Plug-In Hybrid Medium-Duty Truck Demonstration and Evaluation Program

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Program Objectives

- Nationwide demonstration and evaluation of approximately 250 medium-duty PHEV's
- Develop a production-ready, commercializable PHEV system for class 4 to 7 vehicles
- Develop production-ready "smart charging" capability for the vehicle
- Build customer familiarity
- Quantify performance attributes and environmental impact
- Use project results for system development to optimize performance and reduce costs

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Project Status

- March 22, 2011, Eaton advised that the best case delivery of the first F550 hybrid system would occur in March of 2012
  - Eaton has advised that there is no commercial potential for their PHEV system in an F550
- May 5, 2011, DOE suspended performance, requesting corrective action plan
- Program was restructured to include Class 4 – 7 vehicles
- DOE approved the restructured program on December 16, 2011

Vehicle Overview

- Azure Shuttle Bus Application (Class 4)
  - Ford E450 Chassis
  - Ford 5.4L Gasoline Engine
  - Azure Dynamics Plug-in Hybrid Drive System
- Odyne Utility Truck Application (Class 6/7)
  - Class 6/7 Chassis
  - Diesel Engine
  - Odyne Plug-in Hybrid Drive System
- Azure Utility Truck Application (Class 5)
  - Ford F550 Chassis
  - Ford 6.7L Diesel Engine
  - Azure Dynamics Plug-in Hybrid Drive System

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Vehicle Deployment Schedule

- Azure E450s

First Vehicle Oct 2012 → Last Vehicle Dec 2012

- Odyne Class 6 – 7s

First Vehicle Dec 2012 → Last Vehicle Jul 2013

- Azure F550s

First Vehicle Q4 2013 → Last Vehicle Q2 2014

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E450 Shuttle Bus

- Vehicle Design:
  - Azure Hybrid System
  - Ford 5.4L Gasoline Engine
  - High Energy Lithium-Ion Battery
  - Blended Regenerative Braking
  - Engine Off at Zero Speed
  - On-board Charger (3.3 kW)
  - Charging-Level 1 (120 Vac) and Level 2 (240 Vac)
  - Electrified Accessories (Steering, Brakes, and HVAC)

- Performance Specifications:
  - At least 20 miles of charge depleting range
  - Charge time less than 4 hours with Level 2

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Azure PHEV E-450 Shuttle Bus

balance™ plus architecture

1. **INTEGRATED STARTER/ GENERATOR (ISG)**
Used to start the engine and to generate power.

