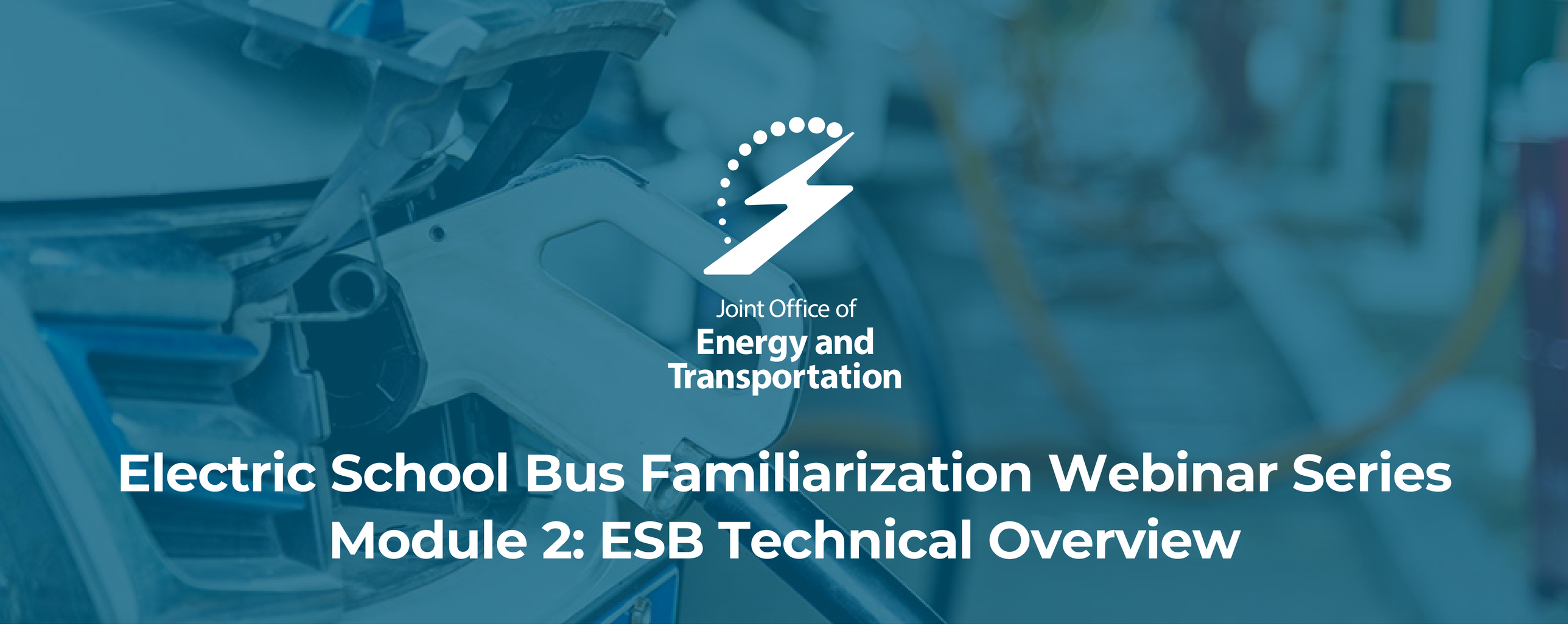


Joint Office of
Energy and
Transportation

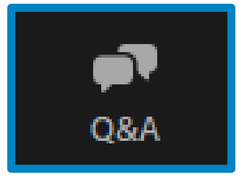
Electric School Bus Familiarization Webinar Series
Module 2: ESB Technical Overview

8/7/2024

driveelectric.gov

Zoom Tips and Housekeeping

- Controls are located at the bottom of your screen. If they aren’t appearing, move your cursor to the bottom edge.
- Submit questions using the “Q&A” window
- Please take a moment to fill out the poll



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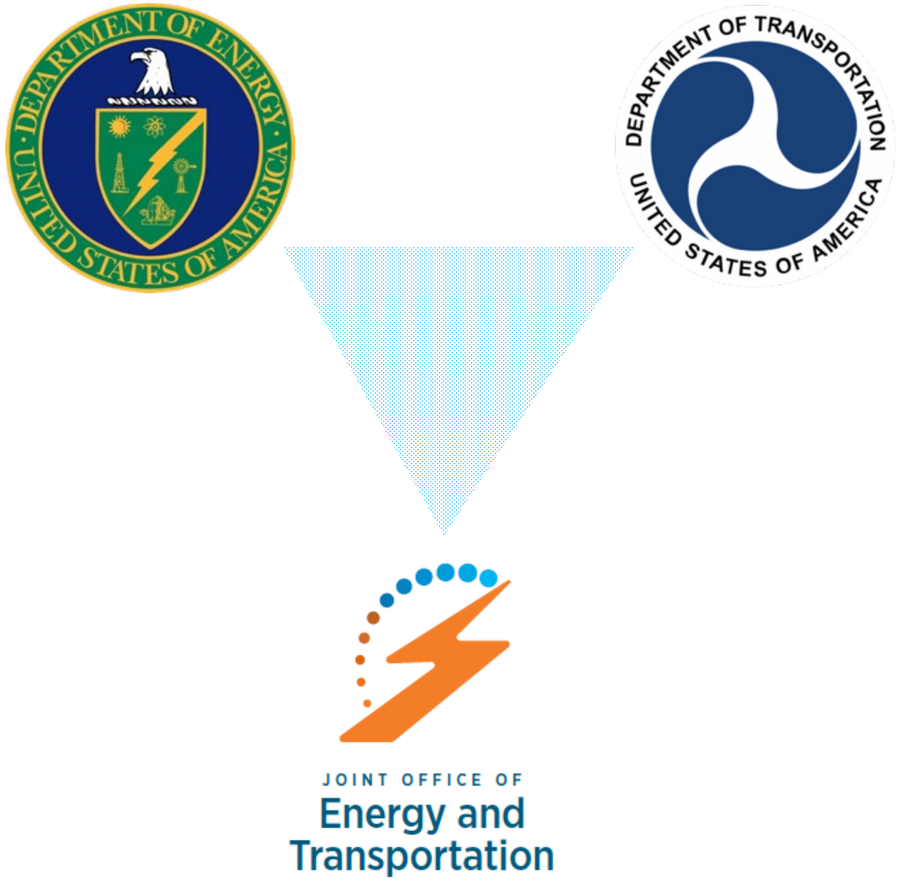
Mission and Vision



Mission

To accelerate an electrified transportation system that is affordable, convenient, equitable, reliable, and safe.

Vision

A future where everyone can ride and drive electric.

BIL Programs Supported by the Joint Office

The Joint Office will provide unifying guidance, technical assistance, and analysis to support the following programs:

National Electric Vehicle Infrastructure (NEVI) Formula Program (U.S. DOT)
$5 billion for states to build a national electric vehicle (EV) charging network along corridors

Charging & Fueling Infrastructure (CFI) Discretionary Grant Program (U.S. DOT)
$2.5 billion in community and corridor grants for EV charging, as well as hydrogen, natural gas, and propane fueling infrastructure

Low-No Emissions Grants Program for Transit (U.S. DOT)
$5.6 billion in support of low- and no-emission transit bus deployments

Clean School Bus Program (U.S. EPA)
$5 billion in support of electric school bus deployments

Clean School Bus Technical Assistance

The Joint Office of Energy and Transportation (Joint Office) is providing **FREE** technical assistance for the EPA's Clean School Bus program

Technical Assistance Offerings:

- **Fleets receiving funds or planning to apply are eligible**
- Proactive and reactive, hands-on assistance tailored to each fleet
- New and updated tools and resources.

Clean School Bus Technical Assistance

CleanSchoolBusTA@nrel.gov

driveelectric.gov/contact

Examples of How We Can Help

- Electric utility coordination
- Identifying available funding and incentives
- Analyzing charging infrastructure needs
- Conducting route analysis and planning
- Conducting training and workforce development
- Bus evaluation
- Analyzing energy needs and grid impact
- Identifying solar and battery storage opportunities

New Electric School Bus Familiarization Webinar Series

Brought to you by:

- Joint Office of Energy and Transportation
- National Renewable Energy Laboratory (NREL)
- International Transportation Learning Center (ITLC)
- School bus manufacturers

- Four-part module-based series for operators, technicians, and other school bus fleet members.
- Learn fundamentals of electric school bus (ESB) technology.
- Live Q&A during each session.
- Recordings with testing materials for internal training programs.

Agenda

Introduction from Ryan Frasier, National Renewable Energy Laboratory (NREL)

Presentations moderated by the International Transportation Learning Center (ITLC) with Q&A after each presentation

- *Fundamentals of ESB Technology*
  - Angel Yin, BYD-Ride
- *ESB Preventive Maintenance & Diagnostics*
  - Mark Richardson, Thomas Bus/Daimler Truck
- *ESB ESS Overview and Battery Management*
  - Sean Ashcraft, Greenpower Motor Company

Today’s Moderator

John Schiavone
International Transportation Learning Center (ITLC)

2024 Sessions

Session 1

ESB Overview for Operators

Session 2

ESB Technical Overview

Session 3

High Voltage Safety Considerations

Session 4

ESB Charging Methods and Considerations

Fundamentals Of Electric School Buses

Welcome

- ITLC Mission – advance training on joint labor-management basis
- Organized similar webinar series for transit buses
- Purpose – provide introductory information

Topics for Today

Presentation 1

Fundamentals of ESB Technology

Angel Yin, Policy Analyst

Presentation 2

ESB Preventive Maintenance & Diagnostics

Mark Richardson, Charging Infrastructure eConsultant

Presentation 3

ESB ESS Overview and Battery Management

Sean Ashcraft, Electrical Engineer

Key Terms

AC (Alternating Current) Powers drive wheels	**CAN (Controller Area Network)** Vehicle data communication	**Charging Port** Accepts external charging plug
DC (Direct Current) Battery voltage	**DC-DC Converter** Converts DC HV to lower DC voltages as needed	**ESS (Energy Storage System)** 400-900V DC battery pack
HVIL (High Voltage Interlock Loop) HV safety disconnect	**HVJB (High Voltage Junction Box)** Protected HV connections	**Inverter** Converts DC HV to AC
Regenerative Braking Uses braking energy to charge batteries	**Traction Motor** Uses AC to power vehicle (replaces ICE)	**V2G (Vehicle-to-Grid)** Uses bus to supply grid, other AC sources

Presentation 1

Fundamentals of ESB Technology

Angel Yin

INTERNATIONAL TRANSPORTATION LEARNING CENTER

Learning Outcomes

- Define an Electric School Bus (ESB)
- Identify key High Voltage (HV) ESB propulsion system components
- Discuss principles of operation for key HV components
- Identify key Low Voltage (LV) ESB Telematics & V2G components
- Compare similarities and differences with ICE School Buses

What is an Electric School Bus (ESB)?

