EPRI

Grid-Connected Electric Coach

Feasibility Study

Technical Report

Grid Connected Electric Coach

Feasibility Study

1006752

Final Report, February 2002

EPRI Project Manager
L. Sandell

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Transportation Design and Manufacturing
13000 Farmington Road
Livonia, MI 48150

Principal Investigators
J. Rief
T. Bland

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REPORT SUMMARY

Lower cost of operation along with other benefits—such as zero or reduced emissions and the ability to adapt to varying route lengths—make the electric vehicle a clear choice for the future. This feasibility study examined a grid-connected electric coach in terms of packaging, batteries, drive system, auxiliary power unit, vehicle charging, accessory drive system, and cost of operation. It concluded that both the Ford E-450 Super Duty Cutaway chassis and the Ford Explorer chassis provided viable platforms for the hybrid electric vehicle (HEV) and pure electric vehicle (PEV), respectively.

Background

Each electric vehicle is required to operate in a typical urban service environment—under the Federal Urban Driving Schedule (FUDS)—with the capability of achieving 20 miles on pure battery power (all-electric range). The HEV will be equipped with an auxiliary power unit (APU) for range extension capabilities. The concept is to operate the vehicle during the day using energy supplied by the batteries and recharge the vehicle through grid connection overnight. Until such time that the battery provides the required range for daily operation, the APU is available for range extension. In addition, the APU—rather than the battery pack—will provide power for ancillary equipment, such as air conditioning, power steering, and the cab heater. EPRI sponsored this project to explore the feasibility of a grid-connected electric coach.

Objective

To perform an engineering feasibility study to determine the potential of converting a Ford E-350 or E-450 Super Duty Cutaway chassis to a grid-connected HEV shuttle bus and a Ford Explorer chassis to a dedicated PEV delivery van.

Approach

The project team performed an analysis of the impact to the chassis when the APU and battery systems have been installed. This analysis included evaluating the weight of the vehicles, system-mounting locations, system integration, mounting requirements, and impact on conversion to the vehicle body. The team employed ADVISOR to perform the battery evaluations using several different criteria, including FUDS, top speed, acceleration, battery life, and power acceptance. Based on previous programs and evaluations as well as battery manufacturer contacts, the team selected nickel-metal hydride and lithium-ion battery configurations as the most promising ones that should be considered for further review. They specifically evaluated the pros and cons of on- and off-board charging systems. For a PEV, the project team performed a similar analysis. Some assumptions had to be made concerning the Explorer since it would be converted from a stripped chassis to a delivery van. The team

analyzed the Explorer chassis for the pure battery system only. Finally, they performed a cost analysis comparing electric vehicle and internal combustion vehicle cost per mile.

Results

An evaluation of the vehicle weight after conversion to a hybrid—considering its gross vehicle weight rating (GVWR) and gross axle weight rating (GAWR)—concluded that the Ford E-350 Super Duty Cutaway chassis would not be able to carry a sufficient payload to meet the requirements of an airport shuttle. The size of the components along with other influences on vehicle weight caused the GVWR to exceed manufacturer's recommendations for the vehicle.

Although detailed engineering and design analysis would be required for the actual build of the prototype vehicle, this study concluded that the Ford E-450 Super Duty Cutaway chassis provides an optimal platform for conversion to an HEV. The study recommends the use of a small diesel engine coupled to a generator/alternator sized for the required range extension. Such a configuration best meets packaging, heat management, and emissions standards. The study also concluded that the Ford Explorer chassis meets all selection criteria and is therefore a viable platform to meet EPRI's PEV requirements.

EPRI Perspective

The next phase of the program, if approved, would involve a detailed engineering study and a prototype build. Specifications for that phase must clearly define requirements in following areas: 1) battery selection/battery management system, 2) thermal management involving use of a small diesel engine or internal combustion engine to address concerns over heat management, 3) vehicle weight analysis, 4) APU selection, with emphasis on an exact definition of the range extension required, 5) optimization of bracket designs to account for vibration testing, 6) vehicle control systems, 7) calibration of gauges and design of the dash panel for driver interface, and 8) vehicle system integration, involving design of a robust communications network in order to optimize performance and allow each component to share information. This report provides an invaluable feasibility study for future development of HEV and PEV coaches. Clearly, the PEV or HEV has substantial potential for savings over its gasoline counterpart. With the rapid increase in electric vehicle technology and the production of more electric vehicles, the cost for conversions and hardware will decrease over time—making the electric vehicle an excellent transportation choice.

Keywords

Hybrid electric vehicle
Electric vehicle feasibility
Grid-connected electric coach

NOMENCLATURE

Variable	Explanation
G	Road Gradient (% Grade)
m	Mass
C_{rr}	Tire Rolling Resistance Coefficient
C_d	Aerodynamic Drag Coefficient
A	Frontal Area
p	Air Density
n	Total Efficiency = $n_m \cdot n_d \cdot n_v$
n_m	Efficiency of Motor / Controller
n_d	Efficiency of Drive System
n_v	Efficiency of Vehicle
v	Vehicle Speed
g	Gravitational Constant
VCEM	Vehicle Control Energy Management
PLC	Programmable Logic Circuit
DIAC	Diagnostic Interface Assembly Cable
IC Engine	Internal Combustion Engine
PEV	Pure Electric Vehicle
HEV	Hybrid Electric Vehicle
FUDS	Federal Urban Driving Schedule
Simulink	MathWorks, Inc. version 3.0
Matlab	MathWorks, Inc. version 11.1
ADVISOR	NREL, version 2.2
DC Motor	Direct Current Motor
AC Motor	Alternating Current Motor
SIADIS	Siemens Automotive Diagnostic System
SOC	State of Charge
FEAD	Front End Accessory Drive
PTC Heater	Positive Temperature Coefficient Heater
APU	Auxiliary Power Unit
TDM	Transportation Design & Mfg. Co.
GVWR	Gross Vehicle Weight Rating
GAWR	Gross Axle Weight Rating
FMVSS	Federal Motor Vehicle Safety Standards
USABC	United States Advanced Battery Consortium
EPRI	Electric Power Research Institute

SOW	Statement of Work
TBCM	Traction Battery Control Module
HVPDB	High Voltage Power Distribution
VRLA	Valve Regulated Lead-Acid
TMCM	Traction Motor Control Module
APUCS	Auxiliary Power Unit Control System
ADMCM	Accessory Drive Motor Control Module

CONTENTS

***1* FEASIBILITY** **1-1**

Ford E-350 Grid Connected HEV 1-1

Ford E-450 Grid Connected HEV 1-2

Ford Explorer Grid Connected PEV 1-3

Summary 1-5

***2* PACKAGING** **2-1**

Ford E-350 Super Duty Cutaway 2-2

Ford E-450 Super Duty Cutaway 2-2

Ford Explorer 2-3

Conclusion 2-4

***3* BATTERIES** **3-1**

Objective 3-1

Battery Selection Criteria 3-1

Maximum Power 3-1

Variable Power 3-2

Sustained Hill Climb 3-2

Gradeability 3-2

Life 3-3

Power Acceptance 3-3

Mathematical Analysis 3-3

Steady State 3-3

Variable Power 3-4

Acceleration Loads 3-4

Ford E-350 / E-450 Super Duty Cutaway Chassis 3-4

Vehicle Definition 3-4

Simulation 3-5

Steady State Power Requirements Based on Vehicle Speed 3-5
FUDS - Variable Power Capacity Simulation 3-6
Vehicle Acceleration Study 3-9
Conclusions 3-10
Battery Pack Needs 3-11
Pack Proposals 3-11
Budget Estimate 3-13
Ford Explorer 3-13
Simulation 3-14
Steady State Power Requirements Based on Vehicle Speed 3-14
FUDS - Variable Power Capacity Simulation 3-15
Vehicle Acceleration Study 3-17
Conclusions 3-18
Pack Needs 3-19
Pack Proposals 3-19
Battery Cell / Modules 3-21
Engineering Requirements of Battery Pack Design 3-22

***4* DRIVE SYSTEM 4-1**
Inverter for Electric Vehicle Applications 4-2

***5* AUXILARY POWER UNIT 5-1**
Previous Applications 5-1
Mathematical Analysis 5-1
Steady State Power 5-1
Variable Power 5-2
FUDS Base Line 5-3
FUDS w/ 65 kW Generator 5-4
FUDS w/45 kW Generator 5-5
FUDS w/28 kW Generator 5-6
Auxiliary Power Unit Options 5-7
THE MICRO TURBINE SYSTEM 5-7
The Turbo Diesel System 75 kW 5-9
The Turbo Diesel System 45 kW 5-10

6 VEHICLE CHARGING..6-1

7 ACCESSORY DRIVE SYSTEM..7-1

Air Conditioning System..7-1
Power Steering..7-2
Positive Temperature Coefficient (PTC) Cab Heater..7-2
Positive Temperature Coefficient (PTC) Heater Specifications..7-2
Resistive High Voltage Rear Heater..7-2
Vacuum System..7-3
DC/DC Power System..7-3

8 COST OF OPERATION..8-1

Electric Vehicle vs. Internal Combustion Vehicle..8-1
Ford E-450 Vehicle..8-2
Explorer..8-2

9 CONCLUSION / SUMMARY..9-1

Conclusion and Recommendation..9-1
Plan to Proceed..9-1

A APPENDIX – COMPONENT INFORMATION..A-1

Battery Information..A-1

B APPENDIX – REFERENCE INFORMATION..B-1

Previous Programs..B-1
  Warner Robins Hybrid..B-1
  Ford EV Ranger..B-19

LIST OF FIGURES

Figure 1-1 E-450 System Schematic 1-3
Figure 1-2 Explorer System Schematic 1-4
Figure 3-1 Typical FUDS Cycle 3-2
Figure 3-2 Ford E-450 Velocity vs. Power 3-5
Figure 3-3 Ford E-450 FUDS Simulation 3-6
Figure 3-4 Ford E-450 FUDS Distance 3-7
Figure 3-5 Ford E-450 Power Requirements 3-8
Figure 3-6 Ford E-450 Acceleration 3-9
Figure 3-7 E-450 Power Required in Acceleration 3-10
Figure 3-8 Explorer Velocity vs. Power 3-14
Figure 3-9 Explorer FUDS Simulation 3-15
Figure 3-10 Explorer FUDS Distance 3-16
Figure 3-11 Explorer Power Requirement 3-16
Figure 3-12 Explorer Acceleration 3-17
Figure 3-13 Explorer Power Required in Acceleration 3-18
Figure 5-1 APU Power Potential 5-2
Figure 5-2 APU Regenerative Potential 5-3
Figure 5-3 65kW APU Power 5-4
Figure 5-4 45 kW APU Power 5-5
Figure 5-5 28 kW APU Power 5-6
Figure 5-6 Vehicle Comparisons 5-7
Figure 5-7 Micro Turbine 5-8
Figure 6-1 Posi Charge PC-60 6-3
Figure 7-1 Drive Motor Example 7-1
Figure 9-1 Ford Parcel Delivery Van B-3
Figure 9-2 Ford E-350 Super Duty Cutaway Chassis B-4

LIST OF TABLES

Table 1-1 Feasibility Matrix 1-5
Table 2-1 E-350 Weight Table 2-2
Table 2-2 E-450 Weight Table 2-3
Table 2-3 Explorer Weight Table 2-3
Table 3-1 E-450 Simulation Variables 3-4
Table 3-2 LiON HP-30 3-9
Table 3-3 E-450 Battery Requirements 3-11
Table 3-4 E-450 Battery Specifications 3-12
Table 3-5 E-450 Battery Cost 3-13
Table 3-6 Explorer Simulation Variables 3-13
Table 3-7 Explorer Battery Requirements 3-19
Table 3-8 Explorer Battery Specifications 3-20
Table 3-9 Battery Comparison 3-21
Table 3-10 Battery Comparison (cont.) 3-22
Table 4-1 Electric Motor Comparitor 4-2
Table 5-1 APU Power Required 5-2
Table 5-2 28 kW Micro Turbine Generator Specifications 5-8
Table 5-3 75 kW Hybrid Generator Specifications 5-9
Table 5-4 45 kW Hybrid Generator Specifications 5-10
Table 5-5 Decision Matrix 5-11
Table 6-1 On-Board Charging 6-1
Table 6-2 Off-Board Charging 6-1
Table 6-3 Lockheed Martin Charger Specifications 6-2
Table 7-1 PTC Heater Specifications 7-2

1

FEASIBILITY

TDM was contracted to perform an engineering feasibility analysis of converting a Ford E-350/450 Super Duty chassis into a grid connected HEV shuttle bus. As a part of the study, TDM was also requested to evaluate converting an Explorer chassis into a grid connected PEV. The parameters for the feasibility study were as follows:

- Each vehicle is required to operate in a typical urban cycle (FUDS) with the capability of obtaining a minimum of 20 miles using battery power only.
- The weight, system mounting locations and mounting requirements, system integration, and impact of the conversion to the vehicle body are to be addressed.
- The E-350/450 Super Duty chassis is to be used as a shuttle bus and must be evaluated for a hybrid application with the capability of extending the range beyond 20 miles in case of emergency, i.e. low battery state due to driver variables, range variables, or terrain variables.
- The vehicles must meet FMVSS requirements such as top speed, braking distance, crash standards, rollover standards and emissions.
- The analysis must show the performance of the vehicles in terms of acceleration, top speed and power consumption.
- TDM must identify “off the shelf” grid connected vehicle systems appropriate to meet design intent requirements.
- TDM is to evaluate the end user cost of operation for the electric and hybrid vehicles vs. the gasoline vehicles.
- TDM must identify areas requiring further engineering analysis in order to create a grid connected hybrid vehicle prototype.
- TDM will receive written direction from to proceed or not to proceed with the design phase of each specific vehicle.

Ford E-350 Grid Connected HEV

TDM began the analysis of the feasibility by looking over the packaging constraints of each vehicle. Assumptions were made and guidelines were set in order to evaluate each vehicle. A more detailed description can be found in the packaging section of the report.

While evaluating the weight of the vehicle after conversion to a hybrid, considering its gross vehicle weight rating (GVWR) and the gross axle weight (GAWR) rating, it was concluded that the E-350 Super Duty Cutaway chassis would not be able to carry a sufficient payload to meet the requirements of an airport shuttle as stated in the contract. The size of the components along with the other influences on the vehicle weight caused the GVWR to exceed the manufacturer's recommendations for the vehicle. **Data from previous TDM programs also supported the conclusion that the E-350 would not be a viable solution for EPRI's application.**

Ford E-450 Grid Connected HEV

Following the same procedure as the E-350, the E-450 Super Duty chassis showed potential for a successful package. Once the added weight of the components was analyzed in this chassis in terms of GVWR and GAWR, TDM began further studies into packaging the components into the chassis. TDM collected data from previous programs and other sources for the chassis and began to evaluate the vehicle for system requirements in order to achieve a minimum of 20 miles range. ADVISOR was utilized to perform the battery evaluations using several different criteria including the Federal Urban Driving Schedule (FUDS), gradeability, top speed, acceleration, battery life and power acceptance. This analysis was conducted several times until the power requirement for the batteries was determined. During the study, several manufacturers of batteries were contacted to obtain the latest technology available and determine what was offered as off the shelf items. Based on previous programs and quick evaluations, it was decided that lead acid batteries would not be able to meet the requirements of these vehicles. Two battery configurations were selected for further review, Nickel-Metal Hydride and Lithium-Ion.

While the battery pack requirements were being developed, Ford Motor Company's proprietary software PDGS was used to begin positioning the components to the chassis. Mounting locations and system integration studies were started. Studies into the auxiliary power unit were conducted and several meetings with leaders in the automotive auxiliary electric power unit field occurred. Vehicle integration was researched and a basic schematic was produced.

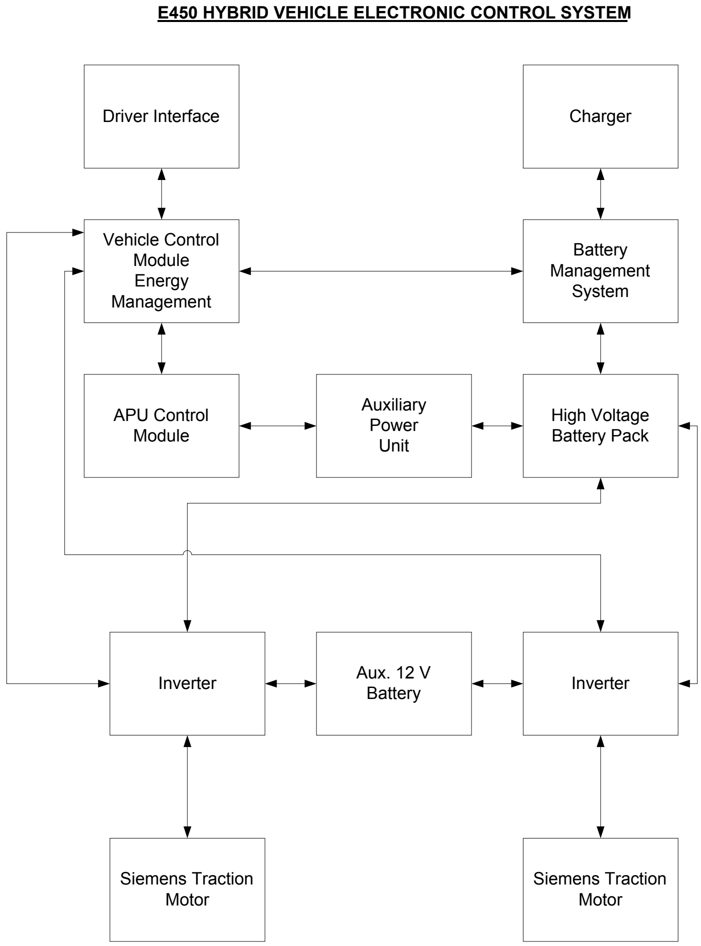


Figure 1-1
E-450 System Schematic

TDM also researched the FMVSS requirements for the vehicle. Based on past experience with electric vehicles, these vehicles can be engineered to be in full compliance to FMVSS standards. The conversion of the vehicles will not impact the validated safety items of the base vehicle (i.e. seats, occupant restraint systems, and GVWR). Depending on the final configuration of the components, a re-evaluation of the FMVSS standards must be performed. If any changes to the vehicle safety items during the actual vehicle build occurs, FMVSS validation tests must be performed. **Although further detailed engineering and design analysis would be required for the actual build of the prototype vehicle, TDM concluded that the E-450 is a optimal platform for the conversion to a hybrid electric vehicle.**

Ford Explorer Grid Connected PEV

TDM performed a similar analysis as described for the E-450 Super Duty Cutaway chassis. TDM had to make some assumptions concerning the configuration of the body for the Explorer since it will be converted from a stripped chassis to a delivery van body. Research into the performance of the vehicle and the packaging of the components occurred at the same time as the evaluation of the E-450 shuttle bus took place. The Explorer chassis was analyzed for the use of a battery system only. The chargers for both vehicles were identified and located for packaging confirmation. The vehicle integration was also reviewed and is as follows:

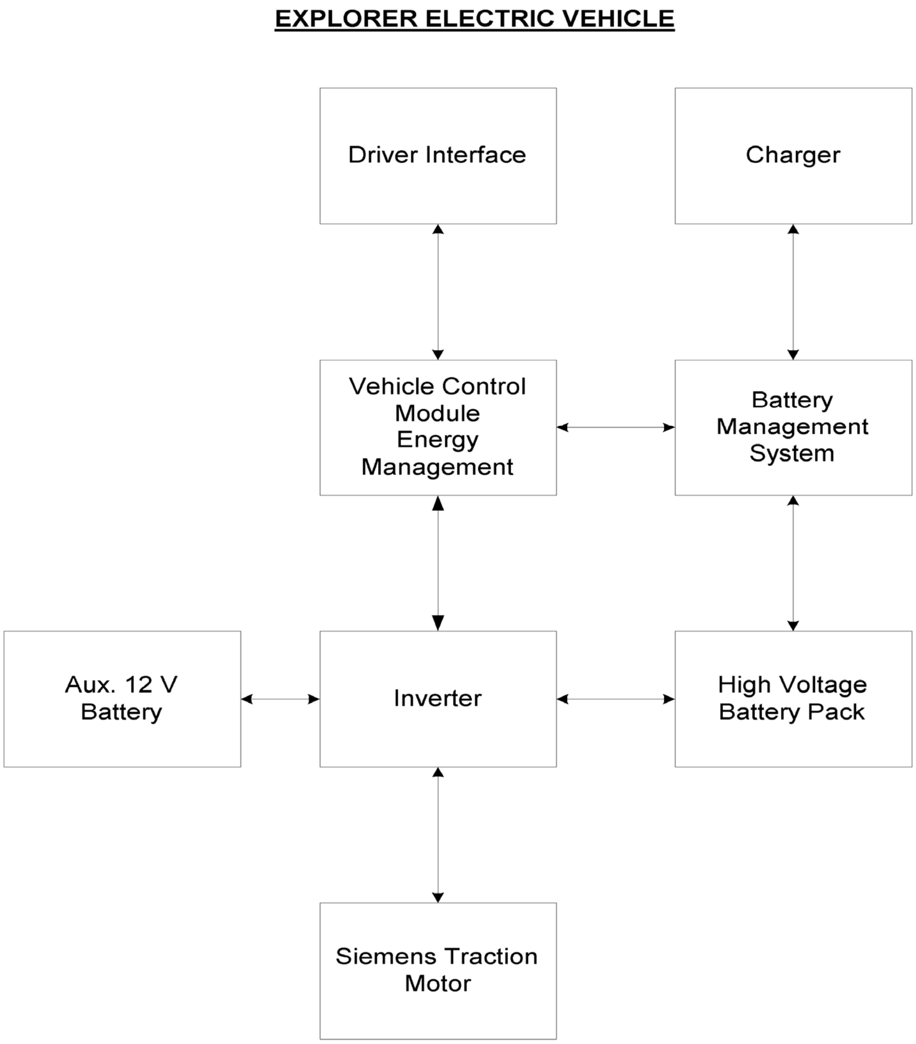


Figure 1-2
Explorer System Schematic

Following the evaluation of the data, TDM concluded that the Explorer chassis is a viable platform to meet EPRI's PEV requirement.

Summary

Based on this feasibility study, the E-350 will not be a good choice for this application due to the fact that the GVWR for the vehicle will be exceeded. A deregulation of the GVWR cannot support the extra weight due to passenger load and components. In turn, the E-450 conversion has been found to be an acceptable chassis for the HEV airport shuttle application. Evaluations of the performance requirements including range, packaging, and safety confirm the decision. The Explorer chassis was also proven to be a viable solution for a PEV conversion. TDM has developed the following feasibility matrix for quick reference:

Table 1-1
Feasibility Matrix

Vehicle	Packaging	Range Required	Performance Requirements	GVWR	Safety
E-350	YES	YES	YES	NO	YES
E-450	YES	YES	YES	YES	YES
Explorer	YES	YES	YES	YES	YES

Until such time that Ford awards a contract to Grumman Olson to build EV postal vehicles, no contractual information is available on which chassis may be finally selected. At present both the Explorer chassis and F-350 base chassis have been used in EV and Hybrid applications. TDM has experience with both chassis designs and upon an EPRI award of a prototype development contract, resolution of the type of chassis to be used in a hybrid grid connected step van application would have to be made; however, both chassis are capable of being hybrid grid connected with resultant impacts on payload based on final engineering and design decisions that would be made jointly by EPRI and TDM to meet vehicle operational specifications.

