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**Dynamometer Tests
of the
Ford/TDM Ranger Electric Pickup Truck**

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MASTER

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ABSTRACT

A Ford Ranger electric vehicle was performance tested in the Idaho National Engineering and Environmental Laboratory (INEEL) Hybrid Electric Vehicle (HEV) Laboratory. The vehicle was converted by TDM, Inc. The test vehicle was delivered to the INEEL and tested for the California Air Resources Board (CARB) under a CRADA with the Department of Energy (DOE). Coastdown tests were performed to determine the vehicle road load versus speed characteristics and the results used to calibrate the chassis dynamometer. Tests included driving the vehicle on the chassis dynamometer using standard driving regimes to determine driving range, acceleration tests to determine full power acceleration times and gradeability at speed, and constant speed driving to determine the vehicle energy consumption at various speeds. Data during battery recharges was also acquired. This report presents the results of these tests.

SUMMARY

A Ford Ranger pickup truck which was converted to electric power by TDM, Inc. was tested in the INEEL HEV Laboratory. The test vehicle was delivered to the INEEL and tested for the California Air Resources Board (CARB) under a CRADA with the Department of Energy (DOE).

The following tables summarize the results of the tests performed.

Table S-1. Driving Cycle Tests.

Test	Range (km)	Net DC Energy Consumption (Wh/km)	AC Energy Consumption (Wh/km)
All-Electric Range Test	45.7 - 48.6	284	NA
Urban Dynamometer Driving Schedule	62.9 - 76.6	284 - 315	616
Highway Fuel Economy Driving Schedule	64.5	274	NA
LA-92 Driving Schedule	66.2	335	NA

Table S-2. Acceleration/Gradeability

Speed (km/h)	Time (s) to attain speed at various traction battery depths-of-discharge			Maximum Grade at Speed (%) at various traction battery depths-of-discharge		
	2.8%	45.3%	66.9%	2.8%	45.3%	66.9%
24	2.1	2.1	3.7	39.2	38.4	16.3
32	2.8	2.9	5.1	39.0	28.7	15.4
40	3.5	3.8	7.0	27.0	21.4	11.1
48	4.5	5.1	9.5	20.7	16.6	8.7
56	5.8	6.7	12.7	15.1	12.2	5.5
64	7.6	8.8	17.1	11.9	10.1	4.6
72	9.9	11.5	23.0	8.7	9.1	3.4
80	13.0	14.9	31.6	6.0	5.5	2.3
88	17.6	19.9	47.0	4.0	3.7	0.9
96	24.6	28.2		2.6	2.3	

Table S-3. Energy consumption and traction battery power at steady speed.

Speed (km/h)	Starting at 0% traction battery depth-of-discharge		Starting at 50% traction battery depth-of-discharge	
	Energy Consumption (DC Wh/km)	Battery Power (DC kW)	Energy Consumption DC Wh/km	Battery Power DC kW
16	268	4.3	216	3.7
32	239	7.8	195	6.4
40	225	9.0	188	7.7
48	217	10.4	190	9.2
56	223	12.6	201	11.3
64	233	15.0	216	13.8
72	246	17.8	231	16.8
80	267	21.5	253	20.3
88	288	25.4	276	24.4
96	315	30.2	316	30.1

CONTENTS

Abstract	iii
Summary	v
Introduction	1
Test Program and Results	7
Measurements and Data Acquisition	7
Vehicle Coastdowns and Test Set-up	7
Battery/Condition/Constant Current Tests	11
Driving Cycle Tests	15
Urban Dynamometer Driving Schedule (UDDS)	15
Highway Fuel Economy Driving Schedule	15
All-Electric (combined UDDS/HFEDS) Tests	23
LA-92 Driving cycle Tests	23
Other Tests	29
Energy Economy Tests	29
Acceleration Tests	29
Battery Recharge Measurements	39

TABLES

S-1. Driving Cycle Tests	v
S-2. Acceleration/Gradeability	v
S-3. Energy consumption and traction battery power at steady speed	vi
1. TDM/Ford Ranger characteristics and specifications	3
2. TDM vehicle data summary sheet	10
3a. Results of UDDS (combined cycles) prior to repairs made by TDM	17
3b. Results of UDDS (separate cycles) prior to repairs made by TDM	17
4a. Results of UDDS (combined cycles) subsequent to repairs made by TDM	18
4b. Results of UDDS (separate cycles) subsequent to repairs made by TDM	18
5a. Results of UDDS (combined cycles) with simulated AC load	19
5b. Results of UDDS (separate cycles) with simulated AC load	19
6a. Results of UDDS (separate cycles) with AC on max., min., and off	20
6b. Results of UDDS (combined cycles) with AC on max., min., and off	20
7. Results of Highway Fuel Economy Driving Schedule testing	21

8a.	Results of All-Electric (combined UDDS/HFEDS) (Cycle 1 & 2) [LTDMA106]	25
8b.	Results of All-Electric (combined UDDS/HFEDS) Testing [LTDMA106]	25
9a.	Results of All-Electric (combined UDDS/HFEDS) (Cycle 1&2) [LTDMA108]	26
9b.	Results of All-Electric (combined UDDS/HFEDS) Testing [LTDMA108]	26
10.	Results of LA-92 Driving cycle tests	27
11.	Acceleration times to reach a specified speed & calculated gradeability-at-speed	35
12.	Traction battery DC energy consumption at steady speeds	36

