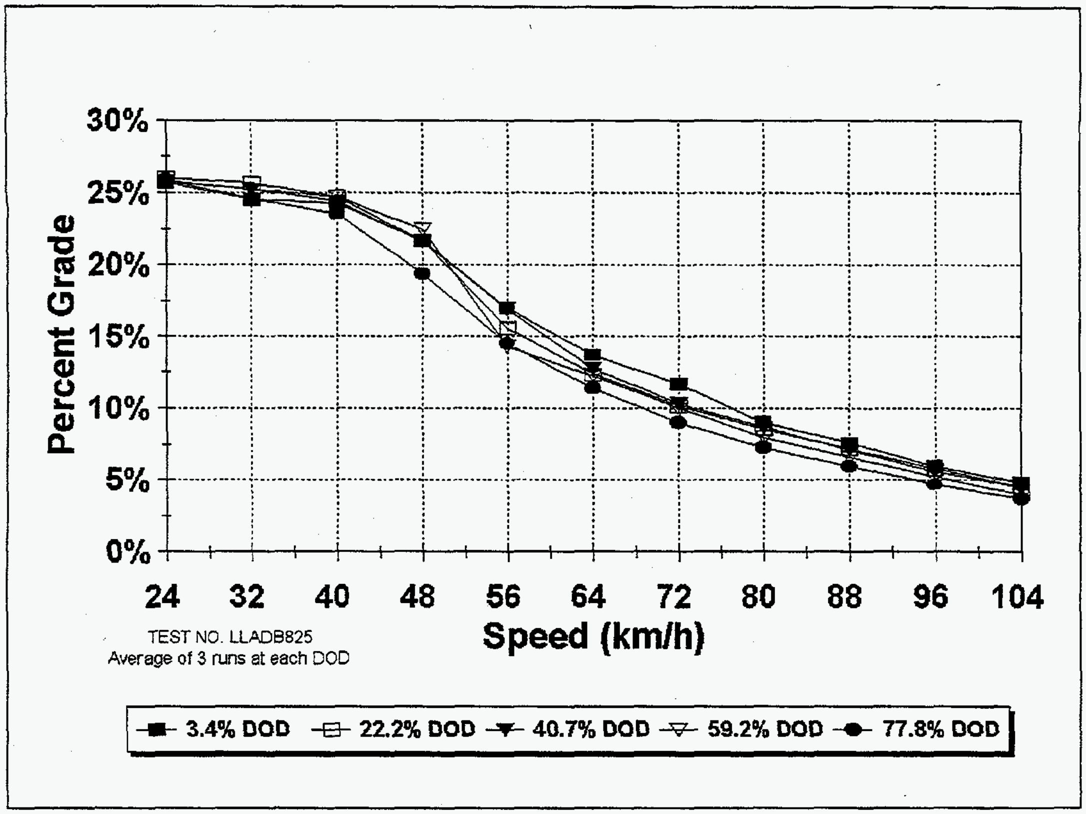

Figure 10. Calculated gradeability at speed derived from maximum effort acceleration tests, Test No. LLADB825.