2
PACKAGING

There are a number of elements that need consideration when packaging an electric drive system into a vehicle designed for an internal combustion engine. For example, the electric motor, drivetrain, and battery must be able to provide enough power to overcome the vehicle weight, aerodynamic drag, rolling resistance, gearing, etc. Several studies must be performed in order to choose the right components to obtain the performance desired. These electric vehicle components must also fit within the space between the frame and body defined by the base vehicle design.

Once the requirements have been developed and a system has been defined the next obstacle is the packaging and placement of all the components. The location and placement of each component could affect the vehicle performance. The location for the components must not adversely affect the overall handling and performance of the vehicle. Considerations for center of gravity locations and torque due to the weight of the components must be evaluated. Once TDM has initial locations for all the components, optimization must take place to obtain the best weight distribution in order to match the base vehicle requirements if vehicle performance is to be maintained.

Packaging studies of the mounting location for the battery, drive motor, auxiliary power unit, generator, on-board charging system and battery management system were performed on PDGS. This allowed TDM to visualize/analyze the system as it will be integrated into the vehicle and provided the ability to verify that each component would fit in the specified E-350, E-450 and Explorer chassis.

In order to match the base vehicle and to avoid affecting any of the other systems such as axles, brakes, suspensions, tires, etc. TDM must design the new system so that it loads the vehicle identical or as close to the base vehicle as possible. The tables below show the weight distributions for the base and converted vehicles.

For the weight loading of the vehicle, there are a few automotive guidelines and assumptions that were typically followed. These are as follows:

- Must not exceed the vehicle GVWR
- Must not exceed the front and rear GAWR
- Maintain proper weight distribution (same as base vehicle)

- Maintain payload capability must be considered for the hybrid shuttle bus. (14 passengers @ 150 lb each, 65 lbs of luggage each)
- Maintain vehicle body weight (conversion coach process from modifier assumed to weigh average of 2500 lbs).

Ford E-350 Super Duty Cutaway

The following table is an estimate of the weight changes before and after conversion. Based on the performance criteria for the hybrid vehicle, this analysis and previous vehicle experience concluded that the packaging feasibility for the **Ford E-350 Super Duty would not work**. The available payload is exceeded for an E-350 stripped chassis when loaded with the modifier body, its passengers and contents.

Table 2-1
E-350 Weight Table

Item	Weight	Front Axle	Rear Axle	Payload Weight
Baseline Vehicle (Curb Weight, no body)	4884	2907	1977	6615
Baseline Vehicle (GVWR)	11500	-	-	-
Baseline Vehicle (GAWR)	-	4600	8350	-
Weight Removed	-2100	-1750	-350	-
Weight Added	3600	1980	1620	-
Grid Connected	6384	3137	3247	5115

Ford E-450 Super Duty Cutaway

The following table is an estimate of the weight changes before and after conversion. Further study is needed to analyze the actual changes to the vehicle weights once actual components are selected and designed into the base vehicle.

Table 2-2
E-450 Weight Table

Item	Weight	Front Axle	Rear Axle	Payload Weight
Baseline Vehicle (Curb Weight)	5501	3041	2460	8545
Baseline Vehicle (GVWR)	14050	-	-	-
Baseline Vehicle (GAWR)	-	4600	9450	-
Weight Removed	-2100	-1750	-350	-
Weight Added	3600	1980	1620	-
Grid Connected	7001	3271	3730	7045

Ford Explorer

The following table estimates the weight changes before and after conversion. Further study is needed to analyze the actual changes to the vehicle weights once actual components are selected. This particular analysis was performed using the weights for a fully equipped Explorer. Stripped chassis weights were not available for the study. It is assumed that the actual vehicle will be representative to the base vehicle package.

Table 2-3
Explorer Weight Table

Item	Weight	Front Axle	Rear Axle	Payload Weight
Baseline Vehicle (Curb)	3845	2010	1635	1350
Baseline Vehicle (GVWR)	-	-	-	-
Baseline Vehicle (GAWR)	-	2620	2900	-
Weight Removed	-800	-650	-150	-
Weight Added	1400	400	1000	-
Grid Connected	4345	1760	2485	850

Conclusion

Based on this preliminary packaging analysis, the conversion of the E-350 is not possible. Part of the issue is the deregulation of the GVWR from 14050 to 11500. TDM recommends the use of the E-450 for the hybrid vehicle. Analysis of the Explorer chassis based on GVWR of the base vehicle shows that a conversion to full electric is possible. This packaging and weight analysis was evaluated with the current parts and technology available at the time of the study. A more detailed engineering study will need to be performed at the prototype vehicle kick off in order to confirm each component and its weight, cube space requirement and detailed engineering analysis for placement in the vehicle.

3

BATTERIES

Objective

The battery pack and electric motor selection will determine overall vehicle performance. Selection and function ability of these components is critical.

Battery Selection Criteria

There are many criteria that a battery pack must meet to have a properly functioning Pure Electric Vehicle (PEV) and/or a Hybrid Electric Vehicle (HEV). The battery pack must meet these following criteria:

- Repeatedly deliver impulses of power during acceleration.
- Meet the desired range of the vehicle for the desired driving cycle(s).
- Provide continuous high levels of power to ensure the vehicle’s ability to scale continuous grades.
- Provide continuous high power levels for ascending steep grades at high speeds.
- Provide reliable & predictable performance for the life of the vehicle.
- Accept large amounts of power during regenerative braking.
- Avoid pack degradation during normal vehicle operation.

Consideration of these criteria is essential to correctly determine the size of the vehicle’s battery pack.

Maximum Power

For the Warner Robins Hybrid Program, TDM used two 75 kW (maximum) motors in the shuttle bus to drive the vehicle. For this study, it’s assumed that 150kw is the maximum power required to operate the vehicle. Instantaneously, the maximum generation power of the battery pack is 150 kW + inefficiencies of the battery system + inefficiencies of the motor/controller system.

Variable Power

The Statement of Work (SOW) for this feasibility study states "the vehicle must be able to drive 20 miles of a common urban cycle on a full charge and then be able to operate off of the hybrid range extension". "The Federal Urban Driving Schedule (FUDS) is the most commonly used … It's an automobile industry standard vehicle time-velocity profile … used for a number of years for electric vehicle performance standards" (Electric Vehicle Battery Test Procedure Rev. 2, USABC). This cycle is the same as the EPA Urban Dynamometer Driving Schedule defined in 40 CFR Part 86 Appendix I (shown below). This is the most representative cycle that a vehicle undergoes while in an urban setting. The FUDS data is shown in the Vehicle Simulation section.

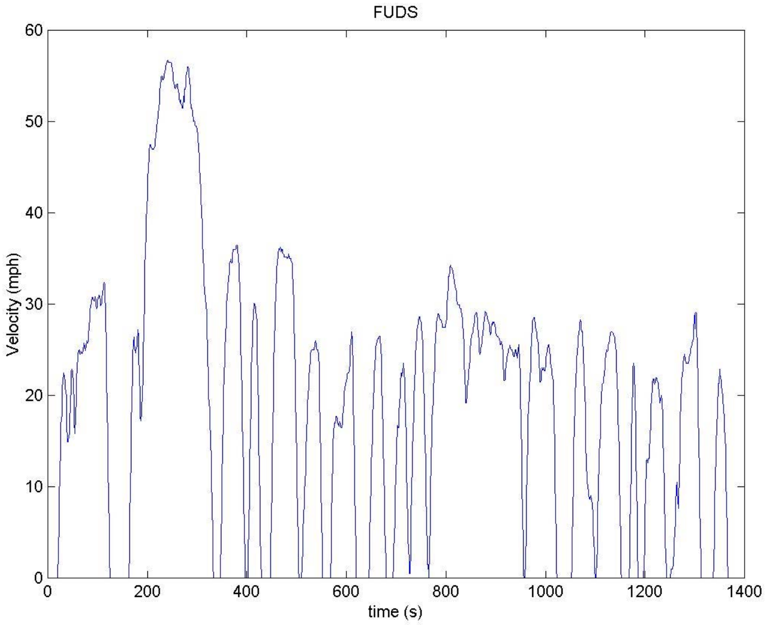


Figure 3-1
Typical FUDS Cycle

Sustained Hill Climb

Although a vehicle may not encounter continuous hill climbs on a day-to-day basis, it should be designed to negotiate a substantial climb. The "Sustained Hill-Climbing Power Test" depicted in the USABC battery "Electric Vehicle Battery Test Procedures" indicates that a vehicle should have the capability to negotiate a 7% grade at 30 mph for 6 minutes.

Gradeability

The battery system should support steep grade hill climbs. During this time the motor requires its maximum torque. Assuming the vehicle will only encounter steep grades for less than 30 seconds, the battery must deliver the maximum energy required by the motor plus the inefficiencies of the powertrain system for no more than 30 seconds without sustaining any permanent damage.

Life

To build a cost-effective electric vehicle the battery system must provide reliable and predictable performance throughout the life of the vehicle. Batteries must have low internal losses during discharging and charging, maintain consistent cell performance, and provide all of the above criteria. To obtain these performance requirements the battery pack requires sophisticated battery management techniques and may require an oversized capacity for the application.

Power Acceptance

To minimize the necessary battery pack size needed for the hybrid vehicle and provide extended urban driving range, regenerative braking is required. The battery pack needs to have a high charge acceptance rate to make the regenerative braking system usable. Regenerative braking simulates the feel of the engine braking in an internal combustion engine vehicle and feeds power back into the traction battery.

The following criteria were used to initially size the battery pack:

- Acceleration Loads – Maximum Power of Motor Controller System
- Maintain 70 mph for 5 miles
- Variable Power – 20 miles range FUDS
- Sustained Hill Climb 7% Grade at 30 mph for 6 minutes
- Life Cycle
- Charge Accept

Mathematical Analysis

Three basic calculations were used to determine the vehicle's instantaneous power requirement and battery pack capacity.

Steady State

The first calculation provides steady state power requirements based on vehicle speed. The formula and its variable explanation is provided below:

$$Power = {}^{v}\!/_{n} \cdot \left[m \cdot g(\sin(\arctan(G)) + C_{rr} \cdot \cos(\arctan(G))) + \frac{1}{2} \cdot C_d \cdot A \cdot p(v)^2 \right]$$

This calculation estimates the power requirements during steady state conditions, i.e. constant speed driving and sustained hill climbs.

Variable Power

The second calculation utilized more sophisticated tools to simulate the power requirements of a more realistic driving situation. TDM simulated this cycle using Advanced Vehicle Simulator (ADVISOR), a simulation tool created in MATLAB/Simulink.

Acceleration Loads

A third study was performed to simulate the vehicle's maximum acceleration rate on flat ground. This simulation, providing information to correctly size the power characteristics of the batteries, was performed using ADVISOR.

Ford E-350 / E-450 Super Duty Cutaway Chassis

Vehicle Definition

The following variables were derived from previously existing hybrid bus data and used in the simulations. The mass of the vehicle was adjusted to the Gross Vehicle Weight Rating (GVWR) of the 2000 model Ford E-450 Super Duty Cutaway vehicle. These parameters are very critical in determining the vehicle's power requirements. Other, less critical, variables are also selected for simulations done in ADVISOR. Parasitic power requirements have been ignored in the following analysis. The Ford E-450, with an attached shuttle bus body, comes with a 60,000 BTU heating system and a 75,000 BTU air conditioning system. When operated at maximum power these units will consume 17.6 kW and 22 kW, respectively. Either the battery pack or the generator can supply the necessary power to operate the heating and cooling systems. The impact of the accessory drives on overall system performance will be studied in the next phase: full design effort.

Table 3-1
E-450 Simulation Variables

Variable	Value
m	14050 lbm
C_{rr}	0.007
C_d	0.571
A	5.69 m^2
n	0.8

Simulation

Three studies were performed for each vehicle: (a) a steady state prediction of power requirements based on vehicle speed, (b) FUDS variable power capacity simulation, (c) and vehicle acceleration. These studies will help determine the size of the battery pack required.

Steady State Power Requirements Based on Vehicle Speed

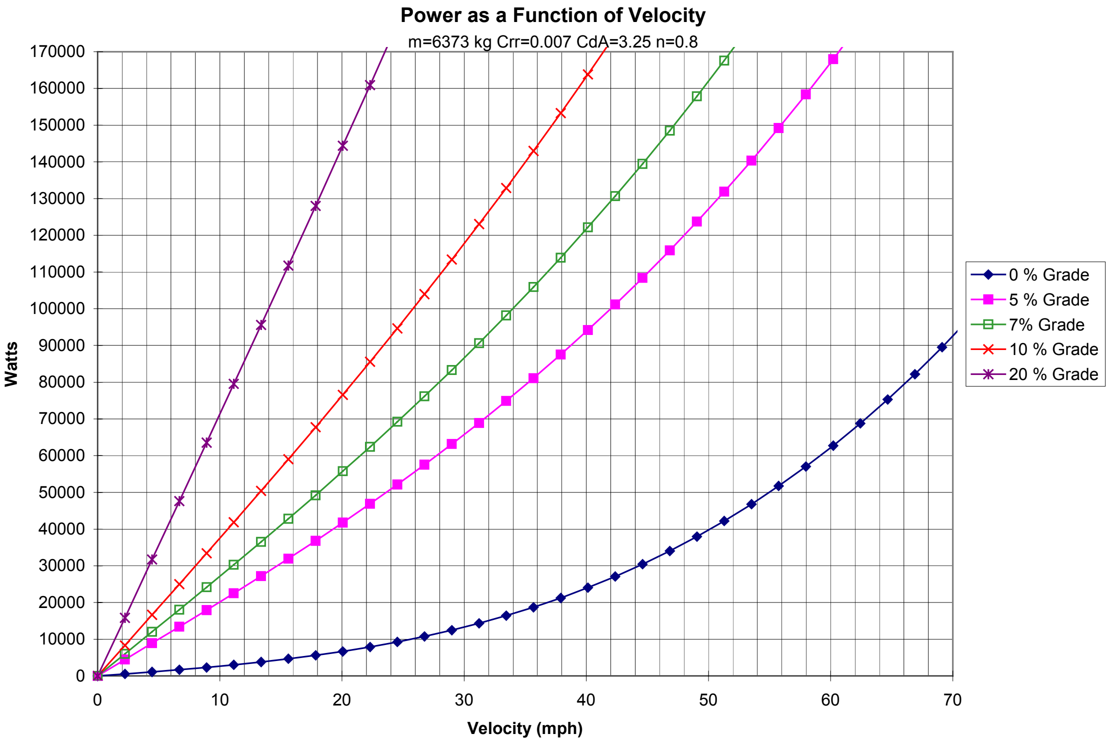


Figure 3-2
Ford E-450 Velocity vs. Power

Figure 3-2 demonstrates the vehicle's power requirements in Watts as a function of vehicle speed and grade. This chart also provides vital information for the sizing of the battery pack. This information outlines:

- The vehicle would require approximately 90 kW while driving at 70 mph at highway speeds.
- The vehicle would require 85 kW while driving at 30 mph on a 7% grade.
- The vehicle could maintain approximately 22 mph on a 20% grade at the maximum power of 150 kW for the motors.

FUDS - Variable Power Capacity Simulation

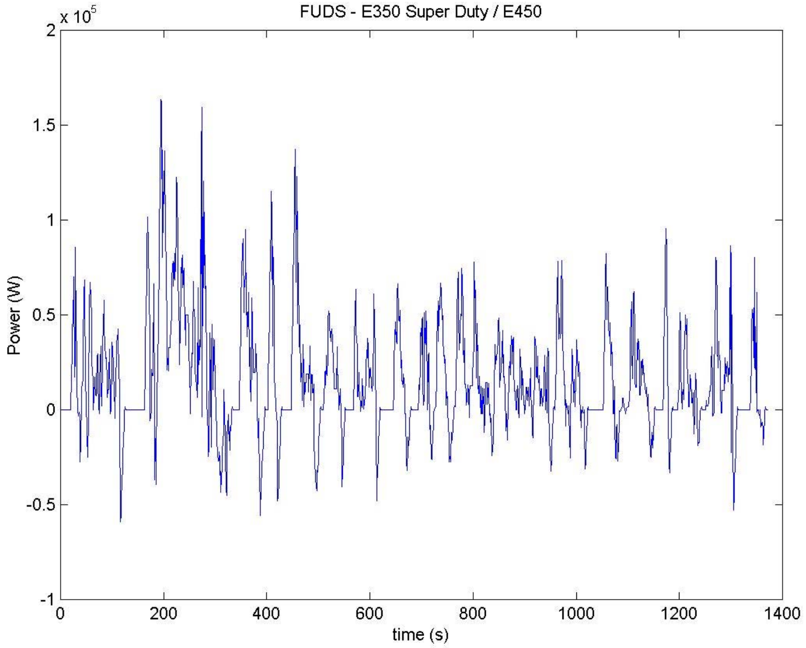


Figure 3-3
Ford E-450 FUDS Simulation

Figure 3-3 provides the power required to operate the vehicle through one FUDS cycle. It displays the power (Watts) used as a function of time (seconds) throughout the cycle. On this graph negative power represents available regenerative braking power.

- This data determines the amount of energy required to drive one FUDS cycle.
- The vehicle uses 160 kW peak power during one FUDS cycle.
- Regenerative power can replenish spent energy during the driving cycle.

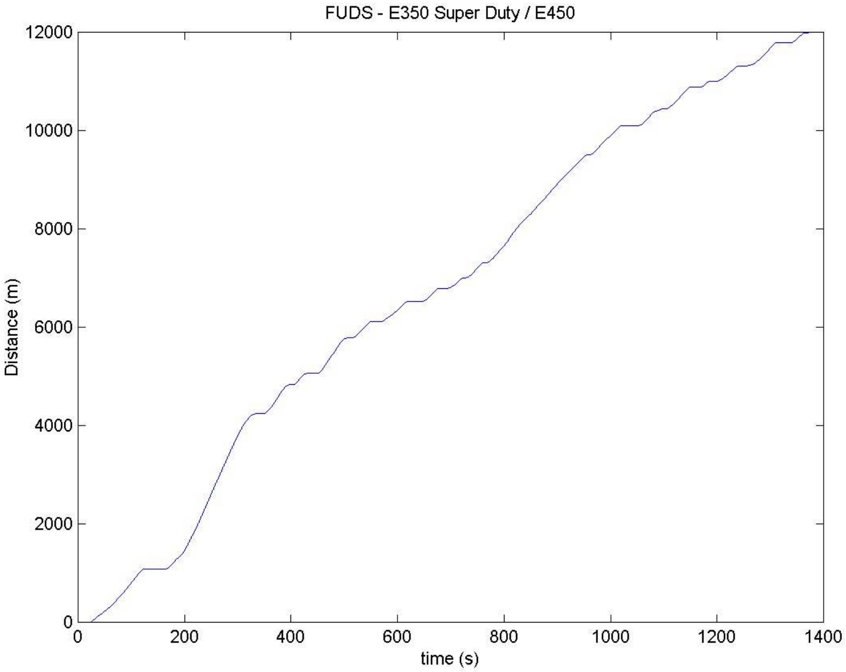


Figure 3-4
Ford E-450 FUDS Distance

Figure 3-4 shows the total distance traveled as a function of time during one FUDS cycle. The total distance traveled by the hybrid during one FUDS cycle is 12 km (7.45 miles).

ADVISOR also reports an estimate of the gasoline equivalent fuel consumption rate of L/100km. The gasoline equivalent fuel consumption rate reported is 7.7 L/100km or 30.6 mpg (miles per gallon).

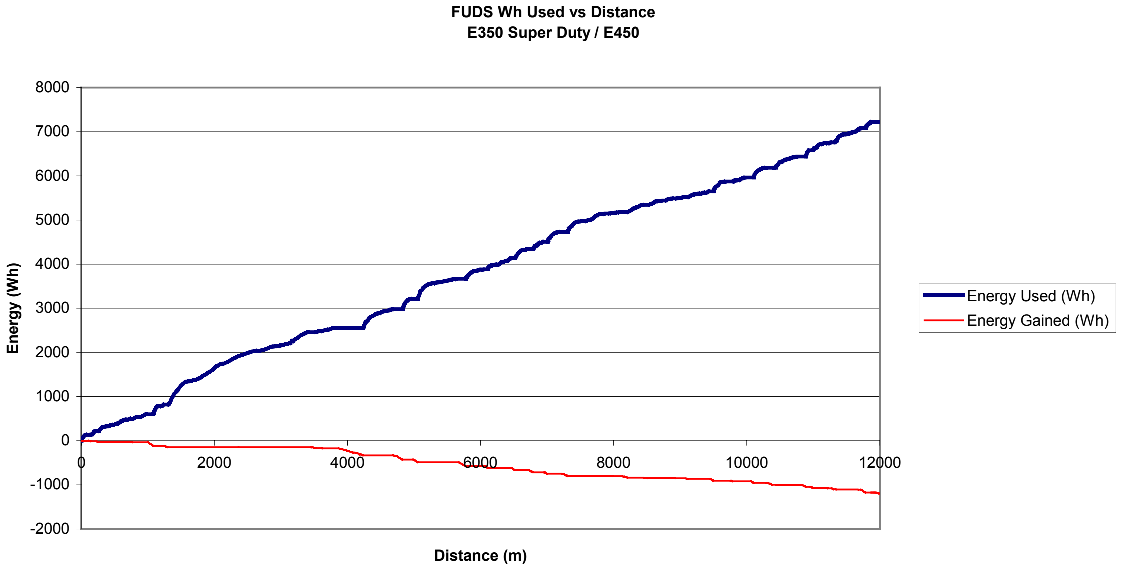


Figure 3-5
Ford E-450 Power Requirements

The data obtained from the ADVISOR simulation is further analyzed to determine the energy the vehicle needs through one cycle. The following information can be extracted from Figure 3-5:

- The vehicle requires 7.2 kW-hr for one FUDS cycle.
- The vehicle gains extended range through regenerative braking.
- Generally the vehicle uses 1kw-hr per mile during the FUDS cycle.

The actual energy accepted by the battery during regenerative braking will need further investigation in the design phase of the project. As an example see Table 3-2. Over 20 miles of FUDS operation the vehicle has 2.8 kWh of energy available to the battery system due to regenerative braking (assuming 90% charge accept rate). This will extend the vehicle's range by 2.8 miles. The amount of energy available to the battery is highly dependant upon the percentage of braking the motors are allowed to do. For this study the vehicle relies on the motors to do 80% of the braking effort at speeds greater than 60 mph, 50% at speeds between10 mph and 60 mph, and 0 % at speeds from 0 mph to 10mph.

SAFT engineering provided the following information in table 3-2.

Table 3-2
LiON HP-30

Power	SOC	Efficiency
High	> 70%	80%
High	30 – 70%	90 – 95%
Medium / Low	10 – 90%	> 95%

Vehicle Acceleration Study

A vehicle acceleration test was simulated using ADVISOR. A Power vs. Time for maximum acceleration, and velocity versus time are shown below.