FIGURES

1.	TDM/Ford Ranger test vehicle on the chassis dynamometer at the INEEL	2
2.	Data recorded during test in which failure occurred	5
3.	Data recorded during test in which failure occurred	6
4.	Schematic diagram showing the location of current shunts placed on the vehicle	9
5.	Typical traction battery recharge data prior to repairs made by TDM	13
6.	Typical traction battery recharge data after repairs made by TDM	14
7.	Comparison of energy consumption as reported by TDM	31
8.	Results of energy consumption test prior to vehicle repairs	32
9.	Results of energy consumption tests subsequent ot vehicle repairs	33
10.	Maximum effort acceleration time to attain speed at various traction battery DODs	37
11.	Percent gradeability at speed derived from maximum effort acceleration tests	41
12.	Charger efficiency during battery recharge	42

DYNAMOMETER TESTS OF THE FORD/TDM RANGER ELECTRIC PICKUP TRUCK

INTRODUCTION

This report presents the results of dynamometer tests performed in the INEEL Hybrid/Electric Vehicle Laboratory on an electrically powered Ford/TDM Ranger pickup truck. The intent of these tests was to determine the performance of the vehicle under standard driving regimes. By measuring significant parameters under these driving regimes, information was obtained by which the overall vehicle performance may be compared to other electric vehicles. The performance of vehicle subsystems may also be judged.

The Ford/TDM Ranger electric vehicle was received at the INEEL on October 16, 1996. Tests were performed during the period from October 30, 1996 through January 31, 1997. A photograph of the vehicle is shown in Figure 1. The salient characteristics and other specifications of the test vehicle are provided in Table 1.

During the test program, a catastrophic failure occurred while performing an all-electric (combined UDDS and HFEDS) driving cycle test. The failure occurred at approximately 180 seconds into the test during the initial stop-start portion of the UDDS segment. The failure was unexpected and there were no prior indications of abnormal operation. It appeared to test personnel that a sudden power loss had occurred. Since there was no motive power, test personnel then brought the vehicle to a stop. Figures 2 and 3 show the data that were recorded during the test. The failure occurred while the vehicle speed was 77 km/h and accelerating at a moderate rate. The battery voltage and current just prior to the event was 312.8 V and 89.7 A, respectively. The battery power measured at this point was 28.1 kW.

After an initial inspection of the vehicle, TDM personnel were contacted. Our initial inspection included removal of the controller cover. Upon removal of the cover, test personnel noted the characteristic odor of electronic component failures. Some discoloration inside the controller cover and above one of the high power electronic components was noted.

After further diagnosis in consultation with TDM personnel, it was determined that the damage was quite extensive and could not be practically repaired at INEEL. Subsequently the vehicle was shipped to TDM for more detailed diagnosis, analysis and repair on November 24, 1996.

The repaired vehicle was returned to INEEL on December 14, 1996 and testing was resumed. The results of the tests performed prior to the repairs differ from those performed after the repairs. Most notable is the difference in the traction battery charge behavior.

Figure 1. TDM/Ford Ranger test vehicle on the chassis dynamometer at the INEEL. [97-0008-1-5]

Table 1. TDM/Ford Ranger characteristics and specifications.

Base Vehicle	Ford Ranger Pickup Truck
Model Year	1996
Color	Red
VIN	1FFDR1007TTA30129
Overall Length	5004 mm
Overall Width	1702 mm
Overall Height	1626 mm
Wheelbase	2921 mm
Track	1676 mm front/1727 mm rear
Curb Weight	2304 kg
Test Weight	2440 kg
Weight Distribution	1016 kg front/1288 kg rear
Tires	Michelin P225/70 R14
Drive line	Rear wheel drive, Westinghouse 3 ϕ AC Induction Motor, single speed transmission
Battery	28 $\times$ 12 V, 80 Ah GNB sealed lead acid modules arranged in series and divided into two battery packs. One pack located under the cargo floor and one located in the truck bed.
Charger	Input: 208 or 220 VAC, 18 A maximum
Features	Air conditioning, power steering, power brakes (front disc), tilt steering wheel

TDM Ranger Pickup

LTDMAN26

Figure 2. Data recorded during test in which failure occurred.

Figure 3. Data recorded during test in which failure occurred.

TEST PROGRAM AND RESULTS

Measurements and Data Acquisition

In total, 15 dynamometer tests were performed during the period from November 19, 1996 and January 31, 1997. These tests included tests to determine the energy consumption at various steady speeds, constant battery current tests to ascertain the traction battery capacity, maximum effort acceleration tests, and driving schedule tests. The driving schedule tests performed included the Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Driving schedule (HFEDS), LA-92 schedule and the combined UDDS/HFEDS driving schedules. Driving schedule tests are performed to determine the vehicle range on a single charge on these standard speed-time profiles.

Measurements were made using calibrated instruments, and acquired with either of two data acquisition systems. On-road data was acquired and recorded using the INEEL-developed Versatile Data Acquisition System (VDAS). Tests performed on the chassis dynamometer were acquired using the INEEL Laboratory Data Acquisition System (LDAS). Data for most driving tests were recorded at one second intervals. The schematic diagram of Figure 4 shows the location of the current shunts placed on the vehicle for current measurements.