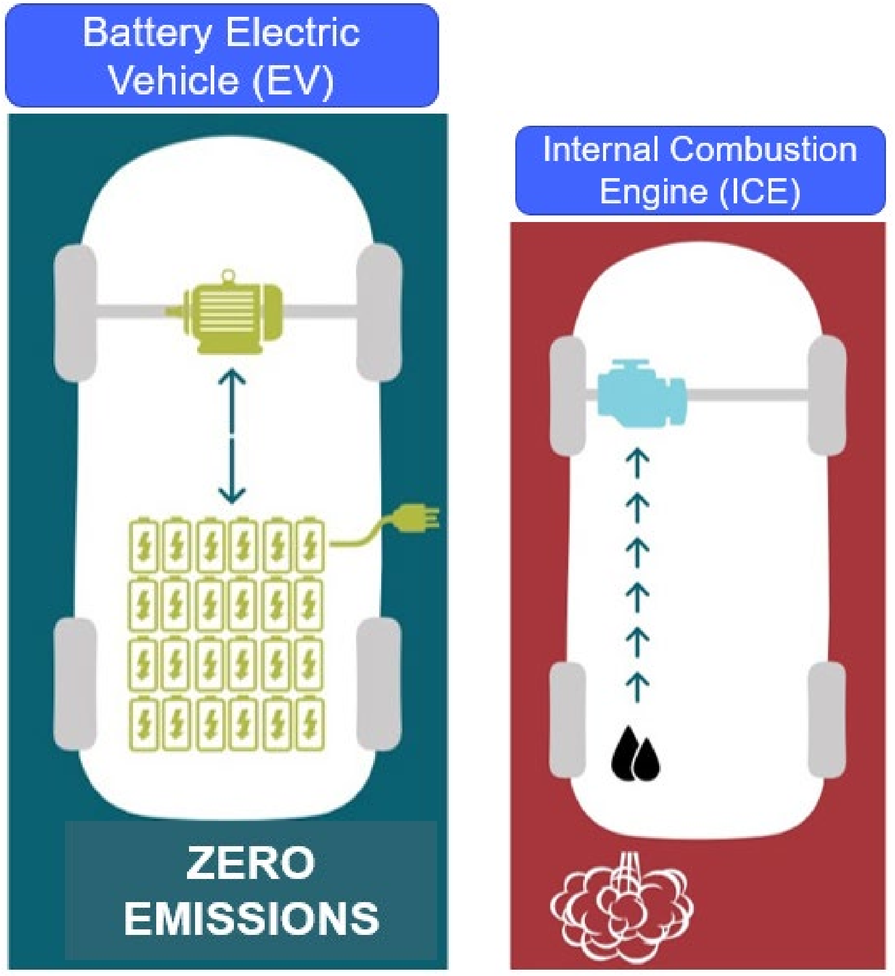
Defining a Battery Electric School Bus

A vehicle is a *Battery Electric Vehicle* if:

- Its propulsion system is **powered only by batteries**
- The vehicle **runs on electricity** only
- These batteries are charged by an **external power source**

Key features of an ESB:

- The absence of internal combustion-related components
- The presence of **high-voltage (HV) electric propulsion systems**
- The power battery provides the driving force for the entire vehicle and accessories



ESB Component Identification

High-Voltage (HV)

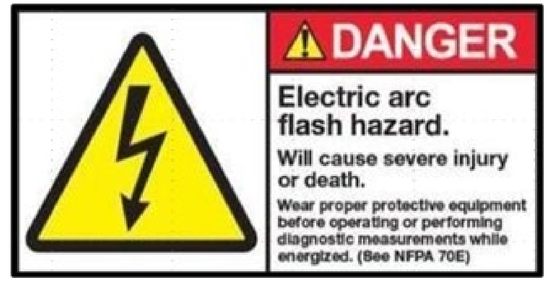
Safety First!

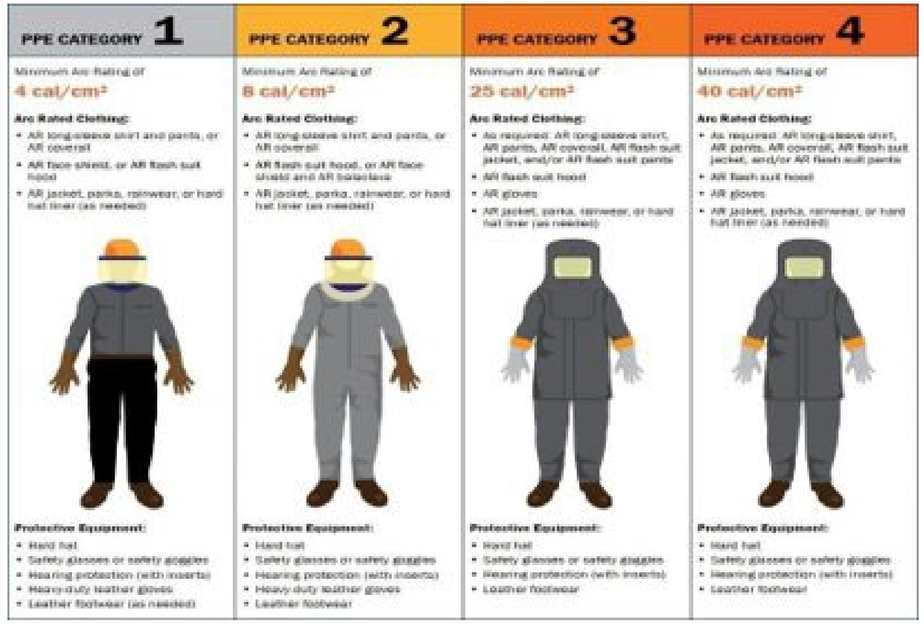
For automotive applications, any voltage **greater than 30 volts AC (or 60 volts DC)** is considered high or hazardous voltage

Most ESBs in the market **use HV systems (400V-900V) to operate major vehicle components including motors, controllers, AC**, etc.

Proper care and tools must be taken when operating and servicing this type of vehicle

Electric Propulsion Systems require an AR rated **Category 2 level PPE** with an 8 cal/cm² minimum protection





ESB Component Identification

Overview of Electric Propulsion – Key HV Systems & Power Flow

1 Charging interface

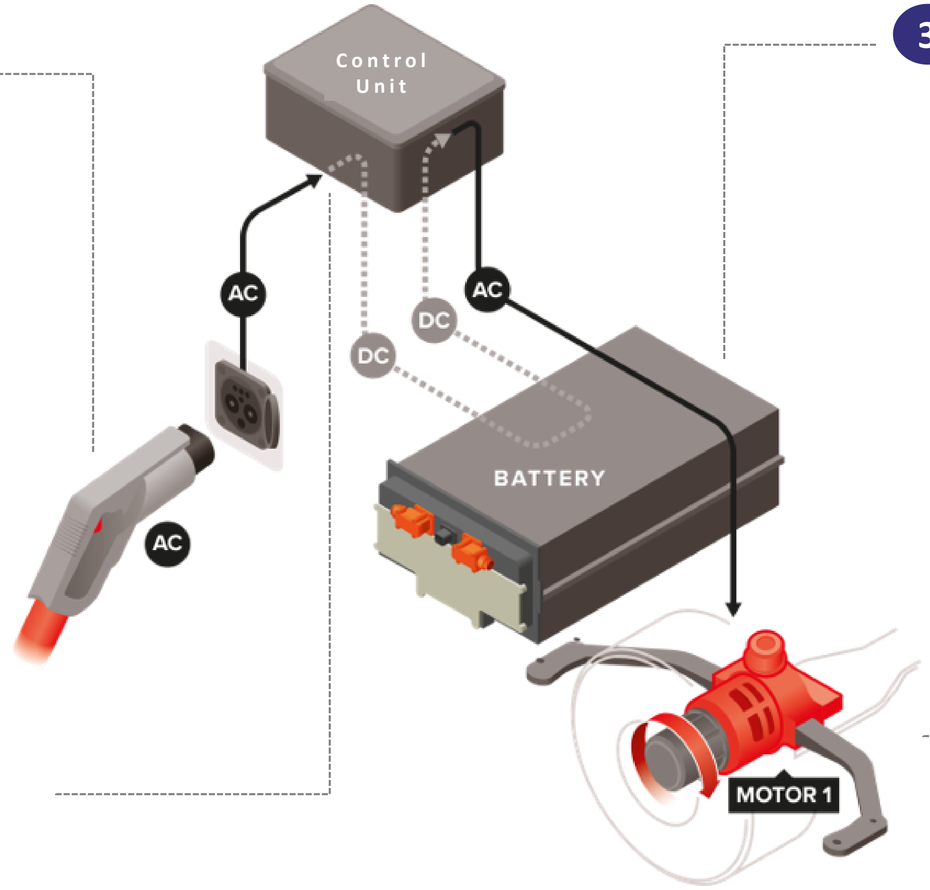
Connected via charging plugs to the charging ports on the side of each bus

Charging can include either AC or DC current

2 Electric Power Control Unit (include DC-AC Inverter & DC-DC Converter; may be standalone)

A **bi-directional inverter capable of charging and discharging**

Manages HV battery modules via HV cables, converts AC to DC to charge batteries and invert DC to AC to power drive motors and other accessories