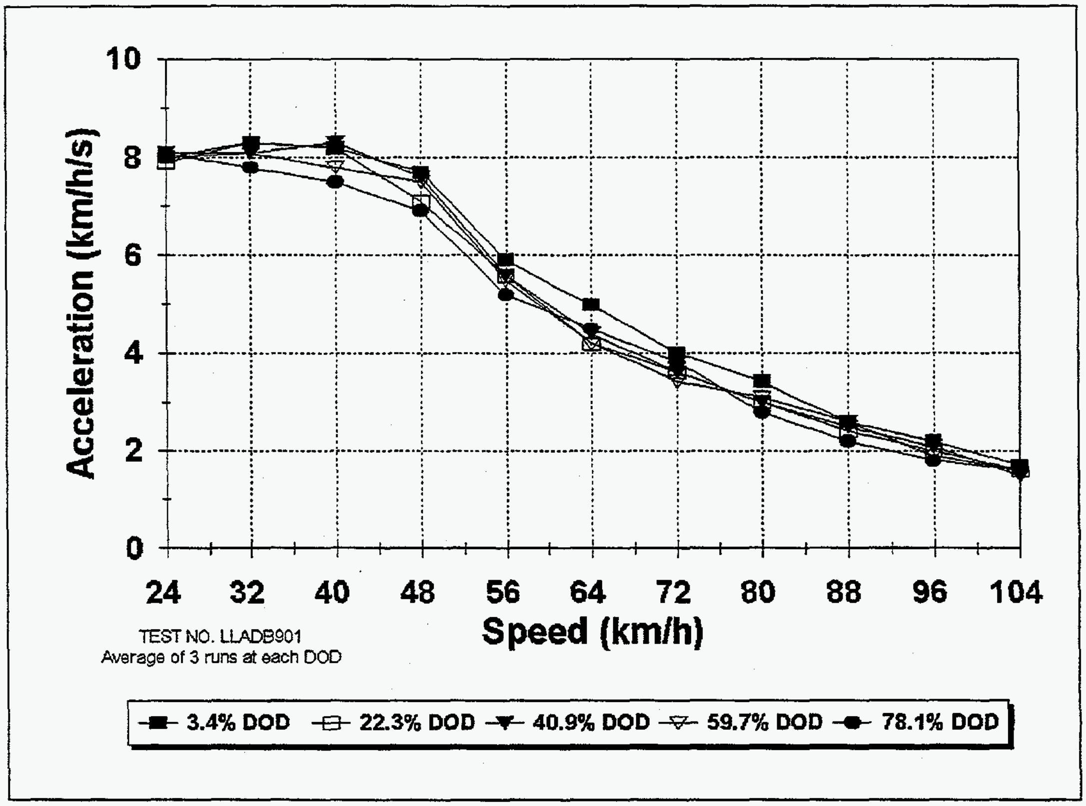

Figure 11. Calculated gradeability at speed derived from maximum effort acceleration tests, Test No. LLADB901.