Test numbers coincide with filenames of the INEEL standard format data files for each test. The Vehicle Test Data Summary Sheet shown in Table 2 provides a summary of the information contained in the data files archived at the INEEL.

Vehicle Coastdowns and Test Set Up

The road loads programmed into the dynamometer were determined from coastdown trials performed at the INEEL. Speed-time data was acquired using a fifth wheel and recorded at 0.1 second intervals using the VDAS. Coastdowns were performed at a vehicle test weight of 2440 kg (5380 lb.) with all drive line components and brakes in their normal configuration. A total of twelve coastdown trials were performed which resulted in four paired runs (i.e., eight coastdown runs). The data from these coastdown runs were reduced according to SAE J1634 to determine the road load vs. speeds relationship for a dynamometer setup. The resultant road load

force equation (corrected to standard conditions and accounting for non-rotating inertia) used for determining the set points on the chassis dynamometer is given by the following equation.

$$F(N) = 324.21 (N) + 0.06965(N/km^2) v^2$$

Application of the above equation yields the following dynamometer coastdown times:

<u>Speed</u>	<u>Time</u>
88 to 72 km/h	14.34 sec
96 to 16 km/h	104.66 sec
32 to 16 km/h	30.16 sec

Figure 4. Schematic diagram showing location of current shunts placed on the vehicle.

10

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Battery Condition/Constant Current Tests

Two constant current discharge tests were performed to investigate the battery condition. One test was performed prior to the repairs and one after the repairs were performed by TDM. The vehicle was driven on the chassis dynamometer such that a constant current at the C/3 rate (27 A) from the traction battery was maintained as closely as possible. The discharge was completed when the vehicle automatically shut down.

Results of these two tests differ significantly. Prior to the vehicle repairs, 84.5 net Ah were removed from the battery after a full charge. When this test was repeated, 68.2 net Ah were removed. Prior to the repairs made by TDM the vehicle battery monitoring system would measure all of the cell voltages and initial battery temperature and then calculate the charging algorithm using this information. TDM personnel felt that this method could over charge some modules. During the repairs at TDM, the calculation of the charging algorithm was changed by "floating" the modules that were 2.5 to 2.6 volts per cell adjusting the algorithm as a function of the current battery temperature. It was also reported that the battery manufacturer, GNB, modified the battery heater system while the vehicle was at TDM.

It is unclear from the information available if the difference in apparent battery capacity before and after the repair is due to degradation of the battery electrochemistry or changes made by TDM and GNB when they repaired the vehicle. However, the following observations regarding battery charging are made:

- The open circuit voltages at the start of the constant current discharge prior to the repairs was measured to be 336.5 V, and 331.2 V after the repairs.
- The voltage under load just prior to shut down prior to the repairs was 274.3 V while the voltage after the repairs was 285.8 V.
- The charge algorithm was changed during the time the vehicle was at TDM. Figures 5 and 6 show the typical battery charge behavior before and after the repairs. Note that after the repairs, the end-of-charge voltage was lower and that the charge current at the end-of-charge voltage was not held for as long a period of time.

Figure 5. Typical traction battery recharge data prior to repairs made by TDM.

Figure 6. Typical traction battery recharge data after repairs made by TDM.

DRIVING CYCLE TESTS

All driving cycle range tests were terminated when the vehicle shut itself off after sensing a depleted battery. In most instances, this occurred shortly after the performance criteria specified by SAE J1634, "Electric Vehicle Energy Consumption and Range Test Procedure," was realized.

Urban Dynamometer Driving Schedule (UDDS)

One Urban Dynamometer Driving Schedule (UDDS) test was performed prior to the vehicle repairs (test number LTDMFN25) and one after the repairs (test number LTDMF113). The results of these respective tests are shown in Tables 3a, 3b, 4a and 4b, respectively.

Two additional UDDS tests were performed to ascertain the effect of the vehicle air conditioning on vehicle performance. Test number LTDMF122 was performed as in the standard UDDS test with a load equivalent to 1.4 horsepower added to the dynamometer load at 88 km/h. Summarized results of this test are shown in Tables 5a and 5b.

In order to better ascertain the effect of air conditioning, a modified UDDS test was defined. In this test (test number LTDMFD20), the air vehicle air conditioner was set to "maximum" for the first two UDDS sub-cycles, "minimum" for the third and fourth subcycles, and "off" for the remainder of the discharge. For the "maximum" cooling condition, the air condition controls were set for the coldest air temperature and the fan at its highest setting. For the "minimum" cooling condition, the air temperature was set at the coolest setting and the fan was set at its lowest setting. During this test, the vehicle windows were open and the ambient temperature ranged between 19.4°C and 22.1°C. Tables 6a and 6b provides summary results of this test.

Highway Fuel Economy Driving Schedule

One Highway Fuel Economy Driving Schedule (HFEDS) driving profile test was performed (test number LTDMMD17). Cycle-by-cycle results are given in Table 7.

Table 3a. Results of UDDS Test No. LTDMFN25 (combined cycles) prior to repairs made by TDM.