3 Energy Storage System (ESS)

The **central power unit of the vehicle**

Consists of DC batteries converted by the motor controller to AC

4 Electric Drive Motor

Provides the power to move the vehicle

AC from the motor controller is converted to mechanical energy and directed to traction motor(s) for smooth and quiet operation

ESB Component Identification & Principal of Operation

High-Voltage (HV) Electrical System Components Bus Layout

Charging Interface

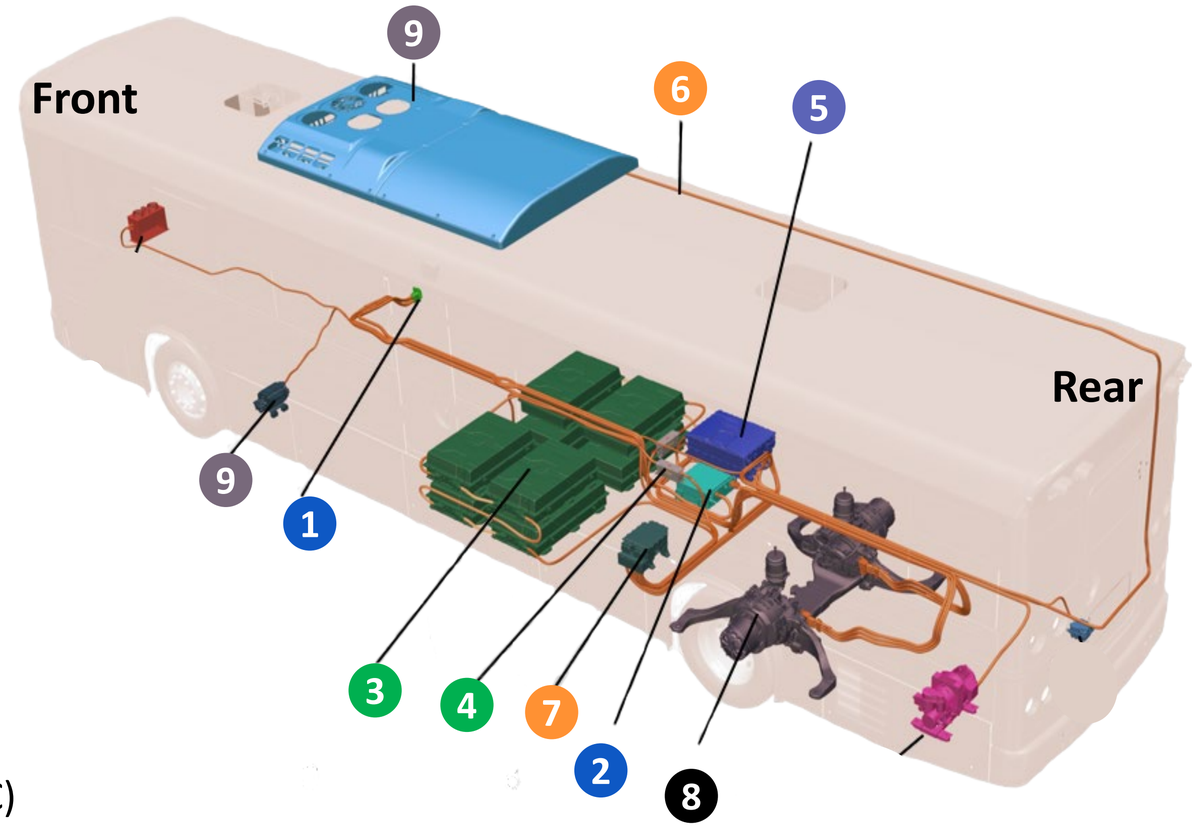
1. Charging Port
2. Onboard Charger

ESS System

3. Power Battery Modules
4. HV Battery Pack Contact
5. Motor & Accessories Controller (may include DC-AC Inverter & DC-DC Converter)

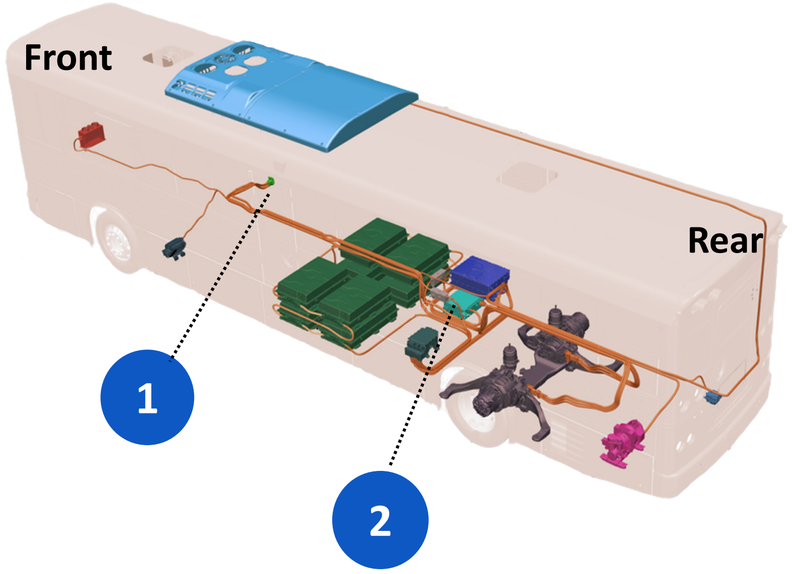
HV Distribution System

6. High-Voltage Cables
7. High-Voltage Service Plugs
8. Drive Motor & Axle Assembly
9. AC Powered Accessories (includes HVAC)



ESB Component Identification & Principal of Operation

HV Electrical System Component – Charging Interface



1 Charging Port

Charging the HV batteries is a safe operation. PPE is not required to charge the bus. **There are 2 common charging ports: AC & DC.**

2 Onboard Charger (for AC Charger)

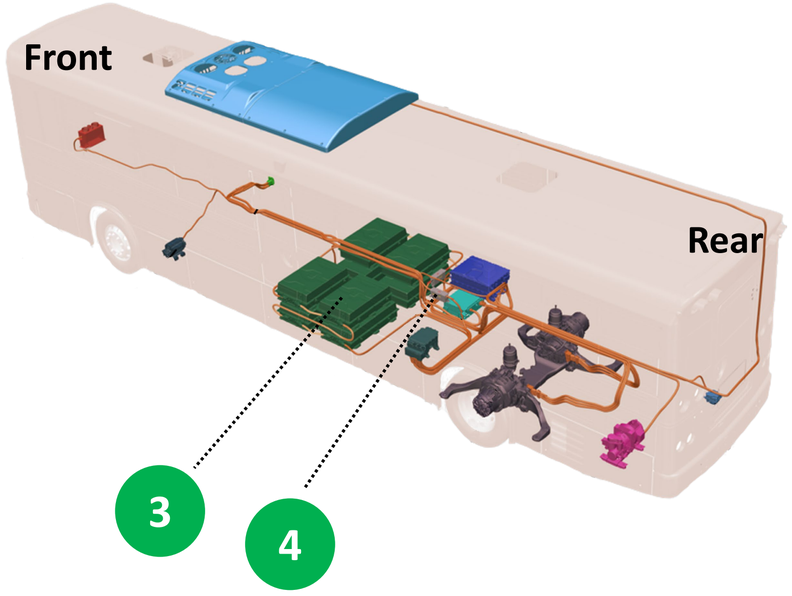
The OBC converts AC current coming from a charging station to DC current to charge the HV batteries. It is liquid-cooled.

SAE J1772
AC CHARGING GUN
(≤19.2kW)

CCS 1.0 Combination
CHARGING GUN
(up to 350kW)

ESB Component Identification & Principal of Operation

HV Electrical System Component – ESS System



3 Power Battery Modules

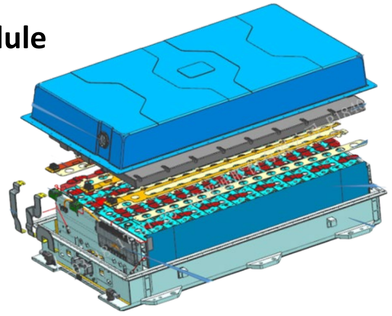
The battery system is the power source of electric vehicle. The bus battery pack contains cells, enclosed in modules, connected in series to form a pack

Common composition of battery is **Lithium-ion or Lithium-ion Phosphate (LFP)**

Generally, larger battery size = longer range

Cell

Module



4 HV Battery Pack Contactors

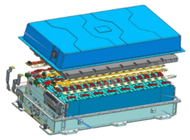
High-voltage contactors control the current flow from the battery packs

Usually several contractors installed in the bus, acting as a switch and battery safety components

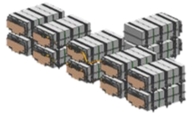
ESB Component Identification & Principal of Operation