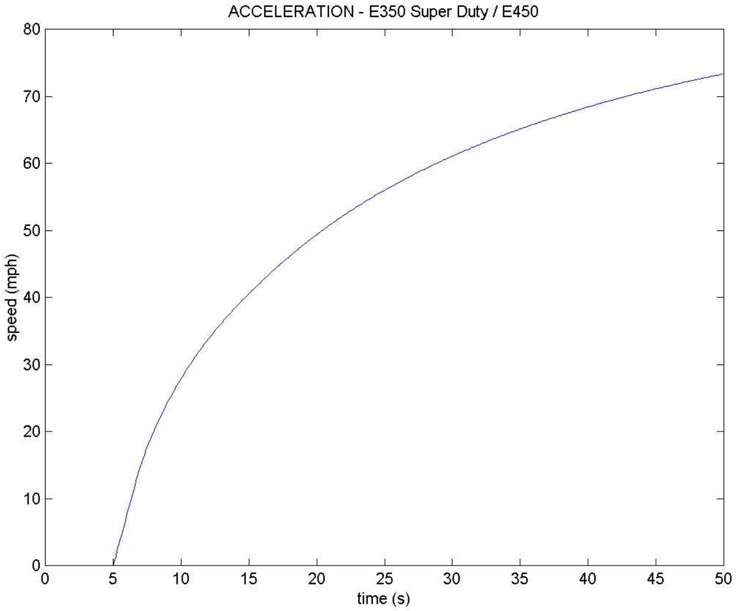


Figure 3-6
Ford E-450 Acceleration

Figure 3-6 shows the required time to accelerate to a given speed on a heavy acceleration profile. Based on information provided from ADVISOR, the PEV requires 24.0 seconds to accelerate from 0 to 60 mph.

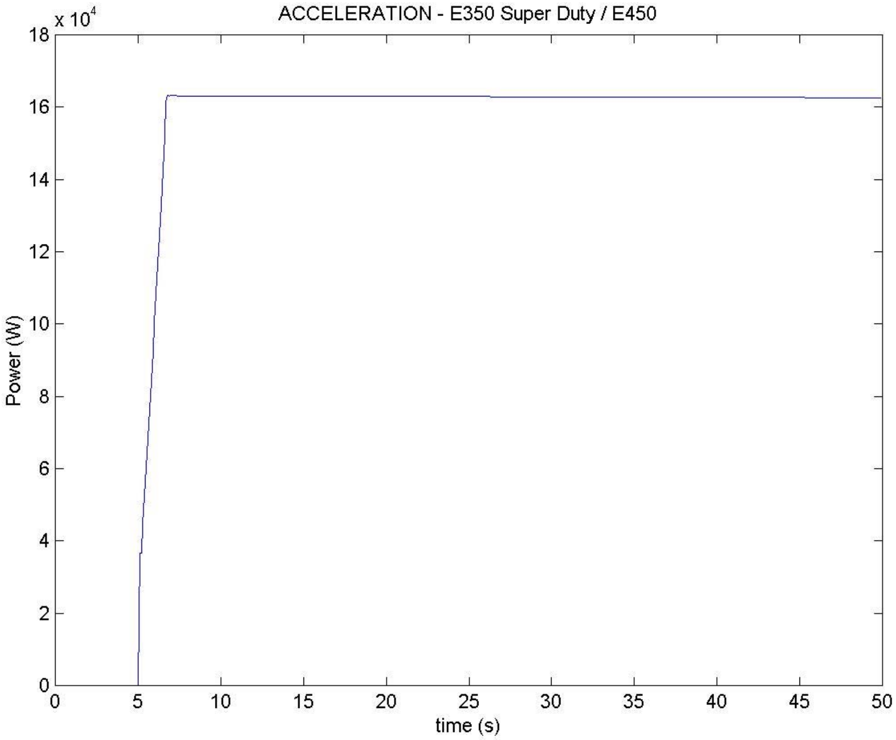


Figure 3-7
E-450 Power Required in Acceleration

Figure 3-7 demonstrates that the vehicle uses approximately 160kW during heavy acceleration.

Conclusions

- The vehicle requires approximately 90 kW while driving 70 mph continuously on level ground.
- The vehicle requires 85 kW while driving 30 mph on a 7% grade.
- The vehicle could maintain approximately 22 mph on a 20% grade at the motors’ maximum power of 150 kW.
- This data can determine the amount of energy required to drive one FUDS cycle.
- The vehicle uses 160 kW peak power during the FUDS cycle.
- Regenerative power can replenish spent energy during the FUDS driving cycle.
- During one FUDS cycle the vehicle travels 12 km (7.45 miles).
- The equivalent gasoline fuel consumption rate reported is 7.7 L/100km or 30.6 mpg (miles per gallon).

- The vehicle requires 7.2 kW-hr for one FUDS cycle.
- On average, the vehicle will use 1kw-hr per mile during the FUDS cycle.
- The vehicle uses approximately 160kW during heavy acceleration.

Battery Pack Needs

Table 3-3 summarizes the requirements of a properly sized battery pack for the E-350 Super Duty / E-450 Battery Pack.

Table 3-3
E-450 Battery Requirements

Vehicle Performance	Battery Performance
Acceleration	160 kW for 30 sec at 0% - 90% DOD
Constant Speed (70 mph for 5 miles)	90 kW for 6 minutes at 40, 60, & 80% DOD
Variable Power – FUDS 20 miles	19.3 kW-hr at variable rate, total time = 1 hr
Sustained Hill Climb – 7% Grade @ 30 mph	85 kW for 6 minutes at 40, 60, & 80% DOD
Power Accept	40 kW for 30 seconds at 60 % & 80% DOD
Power Accept	70 kW for 10 seconds at 0% - 90% DOD
Life Cycle	1000 FUDS cycles
Thermal Considerations	Economically Feasible Thermal Management
Vibration	Long Term Durability
Life (Years)	5
Fast Recharge	40% to 80% SOC in 15 minutes
Normal Recharge Time	6 hours

The heating and air-conditioning system when operated at full strength consumes approximately 22 kWh of energy per hour of operation. This will increase battery pack requirements for the vehicle. Based on previous experience the potential for increasing the battery for parasitic power loads is possible.

Pack Proposals

The following information is extracted from a proposal from SAFT.

Table 3-4
E-450 Battery Specifications

	LiON			NiMH	
Cell Type	HP 30	HP 30	HP 12	NH 12.4 24 V	4/5 SF
Number of Cells (Parallel x Series)	2 x 90	3 x 90	4 x 90	14 (24V Mod)	5 x 250
Initial Capacity (Ah)	62	93	64	109	70
Voltage Max (V)	351	351	351		400
Nominal (V)	324	324	324	336	300
Energy (kWh)	20	30	20.5	36.6	21.2
Discharge Power (kW)					
30 sec pulse/25 to 100% SOC	188	283	317	95	300
Continuous (6 min)/10 to 100% SOC	75	133	116	45	100
Recharge Power (kW)					
10 sec / 0 to 80%	113	170	195	60	150
30 sec / 0 to 70%	94	141	150	50	120
Cycle from 5 to 95%	>1000			>1200	>1000
Life	5 years at 25 °C			5 years	OK
Fast Charge	40 to 80% in 15 min OK			OK	OK
Typical Charge	6 hours OK			OK	OK
Mass cells (kg)	189	283	244	532	450
Battery Mass (kg)					
(Estimate/depends on requirement)	246	368	317	690	585
(Assuming 30% burden)					
Volume (liter)					
(Estimate/depends on requirement)	127	190	167	260	187
(Assuming 50% burden)					

Note: Burden may be higher if extreme temperature environment and heavy-duty cycles have to be met.

Budget Estimate

Table 3-5
E-450 Battery Cost

	LiON			NiMH	
	HP30 **2 x 90**	**HP30** **3 x 90**	**HP12** **4 x 90**	**HE**	**HP**
Prototype (each) ($K)	250	300	330	200	200
Production (100 vehicles/year)	45	65	69	44	40
Production (1500 vehicles/year)	12	18	20	21	18

Ford Explorer

The following variables shown in Table 3-6 were estimated. They were taken from the ADVISOR database as the average sport utility vehicle's parameters. The mass of the vehicle was adjusted to the GVWR of the 2000 Ford Explorer. These parameters are very critical in determining the vehicle's power requirements. Other, less critical, variables are also selected for simulations done in ADVISOR. Parasitic power requirements have been ignored for the following analysis. Further investigation and vehicle definition is needed for determining accessory drive power requirements.

Table 3-6
Explorer Simulation Variables

Variable	Value
m	5560 lbm
C_{rr}	0.007
C_d	0.44
A	2.66 m^2
n	0.8

Simulation

Three studies were performed for each type of vehicle: (a) a steady state prediction of power requirements based on vehicle speed, (b) FUDS variable power capacity simulation, and (c) vehicle acceleration. These studies will help estimate the size of the battery pack required.

Steady State Power Requirements Based on Vehicle Speed

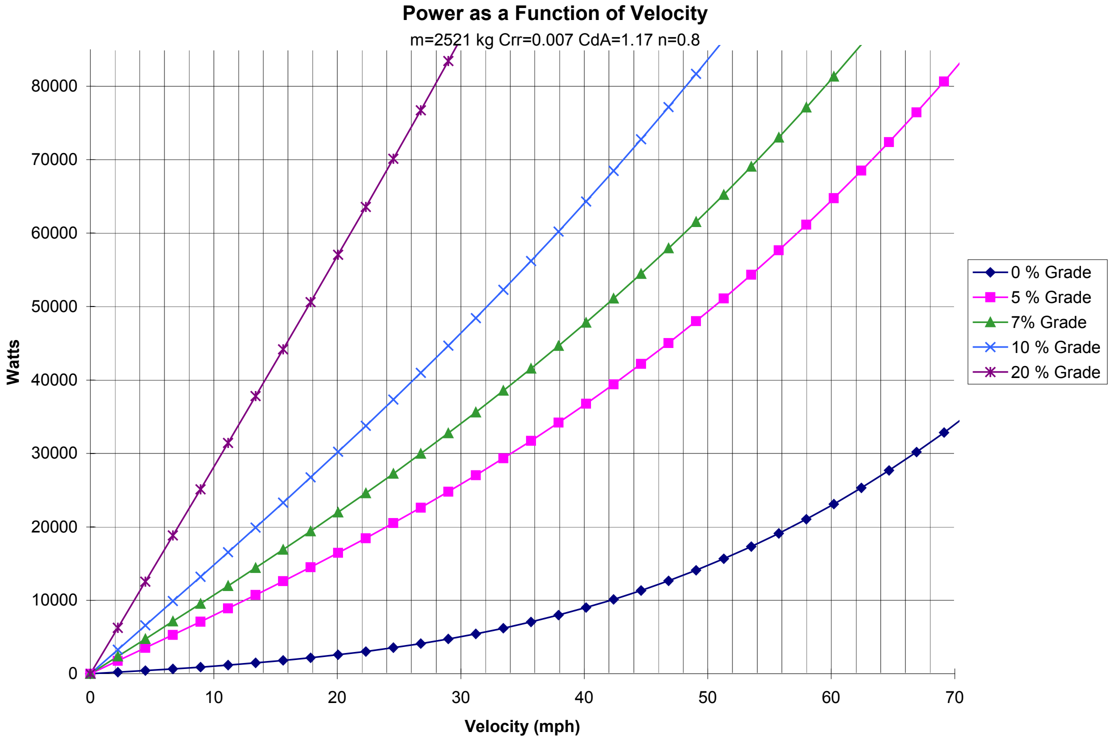


Figure 3-8
Explorer Velocity vs. Power

Figure 3-8 demonstrates the Explorer's power requirements in Watts as a function of vehicle speed and grade. This chart also provides vital information for the sizing of the battery pack. This information outlines:

- The Explorer would require approximately 33 kW while driving at 70 mph at highway speeds.
- The Explorer would require 34 kW while driving at 30 mph on a 7% grade.
- The Explorer could maintain approximately 26 mph on a 20% grade at the maximum power of 150 kW for the motors.

FUDS - Variable Power Capacity Simulation

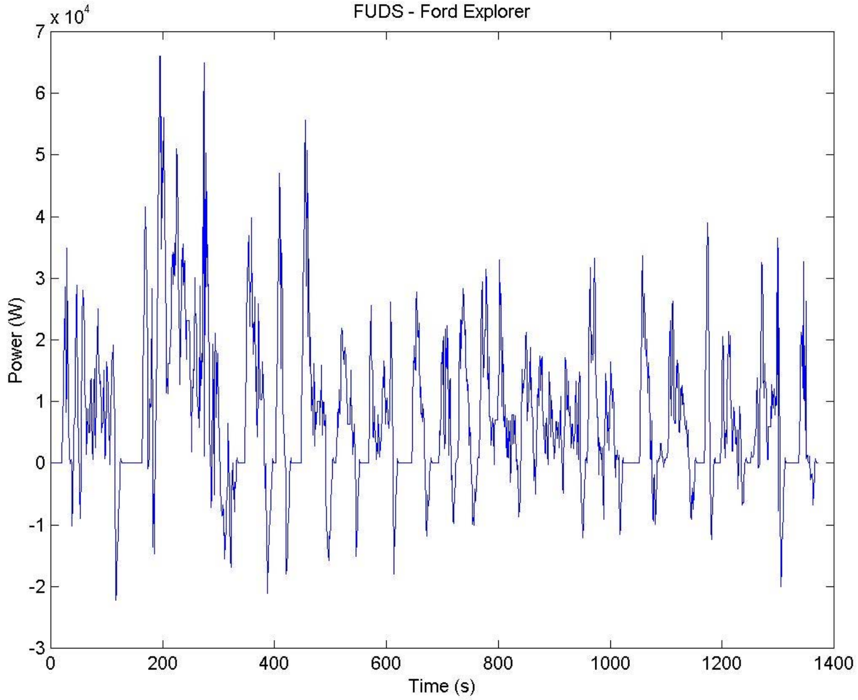


Figure 3-9
Explorer FUDS Simulation

Figure 3-9 provides the power required to operate the vehicle through one FUDS. It displays the power (Watts) used as a function of time (seconds) throughout the cycle. On this graph negative power represents available regenerative braking power.

- This data can determine the amount of energy required to drive one FUDS cycle.
- The vehicle uses 68 kW peak power during the cycle.
- Regenerative power can replenish spent energy during the driving cycle.

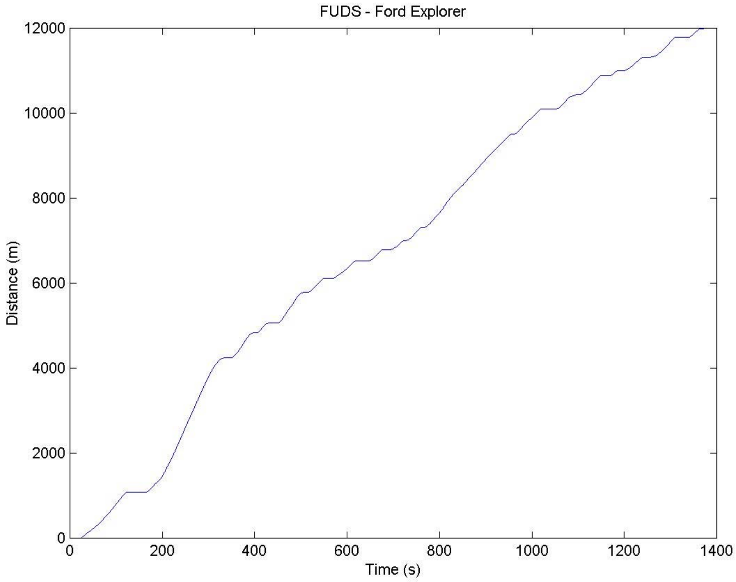


Figure 3-10
Explorer FUDS Distance

Figure 3-10 shows the total distance traveled as a function of time during the FUDS cycle. During one cycle the vehicle travels 12 km (7.45 miles).

ADVISOR also reports an estimate of the gasoline equivalent fuel consumption rate of L/100km. The gasoline equivalent fuel consumption rate reported is 3.7L/100km or 63.6 mpg.

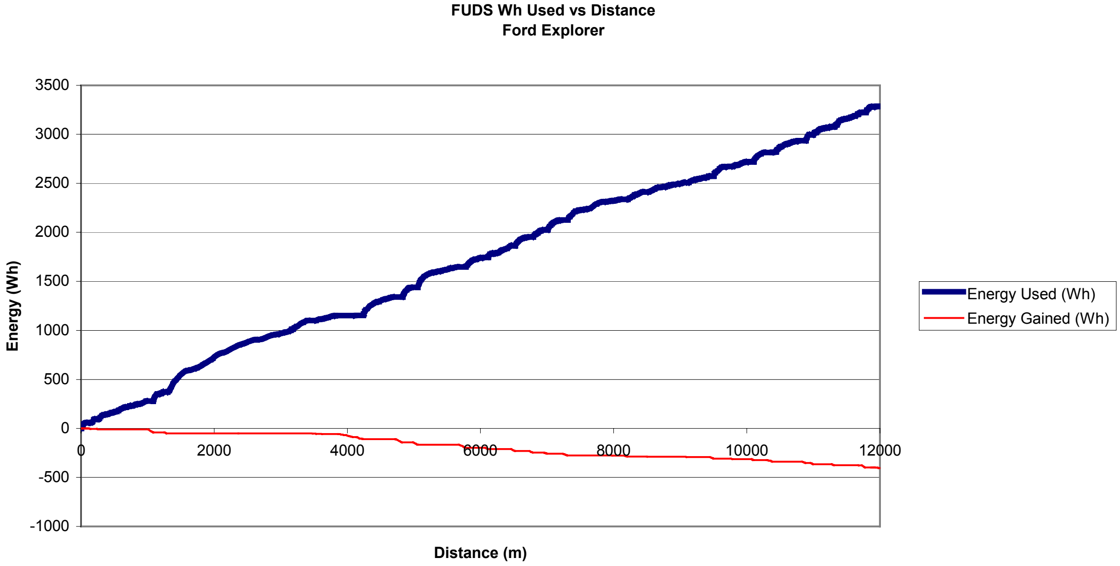


Figure 3-11
Explorer Power Requirement

The FUDS data shown in Figure 3-11– Power as a function of time – determines the energy the Explorer requires through one FUDS cycle. The following information can be extracted:

- The vehicle requires 3.3 kW-hr for one FUDS.
- The vehicle gains extended range through regenerative braking.
- Generally the vehicle uses 0.44 kW-hr per mile during the FUDS.

The actual energy accepted by the battery during regenerative braking will need further investigation in the design phase of the project. As an example of charge accept rate see Table 3-2. Over 20 miles of FUDS operation the vehicle has 964 Wh of energy available to the battery system due to regenerative braking (assuming 90% charge accept rate). This will extend the vehicles range by 2.2 miles. The amount of energy available to the battery is highly dependant upon the percentage of braking the motors are allowed to do. For this study the vehicle relies on the motors to do 80% of the braking effort at speeds greater than 60 mph, 50% at speeds between10 mph and 60 mph, and 0 % at speeds from 0 mph to 10mph.

Vehicle Acceleration Study

The explorer's maximum acceleration test was simulated using ADVISOR. A Power vs. Time acceleration, and velocity versus time are shown below on next page.

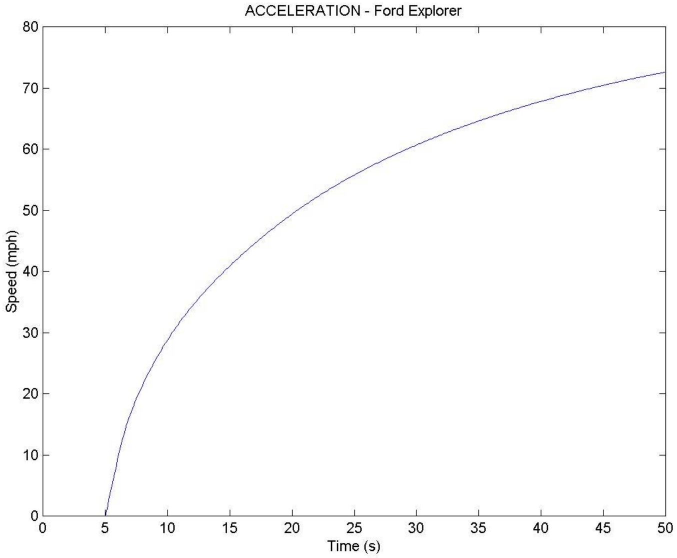


Figure 3-12
Explorer Acceleration

Figure 3-12 shows the required time to accelerate to a given speed for a heavy acceleration.

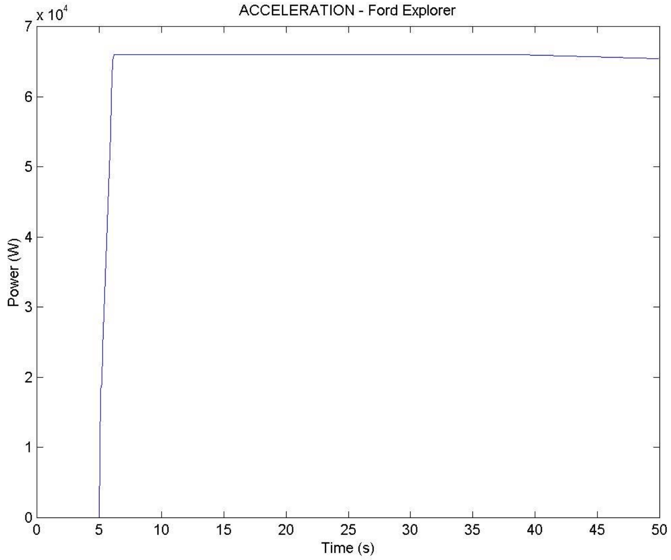


Figure 3-13
Explorer Power Required in Acceleration

Figure 3-13 demonstrates that the Explorer uses approximately 68 kW during maximum acceleration.

Conclusions

- The Explorer would require approximately 33 kW while driving at 70 mph at highway speeds.
- The Explorer would require 34 kW while driving at 30 mph on a 7% grade.
- The Explorer could maintain approximately 26 mph on a 20% grade at the maximum power of 75 kW for the motor.
- The Explorer uses 68 kW peak power during the FUDS.
- Regenerative power can replenish spent energy during the driving cycle.
- During one cycle the vehicle travels 12 km (7.45 miles).
- The gasoline equivalent fuel consumption rate reported is 3.7L/100km or 63.6 mpg.
- The Explorer requires 3.3 kW-hr for one FUDS.
- Generally the Explorer uses 0.44 kW-hr per mile during the FUDS.
- The Explorer uses approximately 68 kW during maximum acceleration.

Pack Needs

Table 3-7
Explorer Battery Requirements

Vehicle Performance	**Battery Performance**
Acceleration	68 kW for 30 sec at 0% - 90% DOD
Constant Speed (70 mph for 5 miles)	33 kW for 6 minutes at 40, 60, & 80% DOD
Variable Power – FUDS 20 miles	8.86 kW-hr at variable rate, total time = 1 hr
Sustained Hill Climb – 7% Grade @ 30 mph	34 kW for 6 minutes at 40, 60, & 80% DOD
Power Accept	70 kW for 10 seconds at 0% - 90% DOD
Life Cycle	1000 FUDS cycles
Thermal Considerations	Economically Feasible Thermal Management
Vibration	Long Term Durability
Life (Years)	5
Fast Recharge	40% to 80% SOC in 15 minutes
Normal Recharge Time	6 hours

Pack Proposals

The following information is extrapolated from the SAFT proposal for the E-350 Super Duty / E-450 and adapted to the Ford Explorer chassis.