Federal Urban Driving Schedule Test Results						
General:	Cycle Number					Total
	1-2	3-4	5-6	7*		
Distance (km)	24.2	24.2	24.3	4.1		76.6
Vehicle DC Energy Consumption (Wh/km)	299	293	289	286		294
Gross Ampere-hours (Ah)	25.2	25.1	26.0	4.9		81.3
Regen Ampere-hours (Ah)	1.8	1.7	1.8	0.3		5.6
Net Ampere-hours (Ah)	23.3	23.4	24.3	4.6		75.7
Gross DC Energy (kWh)	7.8	7.6	7.6	1.3		24.3
Regen DC Energy (kWh)	0.6	0.6	0.6	0.1		1.8
Net DC Energy (kWh)	7.2	7.1	7.0	1.2		22.5
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	283.9	272.7	254.4	233.8		233.8
Maximum Battery Current (A)	260.3	275.0	158.4	158.2		275.0
Maximum Battery Power (kW)	73.9	75.0	45.1	40.5		75.0
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	356.7	336.7	328.2	320.4		356.7
Maximum Battery Current (A)	73.0	80.2	68.6	54.5		80.2
Maximum Battery Power (kW)	34.3	27.0	22.5	17.5		34.3
* Partial cycle						

Table 3b. Results of UDDS Test No. LTDMFN25 (separate cycles) prior to repairs made by TDM.

Federal Urban Driving Schedule Test Results								
General:	Cycle Number							Total
	1	2	3	4	5	6	7*	
Distance (km)	12.1	12.1	12.1	12.1	12.1	12.1	4.1	76.6
Vehicle DC Energy Consumption (Wh/km)	305	292	295	291	292	288	286	294
Gross Ampere-hours (Ah)	12.9	12.3	12.6	12.6	12.9	13.2	4.9	81.3
Regen Ampere-hours (Ah)	1.0	0.9	0.8	0.8	0.9	0.9	0.3	5.6
Net Ampere-hours (Ah)	11.9	11.4	11.7	11.7	12.0	12.3	4.6	75.7
Gross DC Energy (kWh)	4.0	3.8	3.8	3.8	3.8	3.8	1.3	24.3
Regen DC Energy (kWh)	0.3	0.3	0.3	0.3	0.3	0.3	0.1	1.8
Net DC Energy (kWh)	3.7	3.5	3.6	3.5	3.5	3.5	1.2	22.5
Driving Cycle Discharge Information:								
Minimum Battery Voltage (V)	286.9	283.9	283.4	272.7	279.0	254.4	233.8	233.8
Maximum Battery Current (A)	239.8	260.3	236.9	275.0	158.4	158.3	158.2	275.0
Maximum Battery Power (kW)	68.8	73.9	67.1	75.0	45.1	43.4	40.5	75.0
Driving Cycle Regen Information:								
Maximum Battery Voltage (V)	356.7	339.6	336.7	330.5	328.2	323.0	320.4	356.7
Maximum Battery Current (A)	73.0	55.9	80.2	52.8	68.6	58.0	54.5	80.2
Maximum Battery Power (kW)	34.3	18.8	27.0	17.0	22.5	18.7	17.5	34.3
* Partial cycle								

Table 4a. Results of UDDS Test No. LTDMF113 (combined cycles) subsequent to repairs made by TDM.

Federal Urban Driving Schedule Test Results						
	Cycle Number					
	1-2	3-4	5-6*			Total
General:						
Distance (km)	24.2	24.1	16.9			65.1
Vehicle DC Energy Consumption (Wh/km)	292	279	279			284
Gross Ampere-hours (Ah)	24.7	24.2	17.6			66.6
Regen Ampere-hours (Ah)	1.9	2.0	1.4			5.3
Net Ampere-hours (Ah)	22.8	22.2	16.2			61.3
Gross DC Energy (kWh)	7.7	7.4	5.1			20.2
Regen DC Energy (kWh)	0.6	0.7	0.4			1.7
Net DC Energy (kWh)	7.1	6.7	4.7			18.5
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	288.5	280.5	269.4			269.4
Maximum Battery Current (A)	217.1	218.1	151.7			218.1
Maximum Battery Power (kW)	62.8	61.4	42.0			62.8
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	352.1	337.4	330.5			352.1
Maximum Battery Current (A)	78.1	77.4	79.9			79.9
Maximum Battery Power (kW)	26.5	25.9	25.0			26.5
* Partial cycle						

Table 4b. Results Test No. LTDMF113 (separate cycles) subsequent to repairs made by TDM.