HV Electrical System Component – ESS System

Cell

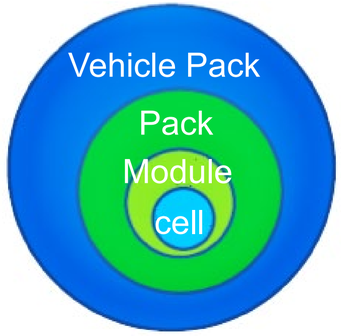


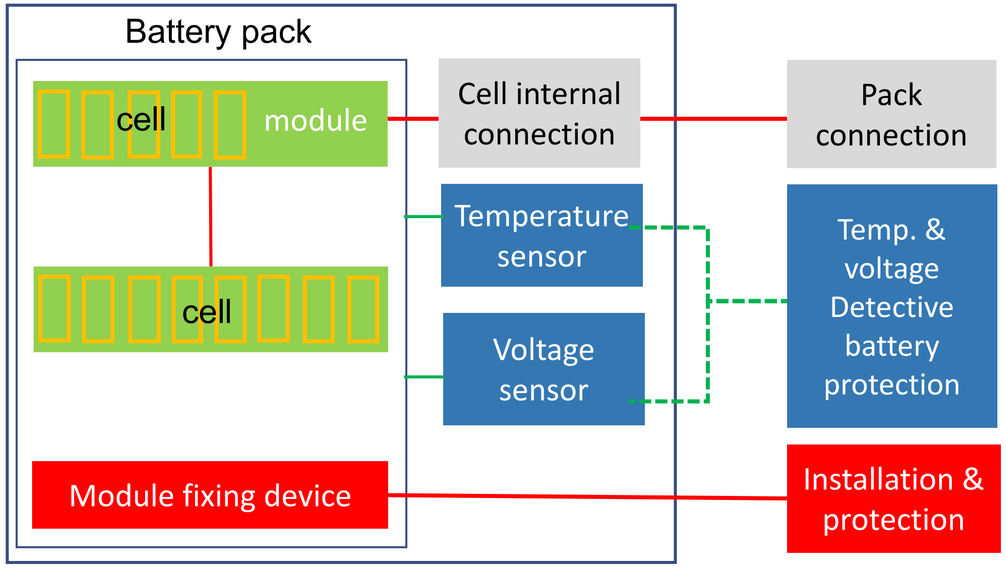
Module

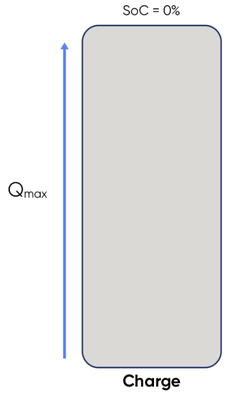


Physical connection

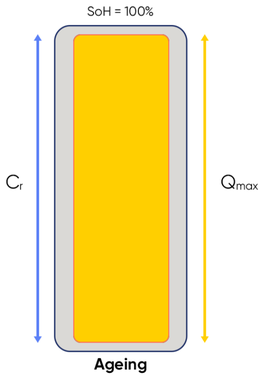
Signal transportation







State of Charge (SOC)
Keep at 20% – 80%



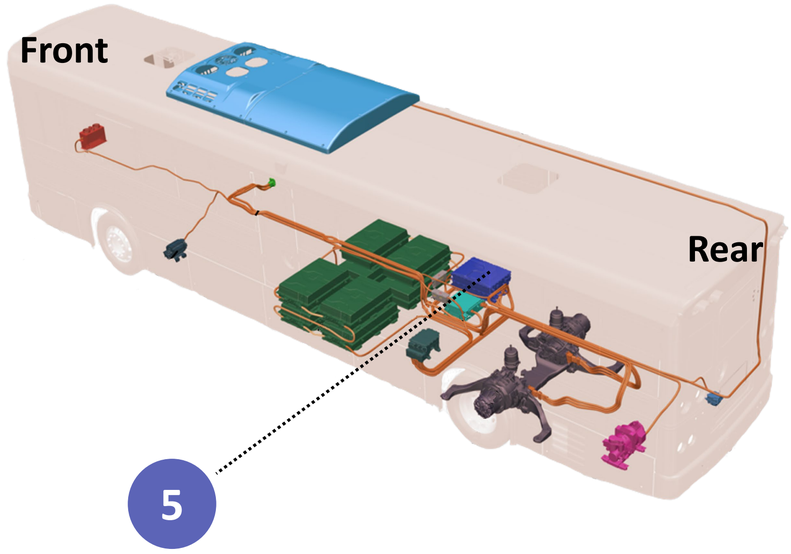
State of Health (SOH)
Store between 59 - 95° F

If a driver notices low SOC on route they should:

1. Immediately turn off all non-critical electrical loads or unload if convenient
2. Rigorously use regenerative braking, minimal usage of the accelerator, drive at minimum safe speed
3. Stop in a safe area and tow the vehicle to a charger

ESB Component Identification & Principal of Operation

HV Electrical System Component – Motor & Auxiliary Controller



5 Motor & Accessories Controller (may include DC-AC Inverter & DC-DC Converter, or standalone)

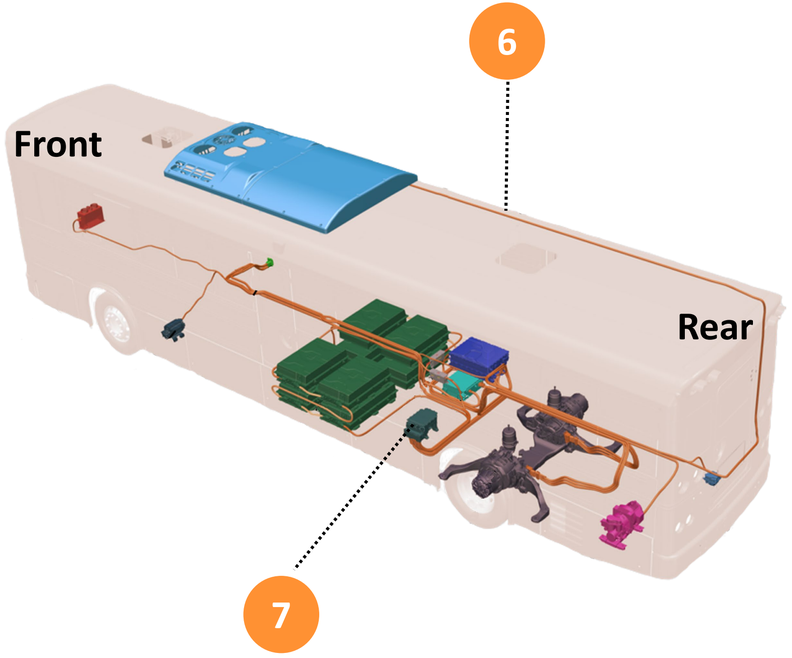
The inverter converts DC from the batteries to AC current to power the traction motor and accessories

The converter converts DC HV from ESS to power low voltage (12v and 24v) devices (lights, horns, etc.)

For some OEMs, the inverter, converter, and management components are integrated into one box, a controller, to power both HV and LV systems

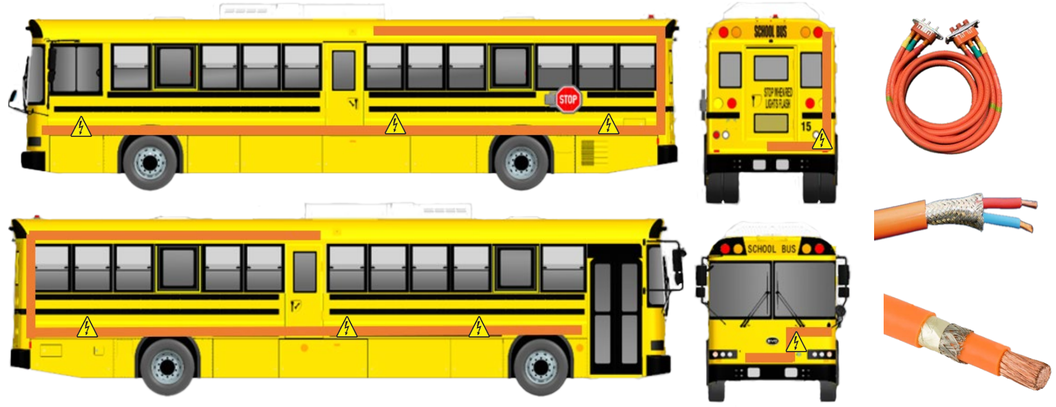
ESB Component Identification & Principal of Operation

HV Electrical System Component – HV Distribution System



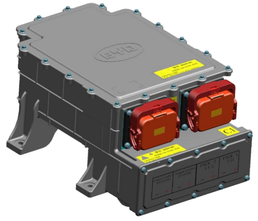
6 High-Voltage Cable

All high-voltage cables are identified with an ORANGE cable covering. Cables are used for AC or DC high-voltage power



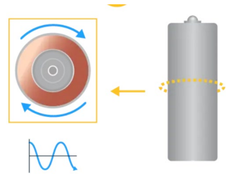
7 High-Voltage Service Plug

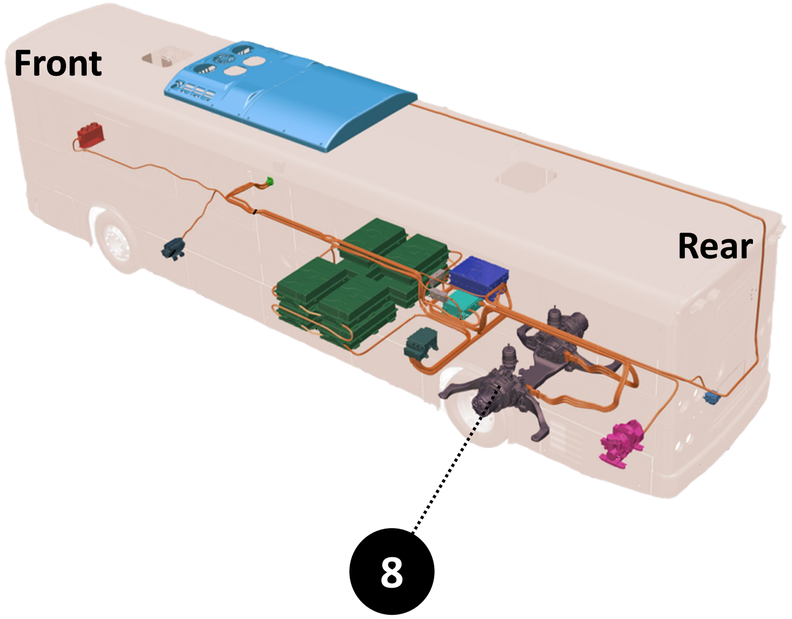
A circuit breaker within the HV power supply circuit **used to used to physically disconnect and de-energize the HV system**