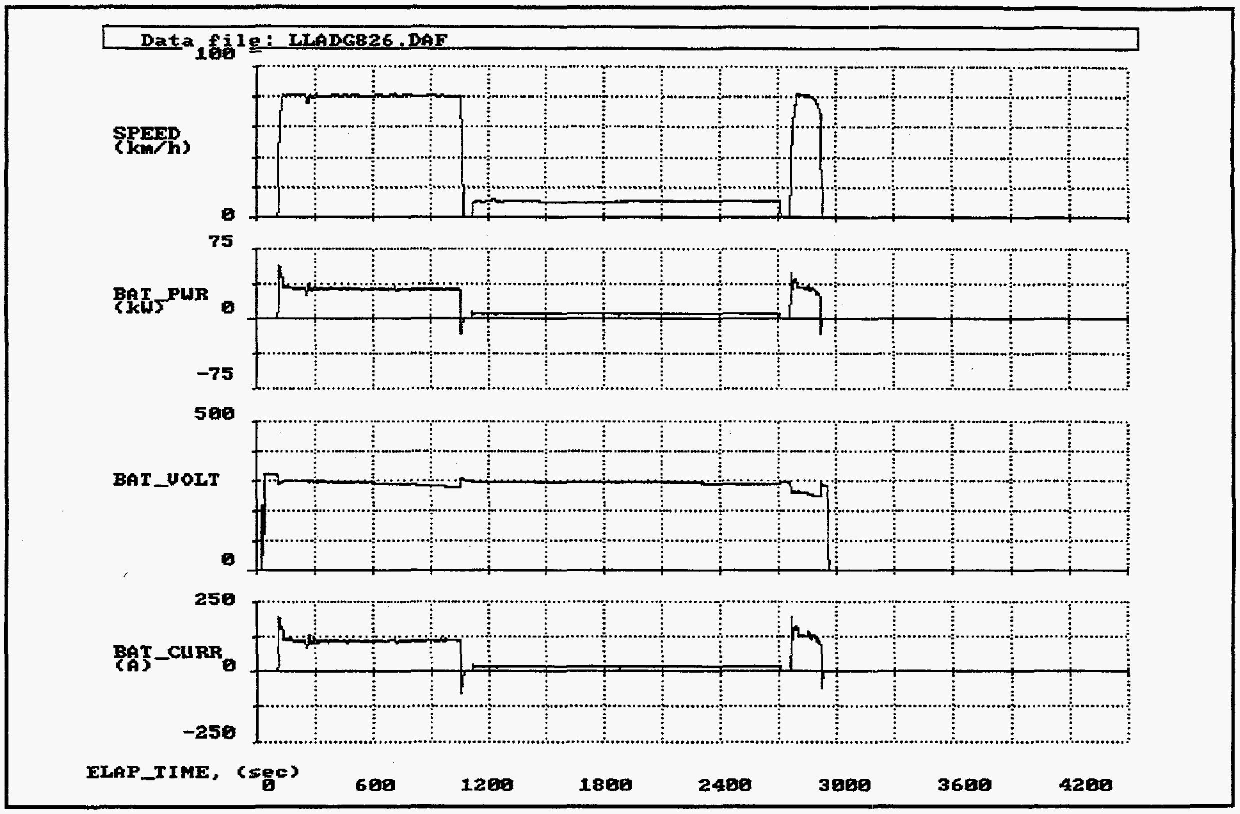

Figure 12. Fifteen (15) minutes at 80 km/h on simulated grade of 5% at 0% and 80% DOD.

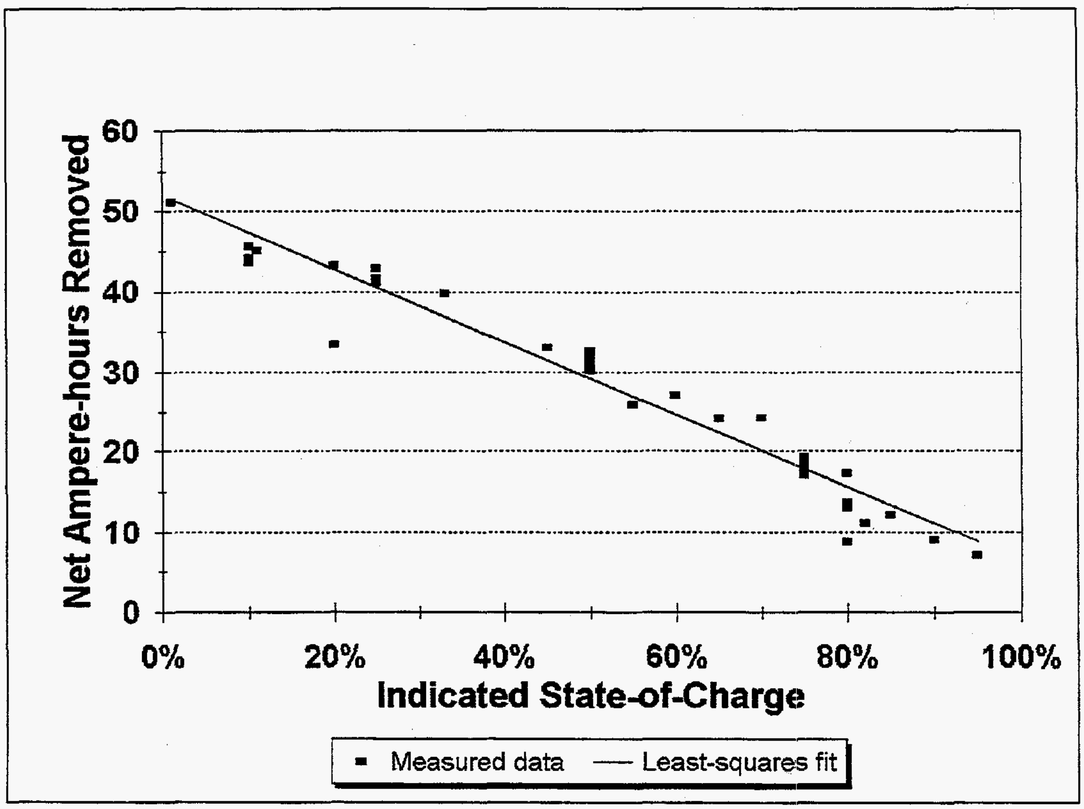

Figure 13. Results of SOC meter evaluation.