Federal Urban Driving Schedule Test Results								
General:	Cycle Number							Total
	1	2	3	4	5	6*		
Distance (km)	12.1	12.1	12.1	12.0	12.0	4.9		65.1
Vehicle DC Energy Consumption (Wh/km)	302	282	282	276	276	285		284
Gross Ampere-hours (Ah)	12.7	12.0	12.2	12.1	12.3	5.3		66.6
Regen Ampere-hours (Ah)	0.9	1.0	1.0	1.0	1.0	0.4		5.3
Net Ampere-hours (Ah)	11.8	11.0	11.2	11.1	11.3	4.9		61.3
Gross DC Energy (kWh)	4.0	3.7	3.7	3.6	3.6	1.5		20.2
Regen DC Energy (kWh)	0.3	0.3	0.3	0.3	0.3	0.1		1.7
Net DC Energy (kWh)	3.6	3.4	3.4	3.3	3.3	1.4		18.5
Driving Cycle Discharge Information:								
Minimum Battery Voltage (V)	290.5	288.5	286.1	280.5	283.0	269.4		269.4
Maximum Battery Current (A)	207.5	217.1	214.5	218.1	140.4	151.7		218.1
Maximum Battery Power (kW)	59.7	62.8	61.4	61.2	40.3	42.0		62.8
Driving Cycle Regen Information:								
Maximum Battery Voltage (V)	352.1	340.8	337.4	333.9	330.5	327.8		352.1
Maximum Battery Current (A)	68.6	78.1	75.8	77.4	68.0	79.9		79.9
Maximum Battery Power (kW)	23.4	26.5	25.5	25.9	22.4	25.0		26.5
* Partial cycle								

Table 5a. Results of UDDS test (combined cycles) with simulated AC load of 1.44 hp added to the 88 km/h dynamometer set point for Test No. LTDMF122.

Federal Urban Driving Schedule Test Results						
General:	Cycle Number					
	1-2	3-4	5-6*			Total
Distance (km)	24.2	24.2	14.5			62.9
Vehicle DC Energy Consumption (Wh/km)	300	288	287			292
Gross Ampere-hours (Ah)	25.5	25.2	15.6			66.3
Regen Ampere-hours (Ah)	1.9	2.0	1.1			5.1
Net Ampere-hours (Ah)	23.5	23.3	14.5			61.3
Gross DC Energy (kWh)	7.9	7.6	4.5			20.0
Regen DC Energy (kWh)	0.7	0.6	0.4			1.7
Net DC Energy (kWh)	7.2	7.0	4.2			18.4
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	287.5	275.9	265.4			265.4
Maximum Battery Current (A)	224.2	231.1	139.7			231.1
Maximum Battery Power (kW)	64.9	64.6	39.6			64.9
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	358.0	339.1	332.0			358.0
Maximum Battery Current (A)	74.5	71.9	83.3			83.3
Maximum Battery Power (kW)	25.9	22.5	27.4			27.4
* Partial cycle						

Table 5b. Results of UDDS test (separate cycles) with simulated AC load of 1.44 hp added to the 88 km/h dynamometer set point for Test No. LTDMF122.

Federal Urban Driving Schedule Test Results							
General:	Cycle Number						
	1	2	3	4	5	6*	Total
Distance (km)	12.1	12.1	12.1	12.1	12.0	2.4	62.9
Vehicle DC Energy Consumption (Wh/km)	308	291	290	285	288	281	292
Gross Ampere-hours (Ah)	13.0	12.5	12.6	12.6	13.0	2.6	66.3
Regen Ampere-hours (Ah)	1.0	1.0	1.0	1.0	1.0	0.1	5.1
Net Ampere-hours (Ah)	12.0	11.5	11.6	11.6	12.0	2.5	61.3
Gross DC Energy (kWh)	4.1	3.8	3.8	3.8	3.8	0.7	20.0
Regen DC Energy (kWh)	0.3	0.3	0.3	0.3	0.3	0.0	1.7
Net DC Energy (kWh)	3.7	3.5	3.5	3.4	3.5	0.7	18.4
Driving Cycle Discharge Information:							
Minimum Battery Voltage (V)	289.2	287.5	280.7	275.9	271.4	265.4	265.4
Maximum Battery Current (A)	224.2	220.9	231.1	223.7	139.7	113.0	231.1
Maximum Battery Power (kW)	64.9	63.5	64.6	61.7	39.6	30.5	64.9
Driving Cycle Regen Information:							
Maximum Battery Voltage (V)	358.0	342.9	339.1	334.4	332.0	329.2	358.0
Maximum Battery Current (A)	74.5	74.3	66.9	71.9	77.8	83.3	83.3
Maximum Battery Power (kW)	25.9	25.3	22.5	22.5	24.5	27.4	27.4
* Partial cycle							

Table 6a. Results of UDDS test (separate cycles) with air conditioning on "maximum, "minimum," and "off" for Test No. LTDMFD20.

Federal Urban Driving Schedule Test Results								
	Cycle Number							Total
	1	2	3	4	5	6*		
General:								
Distance (km)	12.1	12.1	12.1	12.1	12.0	4.0		64.4
Vehicle DC Energy Consumption (Wh/km)	348	308	331	324	278	265		315
Gross Ampere-hours (Ah)	14.3	12.8	13.9	13.9	12.5	4.2		71.7
Regen Ampere-hours (Ah)	0.8	0.8	0.8	0.8	0.9	0.3		4.4
Net Ampere-hours (Ah)	13.5	12.0	13.2	13.1	11.5	3.9		67.3
Gross DC Energy (kWh)	4.5	4.0	4.3	4.2	3.7	1.2		21.7
Regen DC Energy (kWh)	0.3	0.3	0.3	0.3	0.3	0.1		1.4
Net DC Energy (kWh)	4.2	3.7	4.0	3.9	3.3	1.1		20.3
Driving Cycle Discharge Information:								
Minimum Battery Voltage (V)	284.3	289.2	284.5	277.6	274.3	267.0		267.0
Maximum Battery Current (A)	290.2	222.1	224.2	226.0	145.4	143.0		290.2
Maximum Battery Power (kW)	82.5	62.7	63.8	62.8	41.3	38.7		82.5
Driving Cycle Regen Information:								
Maximum Battery Voltage (V)	343.2	338.9	334.8	333.2	329.7	326.2		343.2
Maximum Battery Current (A)	55.8	60.5	56.3	69.8	63.6	66.9		69.8
Maximum Battery Power (kW)	19.1	20.4	18.7	23.2	20.9	21.5		23.2
* Partial cycle								
Cycles 1-2: AC on maximum								
Cycles 3-4: AC on minimum								
Cycles 5-6: AC off								