ESB Component Identification & Principal of Operation

HV Electrical System Component – Drive Motor & Axle Assembly



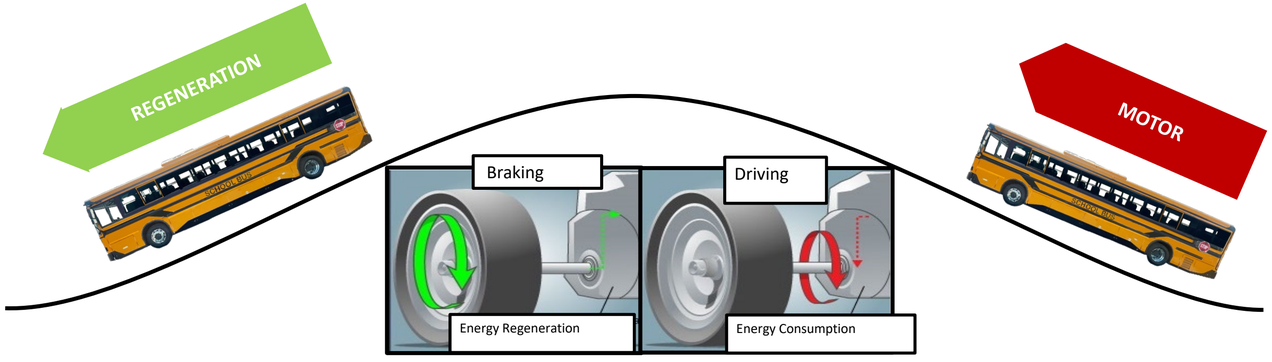


8 Drive Motor & Axle Assembly

The drive motors are supplied AC power from the inverter/motor controller

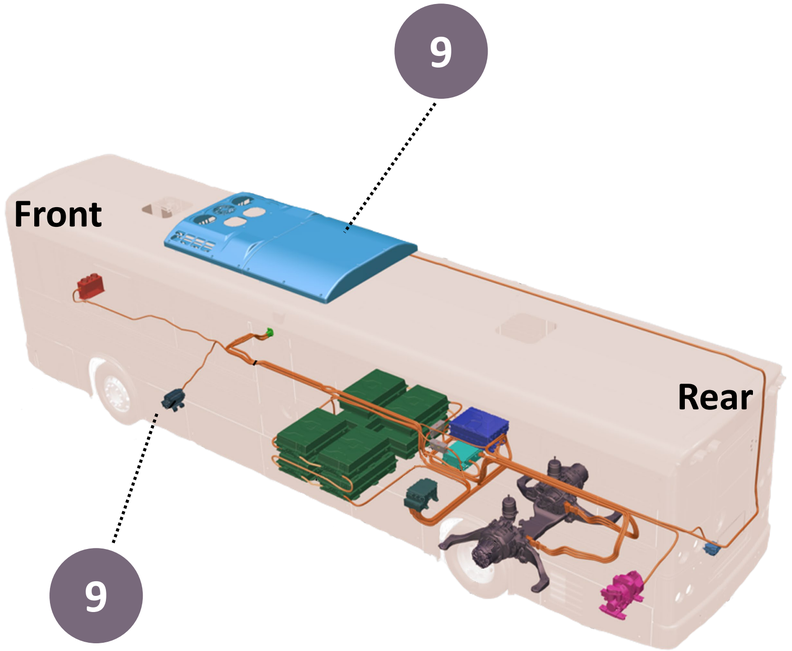
Also responsible for creating the **regeneration function (Regenerate Braking)** during normal driving, which reduces speed during deceleration while charging the HV batteries at the same time

Regenerative braking works only when the batteries are below 95% charged



ESB Component Identification & Principal of Operation

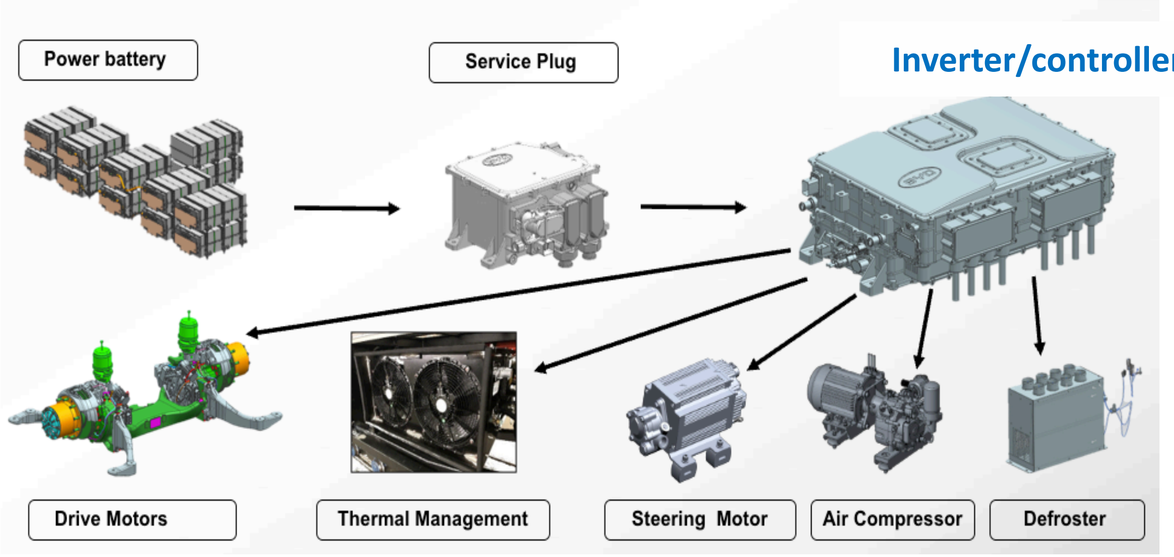
HV Electrical System Components – AC - Driven Accessories



9 AC-Driven Accessories

The inverter, which converts DC current from the battery to AC current also powers accessories

These accessories include the steering motor, air compressor, HVAC, front windshield defroster, and heater



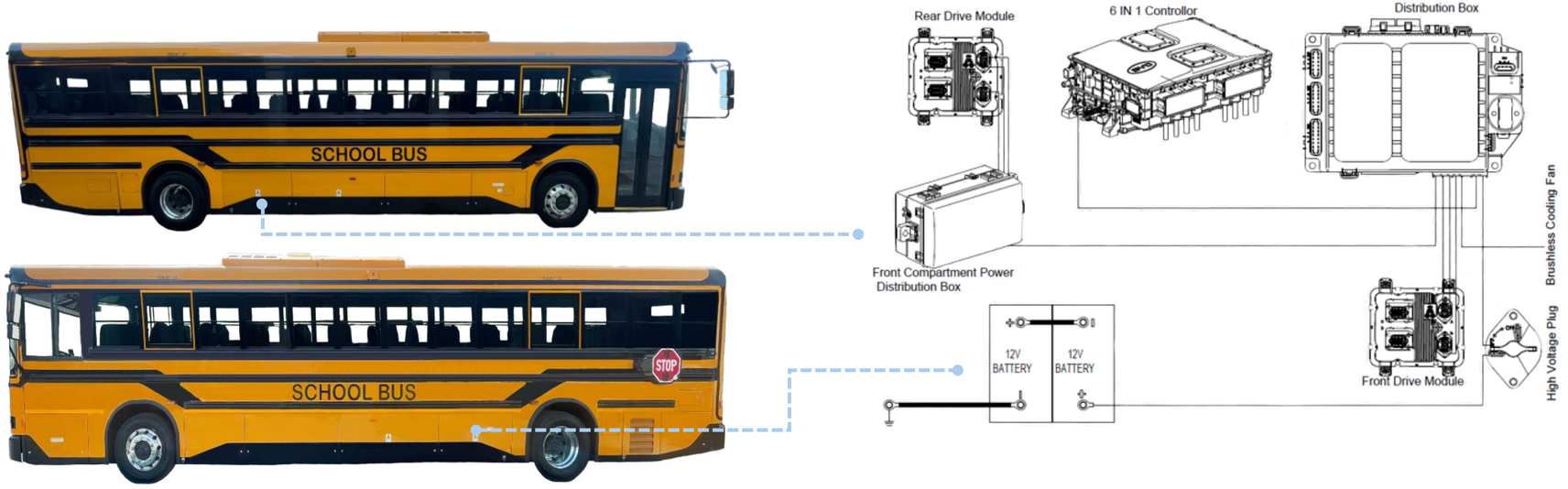
ESB Component Identification & Principal of Operation

Low Voltage (LV) System – DC-DC Converter

A low-voltage electrical circuit operates on 12 or 24 volts. LV circuits require a power source (battery) to provide electrical energy to activate a circuit. The LV system operates vehicle management components including dashboards, lights, accessories, telematics, etc.

ESBs normally have a standalone DC-DC step-down converter or a converter in an integrated controller to convert HV to LV and power the LV system. Also have two separate 12V or one 24V rechargeable battery to power the LV system when HV is not engaged

Buses normally have a front and rear power distribution box, with a low voltage power disconnect switch between the batteries and power distribution boxes for lockout tagout (LOTO)



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ESB Component Identification & Principal of Operation

LV System Components – Telematics

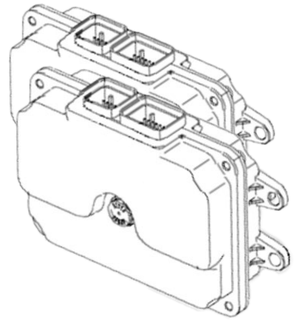
Electronic Control Unit (ECU)

An embedded system in the vehicle's components to control one or more electrical systems in the vehicles

ECUs are the source of vehicle telematics, and collectively referred to as the vehicle's computer. A vehicle can include multiple ECUs

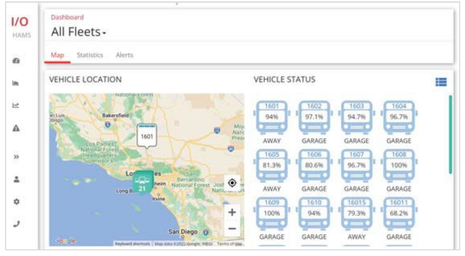
Examples of ECUs include: Battery Management Controller (BMC) which manages and receives all battery information, or Vehicle Control Module (VCM) which manages throttle accelerator signals and gear selection position signals

ECUs are interconnected by the Controller Area Network (CAN) and Multiplex (MPX) for communication and monitorization; Information is collected by the telematics/management devices



Electrical Load Management System (ELMS)

Software based operation uses controller above; Charging management solution for fleet to manage how & when they charge vehicles