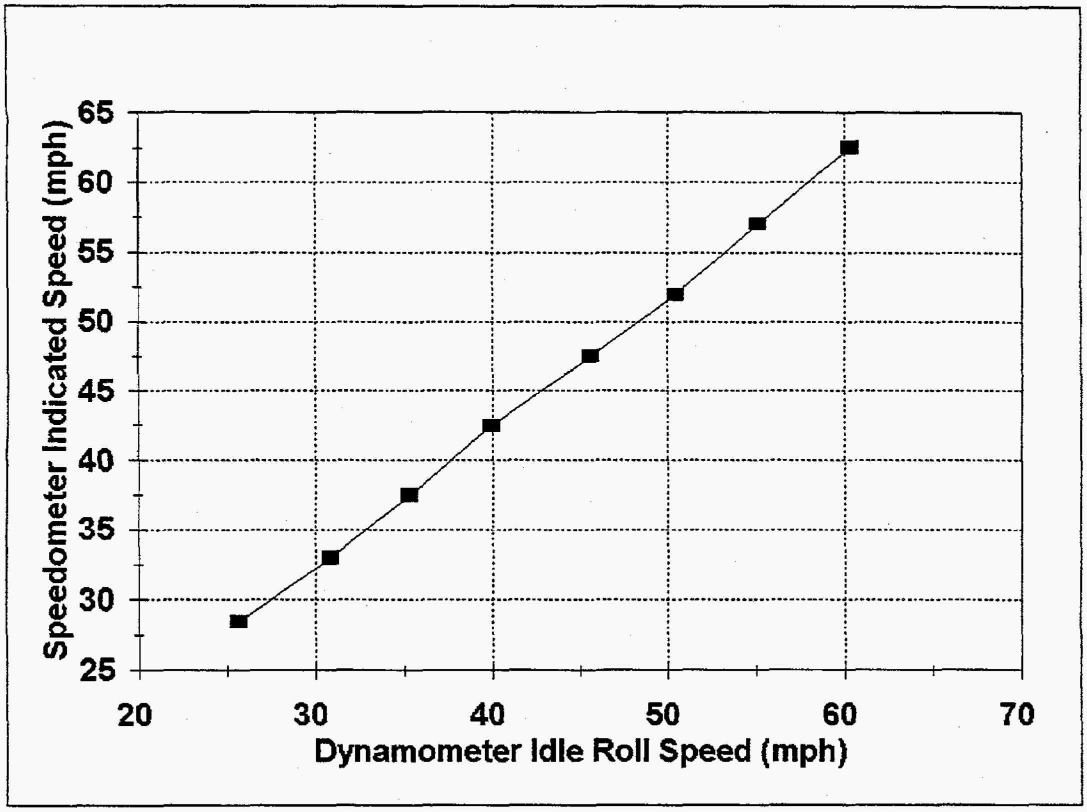

Figure 14. Evaluation of speedometer accuracy.

Traction Battery Charging

The battery pack consisted of two banks of Hawker Genesis G12V26AH10C sealed lead acid modules. Twenty-five modules were connected in series to form each bank, and the two banks were connected in parallel resulting in a nominal pack voltage of 300 Vdc. The modules were connected in a center-tapped configuration with the center tap grounded to the vehicle chassis. The entire battery pack is housed in a steel box underneath the vehicle below the passengers' compartment. There is no battery cooling system implemented, or any capability for air flow around the modules. This condition could cause battery overheating in hot climates and/or heavy use.