Table 6b. Results of UDDS test (combined cycles) with air conditioning on "maximum, "minimum," and "off" for Test No. LTDMFD20.

Federal Urban Driving Schedule Test Results							
	Cycle Number						
	1-2	3-4	5-6*			Total	
General:							
Distance (km)	24.2	24.2	16.1			64.4	
Vehicle DC Energy Consumption (Wh/km)	328	328	274			315	
Gross Ampere-hours (Ah)	27.2	27.9	16.6			71.7	
Regen Ampere-hours (Ah)	1.6	1.6	1.2			4.4	
Net Ampere-hours (Ah)	25.6	26.3	15.4			67.3	
Gross DC Energy (kWh)	8.5	8.4	4.8			21.7	
Regen DC Energy (kWh)	0.5	0.5	0.4			1.4	
Net DC Energy (kWh)	7.9	7.9	4.4			20.3	
Driving Cycle Discharge Information:							
Minimum Battery Voltage (V)	284.3	277.6	267.0			267.0	
Maximum Battery Current (A)	290.2	226.0	145.4			290.2	
Maximum Battery Power (kW)	82.5	63.8	41.3			82.5	
Driving Cycle Regen Information:							
Maximum Battery Voltage (V)	343.2	334.8	329.7			343.2	
Maximum Battery Current (A)	60.5	69.8	66.9			69.8	
Maximum Battery Power (kW)	20.4	23.2	21.5			23.2	
* Partial cycle							
Cycles 1-2: AC on maximum							
Cycles 3-4: AC on minimum							
Cycles 5-6: AC off							

Table 7. Results of Highway Fuel Economy Driving Schedule (HFEDS) Test No. LTDMHD17.

		Cycle Number				
		1	2	3	4*	Total
General:						
	Distance (km)	16.6	16.6	16.6	14.8	64.5
	Vehicle DC Energy Consumption (Wh/km)	293.4	269.0	270.2	263.3	274.2
	Gross Ampere-hours (Ah)	16.1	15.0	15.4	13.7	60.2
	Regen Ampere-hours (Ah)	0.3	0.4	0.3	0.1	1.1
	Net Ampere-hours (Ah)	15.8	14.7	15.1	13.5	59.0
	Gross DC Energy (kWh)	5.0	4.6	4.6	3.9	18.1
	Regen DC Energy (kWh)	0.1	0.1	0.1	0.0	0.4
	Net DC Energy (kWh)	4.9	4.5	4.5	3.9	17.7
Driving Cycle Discharge Information:						
	Minimum Battery Voltage (V)	294.0	289.7	277.9	270.2	270.2
	Maximum Battery Current (A)	207.4	194.7	196.3	134.7	207.4
	Maximum Battery Power (kW)	61.1	56.5	55.5	39.0	61.1
Driving Cycle Regen Information:						
	Maximum Battery Voltage (V)	349.6	343.1	337.1	324.5	349.6
	Maximum Battery Current (A)	93.8	100.2	98.2	50.6	100.2
	Maximum Battery Power (kW)	32.8	34.7	33.1	16.4	34.7
* Partial cycle						

All-Electric (combined UDDS/HFEDS) Tests

Two all-electric (combined UDDS/HFEDS) driving cycle tests were performed (test numbers LTDMA106 and LTDMA108). The results of these tests are summarized in Tables 8a and 8b, and 9a and 9b.

LA-92 Driving Cycle Tests

One LA-92 driving cycle test was performed (test numbers LTDMLD18). The results of this test is summarized in Table 10.

Table 8a. Results of All-Electric Driving Schedule [combined UDDS/HFEDS (Cycle 1 & 2)] for Test No. LTDMA106.