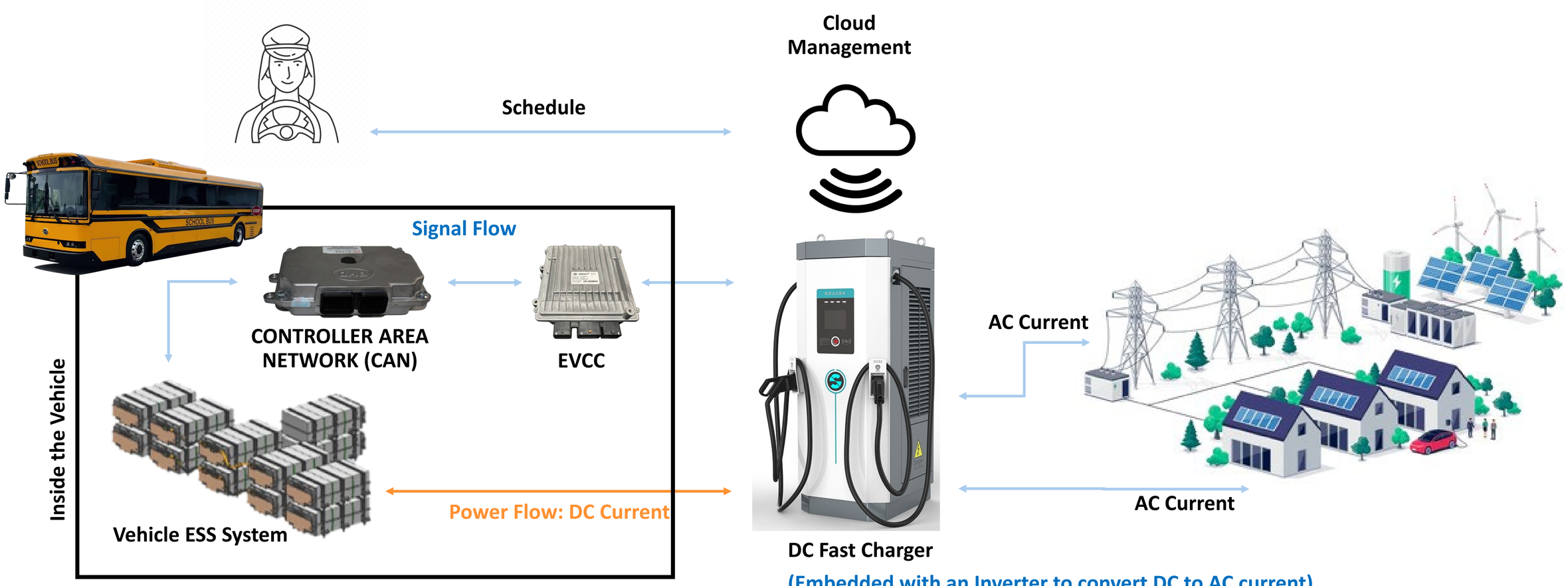
Electric Vehicle Communication Controller (EVCC)

EVCC provides communication information for Grid to Vehicle and Vehicle to Grid (V2G) charging events

Communicates with the EVSE regarding current discharging

ESB Component Identification & Principal of Operation

Vehicle to Grid (V2G) Functionality



ESB vs. ICE School Buses

Similarities & Differences

Engine System	**Completely Customized**	
Exhaust System		
Fuel System		HV Propulsion System
Chassis System	**Modified**	Chassis System
Driveline System		Driveline System
Electrical/Power Supply System		Electrical/Power Supply System
Body System	**Common**	Body System
Suspension System		Suspension System
Brake System		Brake System
Steering System		Steering System
Climate Control System		Climate Control System
Gauge and Warning System		Gauge and Warning System
Communications System		Communications System
Lighting System		Lighting System
Interior System		Interior System
Public Interface		Public Interface

Quieter

Electric motors provide much quieter rides than ICE buses.

Cleaner Power Source

ESBs use electricity whereas traditional ICE buses rely on petroleum-based fuels.

No Tailpipe Emissions

ESBs do not have a tailpipe and do not emit exhaust.

Regenerative Braking

When braking, ESBs reverse the electric motor, recapturing and storing energy. More efficient.

Vehicle to Everything

ESBs have the ability to send extra electricity back to the grid or buildings during emergency.

Questions and Answers

Presentation 2

ESB Preventive Maintenance & Diagnostics

Thomas BUILT BUSES®

Mark Richardson

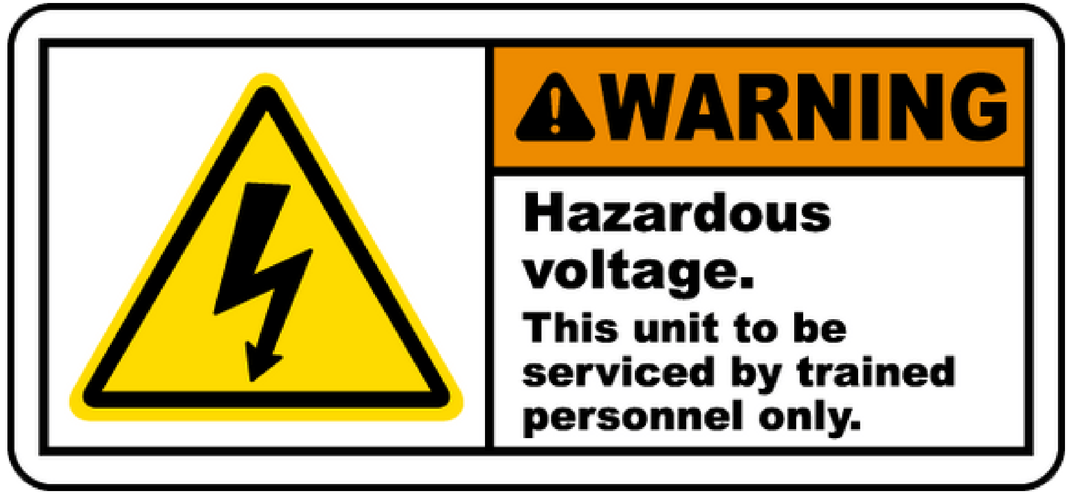
INTERNATIONAL TRANSPORTATION LEARNING CENTER

Learning Outcomes

- Describe the fundamentals of maintaining and troubleshooting battery electric buses
- Recall high voltage safety fundamentals
- Recognize example maintenance schedules
- Identify diagnostic approaches
- Analyze examples based on typical use cases and best practices, though specifics might vary depending on the OEM

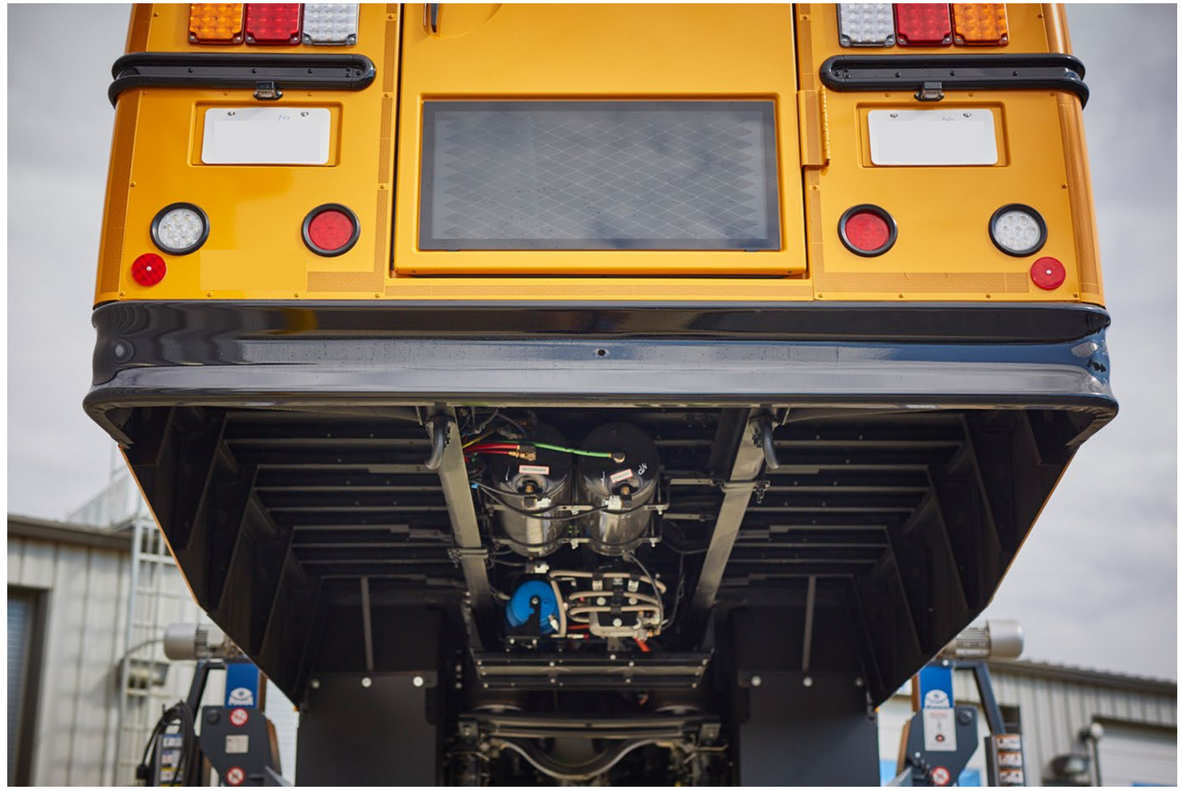
High Voltage Safety

- Components operate at dangerous voltage levels
- Failure to follow HV instructions can be severe
- Consult OEM manuals
- Only trained persons should work on HV components