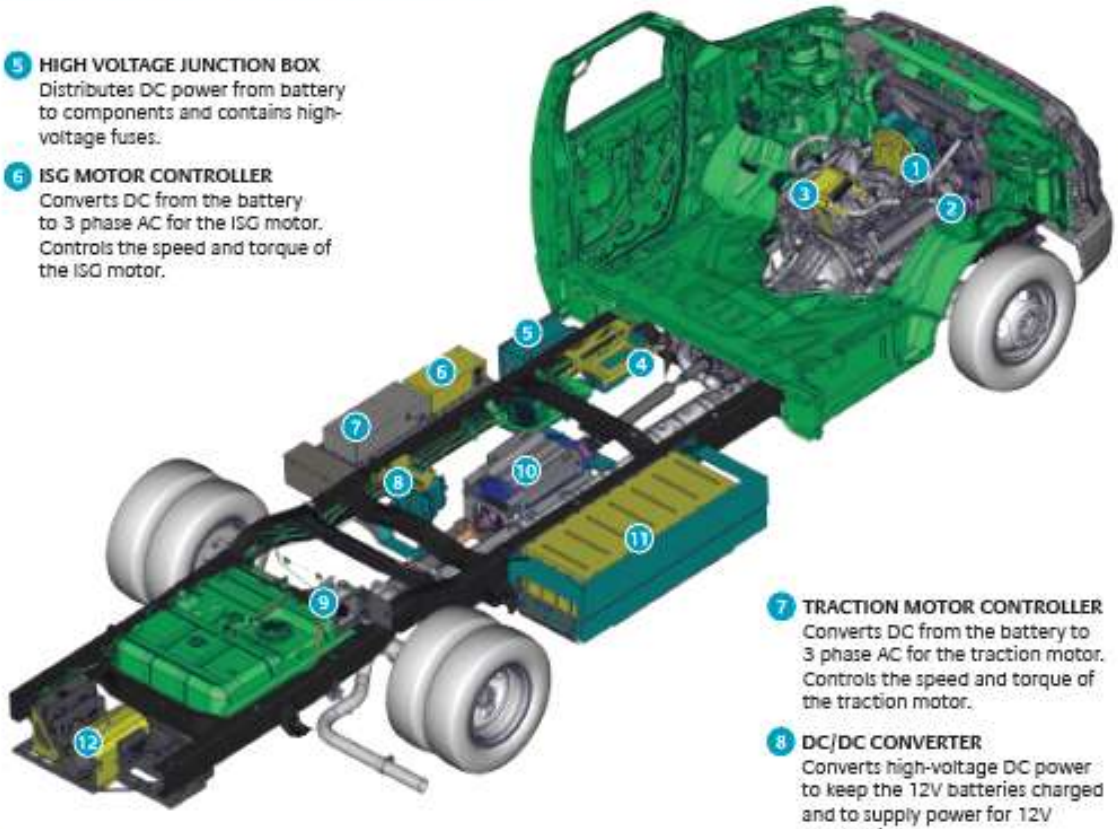
2. **CLUTCHED FEAD**
Clutch at crank shaft opens when engine off & ISG then spins the disconnected Front Engine Accessory Drive (FEAD) system (power steering/brake pump, water pump, alternator & A/C compressor).

3. **VEHICLE CONTROL UNIT (VCU)**
Controls all hybrid components and coordinates their operation with the Ford systems (e.g. start/stop).

4. **ON BOARD CHARGER**
Converts 120V (level 1) or 208/240V (level 2) AC input from the charge port to DC power to charge battery.

5. **HIGH VOLTAGE JUNCTION BOX**
Distributes DC power from battery to components and contains high-voltage fuses.

6. **ISG MOTOR CONTROLLER**
Converts DC from the battery to 3 phase AC for the ISG motor. Controls the speed and torque of the ISG motor.



7. **TRACTION MOTOR CONTROLLER**
Converts DC from the battery to 3 phase AC for the traction motor. Controls the speed and torque of the traction motor.

8. **DC/DC CONVERTER**
Converts high-voltage DC power to keep the 12V batteries charged and to supply power for 12V accessories.

9. **CHARGE PORT**
Vehicle is connected to the electrical grid through this port when charging. Capable of 120V (level 1) or 208/240 (level 2) AC charging.

10. **TRACTION MOTOR**
Converts electrical energy to wheel torque in order to propel the vehicle. Speed & torque outputs are based on accelerator input as well as vehicle operating conditions.

11. **ENERGY STORAGE SYSTEM (ESS): HIGH VOLTAGE BATTERY PACK**
Liquid cooled high voltage Li-Ion battery pack. Stores energy and includes internal sensors and controller.

12. **ELECTRIC AIR CONDITIONING UNIT**
Converts DC from the battery to 3 phase for the air conditioning compressor motor.