Table 3-8
Explorer Battery Specifications

	LiON			NiMH
Cell Type	HP 30	HP 30	HP 12	4/5 SF
Number of Cells Parallel x Series	1 x 90	2 x 90	2 x 90	3x 250
Initial Capacity (Ah)	31	62	32	42
Voltage Max (V)	351	351	351	400
Nominal (V)	324	324	324	300
Energy (kWh)	10.4	20	10.25	12.72
Discharge Power (kW)				
30 sec pulse/25 to 100% SOC	94	188	158.5	180
Continuous (6 min)/10 to 100% SOC	37.5	75	58	60
Recharge Power (kW)				
10 sec / 0 to 80%	56.5	113	97.5	90
30 sec / 0 to 70%	47	94	75	72
Cycle from 5 to 95%	>1000			>1000
Life	5 years at 25 °C			OK
Fast Charge	40 to 80% in 15 min OK			OK
Typical Charge	6 hours OK			OK
Mass cells (kg)	94.5	189	122	270
Battery Mass (kg) (Estimate/depends on requirement) (Assuming 30% burden)	123	246	158	351
Volume (liter) (Estimate/depends on requirement) (Assuming 50% burden)	63.5	127	83.5	112.2

Battery Cell / Modules

This study evaluates the potential of using Lithium-ion modules and Nickel-Metal Hydride modules for use in a grid connected HEV and a grid connected PEV. Table 3-9 lists modules available from SAFT; it also compares a typical Lead -Acid Electric Vehicle battery made by Panasonic to the SAFT batteries.

Table 3-9
Battery Comparison

Cell / Module Type	Capacity (Ah)	Nominal Voltage	Specific Energy (Wh/kg)	Specific Power (W/kg)	Energy Density (Wh/dm^3)	Power Density (W/dm^3)
Li – Ion HP 30	30	3.6	100	950	220	2100
Li – Ion HP 12	13	3.6	70	1350	150	2900
Li – Ion MR 26	26	3.6	110	750	230	2050
Li – Ion HE 44	44	3.6	144	300	308	642
Ni-MH NH 12.4	96	24	66	160	140	340
Ni-MH 4/5 SF	14	1.2	47	690	152	2227
Panasonic Lead-Acid EC-EV1228	28	12	34	300	86	74

Table 3-10
Battery Comparison (cont.)

Cell / Module Type	Dimensions (mm)	Mass (kg)	Storage Temperature (°C)	Operating Temperature (°C)
Li – Ion HP 30	54 OD x 220	1.12	-40 / + 65	-10 / +45
Li – Ion HP 12	47 OD x 180	0.680	-40 / + 65	-10 / +45
Li – Ion MR 26	54 OD x 160	0.77	-40 / + 65	-10 / +45
Li – Ion HE 44	54 OD x 220	1.07	-40 / + 65	-10 / +45
Ni-MH NH 12.4	760x120x195	37	-40 / +65	-10 / +45 (charge) -10 / +60 (discharge)
Ni-MH 4/5 SF	41 OD x 84.5	0.35		
Panasonic Lead-Acid EC-EV1228	175x116x200	10		

*Note – values in table may not be representative of actual values seen in specific applications i.e. values are affected by, but not limited to: cell temperature, discharge rate, manufacturing, quality, lot production etc.

Engineering Requirements of Battery Pack Design

To further engineer the battery pack would require extensive development work. The following is an explanation of areas that would require extensive development:

- Individual Battery Selection – To correctly select the proper battery for any application several factors need consideration. The selected battery must fit into the vehicle's available packaging space, require feasible thermal management, withstand daily driving cycles throughout the life span of the vehicle, handle severe driving conditions, and not interfere with the operator's daily use. Battery models must be created and may require experimental verification of accuracy.
- Battery Packaging – The final packaging of the batteries permits the correct number of batteries stored in a protective environment that allows the batteries to be thermally and electrically managed. The batteries should be placed in an environment that does not expose the batteries to excessive vibration and temperature.

- Thermal Management – To maximize the battery life and overall performance the batteries will be thermally managed during charge and discharge cycles. Each individual cell needs to be kept within the temperature operating range specified by the manufacturer. The battery pack should not have large deviations in temperatures between individual batteries. Depending on application, batteries can be air cooled or liquid cooled.
- Battery Management—A battery control system needs development to protect and extend battery life. The following are requirements of the battery management system: accurate State of Charge (SOC) measurement, battery temperature monitoring, battery voltage monitoring, charge equalization system, SOC optimization strategy, and battery protection from damage (high discharge and low SOC situations). This system needs to be integrated with the vehicle's control system.

4

DRIVE SYSTEM

The electric motor (traction motor) is the key element for the electric vehicle performance. Although electric motors are simple in construction and highly efficient, special care must be taken in choosing the right motor for a specific application. Compared to the internal combustion engine, the electric motor has only one moving part. This feature makes the electric motor highly dependable and if the correct motor is chosen, it will outlast any IC engine over the vehicle's useable life. Generally the vehicle manufacturer looks for an ideal compromise between price, performance and technology. Typically, if the performance of an electric vehicle is poor, it is due to the improper selection of the electric motor. For this reason, TDM must ascertain the customer requirements in order to determine the proper drive system most suitable for the production of electric vehicles. The following objectives specific to EPRI requirements were considered in the analysis for the electric drive system:

- Cost
- Performance
    - Top speed
    - Acceleration
    - Gradeability
    - Regenerative Potential
- Reliability
- Serviceability/Availability
- System Integration

The selection and optimization of the traction drive system for electric powered vehicles must take into account the interaction of all system components and their integration to other vehicle components. There are three basic motor types available:

- DC motors with parallel-switched field excitation.
- 3-phase AC motors with an induced field (asynchronous motor)
- 3-phase AC motors with a permanent-magnet field (PM-synchronous motor)

Table 4-1 best illustrates a comparison between the three types of motors in this application.

Table 4-1
Electric Motor Comparitor

Motor	Cost	Performance	Reliability	Availability	Overall
3-phase AC induction	7	6	10	8	31
3-phase AC permanent magnet	3	8	7	2	20
DC (brush type)	5	4	1	4	14

Each type of motor is ranked from one to ten. One being the lowest ranking, therefore, the motor with the highest score is the best fit.

A comparison of drive systems for the above-mentioned motor types shows that the DC drive system (motor and controller) is at present more expensive than its AC counterpart. In smaller vehicles, the DC motor and controller are typically less expensive than its AC counterparts, but in larger vehicles, its size can be a limiting factor. The performance gains that are obtained through AC drive systems (accurate motor control, simple motor direction control, regenerative capabilities, lower maintenance costs) far out weigh the cost advantage of a DC system. Brushless 3-phase AC drives are more efficient, smaller, lighter, more rugged, and offer the superior overload capability that is required for rapid acceleration and higher velocities. The synchronous 3-phase AC motor is more efficient than the asynchronous motor but requires a multi-gear shift transmission because of the limit speed range. The potential for development, in terms of both costs and technology, is higher for AC drives. In reaching a definitive conclusion, consideration of the above-mentioned parameters along with various other quantifiable factors, such as noise and overload capability, but also future development trends must be included in the final selection process. In terms of a vehicle's total costs measured over its expected useful life, the brushless 3-phase AC drive has a distinct advantage. Siemens offers a wide spectrum of special AC drive systems. Their drive systems are highly dependable and offer excellent performance. Their success is derived from their in-house synergies of its automotive business, drive technology, and global presence.

Inverter for Electric Vehicle Applications

Like the motor, the inverter is another key element of the system for an electric vehicle. It contains a DC/DC-converter for charging the auxiliary 12V battery and a controller for the traction motors. An optional integrated main contactor can be offered as part of the inverter. It uses the same hardware to control asynchronous and permanent magnet synchronous AC motors. Siemens has developed an inverter for electric vehicle applications.

Flexibility for different customer inverter applications is provided by standard software architecture with modular structure. The motor control is adaptable to different vehicle requirements through software parameters. Parameters can be adapted with special Siemens diagnostic software called (SIADIS). This offers flexibility in the development phase of the vehicle. For vehicle control, standard modules (e. g. acceleration, brake controls) as well as options (e.g. speedometer, customer specific pedal curves) are available through Siemens or can be custom built.

TDM suggests using the Siemens motor/controller in the EPRI program because of the reliability of the system. TDM electric vehicle hybrid-development program has performed durability testing on the Siemens components, proven their worth and found the performance to be more than adequate with little to zero defects. TDM has done previous electric vehicle programs based on a Ford E-350 Super Duty chassis and Ford Ranger chassis that involves packaging Siemens components.

TDM has previously designed and developed drivetrain packaging and certified OEM parking pawl systems that would minimize EPRI development costs should this program move to the next phase.

5

AUXILARY POWER UNIT

The Auxiliary Power Unit (APU) is the onboard generator typically powered by a combustion-based source. The size of the APU is dependent on the use of the vehicle in a hybrid mode. In electric vehicles, the key is efficiency of all components. If the APU is oversized for its application, the adaptability of the vehicle to all types of operating profiles increases. Although this is generally considered a good trait, the oversizing of the APU causes a decrease in system efficiency. Not only does the APU provide extra power for propulsion but it also charges the battery to increase the State of Charge by putting energy back into the traction battery pack.

Previous Applications

The Warner Robins Hybrid Program used an Auxiliary Power Unit consisting of a diesel engine driving a permanent magnet alternator. This APU had a 2.5 Liter 88 kW turbo diesel engine coupled to a Unique Mobility 75kW Alternator. The output from this unit will feed a converter able to output 75/45 kW from 240 to 400 VDC. For this study it is assumed that the EPRI vehicle will be operating in a typical urban environment. Systems will be evaluated for the ability to operate at stead state conditions and an urban variable power cycle (FUDS). When the APU is switched on, the SOC must not be allowed to be further depleted in order to protect the battery system from damage. The vehicle needs to operate at acceptable steady state conditions and negotiate FUDS cycle without reduction of the SOC. The performance of three sizes of APUs will be reviewed by two calculations. These three distinct APUs have the ability to output 65 kW, 45 kW, and 28 kW steady state.

Mathematical Analysis

Steady State Power

Figure 5-1 represents the effects of the different power rating of Auxiliary Power Unit (APU) on steady state operation and gradeability.

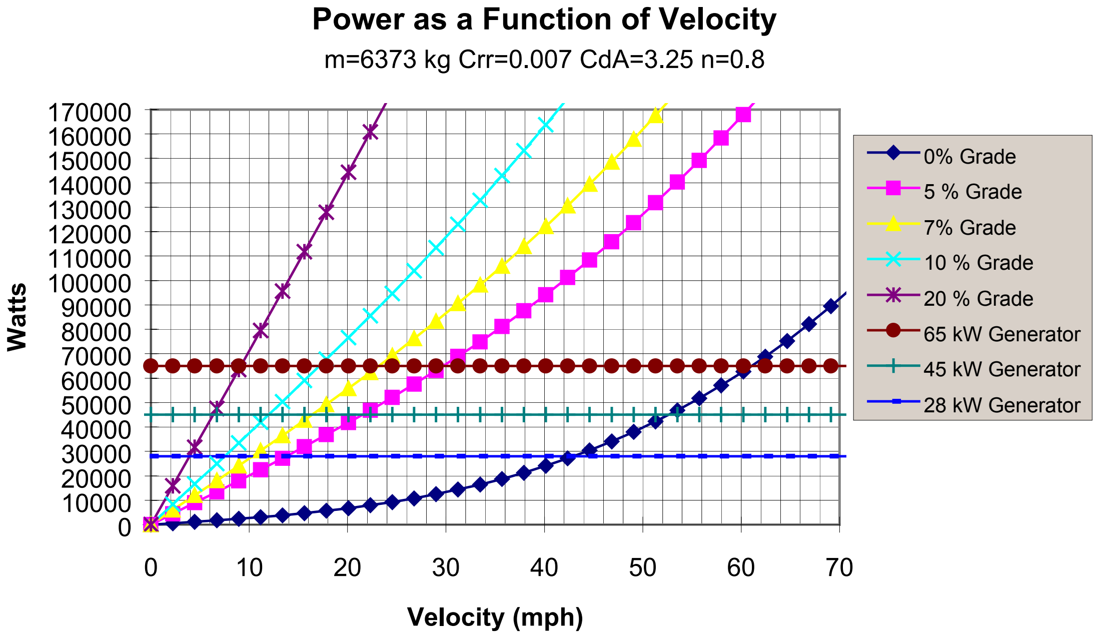


Figure 5-1
APU Power Potential

The APU, during operation, should provide all power to the traction motor during steady state operation. Table 5-1 summarizes a vehicle's ability to operate in various steady state conditions. All calculations are based on assumed system efficiencies. These calculations have been extrapolated from calculations performed in the battery section.

Table 5-1
APU Power Required

Generator Power	20% GRADE MPH	10% GRADE MPH	7% GRADE MPH	5% GRADE MPH	0% GRADE MPH
28 Kw	4.0	7.5	10.5	13.5	43.0
45 Kw	6.5	12.0	16.25	21.5	52.5
75 Kw	9.0	17.25	23.0	29.5	61.0

Variable Power

The FUDS cycle simulation has been extracted from the battery section. It will be extrapolated to determine the effects of using a steady state generator to power the vehicle. The results will determine the amount of energy discharged from the battery pack, and the amount of energy that can be stored into the battery pack during a FUDS cycle.

FUDS Base Line

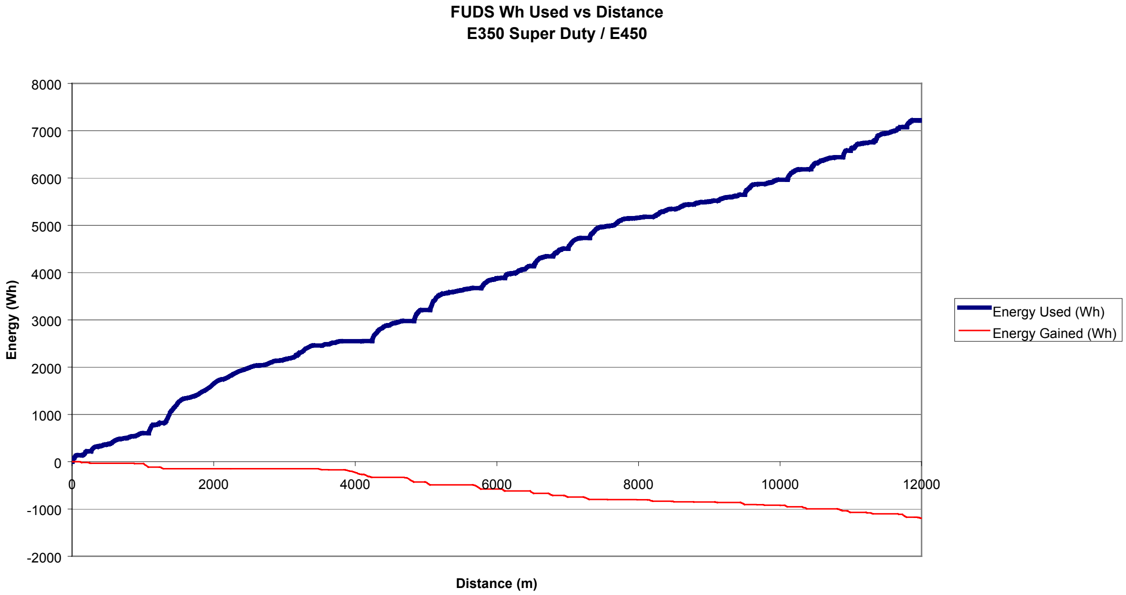


Figure 5-2
APU Regenerative Potential

Figure 5-2 shows the energy taken from the battery (thick line) and the energy available to the battery via regenerative braking (thin line) during one FUDS cycle. When in EV mode, the vehicle draws approximately 7.2 kW-hr of energy from the battery system. It also has 1.1 kW-hr of energy available to the battery system due to regenerative braking which can be used to recharge the batteries.

FUDS w/ 65 kW Generator

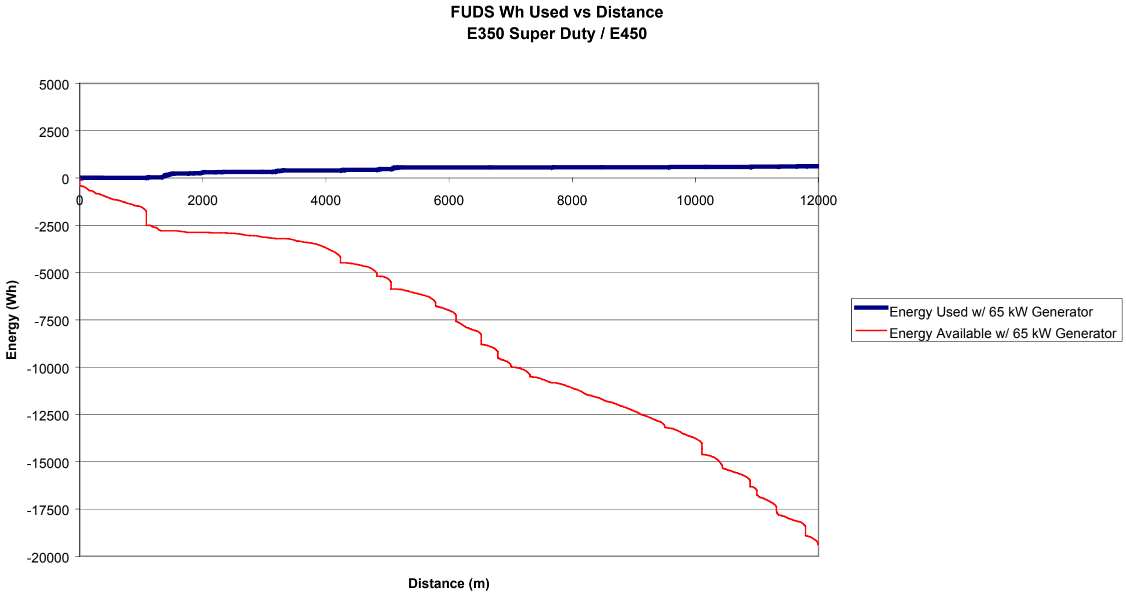


Figure 5-3
65kW APU Power

Figure 5-3 shows the energy taken from the battery (thick line) and the energy available to the battery via the APU and regenerative braking (thin line) during one FUDS cycle. When using a 65kW continuous power APU, the vehicle draws approximately 0.6 kW-hr of energy from the battery system. It also has 19.3 kW-hr of energy available to the battery system primarily due to the APU, which can be used to recharge the batteries.

FUDS w/45 kW Generator

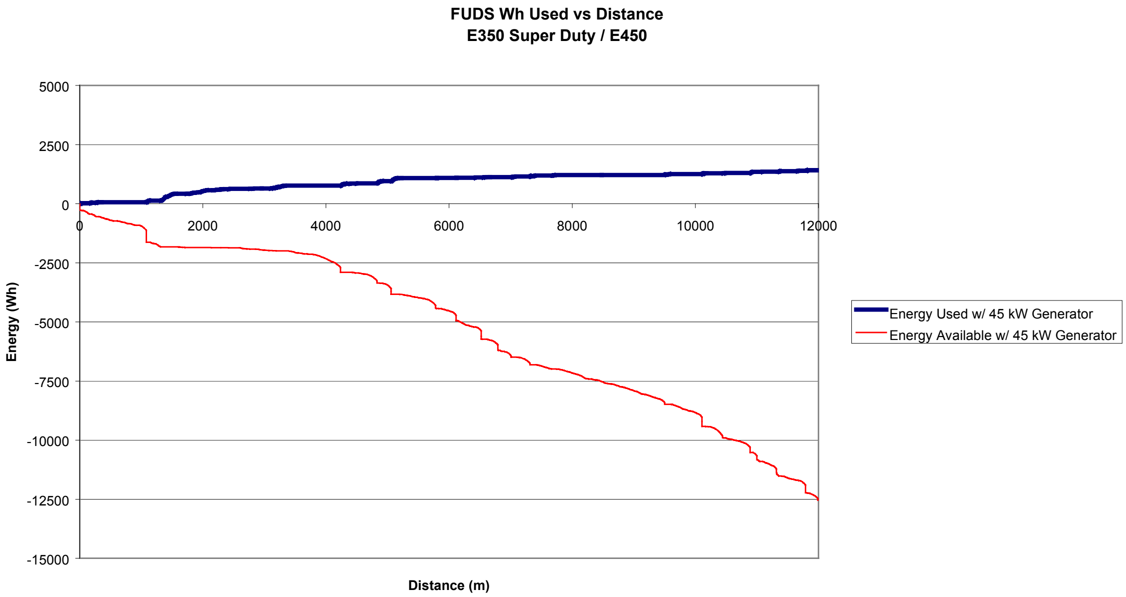


Figure 5-4
45 kW APU Power

Figure 5-4 shows the energy taken from the battery (thick line) and the energy available to the battery via the APU and regenerative braking (thin line) during one FUDS cycle. When using a 45 kW continuous power APU, the vehicle draws approximately 1.4 kW-hr of energy from the battery system. It also has 12.5 kW-hr of energy available to the battery system primarily due to the APU which can be used to recharge the batteries.

FUDS w/28 kW Generator

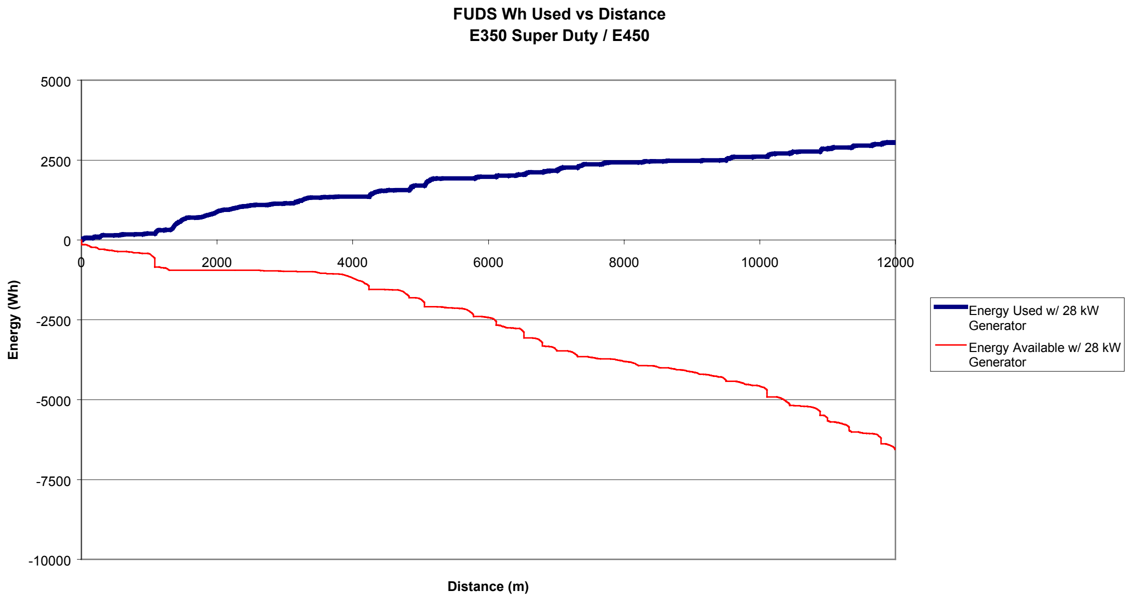


Figure 5-5
28 kW APU Power

Figure 5-5 shows the energy taken from the battery (thick line) and the energy available to the battery via the APU and regenerative braking (thin line) during one FUDS cycle. When using a 28 kW continuous power APU, the vehicle draws approximately 3.0 kW-hr of energy from the battery system. It also has 6.5 kW-hr of energy available to the battery system primarily due to the APU, which can be used to recharge the batteries.