High Voltage Preventive Maintenance

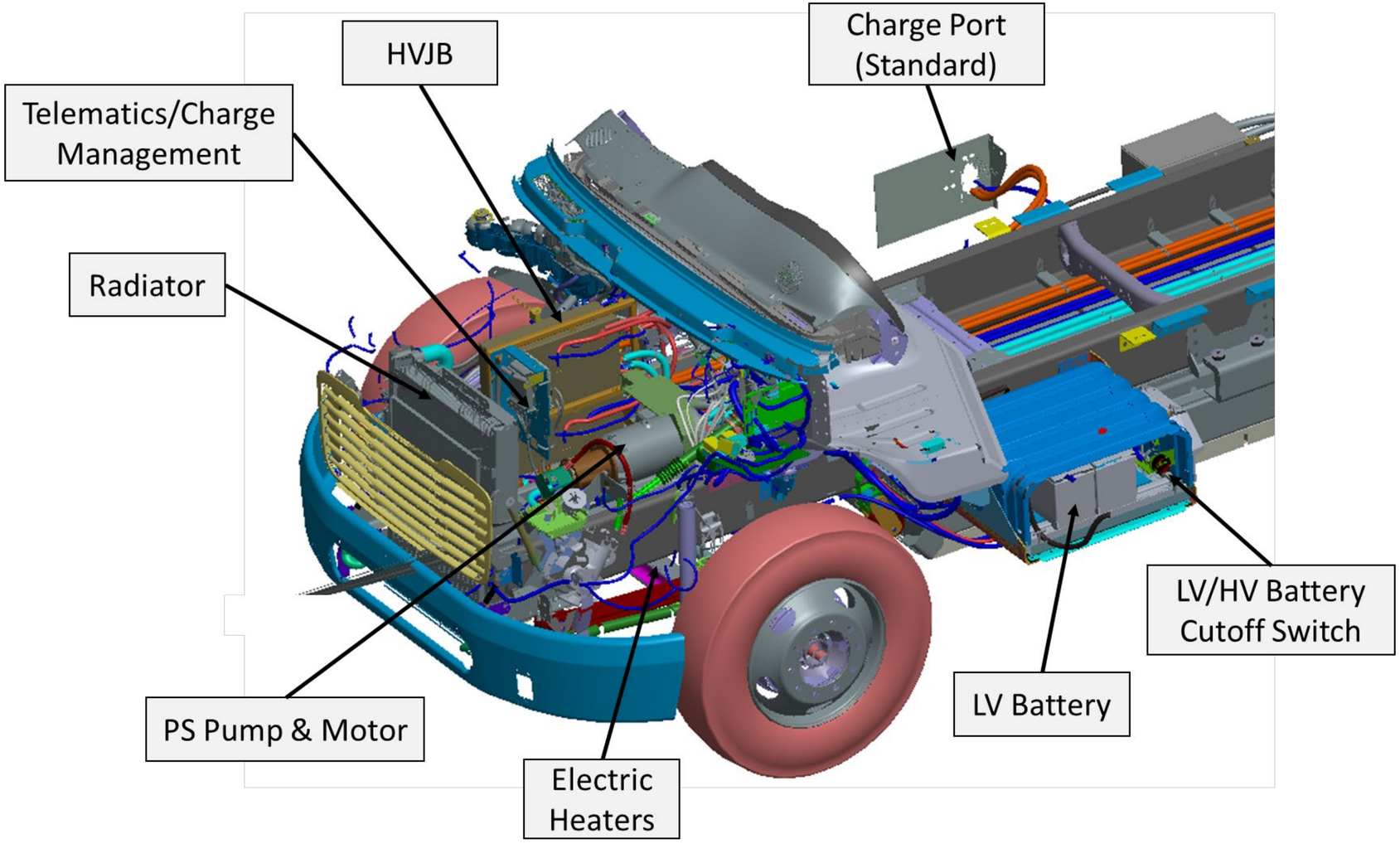
- Based on average vehicle use and typical conditions
- Customer should determine maintenance intervals
- Only trained persons should perform scheduled HV maintenance



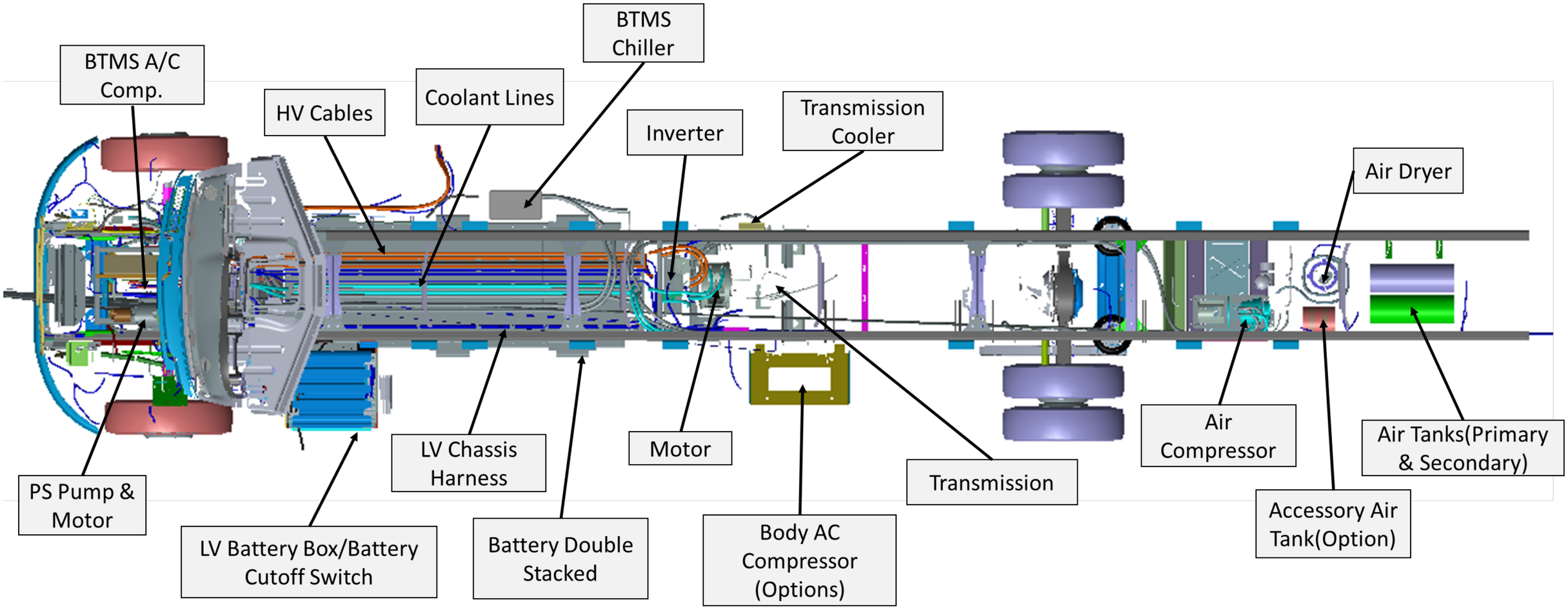
ICE Tasks Not Applicable to ESBs

Title of Maintenance Operation	Maintenance Intervals					
	IM - 4Kmi/6mo	4Kmi/6mo	8Kmi/6mo	16Kmi/12mo	32Kmi/24mo	48Kmi/30mo
Engine Drive Belt Inspecting				•	•	•
Engine Support Fastener Checking					•	
Air Cleaner Element Inspecting and Replacing	•	•	•	•	•	•
Air Compressor Filter Replacement, Propane Engine				•		
Fan Drive Inspection (Noise Emission Control)			•	•	•	•
Coolant Heater Check			•	•	•	•
Clutch Release Bearing Lubricating	•	•	•	•	•	•
Clutch Release Cross-Shaft Lubricating	•	•	•	•	•	•
Clutch Hydraulic Fluid Level Checking		•	•	•	•	•
Clutch Hydraulic Fluid Changing					•	
Electronic Clutch Actuator (ECA) Lubrication	•	•	•	•	•	•
Manual Transmission Oil Level Checking		•	•	•		•
Transmission Fluid Changing and Magnetic Plug Cleaning						
Transmission Breather Checking		•	•	•	•	•
Transmission Fluid and Filter Changing						
Automatic Tire Chain System Checking						
Off-Season Chain Wheel Removal						
Air Dryer AD-9 or AD-IP Desiccant Replacing						•
Hydraulic Brake Lining Wear Checking	•	•	•	•	•	•
Brake Lines and Fittings Inspecting, Hydraulic Brakes	•	•	•	•	•	•
Power Steering Fluid Level Inspecting	•	•	•	•		•
Fuel Tank Band Nut Tightening	•					
Fuel/Water Separator Element Replacing					•	
Inline Fuel Strainer Replacing			•	•	•	•
Fuel Sender Checking			•	•	•	•
Fuel Tank and Line Inspecting, Propane Engine					•	
Fuel Rail Fitting and Injector Inspecting, Propane Engine					•	
Fuel Filter Replacing, Propane Engine					•	
CNG Fuel System Inspection			•	•	•	•
CNG Fuel Filter Replacement		•	•	•	•	•
CNG Fuel Cylinder Inspection				•	•	•
Exhaust System Inspecting (Noise Emission Control)			•	•	•	•

Major Components



Major Components Continued

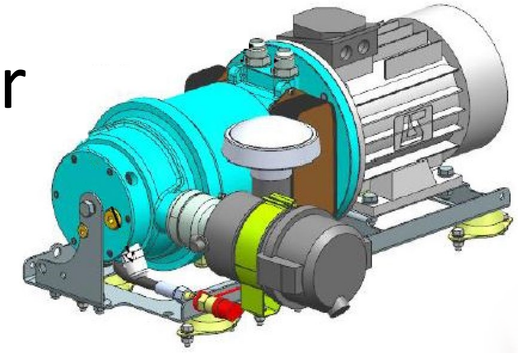


PM Schedule

- Initial Maintenance (IM): 4,000mi or 6mo
- Maintenance 1 (M1): 4,000mi or 6mo
- Maintenance 2 (M2): 8,000mi or 12mo
- Maintenance 3 (M3): 16,000mi or 18mo
- Maintenance 4 (M4): 32,000mi or 24mo
- Maintenance 5 (M5): 48,000mi or 36mo

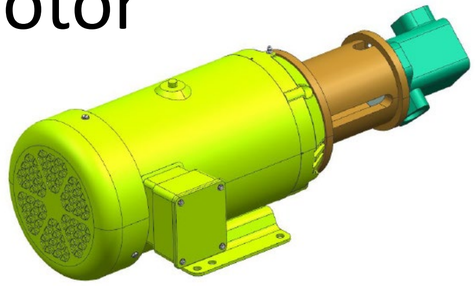
Maintenance 1 (M1) – Every 4,000 Miles or 6 Months