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Class 6/7 Aerial Truck- Odyne

- Vehicle Design
  - Odyne Hybrid System with Allison automatic transmission
  - Diesel Engine
  - High Energy Lithium-Ion Battery- JCS 28.4 kWh
  - Blended Regenerative Braking
  - Launch Assist
  - On-board Charger (>3.3 kW)
  - Charging-Level 1 (120 Vac) and Level 2 (240 Vac)
  - Export Power (>5 kW, 120/240 Vac, 60 Hz)
  - Redundant system that can be returned to conventional driving

- Performance Specifications:
  - ePTO operation (>5 Hours with Engine-Off)
  - Up to 10 miles equivalent all electric range
  - Charge time less than 6 hours with Level 2

Work Truck Applications

Hybrid Bucket Truck

Hybrid Digger Derrick

Hybrid Compressor Truck

Hybrid Crane Truck

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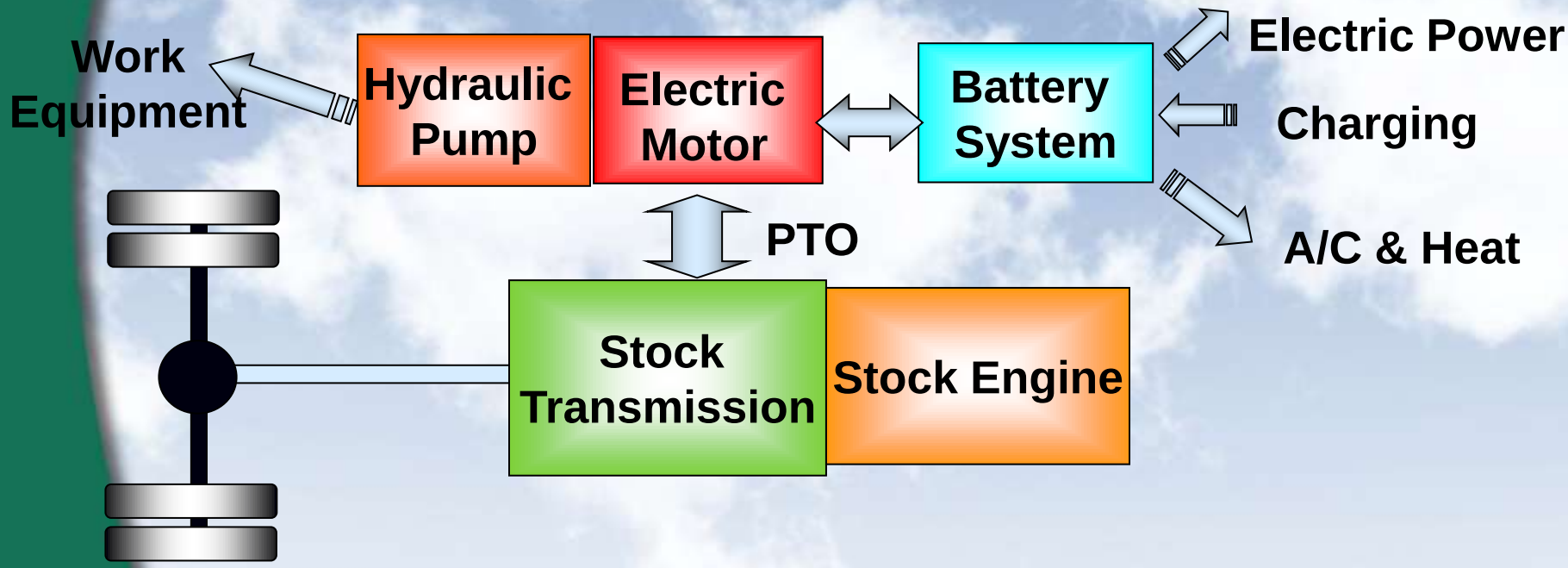
Hybrid Architecture



Parallel Hybrid Solution

- Provides redundant system to operator to minimize downtime.
- Low validation and capital equipment costs,
- Ability to retrofit to existing vehicles