The following chart compares the steady state power requirements of the two different vehicles and the maximum speed these vehicles could maintain off of the APU. Note, the Explorer chassis will require a much smaller APU than the shuttle bus.

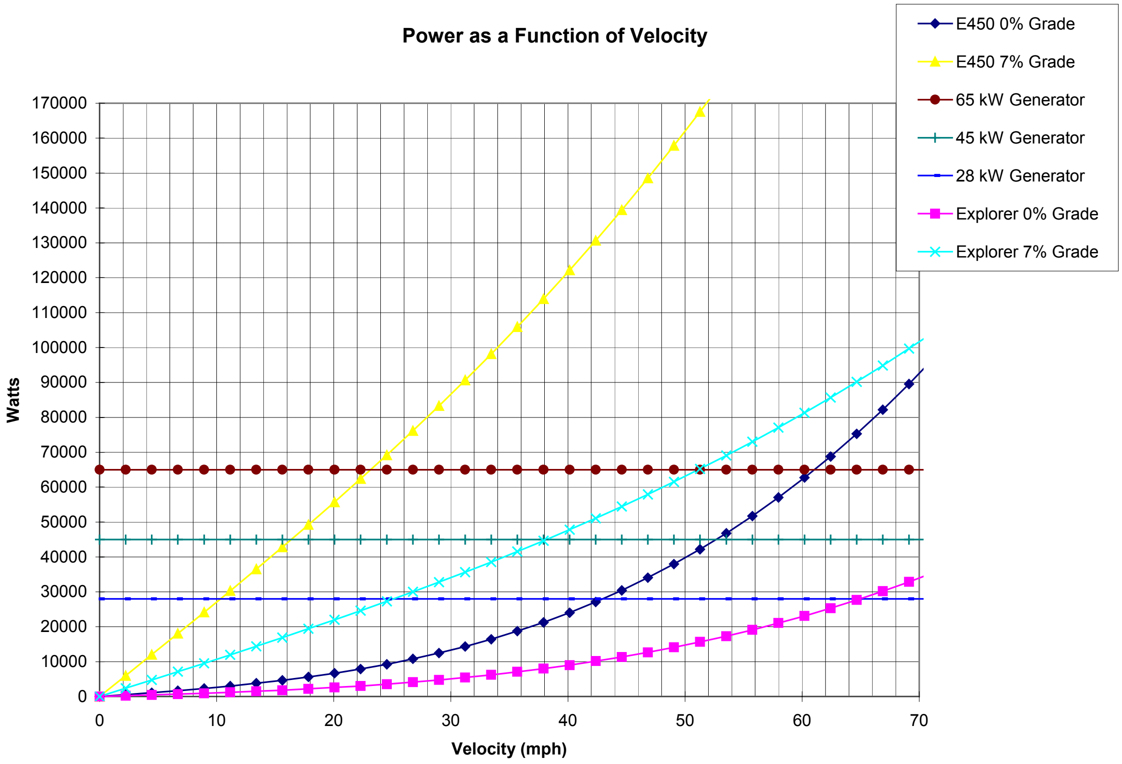


Figure 5-6
Vehicle Comparisons

Auxiliary Power Unit Options

THE MICRO TURBINE SYSTEM

The Micro Turbine exhibits the following key features:

- High speed system – small envelope and footprint
- Lightweight
- Air bearing to ensure low maintenance, low vibration, and low noise operation
- Low emission operation with various fuels including diesel, CNG and propane
- DC output power electronics easy integration into multiple drive systems
- Open architecture communication platform supports a wide variety of protocols

The Micro Turbine System includes a compressor, recuperator, combustor, turbine and 28 kW permanent magnet generator. The rotating components are mounted on a single shaft supported by air bearing. The generator is cooled by the airflow into the gas turbine. The air is compressed and injected into the recuperator where its temperature is elevated by the exhaust gases expelled from the turbine. This process doubles the system efficiency. The heated compressed air is mixed with fuel and combusted in the combustion chamber. The combusted hot gases expand through the turbine, providing the rotational power. Patented techniques in the combustion process result in an extremely low emission exhaust stream. The shaft rotates at up to 96,000 RPM. The output of the generator is variable voltage, variable frequency AC power. Power electronics is employed to convert the variable voltage, variable frequency AC power to programmable DC power.

Table 5-2
28 kW Micro Turbine Generator Specifications

Continuous Electrical Power Output:	28 kW @ 185 °F
Voltage Range for Peak Power Output:	160 to 390 VDC
Output Current Range:	0.0 to 175 amps
DC Output Voltage Limit:	390 VDC
Output Power Regulation:	± 1 kW (Except as noted below)
Ambient Temperature Range for Peak Power	-25 to 185 °F

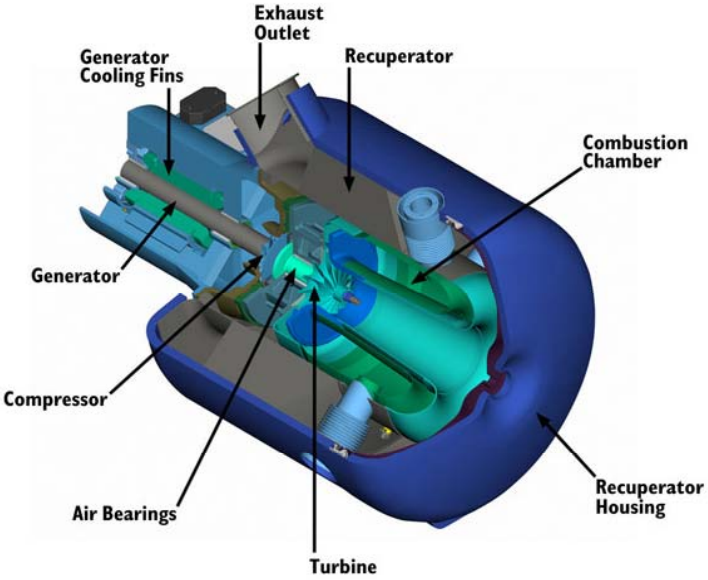


Figure 5-7
Micro Turbine

The Turbo Diesel System 75 kW

The turbo diesel with brushless Permanent Magnet Generator exhibits the following key features:

- Reliable diesel technology
- Typical automobile maintenance cost
- DC output from power electronics, easy integration into multiple drive systems
- Low speed system operates between 750 RPM and 4400 RPM
- Large enough to run the vehicle in continuous HEV mode

The 75 kW turbo diesel system includes an 88 kW indirect injected turbo intercooled diesel 4 cylinder engine, a 75 kW brushless permanent magnet generator, and a microprocessor – controlled inverter.

The brushless permanent magnet generator is mounted to the rear of the turbo diesel engine. The engine and generator are coupled through a flexible coupling. The diesel engine, generator, and microprocessor-controlled inverter are water-cooled. The output of the generator is variable voltage, variable frequency AC power. Power electronics is employed to convert the variable voltage, variable frequency AC power to programmable DC power.

Table 5-3
75 kW Hybrid Generator Specifications

Continuous Electrical Power Output:	75 kW @ 185 °F
Voltage Range for Peak Power Output:	160 to 390 VDC
Engine Speed Range for Peak Power Output:	3500 to 4200 rpm
Engine Speed Range for Power Delivery	1500 to 4200 rpm
Output Current Range:	0.0 to 470 amps
DC Output Voltage Limit:	390 VDC
Output Power Regulation:	± 1 kW (Except as noted below)
Ambient Temperature Range for Peak Power	-25 to 185 °F

The Turbo Diesel System 45 kW

The turbo diesel with brushless permanent magnet generator exhibits the following key features.

- Reliable diesel technology
- Typical operating maintenance
- DC output from power electronics ease integration into multiple drive systems
- Low speed system operates between 750 RPM and 4400 RPM
- Reduced weight
- 45 kW system could be optimized for maximum efficiencies

The 45 kW turbo diesel system includes 55 kW direct injected 4-valve diesel 4 cylinder engine, 45 kW brush less permanent magnet generator, and microprocessor – controlled inverter.

The brushless permanent magnet generator is mounted to the rear of the diesel engine. The engine and generator are coupled through a flexible coupling. The diesel engine, generator, and microprocessor-controlled inverter are all water-cooled. The output of the generator is variable voltage, variable frequency AC power. Power electronics is employed to convert the variable voltage, variable frequency AC power to programmable DC power.

Table 5-4
45 kW Hybrid Generator Specifications

Continuous Electrical Power Output:	45 kW @ 185 °F
Voltage Range for Peak Power Output:	160 to 390 VDC
Engine Speed Range for Peak Power Output:	3500 to 4200 rpm
Engine Speed Range for Power Delivery	1500 to 4200 rpm
Output Current Range:	0.0 to 280 amps
DC Output Voltage Limit:	390 VDC
Output Power Regulation:	± 1 kW (Except as noted below)
Ambient Temperature Range for Peak Power	-25 to 185 °F

Table 5-5
Decision Matrix

Engine	Micro Turbine	Turbo Diesel	Turbo Diesel
Generator Type	Permanent Magnet	Permanent Magnet	Permanent Magnet
Power (kW)	28	45	75
Weight	7	2	5
Efficiency	8	5	4
Cost	5	5	5
Packaging	5	5	5
Power	3	5	8
Operator Familiarity	3	7	7
Maintenance	9	5	5
Coolant System Packaging	8	4	4
Fuel Flexibility	9	1	1
Foot Print	10	8	6
Exhaust Gas Temp	1	10	10
Availability	6	4	4
Exhaust Packaging	1	8	8
Noise Level	8	7	6
Integration	8	4	4
Hybrid Range	4	6	8
Hybrid Gradeability	4	8	8
Emissions	9	7	7
TOTAL	108	101	105

The options for the APU are open. The three options are competitive. TDM has packaged all three for the hybrid build. Considerations for heat management must be re-evaluated. Heat in the turbine exhaust is a critical element in the design. A more detailed engineering study is necessary to better determine the extended range requirements of the vehicle. This will aid in selecting the best option for the APU.

6
VEHICLE CHARGING

The charging of the batteries is a key element in maintaining performance and long life. There are two types of charging, on board grid and off board (post grid). A brief explanation of the two is listed below:

- On board charging - charger is mounted on the vehicle and plugs into VAC outlet.
- Off board charging - the charging station is located off the vehicle, typically set in a closed room.

In choosing a system, it would be best to look at the pros and cons for each system:

Table 6-1
On-Board Charging

Pros	Cons
Lower cost	Packaging
User convenience (plug anywhere)	Additional weight in vehicle
Less complex electronic integration and communication	Slower charge time (rate decrease)
Lower charging power benefits battery life	Radiant heat from charger
Less duplication of expensive electronics	Increased complexity of vehicle system

Table 6-2
Off-Board Charging

Pros	Cons
Faster charge time (rate)	Connector to vehicle interface is bulky
Lighter vehicle	Dedicated facility area
Weight and packaging not a factor	High price
Separate electronics from vehicle system	Complex electronic integration, communication, and added cost

The matrix above illustrates that the on board charger would be the best option for an electric vehicle or hybrid electric vehicle. The convenience of the charging sources along with low cost and complexity make it the most viable option. TDM recommends the use of an on board charger for the E-450 and the Explorer chassis.

The Lockheed Martin 15KW EV charging system supports the SAE 2293 charging protocol for Type C (DC energy transfer) charging. It is an excellent choice for an on board charger. The charger can supply up to 15kW of power when connected to 208Vac three-phase power or up to 10kW when connected to 240Vac single-phase power. Galvanic isolation is provided for reduction in corrosion. Built in protection includes limits for maximum output power, input current, output current, output over-voltage and heat sink temperature. An input ground monitor and output isolation monitor are included. The charger is designed to meet UL 2202.

A patented single stage powertrain provides power factor correction to 96% for single-phase operation and efficiency close to 95%. The single stage approach uses fewer parts and result is more economical than two stage converters.

The compact mechanical package squeezes just over 6.5W of power per cubic inch of volume. The charger is designed to protect against severe environments such as rain, humidity, dust and salt fog, yet provide adequate cooling for the 15kW output. Additional features include compliance to FCC Level B conducted and radiated emissions levels and safe transit shipping and vibration levels.

A quarter-panel graphical display provides charging information as well as set-up and diagnostic features. A serial communications diagnostic port is provided to allow for “no-hassle” service support. The display can be used to configure the charger at installation, to run diagnostic checks and for operational logging. An off-peak economy-charging mode is also provided.

Table 6-3
Lockheed Martin Charger Specifications

Mechanical Dimensions	20 x 12 x 9.0 in (2160 cu-in)
Weight	56.5 lbs
Operating Temperature Range	-40 to +50 degrees C Unit is fan cooled
Input Voltage	240Vac single phase, 208Vac three phase
Input Current	48A continuous maximum
Power Factor	Greater than 0.95
Output Power	15kW maximum with three phases input 10kW maximum with single phase input (Output power is derated at ambient above 40 degrees C)
Output Voltage	320 to 490Vdc

An option for an off board charger would be the Posi Charge PC-60 by AeroVironment Inc. It is a UL listed level 3 charger that meets SAE standards J-1772 for conductive interface and J-2293 for energy transfer systems. It is a 150-450 VDC or 200 ADC - 60 kw charger that may be used with either 240VAC or 480 VAC depending on the model. The physical dimensions for the unit are as follows:

- Base unit: 60” height, 30” depth, and 37” width
- Tower: 84” height, 30” depth, and 13” width
- Weight: approximately 1,100 lbs. (for both units)

Figure 6-1
Posi Charge PC-60

7

ACCESSORY DRIVE SYSTEM

Electric vehicles typically do not have a front-end accessory drive (FEAD) therefore; most electric vehicles need to be equipped with an alternative accessory power system. This system would exhibit the following key features:

- DC/DC Converter powered drive motor
- DC powered drive motor / Microprocessor controlled inverter
- Power steering pump
- Drive belt and mounting bracket
- Multiple Air Conditioner Pumps for transit bus application
- Air cooled motor and controller
- Positive temperature coefficient (PTC) heater
- Vacuum pumps or air pumps as necessary

Shown below is an accessory drive motor direct-mounted to an A/C compressor. The HEV will use a belt drive that allows the use of more than one component to be driven by one motor, this will save space, weight and cost.

Figure 7-1
Drive Motor Example

Air Conditioning System

The air condition system will use an OEM style air conditioner compressor driven by the accessory drive high voltage motor. The air conditioner compressor will be mounted on a bracket with the power steering pump. This will be accomplished by a belt drive system using a serpentine drive belt and a self-adjusting trencher.

Power Steering

The power steering will use an OEM style pump driven by the accessory drive high voltage motor. The power steering pump will be mounted on a bracket with the air conditioner compressor. This will be accomplished by a belt drive system using a serpentine drive belt and a self-adjusting trencher.

Positive Temperature Coefficient (PTC) Cab Heater

The hybrid electric vehicle will use a positive temperature coefficient (PTC) electro-resistive heating element for the purpose of heating the cab area of the vehicle. The PTC heater element is designed to provide a relatively constant temperature output by increasing the resistance of the heater core when an increase in the core itself is detected. The PTC core is designed to replace the original ethylene glycol heater core in the OEM heater plenum.

Positive Temperature Coefficient (PTC) Heater Specifications

Table 7-1
PTC Heater Specifications

Criteria	Specification
Air Flow	
Pressure Drop	140 Cubic Feet / minute
Inlet Air Temperature	.0276 Pounds per Square Inch
Out Let Air Temperature	32 Deg. F +- 3.5 Deg. F
Nominal Voltage	310 +- 0.1 Volts
Maximum In-rush Current	20 Amps.
Time of In-rush	30 Seconds
Voltage Range	280 to 385 Volts DC
Power	5000-6250-Watts

Resistive High Voltage Rear Heater

For the rear heat of the hybrid electric vehicle a resistive high voltage heater is recommended with an auxiliary pump to circulate the ethylene glycol. This system would use energy from the traction battery pack to heat the element.

Vacuum System

Vehicle vacuum will be supplied by a piston drive vacuum pump. This is a 12-volt device that uses a vacuum switch to turn on an electronic control module. The vacuum is only needed to actuate the Heating Ventilation Air Condition (HVAC) blend air doors. On vacuum assisted power brakes vehicles, the same vacuum pump could be used.

DC/DC Power System

Because the Electric Vehicle is built with an Auxiliary Power Unit it does not have a conventional engine or belts to drive the alternator. Because of this, the traction motor is used to supply electricity to the alternator. The DC/DC traction drive control module has a built in DC-to-DC converter that can supply 60 amps continuous and 100 amps peak current to the alternator to keep the vehicle running.

8
COST OF OPERATION

Electric Vehicle vs. Internal Combustion Vehicle

In order to appreciate the benefits of the electric vehicle or a hybrid vehicle, it is best to look at the complexity of the internal combustion engine. The internal combustion engine has been around for several decades and people, in general, have become accustomed to the behavior and the complexities of the system. These complexities mean more things can go wrong and increase cost due to repairs. Periodic repairs to the systems such as cooling, ignition, driveline (transmission), exhaust, and other mechanical components such as oil and transmission filters are needed. In contrast, a pure electric vehicle requires little maintenance. The system is basically made of three components, a battery, electric motor and controller. With the rapid changes in automotive technology, the analysis for the cost of operation can be extremely complex, so it is best to look at the cost of maintenance as a lump sum.

This study was to focus on the use of the vehicle in the Federal Urban Driving Schedule (FUDS) for the period of 20 miles per day. Several assumptions must be made in order to perform the analysis for the cost of operation between a baseline vehicle and its electric vehicle counterpart. More specifically for this analysis the following assumptions were made:

- Average price of gasoline is \$1.63 per gallon. Any increase in fuel cost makes PEV's or HEV's more advantageous over IC engine systems.
- Average price of diesel is \$1.41 per gallon.
- Assume charging to be done during off peak hours. Price per kWh (off-peak hours) is \$0.0917.
- Assume charger efficiency of 80% (correction factor of 1.2 to be applied).
- Average maintenance costs (consumables) for an internal combustion engine is \$700 per year. Assume 15,000 miles per year, gives you \$0.046/mile ~ \$0.05 per mile.
- E-450 will use 1kWh per mile in a FUDS cycle.
- Explorer uses 0.44kWh per mile in a FUDS cycle.
- E-450 gasoline has a MPG rating of 9 MPG (0.11 gallons per mile).
- A diesel four cylinder engine averages 30 MPG (0.03 gallons per mile).

- The IC gasoline Ford Explorer averages 14 MPG (0.07 gallons per mile).
- Consumables (i.e. tires, brakes) are the same between the vehicles thus not included in the analysis.
- Assume PEV mode runs for 20 miles per day and the HEV mode runs for 5 miles per day. (25 miles of total vehicle use per day)

Using the assumptions above, the analysis is as follows:

Ford E-450 Vehicle

Gasoline:

(0.11 gallons/mile x $1.63/gallon) + $0.05/mile = **$0.23 per mile**

Electric:

(1 kWh/mile x $0.0917/kWh) x 1.2 = $0.11 per mile (109% savings over gasoline)

Hybrid:

($0.11/mile) x 20 miles = $2.20
(($0.11/mile) + (0.03 gallons/mile x $1.41/gallon) + $0.05/mile) x 5 miles) = $1.01
Total = ($2.20 + $1.01)/ 25 miles = **$0.13 per mile** (77% savings over gasoline)

Explorer

Gasoline:

(0.07 gallons/mile x $1.63/gallon) + $0.05/mile = **$0.16 per mile**

Electric:

(0.44 kWh/mile x $0.0917/kWh) x 1.2 = **$0.05 per mile** (220% savings over gasoline)

It is clearly evident that the electric vehicle or a hybrid electric vehicle has a substantial potential for savings over its gasoline counterpart. With the rapid increase in technology in the field of electric vehicles and the fact that more electric vehicles are being produced, the cost for conversions and the hardware needed will decrease as time passes. Cost of operation along with other benefits such as zero pollution and high adaptability makes the electric vehicle a clear choice for the future.

9
CONCLUSION / SUMMARY

Conclusion and Recommendation

Based on this feasibility study, TDM recommends that the E-450 Super Duty Cutaway chassis be selected as the platform of choice for the HEV conversion. It is strongly recommended that the E-350 not be considered for the HEV airport shuttle application. TDM recommends the use of a small diesel engine coupled to a generator/alternator sized for the required range extension. The use of this configuration best meets packaging, heat management, and emissions. Although the use of a micro turbine is a good solution, concerns over heat management and emissions need to be addressed. For the pure electric vehicle application, the Explorer meets all selection criteria and is therefore a viable platform based on the information available at time of this study.

TDM recommends continuing on to the next phase of the program. The next phase should include a prototype build including a detailed engineering study in the areas listed in the next section.

Plan to Proceed

In order to proceed, TDM and EPRI must agree to a set of specifications that clearly defines all the requirements in the following areas for the next phase.

- Battery Selection/Battery Management System – based on the selection made in this feasibility study, testing would be recommended for validation. A clear definition of the vehicle use including options such as heater and air conditioning will be required. A test procedure for the validation of the vehicle range must be written.

- Thermal Management – The use of a small diesel engine or alternative internal combustion engine would address concerns over heat management. The use of a micro turbine would require a more detailed study of heat rejection and exhaust configuration.

- Vehicle Weight Analysis- More detailed information would be required of the coach builder’s body in order to verify the assumptions made in the packaging section of this report. There are many body configurations and vendors available for the conversion of a shuttle bus.

- Auxiliary Power Unit Selection- More clear requirements for the “emergency” range extension would be needed including maximum speed, speed on grade, acceleration and range. The selection of the APU is critical in order to meet the range and efficiency requirements. A clear definition of the “emergency” range extension

- Optimized Bracket Designs – Finite element analysis (FEA) would be recommended during the design of mounting brackets. Weight must be minimized in all components while considering safety and durability. Durability studies including vibration testing are recommended.

- Vehicle Control Systems – Calibration and design of motor controller for energy management, efficiency and performance is needed. APU calibration for emissions, efficiency and performance is necessary.

- Driver Interface – Calibration of gauges and design of dash panel for driver information is required.

- Vehicle System Integration – A robust communications network must be designed in order to allow each component to share information and optimize performance.