	All-Electric Cycle Number					
	1	2*				Total
General:						
Distance (km)	28.6	18.2				46.8
Vehicle DC Energy Consumption (Wh/km)	290	274				284
Gross Ampere-hours (Ah)	28.8	17.7				46.5
Regen Ampere-hours (Ah)	1.3	0.6				1.9
Net Ampere-hours (Ah)	27.5	17.1				44.6
Gross DC Energy (kWh)	8.7	5.2				13.9
Regen DC Energy (kWh)	0.4	0.2				0.6
Net DC Energy (kWh)	8.3	5.0				13.3
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	282.4	271.1				271.1
Maximum Battery Current (A)	201.9	186.3				201.9
Maximum Battery Power (kW)	57.5	52.1				57.5
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	347.2	339.4				347.2
Maximum Battery Current (A)	94.7	106.4				106.4
Maximum Battery Power (kW)	28.3	35.8				35.8
* Partial cycle						

Table 8b. Results of All-Electric (combined UDDS/HFEDS) for Test No. LTDMA1

	Sub-cycle					
	HFEDS	UDDS	HFEDS	UDDS*		Total
General:						
Distance (km)	16.6	12.1	15.7	2.4		46.8
Vehicle DC Energy Consumption (Wh/km)	297	281	276	263		284
Gross Ampere-hours (Ah)	16.6	12.2	15.2	2.6		46.5
Regen Ampere-hours (Ah)	0.3	1.0	0.3	0.3		1.9
Net Ampere-hours (Ah)	16.3	11.2	14.9	2.3		44.6
Gross DC Energy (kWh)	5.0	3.7	4.4	0.7		13.9
Regen DC Energy (kWh)	0.1	0.3	0.1	0.1		0.6
Net DC Energy (kWh)	4.9	3.4	4.3	0.6		13.3
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	289.8	282.4	280.0	271.1		271.1
Maximum Battery Current (A)	183.2	201.9	186.3	143.7		201.9
Maximum Battery Power (kW)	54.7	57.5	52.1	34.5		57.5
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	347.2	336.6	339.4	335.2		347.2
Maximum Battery Current (A)	94.7	66.9	106.4	87.4		106.4
Maximum Battery Power (kW)	28.3	22.3	35.8	29.3		35.8
* Partial cycle						

Table 9a. Results of All-Electric [combined UDDS/HFEDS (Cycle 1 and 2)] for Test No. LTDMA108.

	All-Electric Cycle Number					Total
	1	2*				
General:						
Distance (km)	28.7	17.0				45.7
Vehicle DC Energy Consumption (Wh/km)	289	277				284
Gross Ampere-hours (Ah)	12.3	16.4				28.8
Regen Ampere-hours (Ah)	17.1	0.4				17.5
Net Ampere-hours (Ah)	15.9	16.0				31.9
Gross DC Energy (kWh)	8.7	4.9				13.6
Regen DC Energy (kWh)	0.4	0.1				0.6
Net DC Energy (kWh)	8.3	4.7				13.0
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	286.7	278.0				278.0
Maximum Battery Current (A)	209.3	136.9				209.3
Maximum Battery Power (kW)	61.0	39.8				61.0
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	348.0	338.5				348.0
Maximum Battery Current (A)	77.1	96.2				96.2
Maximum Battery Power (kW)	26.8	34.0				34.0
* Partial cycle						

Table 9b. Results of All-electric (combined UDDS/HFEDS) for Test No. LTDMA108.

General:	Sub-cycle						
	HFEDS	UDDS	HFEDS	UDDS*			Total
Distance (km)	16.6	12.1	16.5	0.5			45.7
Vehicle DC Energy Consumption (Wh/km)	297	277	277	280			284
Gross Ampere-hours (Ah)	0.4	12.0	15.8	0.6			28.8
Regen Ampere-hours (Ah)	16.1	1.0	0.3	0.1			17.5
Net Ampere-hours (Ah)	4.9	11.0	15.5	0.5			31.9
Gross DC Energy (kWh)	5.0	3.7	4.7	0.2			13.6
Regen DC Energy (kWh)	0.1	0.3	0.1	0.0			0.6
Net DC Energy (kWh)	4.9	3.4	4.6	0.2			13.0
Driving Cycle Discharge Information:							
Minimum Battery Voltage (V)	287.9	286.7	278.0	292.9			278.0
Maximum Battery Current (A)	209.3	206.8	136.9	73.4			209.3
Maximum Battery Power (kW)	61.0	59.5	39.8	21.5			61.0
Driving Cycle Regen Information:							
Maximum Battery Voltage (V)	348.0	338.9	338.5	322.8			348.0
Maximum Battery Current (A)	77.1	67.0	96.2	42.8			96.2
Maximum Battery Power (kW)	26.8	22.5	34.0	13.8			34.0
* Partial cycle							

Table 10. Results of LA-92 Driving Cycle for Test No. LTDMLD18.

		Cycle Number				
		1	2	3	4*	Total
General:						
Distance (km)		15.9	15.9	15.5	6.6	54.0
Vehicle DC Energy Consumption (Wh/km)		350	337	321	328	335
Gross Ampere-hours (Ah)		20.0	19.5	18.5	8.2	66.2
Regen Ampere-hours (Ah)		1.6	1.6	1.5	0.5	5.3
Net Ampere-hours (Ah)		18.3	17.9	17.0	7.6	60.9
Gross DC Energy (kWh)		6.1	5.9	5.5	2.3	19.8
Regen DC Energy (kWh)		0.6	0.5	0.5	0.2	1.8
Net DC Energy (kWh)		5.6	5.4	5.0	2.2	18.1
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)		282.9	277.0	282.3	270.7	270.7
Maximum Battery Current (A)		292.7	288.3	216.7	140.2	292.7
Maximum Battery Power (kW)		82.8	79.9	61.8	39.9	82.8
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)		360.2	349.8	342.4	337.3	360.2
Maximum Battery Current (A)		131.1	112.5	117.0	100.6	131.1
Maximum Battery Power (kW)		47.2	41.5	39.9	39.3	47.2
* Partial cycle						

OTHER TESTS

Several other standard performance were conducted, including tests to determine the vehicle DC energy consumption at constant speeds, maximum effort acceleration times from a standing start and gradeability-at-speed.