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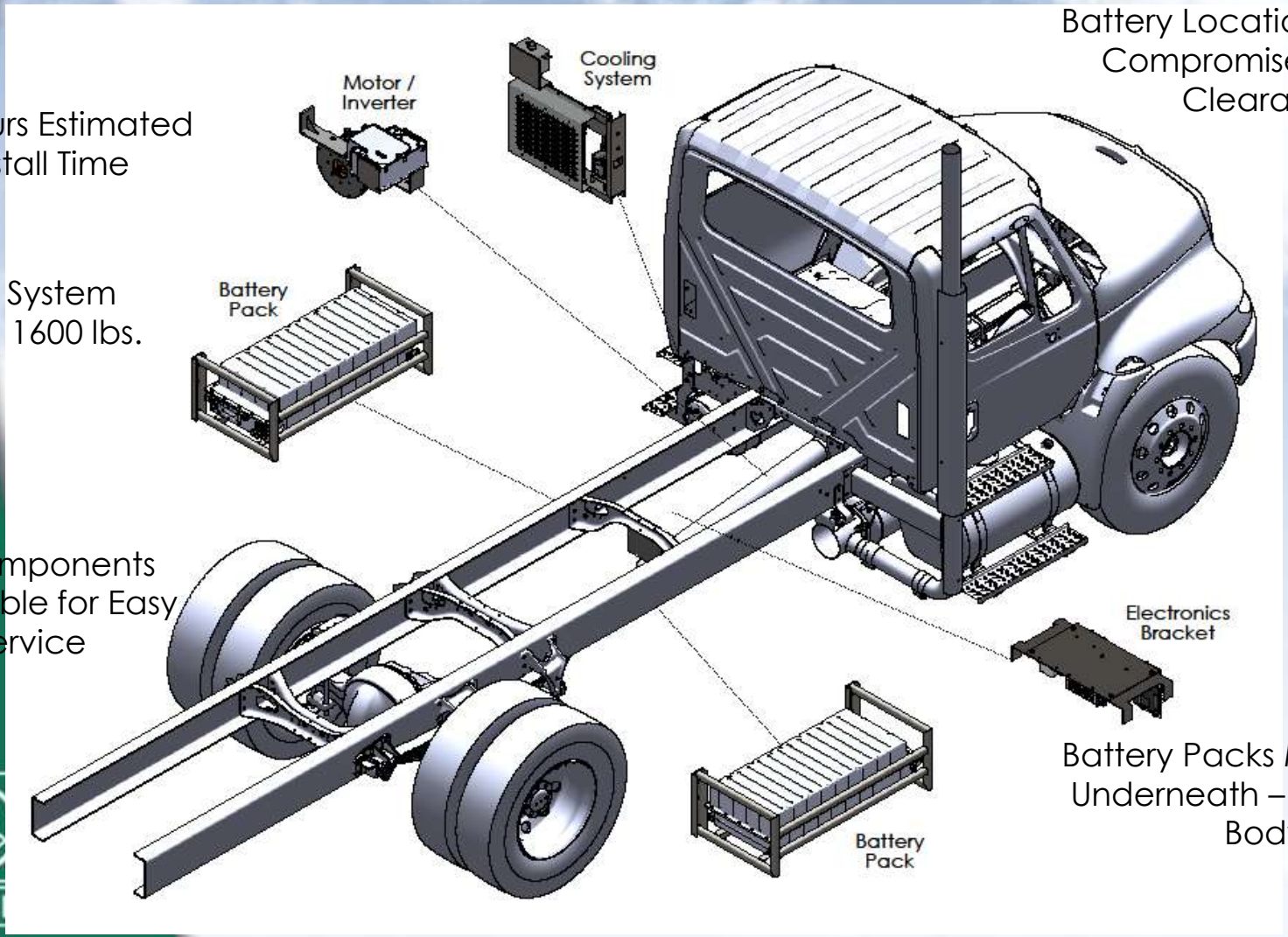
Core Components

40 Hours Estimated Install Time

Hybrid System Weight: 1600 lbs.