A
APPENDIX – COMPONENT INFORMATION

Battery Information

HP30 LiON® CELL

CHARACTERISTIC	**DATA**
Size (mm)	∅ 54 x L 208
Volume (l)	0.48
Mass (kg)	1.05
Capacity at C/3 (Ah)	31 at 3.9V
Voltage, Nominal (V)	3.6
Typical Voltage Range (V)	2.5 to 3.9
Specific Energy at C/3 (Wh/kg)	106
Energy Density at C/3 (Wh/l)	234
Power Capability, 18 sec. Pulse at 50% SOC	
Specific Power (W/kg)	1190
Power Density (W/l)	2600
Power Capability, Continuous Discharge	
Specific Power (W/kg)	800
Power Density (W/l)	1750

6 and 12 Ah High Power

Lithium-ion cells

Electrical characteristics

Nominal voltage (V)	3.6	3.6
Capacity at C/3 rate (Ah)	6.5	13
Specific energy (Wh/kg)	64	70
Energy density (Wh/dm³)	135	150
Specific power (W/kg)	1500	1350
Power density (W/dm³)	3100	2900

Mechanical characteristics

Diameter (mm)	47	47
Height (mm)	104	180
Weight (g)	375	680
Volume (dm³)	0.18	0.31

Operating conditions

Operating temperature range (°C) as given by the thermal management system	– 10 /+ 45
Transport or storage temperature range (°C)	– 40 /+ 65
Voltage limits in charge (V) in discharge (V)	 3.9 2.1

Designed for new generation hybrid vehicles, Saft High Power lithium-ion cells are ideally suited for alternator-starters and power assist applications. The development of this unique technology was successfully achieved in the framework of the United States Partnership for New Generation of Vehicles (PNGV). Saft 6 Ah and 12 Ah cells provide unmatched specific power and power density. Saft's offer also includes standard module of 12 cells, combined with an electronic control management system for the monitoring of charge and discharge voltages as well as temperature. Thanks to that modular concept, larger battery pack can be easily customized.

Applications

- Power Assist hybrid electric vehicles
- Very High pulse power application
- News generations of starters

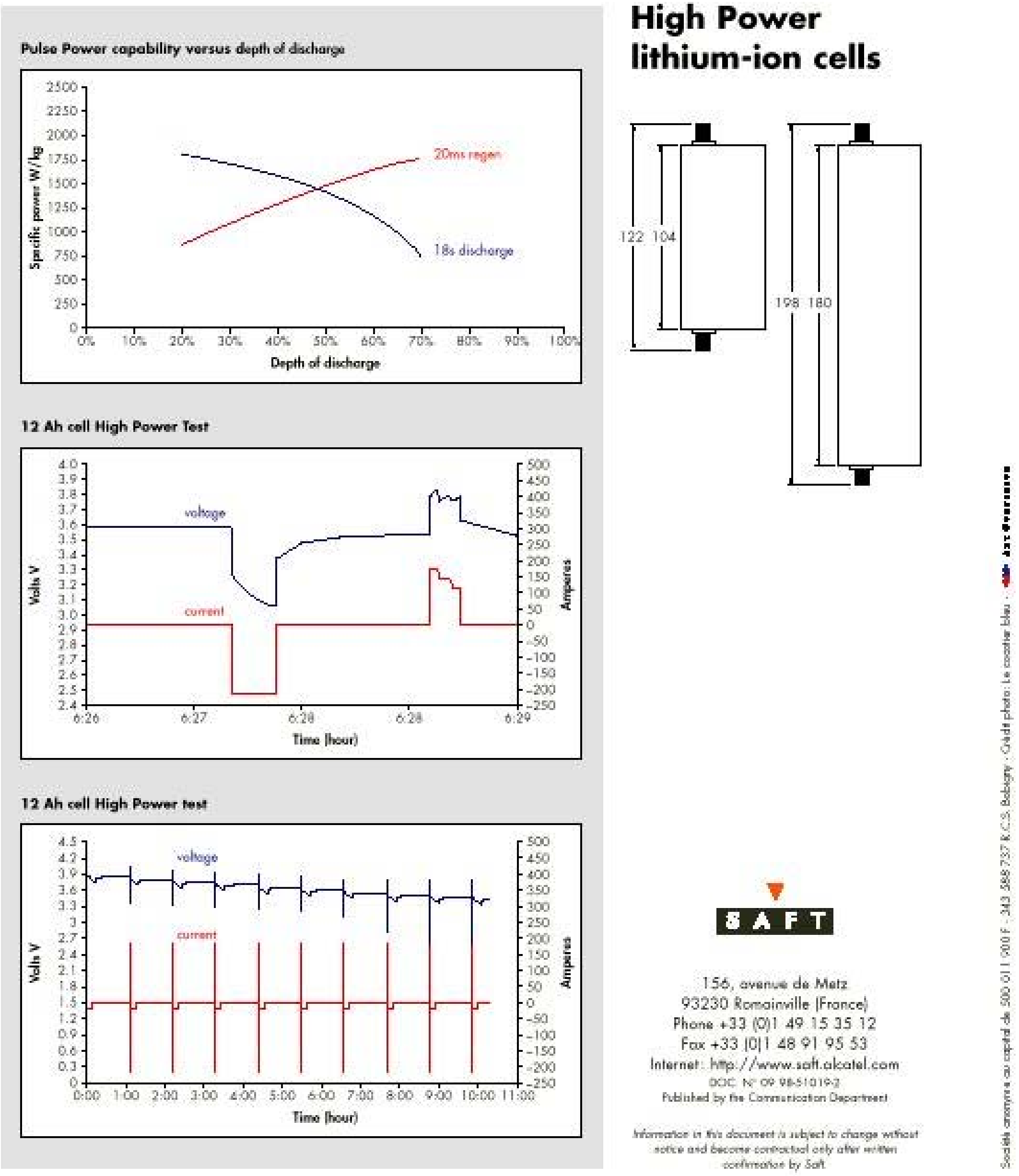
Main advantages

- Very High Specific Power
- Very High Power Density
- Maintenance free
- High cycle life (over 150,000) Compliant with the USABC and EUCAR safety specifications

Technology

- Plastified carbon anode
- Nickel oxyde based cathode
- Organic electrolyte
- Integrated electronic management system at module and battery level

SAFT



High Power lithium-ion cells

156, avenue de Metz
93230 Romainville (France)
Phone +33 (0)1 49 15 35 12
Fax +33 (0)1 48 91 95 53
Internet: http://www.saft.alcatel.com
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PRELIMINARY

26 Ah Medium Range

Lithium-ion cell

Designed to fulfill the battery requirement of new hybrid and electric vehicles, Saft lithium-ion 26 Ah cell offers a unique power-to-energy ratio. This product combines the benefits of high-power lithium-ion electrode technology with an enhanced energy density. It is ideally suited for hybrid vehicles with an electric drive capability. Battery systems developed with Saft Medium Range cells achieved the full spectrum of unparalleled energy and power performances. They are designed with the same modular concept as Saft's High Energy lithium-ion Batteries.

Electrical characteristics

Nominal voltage (V)	3.6
Capacity at C/3 rate (Ah)	26
Specific energy (Wh/kg)	110
Energy density (Wh/dm^3)	230
Specific power (W/kg)	750
Power density (W/dm^3)	2.050

Mechanical characteristics

Diameter (mm)	54
Height max. (mm)	160
Weight (kg)	0.77
Volume (dm^3)	0.36

Operating conditions

Operating temperature range (°C) as given by the thermal management system	– 10 /+ 45
Transport or storage temperature range (°C)	– 40 /+ 65
Voltage limits	
In charge (V)	4
In discharge (V)	2.7

Application

- Hybrid ZEV
- Any application requiring an optimal balance of High Power and Energy

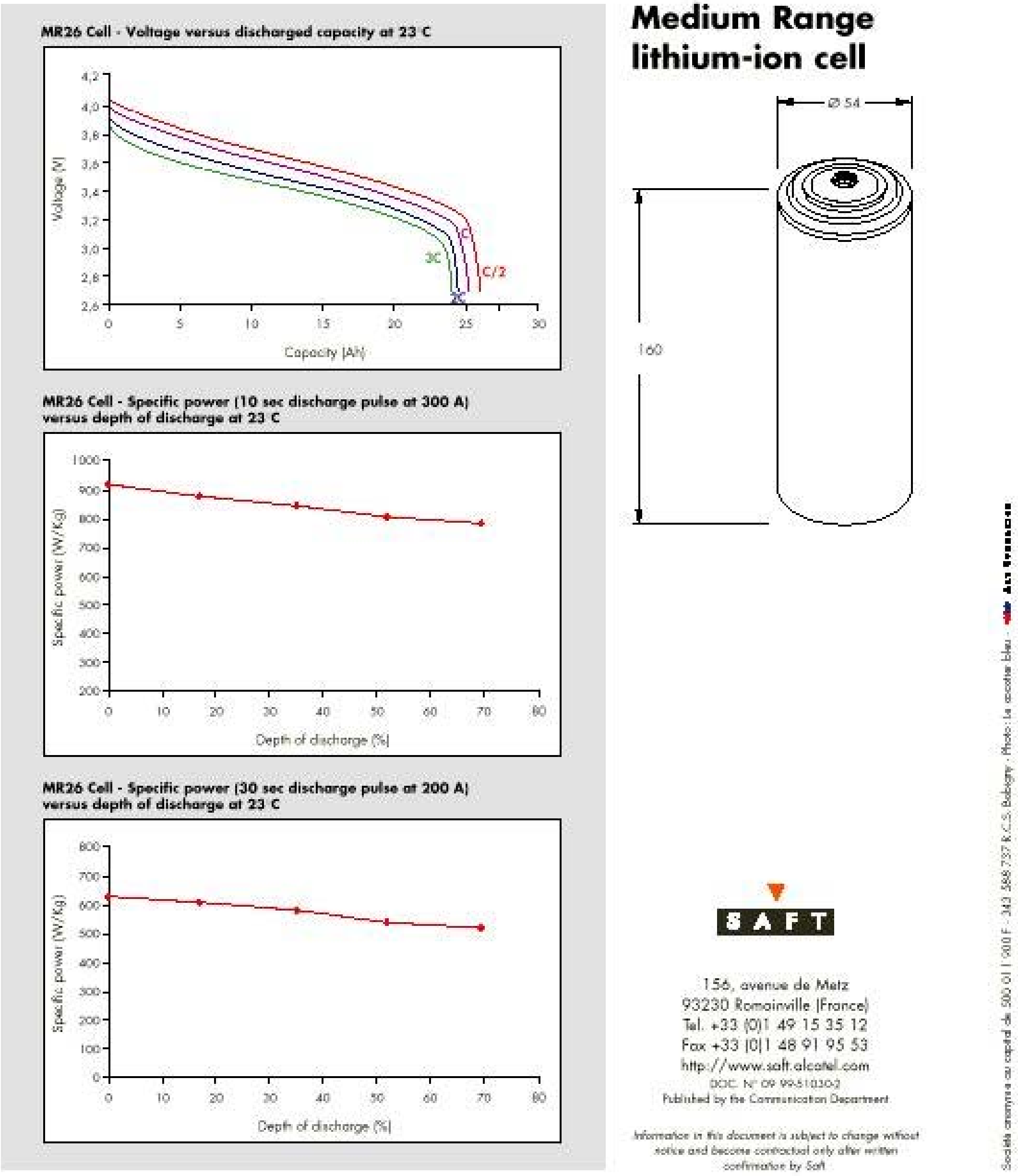
Main advantages

- High Specific Power and Energy
- High Energy and Power Density
- Maintenance free
- High cycle life (over 1000 on EV mode)

Technology

- Plastified carbon anode
- Nickel oxide based cathode
- Organic electrolyte
- Integrated electronic management system at module and battery level

SAFT



MR26 Cell - Voltage versus discharged capacity at 23 C

MR26 Cell - Specific power (10 sec discharge pulse at 300 A) versus depth of discharge at 23 C

MR26 Cell - Specific power (30 sec discharge pulse at 200 A) versus depth of discharge at 23 C

Medium Range lithium-ion cell

SAFT

156, avenue de Metz
93230 Romainville (France)
Tel. +33 (0)1 49 15 35 12
Fax +33 (0)1 48 91 95 53
http://www.saft.alcatel.com
DOC. N° 09 99-51030-2
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44 Ah
High Energy

Lithium-ion cell

Designed to power pure electric vehicles, Saft High Energy lithium-ion cell represents a breakthrough in battery technology. This new generation of products is highly suited to any charge/discharge cycling application that demands battery with weight and volume drastically reduced. Saft 44 Ah cell delivers the ultimate in enhanced performance and autonomy to electric vehicles. Saft's offer also includes standard module of 6 cells, combined with an electronic control management system for the monitoring of charge and discharge voltages as well as temperature. Thanks to this modular concept, larger battery pack can be easily customized.

Applications
- All electric vehicle
- High Energy Applications

Main advantages
- Very High Specific Energy
- Maintenance free
- High cycle life (over 1000)

Technology
- Plastified carbon anode
- Nickel oxide based cathode
- Organic electrolyte
- Integrated electronic management system at module and battery level

Electrical characteristics

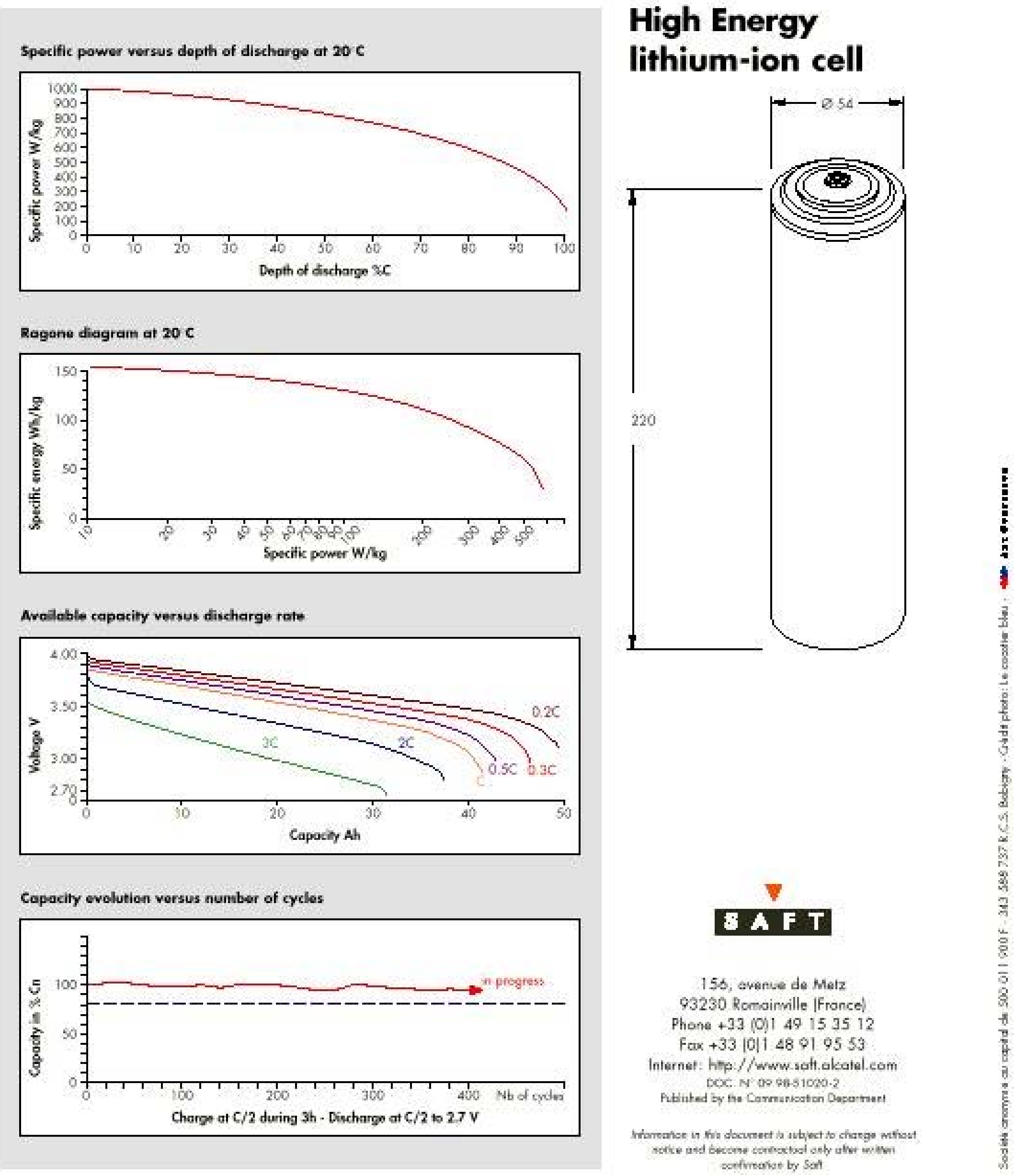
Nominal voltage (V)	3.6
Capacity at C/3 rate (Ah)	44
Specific energy (Wh/Kg)	144
Energy density (Wh/dm^3)	308
Specific power (W/Kg)	300
Power density (W/dm^3)	642

Mechanical characteristics

Diameter (mm)	54
Height max (mm)	220
Weight (kg)	1.07
Volume (dm^3)	0.5

Operating conditions

Operating temperature range (°C) as given by the thermal management system	−10/+45
Transport and storage temperature range (°C)	−40/+65
Voltage limits In charge (V) In discharge (V)	 4 2.7



High Energy lithium-ion cell

Specific power versus depth of discharge at 20°C

Ragone diagram at 20°C

Available capacity versus discharge rate

Capacity evolution versus number of cycles

Charge at C/2 during 3h - Discharge at C/2 to 2.7 V

SAFT

156, avenue de Metz
93230 Romainville (France)
Phone +33 (0)1 49 15 35 12
Fax +33 (0)1 48 91 95 53
Internet: http://www.saft.alcatel.com

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Société anonyme au capital de 500 011 900 F - 343 588 737 R.C.S. Bobigny - Crédit photo: Le cocotier bleu -

Ni-MH

Nickel-Metal Hydride modules for electric vehicles

Designed in partnership with the automotive industry, Saft's Nickel-Metal Hydride (Ni-MH) provides very attractive performance to electric vehicle battery systems. Saft Nickel-Metal Hydride are available in either 12V or 24V configurations and feature a liquid cooling system.
With enhanced specific energy and energy density, Saft Ni-MH batteries help electric vehicles to extend their range up to 150 km.

Applications

- All-electric vehicles

Main advantages

- Maintenance-free operation
- High power/energy ratio
- Excellent safety and flawless
- Resistance to abuse testing
- Easy fast charging
- Fully recyclable
- Liquid cooling
- More than 1,200 charge/discharge cycles
- Monoblock design

Technology

- Nickel foam positive electrode
- AB_5 hydride on steel foil negative electrode

Electrical characteristics

Nominal voltage (V)	12	24
Rated capacity at C/3 rate (Ah)	96	96
Specific energy (Wh/kg at C/3)	66	66
Typical energy density (Wh/dm^3 at C/3)	138	140
Typical specific power (W/kg at 80% DOD, 30 sec, 2/3 Uo)	160	160
Typical power density (W/dm^3)	332	340

Mechanical characteristics

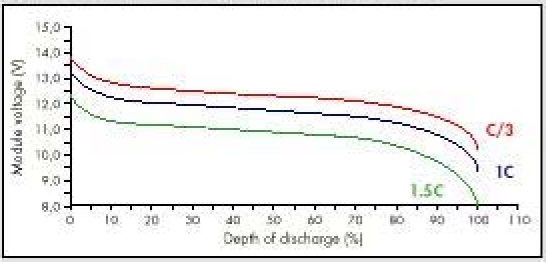
Dimensions (mm): L x W x H	390x120x195	760x120x195
Weight (kg)	18.6	37
Typical volume (dm^3)	8.8	17.3

Operating conditions

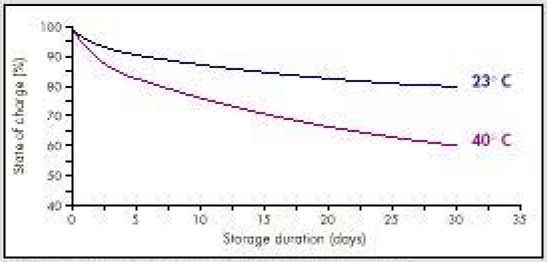
Operating temperature range (°C) as given by the thermal management system	–10/+45 in charge	–10/+60 in discharge
Transport or storage temperature range (°C)	–40/+65	

SAFT

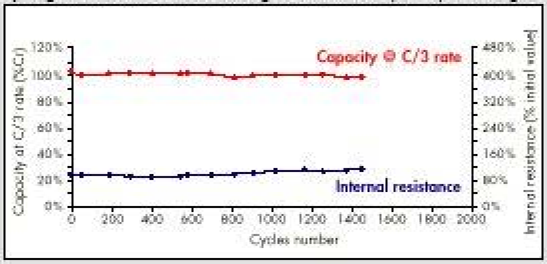
96 Ah Ni-MH Module - Discharge at various rates at +23°C



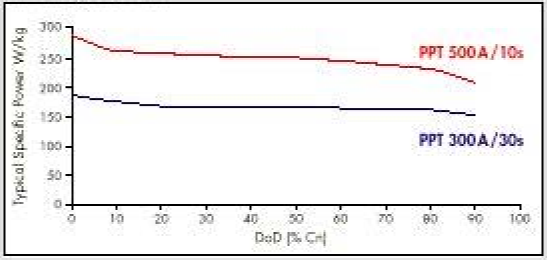
96 Ah Ni-MH Module - Charge retention at temperatures from 0°C to 60°C



96 Ah Ni-MH Module electrochemistry - Capacity at C/3
Cycling test at 80% DoD at RT: charge at C/3 + C/20 (k=1.1) /discharge at 1C



96 Ah Ni-Mh Module - Specific Power during PPT at +23°C
Min Voltage 0.83 V/cell



SAFT

156, avenue de Metz
93230 Romainville (France)
Tel. +33 (0)1 49 15 35 12
Fax +33 (0)1 48 91 95 53
http://www.saft.alcatel.com
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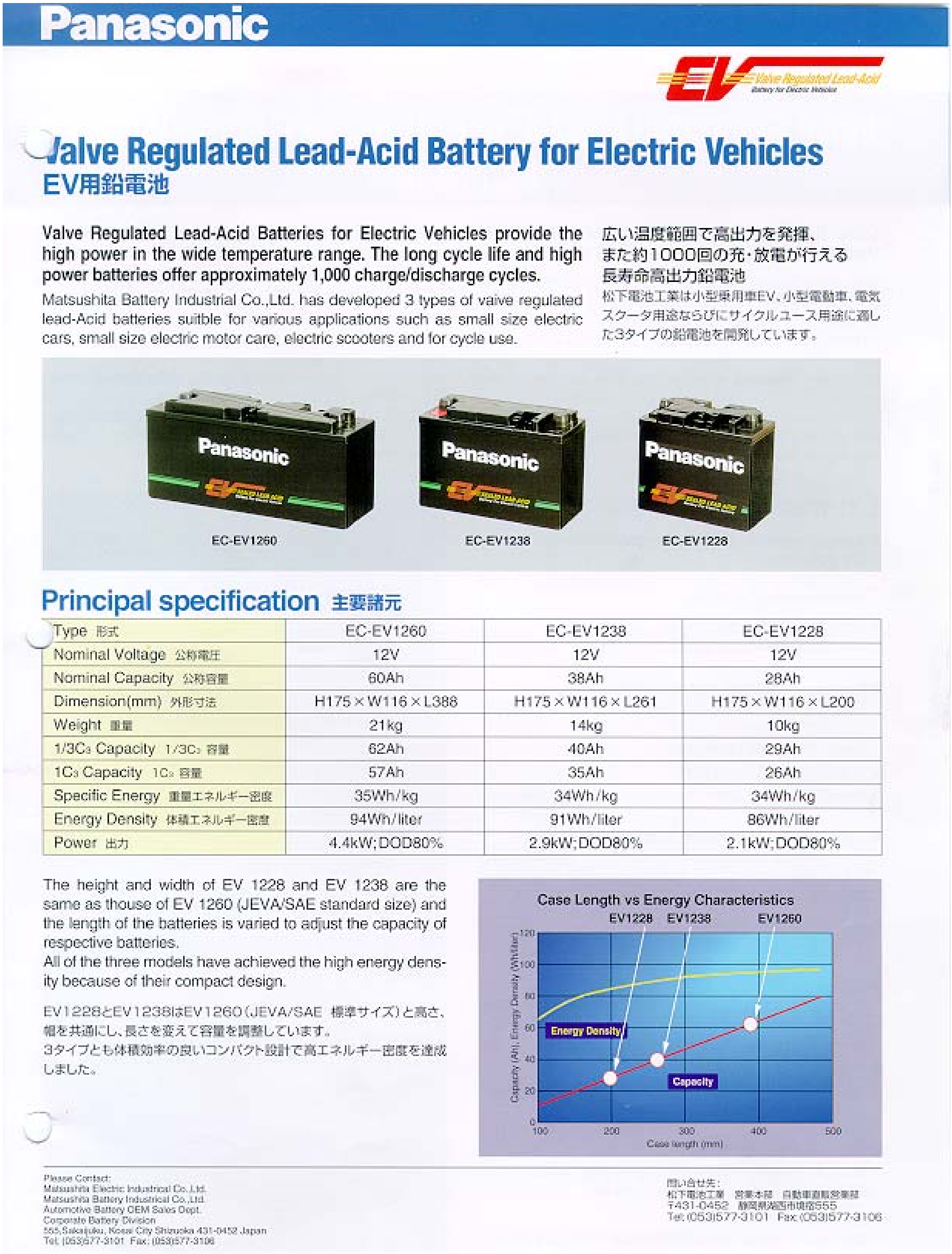
4/5SF NiMH CELL

CHARACTERISTIC	**DATA**
Size (mm)	∅ 41 x L 84.5
Volume (l)	
Mass (kg)	0.35
Capacity at C/3 (Ah)	14 at 1.6V
Voltage, Nominal (V)	1.2
Typical Voltage Range (V)	0.7 to 1.6
Specific Energy at C/3 (Wh/kg)	47
Energy Density at C/3 (Wh/l)	152
Power Capability, 18 sec. Pulse at 50% SOC	
Specific Power (W/kg)	690
Power Density (W/l)	2227
Power Capability, Continuous Discharge	
Specific Power (W/kg)	690
Power Density (W/l)	2227



Panasonic

Valve Regulated Lead-Acid Battery for Electric Vehicles
EV用鉛電池

Valve Regulated Lead-Acid Batteries for Electric Vehicles provide the high power in the wide temperature range. The long cycle life and high power batteries offer approximately 1,000 charge/discharge cycles.