Shortly after receiving the vehicle, concerns were expressed to U. S. Electricar that our observation of the time to recharge the traction battery pack was approximately 18 hours. Charge times of this duration would effectively limit the testing to two tests every three days. It was learned from discussions with U.S. Electricar that the charge algorithm (and thus the time required to recharge the battery) is controlled by software in the vehicle on-board computer. Peter Nortman of U.S. Electricar provided a software modification containing a new charge algorithm to shorten the charge time. This new algorithm decreased the time required to completely recharge the traction battery to between six and eight hours. The data presented in this report represents the traction battery recharge using the modified charge algorithm.

Comparison of these data recorded during the charge half-cycle revealed that the voltage and current profiles are very consistent, charge-to-charge, with the exception of recharge test number LLADX901. Figure 15 shows the voltage, current, and power data typical of 10 of the 11 charge half-cycles for which data was recorded. Figure 16 shows the typical voltage, current, and power behavior of charge number LLADX901. Discussions with the personnel at U.S. Electricar identify this recharge as a "maintenance" charge which occurs after approximately every 10 battery recharges, and is intended to equalize the capacity of the individual battery modules.

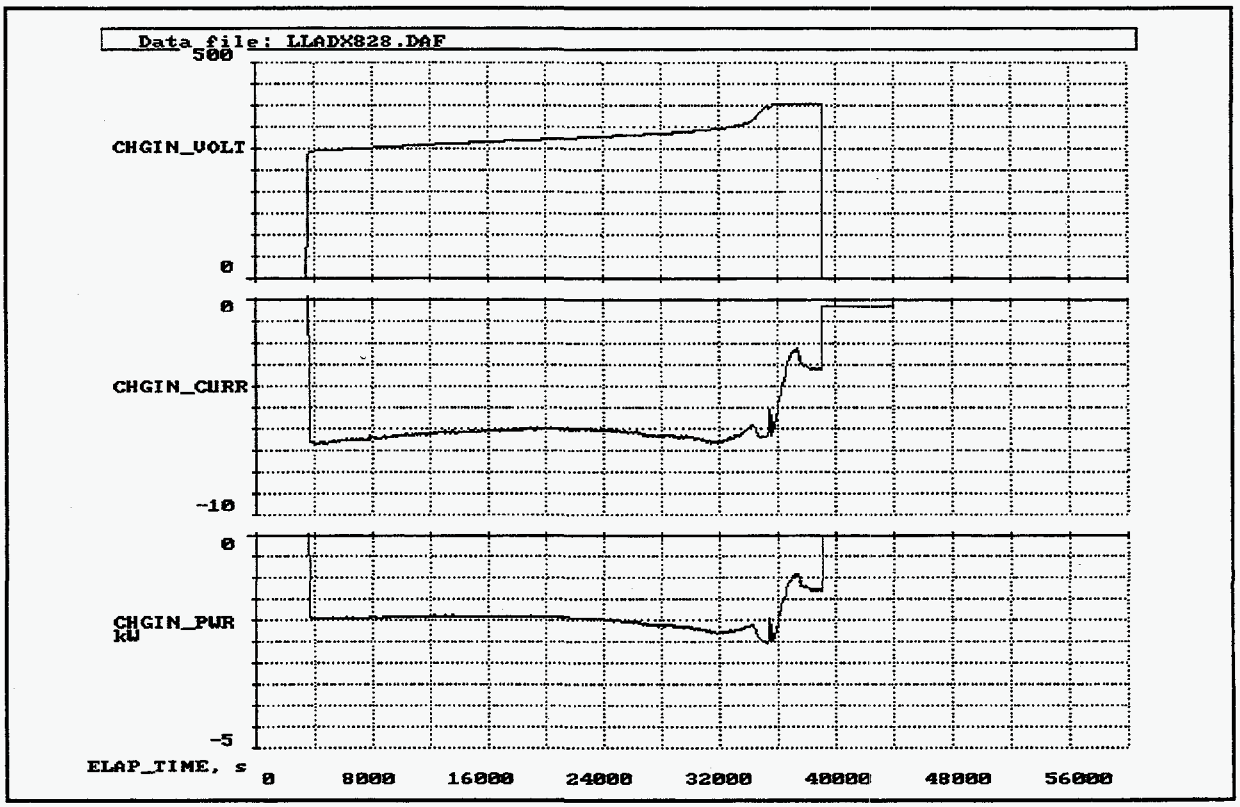

Figure 15. Typical traction battery recharge.