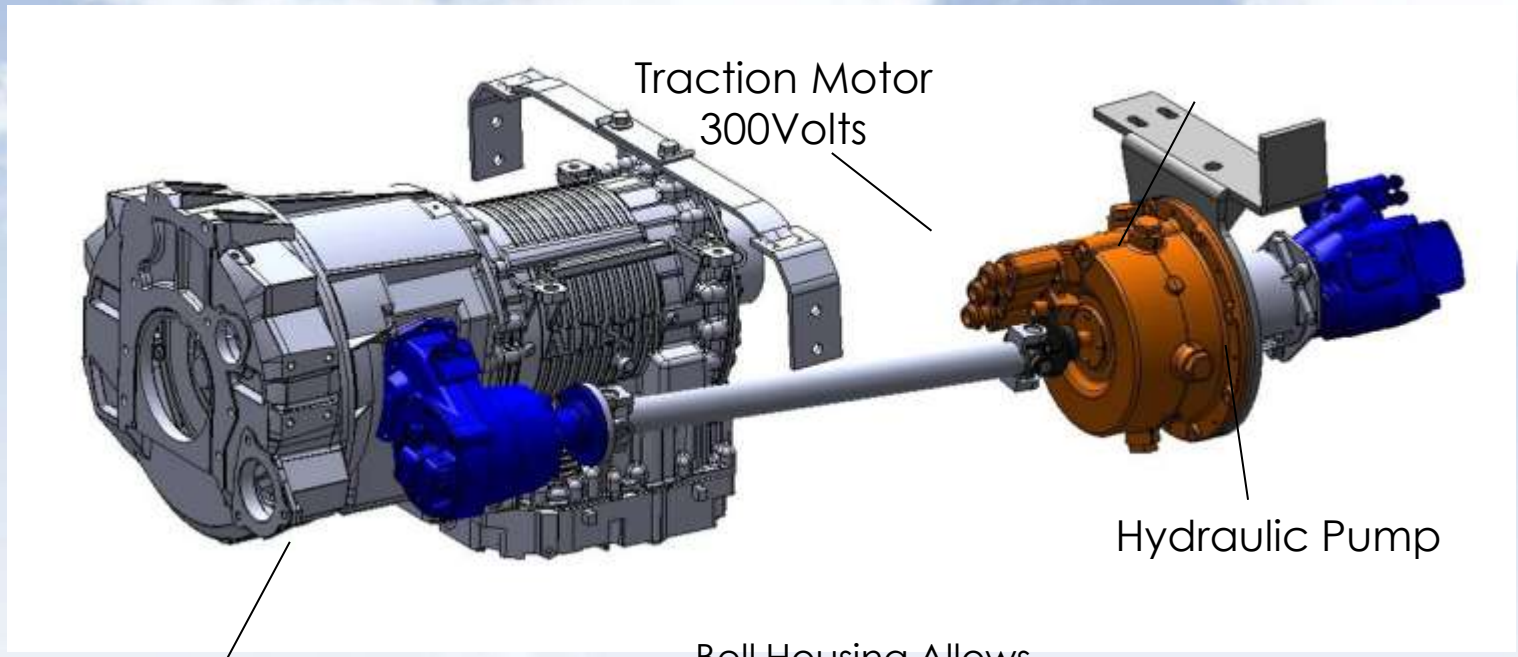
All Components Accessible for Easy Service