Matsushita Battery Industrial Co.,Ltd. has developed 3 types of vaive regulated lead-Acid batteries suitble for various applications such as small size electric cars, small size electric motor care, electric scooters and for cycle use.

広い温度範囲で高出力を発揮、
また約1000回の充·放電が行える
長寿命高出力鉛電池

松下電池工業は小型乗用車EV、小型電動車、電気スクータ用途ならびにサイクルユース用途に適した3タイプの鉛電池を開発しています。

EC-EV1260　EC-EV1238　EC-EV1228

Principal specification 主要諸元

Type 形式	EC-EV1260	EC-EV1238	EC-EV1228
Nominal Voltage 公称電圧	12V	12V	12V
Nominal Capacity 公称容量	60Ah	38Ah	28Ah
Dimension(mm) 外形寸法	H175×W116×L388	H175×W116×L261	H175×W116×L200
Weight 重量	21kg	14kg	10kg
$1/3C_3$ Capacity $1/3C_3$ 容量	62Ah	40Ah	29Ah
$1C_3$ Capacity $1C_3$ 容量	57Ah	35Ah	26Ah
Specific Energy 重量エネルギー密度	35Wh/kg	34Wh/kg	34Wh/kg
Energy Density 体積エネルギー密度	94Wh/liter	91Wh/liter	86Wh/liter
Power 出力	4.4kW;DOD80%	2.9kW;DOD80%	2.1kW;DOD80%

The height and width of EV 1228 and EV 1238 are the same as thouse of EV 1260 (JEVA/SAE standard size) and the length of the batteries is varied to adjust the capacity of respective batteries.
All of the three models have achieved the high energy density because of their compact design.

EV1228とEV1238はEV1260（JEVA/SAE　標準サイズ）と高さ、幅を共通にし、長さを変えて容量を調整しています。
3タイプとも体積効率の良いコンパクト設計で高エネルギー密度を達成しました。

Please Contact:
Matsushita Electric Industrial Co.,Ltd.
Matsushita Battery Industrial Co.,Ltd.
Automotive Battery OEM Sales Dept.
Corporate Battery Division
555,Sakaijuku, Kosai City Shizuoka 431-0452 Japan
Tel: (053)577-3101　Fax: (053)577-3106

問い合せ先：
松下電池工業　営業本部　自動車電池営業部
〒431-0452　静岡県湖西市境宿555
Tel:(053)577-3101　Fax:(053)577-3106

Panasonic

EV Valve Regulated Lead-Acid
Battery for Electric Vehicles

Valve Regulated Lead-Acid Battery for Electric Vehicles
EV用鉛電池

Valve Regulated Lead-Acid Batteries for Electric Vehicles with high performance and high quality.

Matsushita Battery Industrial Co.,Ltd. has invented various energy utilization methods to address the energy conservation issue and environmental issues in the next generation, promoting our policy "Coexistence with the Global Environment".
EVs have attracted a public attention as one of the advanced transportation methods with low exhaust gases and low noise pollution, since their power sources come from an electricity of diverse energy sources. EVs are now entering the stage of commercialization.

Making best use of all of our battery technologies, we have developed high performancs Lead-Acid Batteries with excellent safaty and high reliability for EV applications. Now we offer out batteries to all the users around the world.

高性能·高品質のEV用鉛電池

松下電池工業は、次世代のエネルギー問題、環境問題に対応するさまざまなエネルギー活用方法を創造し、「地球環境との共存」を推進しています。多様なエネルギー源による電気を動力源とし、排気ガスや騒音の少ない次世代の交通手段として注目されてきた電気自動車（EV）はいよいよ実用化の時代を迎えようとしています。松下電池工業は総合技術を結集し、本格的EV用電池として、優れた安全性と信頼性を兼ね備えた高性能鉛電池を全世界のユーザーに提供します。

Characteristics 特徴

●**Approximately 1,000 charge/discharge cycles are possible:**
Since battery replacement is rarely necessary, its cost performance is remarkable.

● 約1000回の充·放電が可能
電池交換の必要性が殆ど不要で、コストパフォーマンスに優れます。

●**High power at the end of discharge:**
Comfortable EV driving is ensured, since excellent performance of acceleration and hill climbing ability are maintained at the end of discharge.

● 放電末期まで高出力を発揮
最後まで優れた加速性、登坂性を維持し、EVの快適走行を実現します。

●**High power in the wide temperature range:**
The battery provides excellent discharge characteristics in the wide temperature range between low temperature and high temperature.

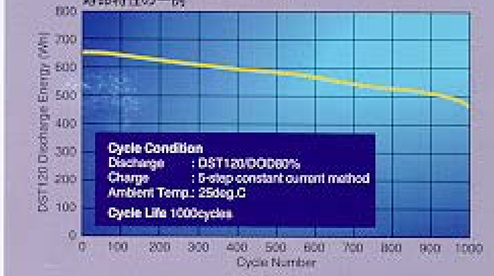
● 広い温度範囲で使用可能
低温から高温まで優れた放電特性を発揮します。

●**Excellent safety and high reliability:**
This is a maintenance-free battery. We have tested the battery under various working conditions and then improved it to ensure excellent safety.

● 安全性に優れた高信頼性
安全性について、さまざまな使用条件を予想した確認と改良を行ったメンテナンスフリータイプです。

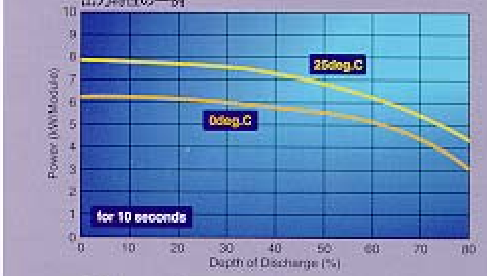
●**Recyclable materials:**
Since the battery materials are recyclable, we can make effective use of precious global resources.

● リサイクルが可能
使用材料はリサイクルが可能で貴重な地球資源を有効に活用できます。

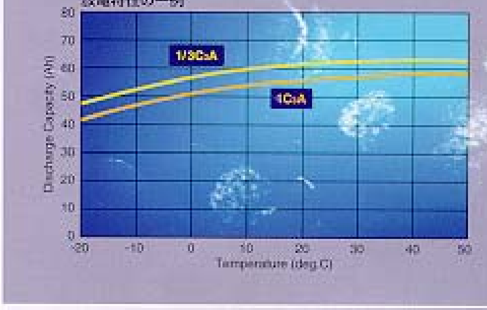


Service Life Characteristics
寿命特性の一例

Cycle Condition
Discharge : DST120/DOD80%
Charge : 5-step constant current method
Ambient Temp.: 25deg.C
Cycle Life 1000cycles



Power Characteristics
出力特性の一例



Discharge Characteristics
放電特性の一例

B

APPENDIX – REFERENCE INFORMATION

Previous Programs

TDM's Hybrid and EV Successes

Specializing in all phases of transportation vehicle design, engineering and manufacturing. TDM delivers niche-market production runs for major automotive companies.

TDM's expertise includes the modification and manufacturing of alternate-fuel vehicles in a QS-9000 environment.

TDM's first venture into the hybrid arena was installing Auxiliary Power Unit (APU) on New York City Transit Authority buses a few years ago.

TDM partnered with Ford on engineering, designing, prototyping, and building the EV Ford Ranger (PEV).

TDM built 11 hybrid vehicles for a U.S. Government agency in Warner Robins, Ga.

Today, TDM's Service & Warranty Department in partnership with Ford provides full 36 month vehicle warranty service to these hybrid vehicles at six locations throughout the U.S.

Whatever services a program may require, from styling, design, engineering or validation; on through to final manufacturing, TDM offers a combination of high-end technology and timesaving expertise in a broad range of capabilities.

Warner Robins Hybrid

TDM designed, engineered and produced powertrains for 11 Hybrid Electric Vehicles (HEV) for a U.S. agency. These vehicles are the Warner Robins Program.

Each HEV'S powertrain consists of the following major components:

Auxiliary Power Unit (APU). The APU has a 2.5-liter turbo diesel engine coupled to a Unique Mobility 75kW Alternator.

25-Module Traction Battery Pack.

TDM’s custom engineered Traction Motor Control Module (TMCM).

TDM’s custom engineered Vehicle Control and Energy Management Module (VCEM).

Siemens Electric Drive Motors

Operating in the hybrid mode, the 75kW continuous output Unique Mobility, Inc., alternator (motor/generator) runs microprocessor governed speeds controlled to achieve engine efficiency and reduce emissions. The APU feeds a layout of 25 valve-regulated lead-acid (VRLA) maintenance-free 12V battery modules. Battery equalization is achieved automatically with on-board equalization charge capabilities.

During Stealth operation, the APU is turned off and the vehicle functions as a zero-emission, pure electric vehicle. During normal operation, the Auxiliary Power Unit is used to charge the battery pack.

VEHICLE OVERVIEW

BASE FORD PARCEL DELIVERY VAN

Figure 9-1
Ford Parcel Delivery Van

- FORD E-350 SUPERDUTY FORD ECONOLINE CUTAWAY CAB CHASSIS
- VAN: 138 INCH WHEELBASE
- 9,600 LB. GVW

VEHICLE OVERVIEW

BASE FORD SHUTTLE BUS

Figure 9-2
Ford E-350 Super Duty Cutaway Chassis

- FORD E-350 SUPERDUTY FORD ECONOLINE CUTAWAY CAB CHASSIS
- BUS: 176 INCH WHEELBASE
- 14,050 LB. GVW

HYBRID ELECTRIC VEHICLE SPECFIC COMPONENTS

THE AUXILIARY POWER UNIT (APU):

- 2.5L VM MOTORI TURBODIESEL ENGINE, DETROIT DIESEL
- BOSCH CONTROL MODULE, BOSCH
- APU ENGINE COOLING SYSTEM, TDM

TRACTION DRIVE SYSTEM

- TRACTION DRIVE MOTOR(S), SIEMENS
- TRACTION MOTOR CONTROL MODULE(S), SIEMENS
- TRACTION MOTOR COOLING SYSTEM, TDM

TRANSFER CASE

- TRANSFER CASE LUBRICATION SYSTEM, TDM

TRACTION BATTERY PACK

- 25 BATTERY MODULES, OPTIMA

HIGH VOLTAGE POWER DISTRIBUTION BOX (HVPDB)

- AUXILIARY HVPDB (BUS ONLY), TDM

TRACTION BATTERY CONTROL MODULE (TBCM)—(BADICHEQ)

BADICHEQ EXTENSION MODULE

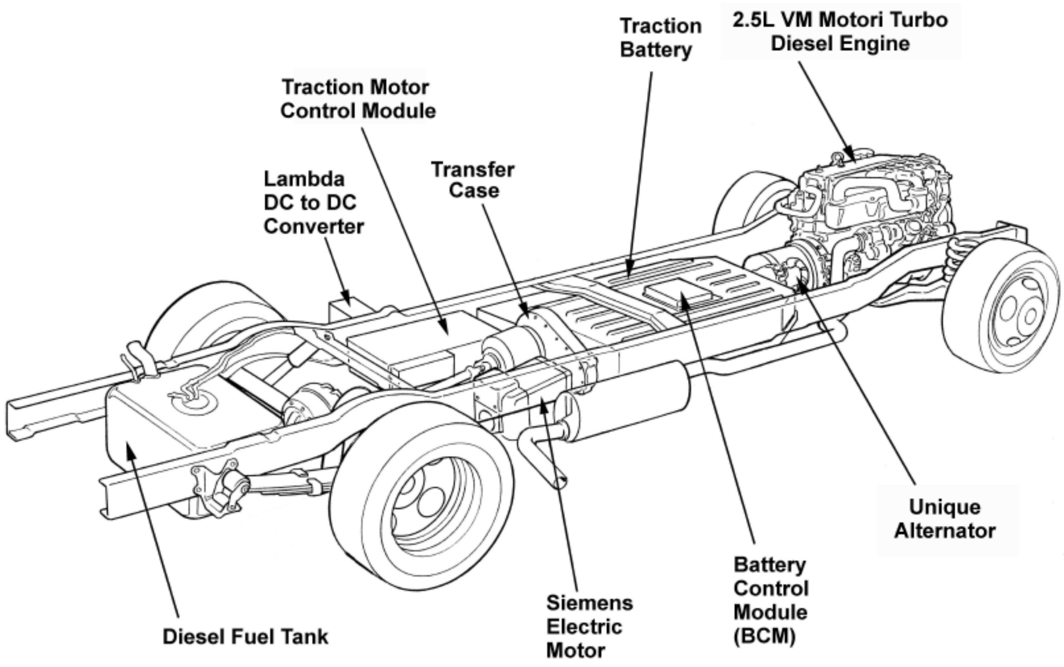
DRIVER INTERFACE COMPONENTS

- DRIVE BY WIRE THROTTLE PEDAL, TDM
- VEHICLE MODE SWITCH, TDM
- HEV INSTRUMENTATION, TDM

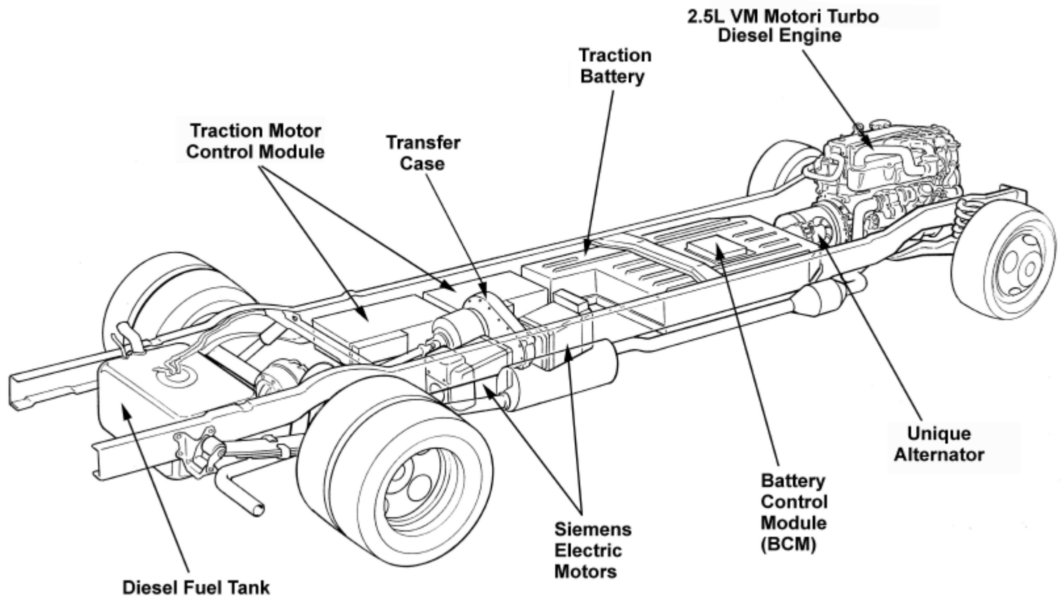
LAMBDA DC-to-DC CONVERTER, LAMBDA

VEHICLE CONTROLLER/ENERGY MANAGEMENT (VCEM) MODULE, TDM

COMPONENT LOCATIONS (VAN)



COMPONENT LOCATIONS (BUS)



MODES OF OPERATION

TDM HEVs can operate in the following modes:

- HYBRID ELECTRIC VEHICLE (HEV)
- STEALTH
- CHARGE (TRACTION BATTERY EQUALIZATION)

OPERATION IN HEV MODE allows the APU to provide power to the Traction Battery System to maintain a specific state of charge in the Traction Battery Pack.

OPERATION IN STEALTH MODE does not allow the APU to run.

Power to the vehicle is provided solely by the energy stored in the Traction Battery Pack.

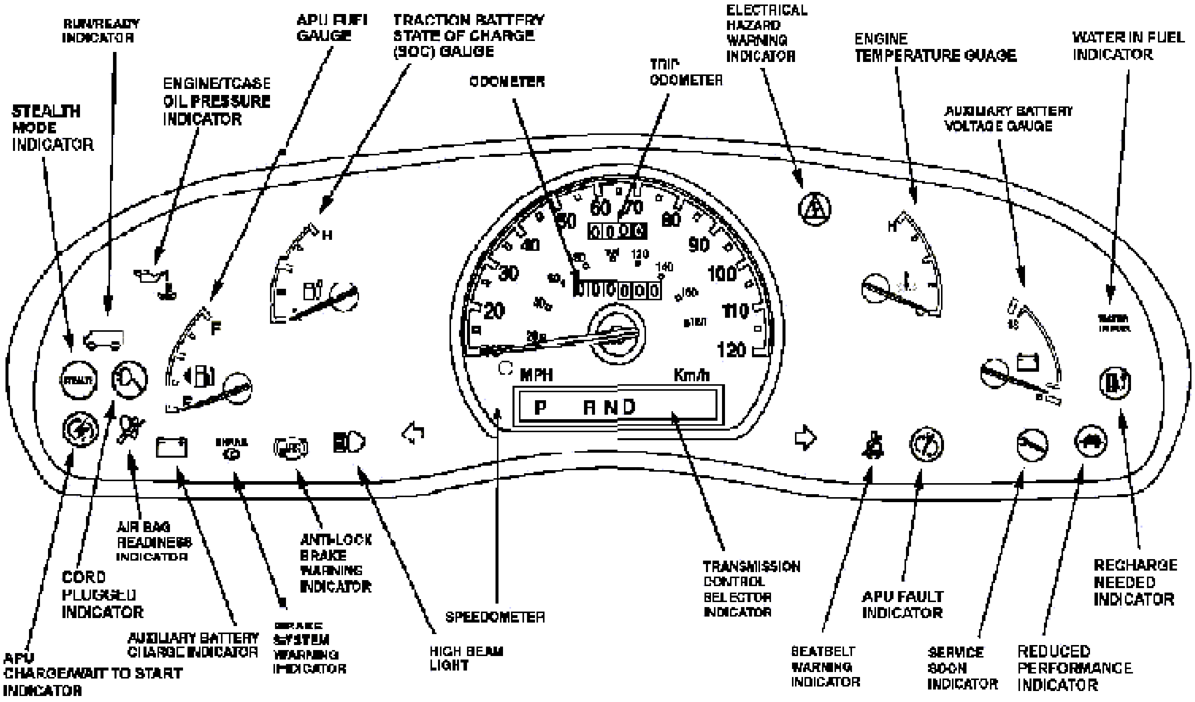
OPERATION IN CHARGE MODE allows the APU to provide power ONLY to the traction battery system to equalize the State Of Charge (SOC) of the individual traction battery modules packaged in the battery pack.

The three modes of operation are dependent on the position of two switches: the Stealth Mode (SM) switch, and the Charge Mode switch.