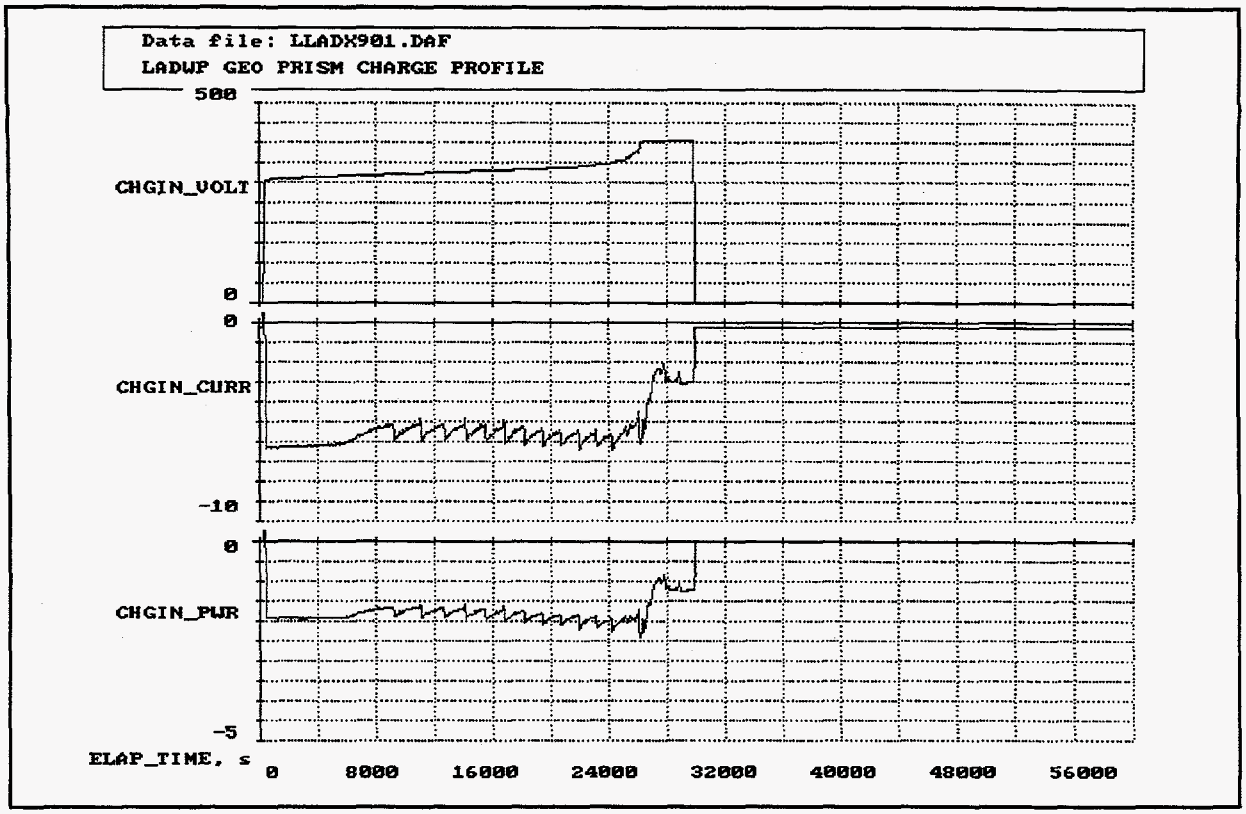

Figure 16. Traction battery maintenance charge.

Because of equipment limitations, it was not possible to obtain time-phased "wall plug" power. However, the total AC wall energy used for each traction battery recharge was measured using a totalizing energy meter. Using this data, and the time-phased data recorded during each recharge, the overall charger efficiency can be calculated as in Table 6.

Table 6. Calculated charger efficiencies.