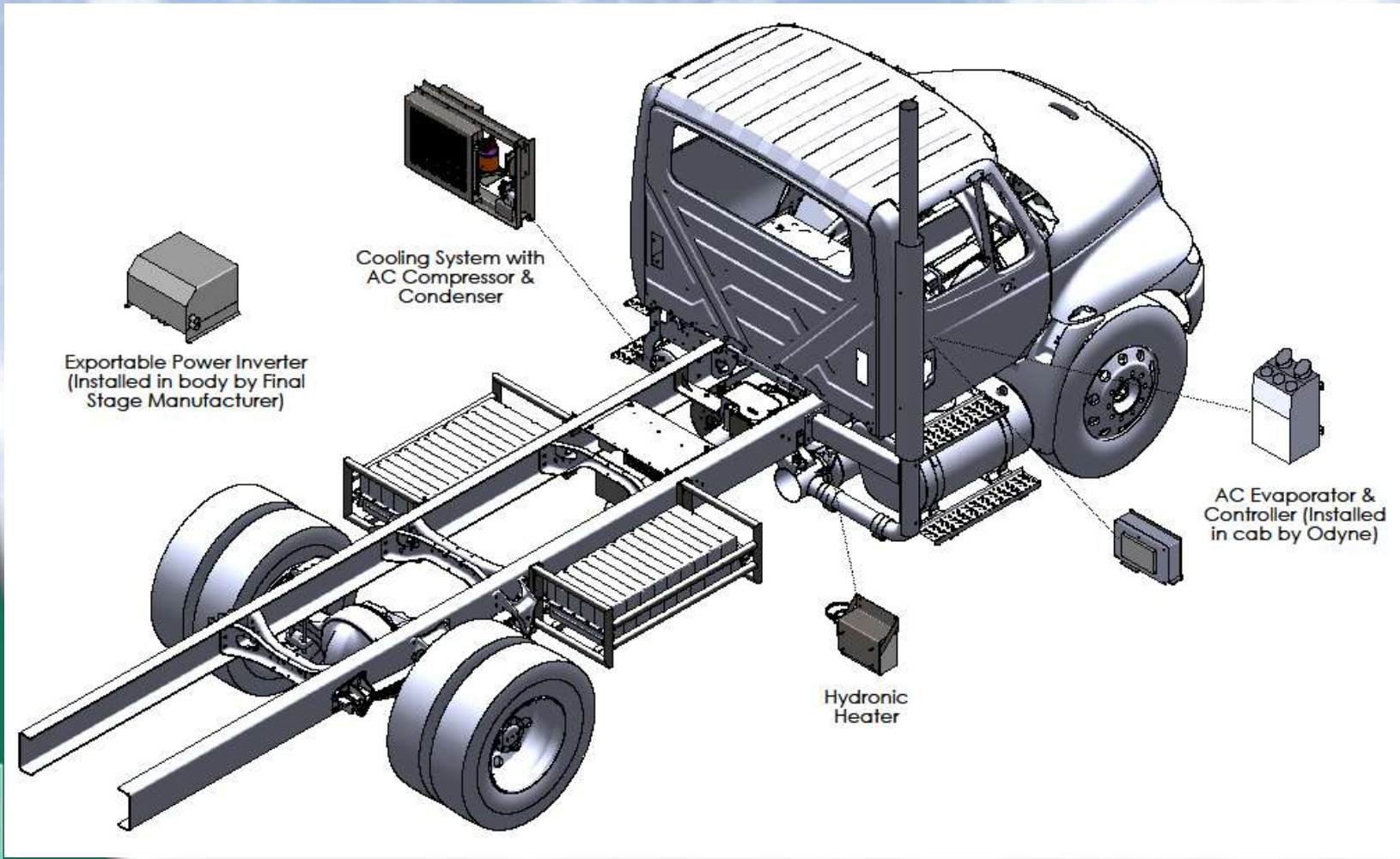
Battery Location Does Not Compromise Ground Clearance