INSTRUMENT CLUSTER EXCLUSIVE TO HEV

GAUGES

WARNING LAMPS



Control System Overview

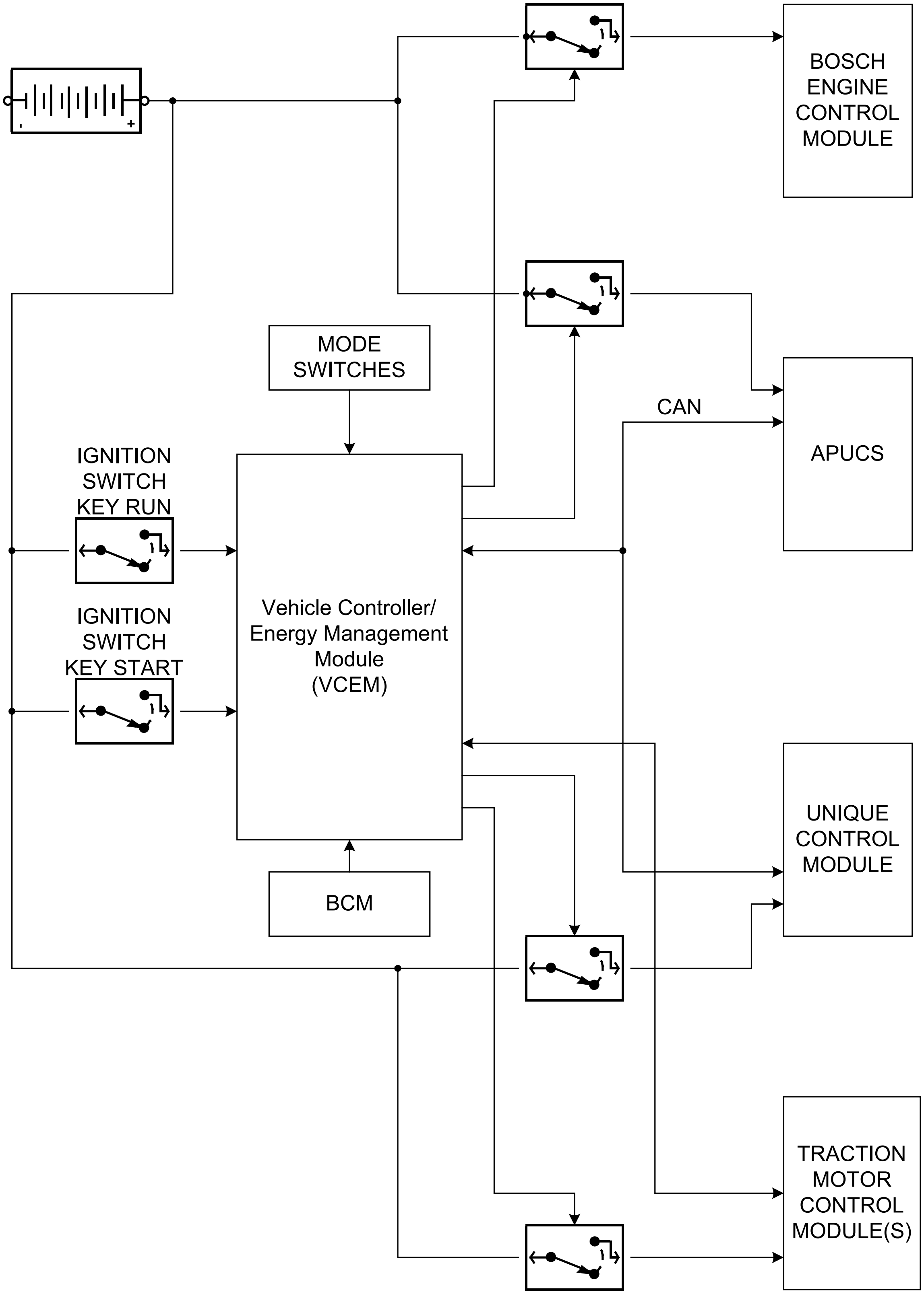
Vehicle Interface

Vehicle Controller / Energy Management (VCEM) Module

The Warner Robins HEV uses a TDM custom designed VCEM to control most of the HEV vehicle functions. The VCEM receives sensor input signals from a number of control modules and sensors that drive the illumination of warning lights and messages. These messages can be read by the DLC (Diagnostic Laptop Computer), using the DIAC (Diagnostic Interface Assembly Cable) to connect the laptop with the VCEM.

The VCEM is mounted in the Van behind and below the driver's seat. In the Bus it is located in a vertical support directly behind the driver's seat.

The VCEM is a non-serviceable part. It should be returned to TDM for replacement if found defective.


-
+
BOSCH ENGINE CONTROL MODULE
MODE SWITCHES
CAN
APUCS
IGNITION SWITCH KEY RUN
IGNITION SWITCH KEY START
Vehicle Controller/ Energy Management Module (VCEM)
UNIQUE CONTROL MODULE
BCM
TRACTION MOTOR CONTROL MODULE(S)

Inputs

- Ignition Switch
- Transmission Range Switch
- Mode Switches
- Battery Control Module

Battery Temperature Sensors
APUCS
Unique Control Module

OUTPUTS

- APUCS
- Unique Control Module
- Traction Motor Control Module
- Bosch Engine Control Module
- Instrument Panel
- Thermal Management System

Vehicle Interface

Auxiliary Power Unit Control System (APUCS) Module

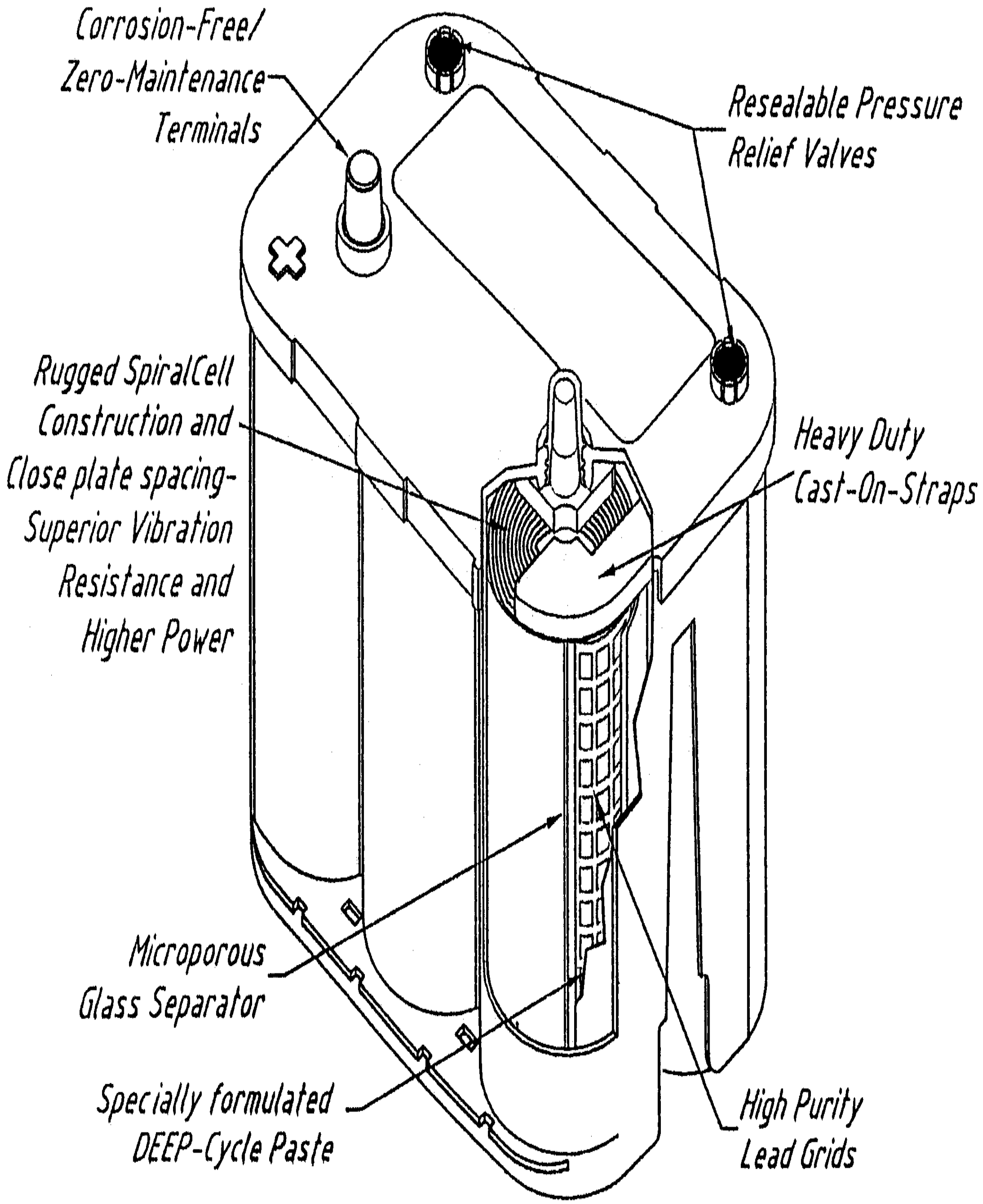
- The TDM HEV uses the APUCS to control APU and vehicle functions.
- Inputs
  - o Outputs VCEM
  - o Unique Control Module
  - o Bosch Engine Control Module
- Outputs
  - o VCEM
  - o Unique Control Module
  - o Bosch Engine Control Module

TRACTION BATTERY CONTROL SYSTEM

The HEV’s traction battery is the heart of the vehicle powertrain. It consists of 25 individual batteries wired together in a series to form one large 300 volt “cell.” These individual batteries, or modules, are made of a lead-acid impregnated fiberglass cloth wrapped around six carbon rod cores. The 12-volt modules are packaged in a weather resistant, ventilated, electrically isolated battery box.

The traction battery’s primary purpose is to supply energy to the Siemens electric motor(s) through the traction motor control module(s) (the Van has one motor and controller assembly, while the bus has two motors and control assemblies). It also supplies energy to drive the accessory drive motor, the Positive Temperature Coefficient (PTC) heater, and the individual component surface heaters.

The individual traction battery modules are electrically protected from over-current conditions with a fuse that is wired between battery number 17 and battery number 18. On the Van, this fuse is rated at 350 Amps, while for the Bus, the fuse is rated at 600 Amps.



The traction battery is located between the frame rails of the HEV, behind the APU. It is held in an electrically isolated enclosure, which is secured to the vehicle using an aluminum frame and four high strength bolts. This traction battery enclosure is made up of the following components:

- the enclosure body (bottom and top)
- the enclosure sealing material

- the battery module separation inserts
- the battery heater insulation and mounting plates
- the battery enclosure fan

THERMAL MANAGEMENT SYSTEM (HEATING & VENTILATION)

The thermal management system heaters are designed to provide auxiliary heat to the traction battery, diesel engine and the Unique Control Module during low ambient temperature conditions. The heaters are powered from an external 120 VAC source.

The source for the 120 VAC power is the plug located in the front grille of the vehicle.

The thermal management system uses a ventilation fan running intermittently during normal operation to eliminate the possibility of hydrogen gas buildup.

The ventilation fan runs at high speeds when a high temperature limit is exceeded to reduce the temperatures in the traction battery pack.

The thermal management system uses four temperature sensors located in the traction battery pack.

The traction battery temperatures are sent to the VCEM for proper control of the heaters and the ventilation fan.

TRACTION BATTERY EQUALIZATION

During normal hybrid operation, the individual traction battery modules will tend to separate into different state of charges. To reverse this trend, the vehicle must be put into the "Equalization" Mode. This procedure should be performed regularly to stabilize the individual modules within the pack, and to bring the battery pack to its maximum state of charge (SOC).

ACCESSORY SYSTEMS

Accessory Drive Motor

- DC brushless motor powered by the Traction Battery.
- Drives the Power Steering Pump.
- Located in the engine compartment.

Power Steering Fluid Reservoir (OEM)

- Located in the engine compartment on the radiator core support.

Power Steering (Van)

- Accessory Drive Motor Control Module (ADMCM)
    - Controls the Accessory Drive Motor with power from the Traction Battery.
    - Located in the engine compartment.
- Power Steering Pump (OEM)
    - Coupled directly to the Accessory Drive Motor.
    - Located in the engine compartment.
- Motor/Pump Coupler
    - Transmits power from the motor to the pump.
- High/Low Pressure Lines
    - Supply high-pressure fluid to steering gear and provide return path for fluid.

Power Steering (Bus)

- Power Steering Pump (OEM)
  - Coupled by belt to Accessory Drive Motor.
  - Located outside frame rail on rear driver's side.
- Accessory Drive Motor
  - DC brushless motor powered by the Traction Battery.
  - Drives the Power Steering Pump.
  - Located outside frame rail on rear driver's side.
- Power Steering Belt
  - Couples power from the motor to pump.
- Mounting brackets and isolators
  - Connect the power steering components to the vehicle frame.
- Accessory Drive Motor Control Module (ADMCM)
  - Controls the Accessory Drive Motor
  - Located outside frame rail on rear driver's side.
- Reservoir (OEM)
  - Located in the engine compartment on the radiator core support.
- High/Low Pressure Lines
  - Provide fluid flow from power steering pump.
  - Located outside frame rail on rear driver's side to steering gear on front end.

VACUUM PUMP

- Auxiliary Vacuum Pump
  - Provides vacuum source for panel controls of AC/Heating system on Bus and Van.
  - Provides vacuum for brake booster on Van.
  - Located in the engine compartment under the master cylinder.
- Vacuum Hoses
  - Route vacuum source to other components.
- Vacuum Reservoir
  - Maintains vacuum to other system components.
    - Located outside the frame rail under the driver's seat.

- Electronic Control Module (ECM)
  - Controls the Auxiliary Vacuum Pump.
  - Located behind the knee bolster under the steering column.

PTC HEATER

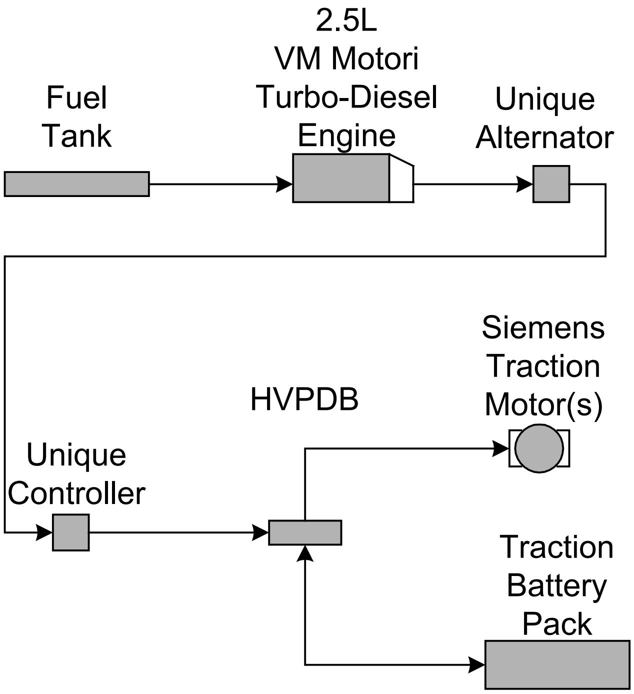
- PTC Heater Element
  - Provides interior heat to vehicle when HRV is operating in Stealth Mode and Diesel engine is not running.
- Thermal Switch
  - Controls operation of the PTC Heater Element

DC-to-DC CONVERTER

- Lambda DC to DC Converter
  - Converts DC Traction Battery voltage to 12-volt auxiliary battery voltage.
  - On the Van it is located outside the frame rail on the rear driver's side.
  - On the Bus it is located under the Traction Motor Control Module.
- Converter mounting bracket
  - Mounts the converter to the vehicle frame.
- Converter cooling system
  - Provides cooling for the DC-to-DC Converter.
  - Located outside the frame rail on the driver's rear side.

HYBRID POWER CONVERSION OVERVIEW

The power from the APU is delivered to the road in a series configuration.



VM MOTORI TURBODIESEL ENGINE

- The Detroit Diesel turbodiesel engine provides the mechanical energy to drive the Unique Mobility's alternator through the coupler.
- It is located in the engine compartment.

UNIQUE MOBILITY ALTERNATOR SYSTEM

Unique Mobility Alternator

- The Unique Mobility alternator converts the mechanical energy from the diesel engine to three phase electrical energy. The mechanical energy is transmitted from the IC engine to the alternator via a rubber coupler.
- The alternator is mounted on the rear of the diesel engine.

Unique Mobility Control Module

- The Control Module converts the three phase AC supplied by the Alternator to DC for charging the Traction Battery.

Engine to Alternator Coupler

- Transfers power from the Motori Turbodiesel to the Alternator.

Unique Mobility Cooling System

- Utilizes a small radiator core mounted under the front bumper to remove heat from the Unique Mobility Alternator Inverter.

TRACTION DRIVE SYSTEM

The Traction Drive System consists of the following components:

- Three phase alternating current (AC) induction motor
- Traction Motor Control Module
- Cooling System
- Transfer Case
- HV Power Distribution Box

TRACTION DRIVE SYSTEM COMPONENT FUNCTIONS

42kW continuous rated three phase alternating current (AC) induction motor(s)

- The Van contains one motor.
- The Bus contains two motors.
- Converts 3 phase electrical energy from the Traction Motor controller to mechanical energy.

Traction Motor Control Module(s) (TMCM)

- The Van contains one TMCM.
- The Bus contains two TMCMs.
- Converts direct current energy from the traction battery pack to 3 phase electrical energy for the Traction Motors.

Traction Motor Cooling System

- Uses an ethylene glycol mixture to cool both the Traction Motors and the TMCM(s).

Transfer Case Assembly

- High velocity chain drive gear reduction system.
- Parking pawl
- Belt driven oil pump off of output shaft.

High Voltage Power Distribution Box (HVPDB)

- Contains high power fuses and relays that route power safely to the APU, Traction Battery Pack and the Siemens Traction Motors.

Ford EV Ranger

The electric powered Ranger is a unique vehicle. The EV Ranger has some familiar vehicle characteristics with some very unique systems and components that utilize high voltage.

Although the energy supplied to the EV Ranger's electric motor and transmission assembly can exceed 300 volts DC, there is no high voltage in the passenger compartment area.

The energy required to operate the EV Ranger is stored in the traction battery. The maximum system voltage occurs at the end of the charge cycle and is about 405 volts. Nominal system voltage is 312 VDC. The traction battery consists of an upper battery pack and lower battery pack, which contain a total of 26 traction battery modules. The upper battery pack is located in the truck bed and the lower battery pack is located under the cab and bed. The traction battery modules are sealed and require no regular watering.

The EV Ranger was equipped with a pair of high voltage gloves with protective leather shells that are located in the vehicles glove box. These gloves are used if the Electrical Warning Indicator remains on, or when the vehicle has been in a severe accident, and whenever servicing of the vehicle is required.

The TDM EV Ranger requires the TDM off-board charging station to recharge the traction battery. It takes from 4-8 hours to reach full charge, depending upon the level of discharge and the voltage powering the charging station (between 208 to 240 volts).

An important feature of the EV Ranger is the Battery Thermal Management System. The function of this system is to maintain the temperature of the battery pack. The battery pack delivers the best performance when its temperature is kept within a predetermined range. The only time the Thermal Management System operates and keeps the battery pack at optimum operating temperature is when the charger is plugged into the vehicle. While the vehicle is being driven, the flow of energy through the battery pack is sufficient to maintain the temperature of the battery pack.

The EV Ranger will experience reduced range if ambient temperatures drop below 60°F for more than 8 hours and the vehicle is not plugged into the charger.

The Ford EV Ranger was built with fleet customer needs in mind, including such features as:

- Cargo carrying capacity
- Usable payload
- 4-wheel ABS
- Climate control
- Dual air bags

Additionally, the EV Ranger includes components unique to EV’s such as:

- Regenerative braking
- Electrohydraulic power steering
- On-board charger
- Optional battery heater
- Re-programmable electronics
- Conductive charging

PROGRAMS

EV Ranger

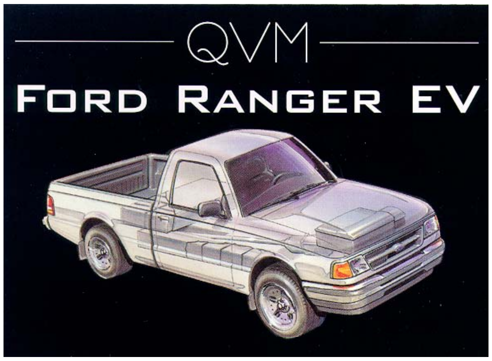
With a significant TDM resource investment into the development of the first-generation EV Ranger as a QVM "glider" program, Ford was able to beat the competition into the marketplace and claim a leadership position among domestic OEMs. Even though the anticipated emerging market for EV's did not materialize, TDM continues to expend significant internal resources to assist in the support of the early EV Ranger, thereby assuring the integrity of the Ford nameplate.

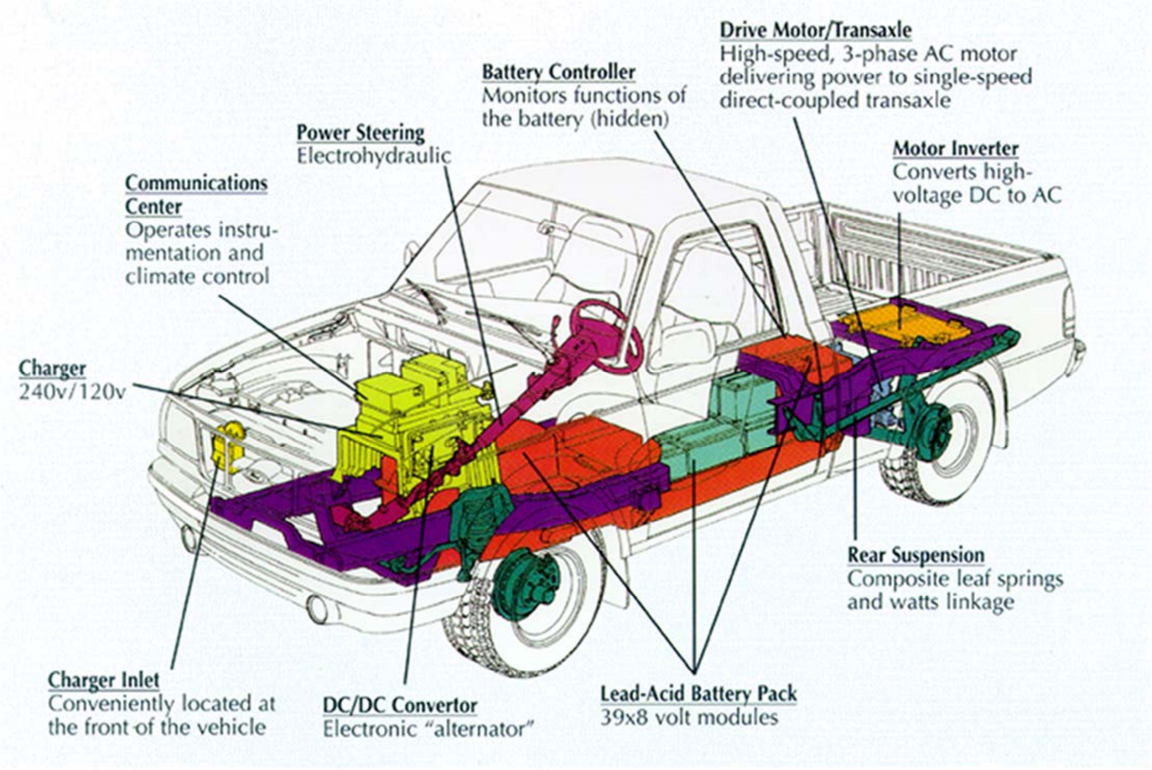
The Ford EV Ranger program facilitization included:

Component Design
- Full QVM Program
- Traction Battery and Battery Energy Management Design
- Off-Board Charging System Design
- Electrical Interface Component Design
- Transfer Case/Parking Pawl Design

Vehicle Integration into Ranger Glider
- Complete Drive System and Energy Storage/Management
- Crashworthiness Design

Vehicle Devlopment and Integration
- FMVSS Crashworthiness Validation
- Brake System Performance
- Ride, Handling and Durability
- Cold and Hot Weather Development
- CARB Certified as a ZEV Production




Drive Motor/Transaxle
High-speed, 3-phase AC motor delivering power to single-speed direct-coupled transaxle
Battery Controller
Monitors functions of the battery (hidden)
Power Steering
Electrohydraulic
Motor Inverter
Converts high-voltage DC to AC
Communications Center
Operates instrumentation and climate control
Charger
240v/120v
Rear Suspension
Composite leaf springs and watts linkage
Charger Inlet
Conveniently located at the front of the vehicle
DC/DC Convertor
Electronic "alternator"
Lead-Acid Battery Pack
39x8 volt modules

Target:
Electric Transportation

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com