Recharge Test No.	Previous Discharge Test	Total time "on charge"	Calculated Overall Charger Efficiency
LLADX824	LA-92	15:27:44	0.85
LLADX825	Accel	17:51:34	0.82
LLADX826	5% Gradeability	27:28:04	0.81
LLADX827	EE	11:09:37	0.81
LLADX828	UDDS	12:13:20	0.83
LLADX829	HFEDS	10:17:39	0.83
LLADX831	LA-92	16:31:54	0.82
LLADX901	Accel	27:20:56	0.79
LLADX905	5% Gradeability	17:44:41	0.82
LLADX906	EE	15:57:00	0.83
LLADX907	CC	17:25:33	0.82

The overall charger efficiency ranged from 79% to 85% for all tests. For those charge periods where the vehicle was left on charge over a weekend (indicated by those tests where the total time "on charge" exceed 27 hours), the charger efficiencies are slightly lower than the tests with a shorter charge time. This observation would indicate that the efficiency of the charger while the vehicle is plugged in, but the traction battery when not charging is somewhat less than the charger efficiency while the battery is recharging. Very little power is consumed during standby periods; and thus, the lower efficiency does not appear to significantly increase the energy used (and therefore the electrical energy cost) should the vehicle remain "plugged in" for extended periods of time after the traction battery charge has been completed.

An estimate of the efficiency of the traction battery can be made from the data recorded during a driving cycle test and its subsequent recharge from the quotient of the Net DC energy measured during a driving cycle and the AC "wall" energy measured during the subsequent recharge. Table 7 shows the resultant battery efficiency estimates from the tests where this data was obtained.

Table 7. Estimated traction battery efficiency.

Recharge Test No.	Previous Discharge Test	Round-trip Battery Efficiency
LLADX824	LA-92	0.71
LLADX825	Accel	0.72
LLADX826	5% Gradeability	0.73
LLADX827	EE	0.75
LLADX828	UDDS	0.74
LLADX829	HFEDS	0.74
LLADX831	LA-92	0.73
LLADX901	Accel	0.73
LLADX905	5% Gradeability	0.71
LLADX906	EE	0.74
LLADX907	CC	0.75

The round-trip battery efficiency for all the tests ranged between 71% and 75%. The round-trip battery efficiency for batteries of this type is typically expected to be ~80%. Thus, the values calculated above are lower than expected. Also, the percent ampere-hours returned (ampere-hours returned during recharge ÷ net ampere-hours during previous discharge) for batteries of this type are typically in the range of 105 to 110%. The percent ampere-hours returned during the testing ranged from 119 to 134% indicating that the charge algorithm furnished by U.S. Electricar may be overcharging the battery pack. Overcharging the battery pack would also lead to the lower than expected battery efficiencies observed in Table 7.

A measure of the overall energy utilization of the battery and charging system is the product of the charger efficiency and the round-trip battery efficiency. This value provides an indicator of the fraction of energy consumed at the "wall" which is used by the vehicle, the propulsion system, and the accessories during the driving-cycle test. From the data in Tables 6 and 7, between 58 to 62% of the "wall" energy is used by the vehicle during driving. Conversely, 38 to 42% of the "wall" energy is lost due to inefficiencies in the charger and battery.

Summary and Conclusions

A 1995 U.S. Electricar Geo Prizm electric conversion vehicles was tested at the INEL HEV Laboratory. The results of these tests indicated a driving range of between 71 km and 95 km, depending on the type of driving, which is judged to be inadequate for wide-spread customer acceptance. Vehicle range could be improved significantly with the use of advanced battery technologies having higher specific energy than the sealed lead-acid batteries which were furnished with the vehicle.

The net DC energy consumption (see Figure 14) as a function of the vehicle test weight measured over the UDDS driving cycle does not indicate an improvement over vehicles tested previously which represented earlier (1994) technologies.

The vehicle proved highly reliable during the test program, and no breakdowns occurred. The improved charge algorithm supplied to the INEL by U.S. Electricar worked well, and shortened the time necessary to charge the traction battery from approximately 18 to 8 hours. Data recorded during the charge half-cycle showed that the battery recharge was very consistent.