Battery Packs Mount from Underneath – Hidden by Body

Minimally Intrusive Design



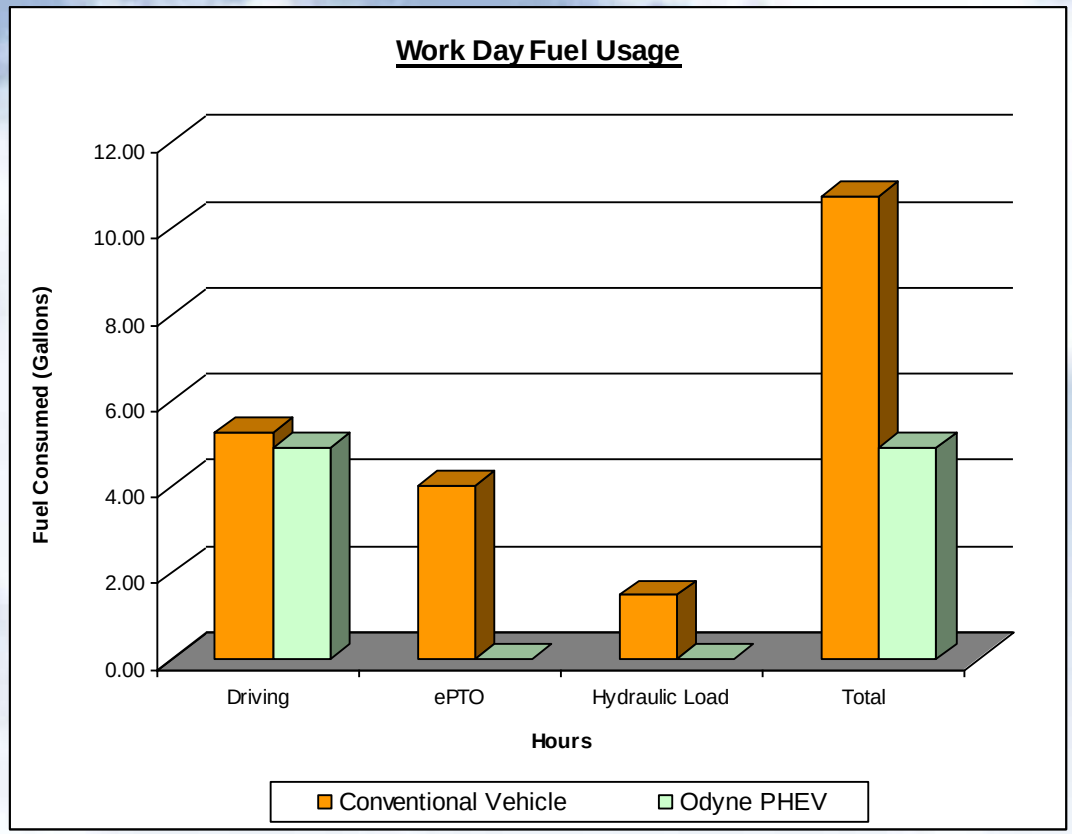
Ancillary Components



Fuel Savings - Utility Bucket Truck

Fuel Consumption (Gallons)
Conventional Vehicle vs. Odyne PHEV

	Baseline Vehicle	Odyne PHEV
Driving (32 miles/day)	5.26	4.89
ePTO at job site (4.2 hours/day)	4.02	0.00
Hydraulic Load (1.0 hours/day)	1.47	0.00
Work Day Total	10.74	4.89
Total Savings	54.5%	



Estimated results based upon SWRI testing of 1st generation system and actual duty cycle measurements.

Overview F550 Aerial Truck – Azure

- Vehicle Design
  - Azure Hybrid System with Ford automatic transmission
  - Ford 6.7L Diesel Engine
  - High Energy Lithium-Ion Battery- JCS 14.4 kWh
  - Blended Regenerative Braking
  - Engine Off at Zero Speed
  - On-board Charger (>3.3 kW)
  - Charging-Level 1 (120 Vac) and Level 2 (240 Vac)
  - Electrified Accessories (Steering, Brakes, and HVAC)
  - Export Power (>5 kW, 120 Vac, 60 Hz)

- Performance Specifications:
  - ePTO operation (>2 to 3 Hours with Engine-Off)
  - Up to 10 miles pure electric range (25 mph max)
  - Charge time less than 4 hours with Level 2