Energy Economy Tests

Several constant speed trials were performed on a smooth level public roadway. The intent of these tests was to collect data to verify the loads programmed into the dynamometer. A set of constant speed tests was then performed on the dynamometer and compared to the results of the tests performed on the road. A graph of the energy consumption at various speeds measured on the road and on the dynamometer is shown in Figure 7 . For reference, the energy consumption reported by TDM is also shown. The INEEL tests were performed prior to the vehicle repairs. The battery state-of-charge at the time of on-road measurements were made and the battery state-of-charge during the TDM measurements was not determined. The energy consumption determined for the on-road case is generally less than that determined on the dynamometer. This result is most likely due to the effect of the rotating driveline components which were not disconnected during coastdown trials, resulting in an additional load programmed into the dynamometer that is not present on the road.

The dynamometer energy economy tests was repeated subsequent to the repairs made by TDM. The graphs in Figures 8 and 9 show the vehicle DC energy economy at various speeds and states-of-charge both prior to and after vehicle repairs. The energy consumption values and traction battery power corresponding to Figure 9 are given in Table 11.

Acceleration Tests

One maximum effort acceleration tests was performed on the dynamometer to determine the best effort acceleration characteristics of the vehicle (test number LTDMB131). The maximum effort acceleration was measured at three different beginning battery states-of-charge. Table 12 and Figure 10 shows the averaged acceleration times to reach given speeds as a function of the battery depth-of-discharge.

Figure 7. Comparison of energy consumption measured (1) on the road at the INEEL, (2) on the dynamometer at the INEEL, and (3) as reported by TDM.

TDM Ranger Pickup Truck
Energy Economy Test

—■— Battery Power —○— Energy Consumption

Figure 8. Results of energy consumption tests prior to vehicle repairs.

TDM Ranger Pickup Truck
Energy Economy Test

■ Battery Power ○ Energy Consumption

Figure 9. Results of energy consumption tests subsequent to vehicle repairs.

Table 11. Acceleration times to reach a specified speed and calculated gradability-at-speed resulting from test number LTDMB131.

Speed (km/h)	Time (s) to attain speed at various traction battery depths-of-discharge			Maximum Grade at Speed (%) at various traction battery depths-of-discharge		
	2.8%	45.3%	66.9%	2.8%	45.3%	66.9%
24	2.1	2.1	3.7	39.2	38.4	16.3
32	2.8	2.9	5.1	39.0	28.7	15.4
40	3.5	3.8	7.0	27.0	21.4	11.1
48	4.5	5.1	9.5	20.7	16.6	8.7
56	5.8	6.7	12.7	15.1	12.2	5.5
64	7.6	8.8	17.1	11.9	10.1	4.6
72	9.9	11.5	23.0	8.7	9.1	3.4
80	13.0	14.9	31.6	6.0	5.5	2.3
88	17.6	19.9	47.0	4.0	3.7	0.9
96	24.6	28.2		2.6	2.3	

Table 12. Traction battery DC energy consumption at steady speeds derived from test number LTDMZ123.

Speed (km/h)	Starting at 0% traction battery depth-of-discharge		Starting at 50% traction battery depth-of-discharge	
	Energy Consumption (DC Wh/km)	Battery Power (DC kW)	Energy Consumption DC Wh/km	Battery Power DC kW
16	268	4.3	216	3.7
32	239	7.8	195	6.4
40	225	9.0	188	7.7
48	217	10.4	190	9.2
56	223	12.6	201	11.3
64	233	15.0	216	13.8
72	246	17.8	231	16.8
80	267	21.5	253	20.3
88	288	25.4	276	24.4
96	315	30.2	316	30.1

TDM Ranger Pickup Truck
Maximum Effort Acceleration at Various DODs
(Average of 3 trials at each average DOD)

Figure 10. Maximum effort acceleration time to attain speed at various traction battery depths-of-discharge.

This data may be used to calculate the gradeability at speed characteristics of the vehicle according to the SAE recommended practice SAE J1666. The resultant "percent Grade" represents the maximum grade that the vehicle can ascend at the given speed and battery depth-of-discharge. This analysis is shown in Table 12 and Figure 11.

Battery Recharge Measurements

Data was acquired during several battery recharges. Due to equipment problems, we were unable to measure battery recharges for all tests. Additionally, AC power and energy were not measured until near the end of the test program. Figure 12 shows the momentary charger efficiency during the battery recharge following a UDDS test. As shown, the charger efficiency is approximately 65% during the constant current portion of the recharge, and drops to between 20% and 45% during the "top-off" portion of the recharge. The average charger efficiency for the complete recharge is 60%.

TDM Ranger Pickup Truck
 Calculated Percent Gradability at Speed
 (Average of 3 trials at each average DOD)

Figure 11. Percent gradeability at speed derived from maximum effort acceleration tests.

Traction Battery Recharge Efficiency LTDMX122

Figure 12. Charger efficiency during battery recharge.