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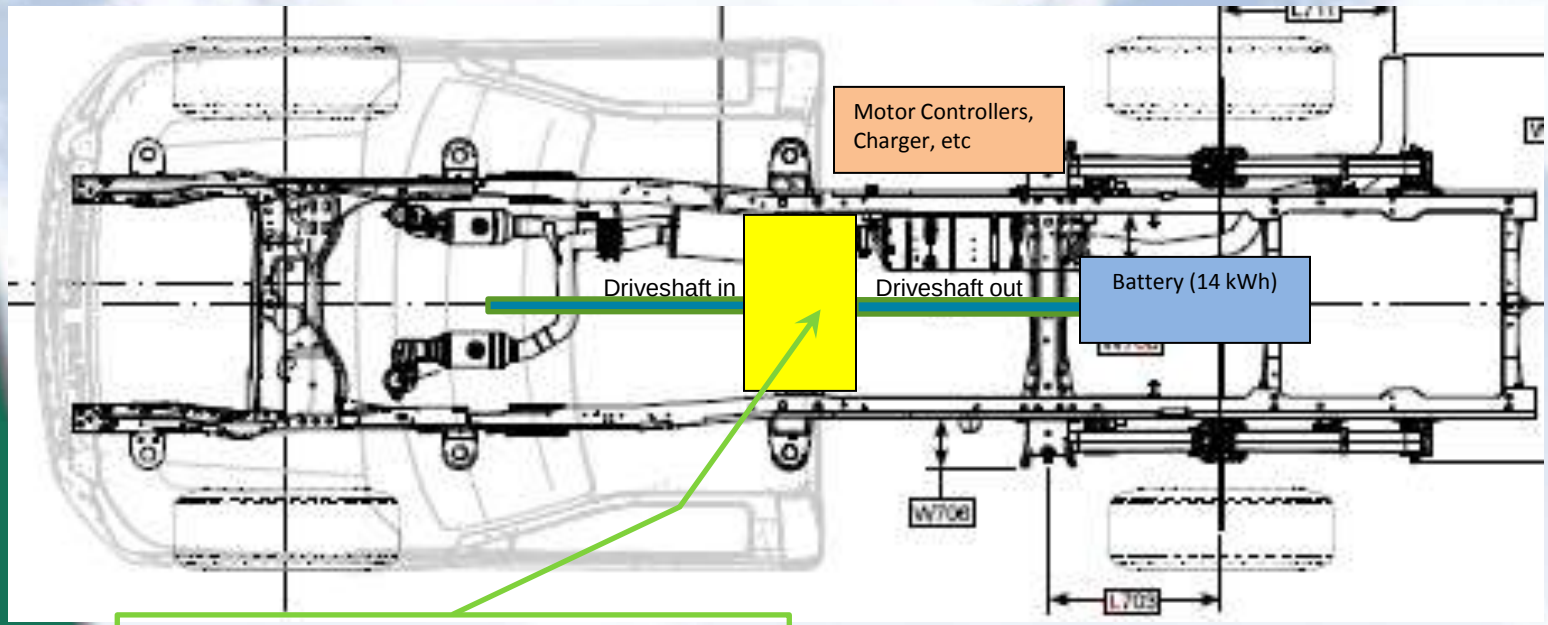
Azure PHEV F-550 Super Duty

Preliminary Packaging



Universal Gear Box (UGB), electric Motor (drive motor and ePTO function)

Azure PHEV F-550 Super Duty

Technical Targets

- Engine off at zero speed, electric-only operation at low speed
- Engine off time at worksite: 2 to 3 hours
- 10 mile equivalent electric range (may reduce available kWh at worksite)
- Fuel Economy Improvement: 50% target (depending on duty cycle)
- Exportable Power: Target 5 kW minimum

Supporting Program Activities

- A charging infrastructure is purchased and installed for each vehicle
- A Smart Charging Module is provided with each vehicle and allows smart charging with the grid
- A data acquisition system is provided with each vehicle and data is recorded and analyzed for two years of the program
- Emissions testing based on measured use-profiles from the field study

Questions