Air Compressor Filter Replacement - EV



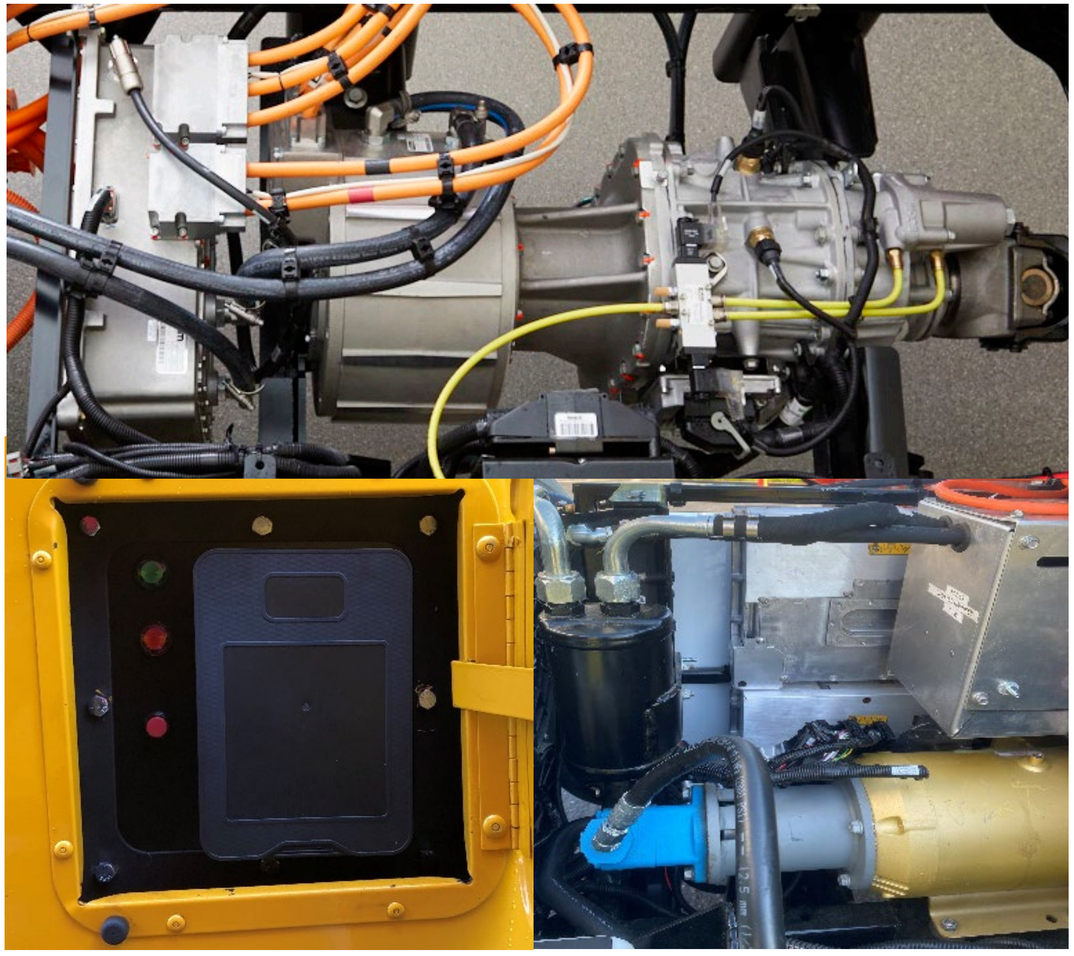
Ancillary Bay Desiccant Plug Inspection and Replacement - EV

Power Steering Motor Lubrication - EV



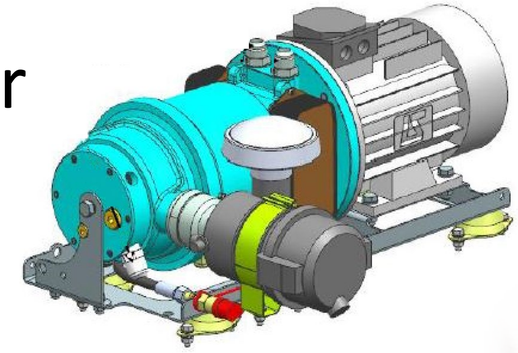
Maintenance 2 (M2) – Every 8,000 Miles or 12 Months

Title of Maintenance Operation
Torque Mark Inspection - EV
Electric Motor Inspection - EV
Transmission Inspection - EV
Air Compressor Filter Replacement - EV
Coolant System Maintenance - EV
Transmission Fluid Level Checking - EV
Power Steering Motor Lubrication - EV
Charge Port Inspection - EV
Ancillary Bay Desiccant Plug Inspection/Replacement - EV
Battery Pack Desiccant Replacement - EV



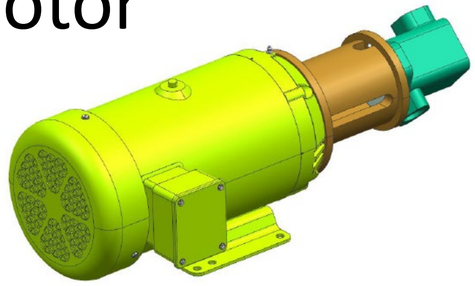
Maintenance 3 (M3) – Every 16,000 Miles or 18 Months

Air Compressor Filter Replacement - EV



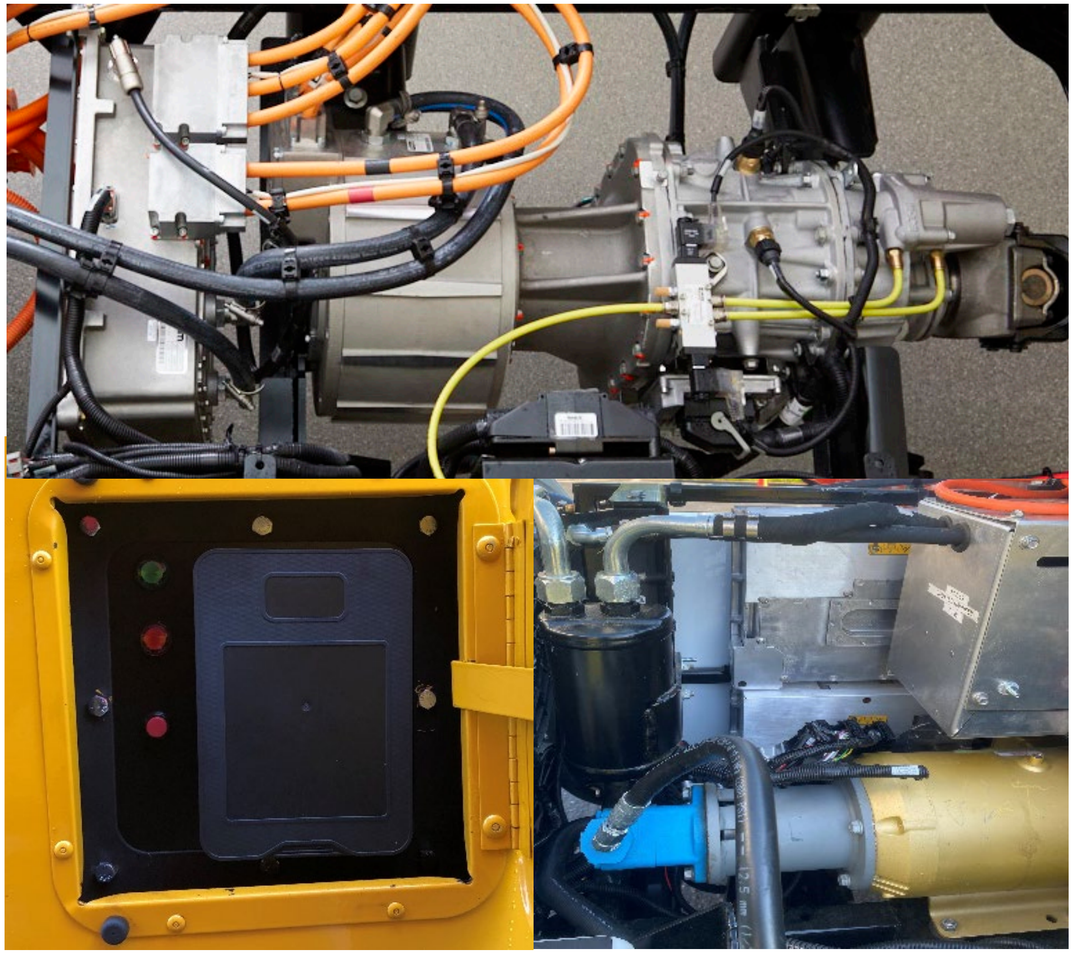
Ancillary Bay Desiccant Plug Inspection and Replacement - EV

Power Steering Motor Lubrication - EV



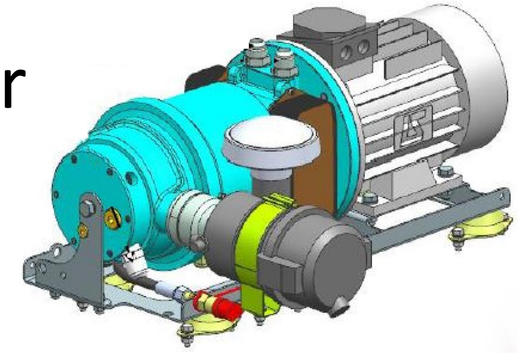
Maintenance 4 (M4) – Every 32,000 Miles or 24 Months

Title of Maintenance Operation
Torque Mark Inspection - EV
Electric Motor Inspection - EV
Transmission Inspection - EV
Air Compressor Filter Replacement - EV
Coolant System Maintenance - EV
Transmission Fluid Level Checking - EV
Power Steering Motor Lubrication - EV
Charge Port Inspection - EV
Ancillary Bay Desiccant Plug Inspection/Replacement - EV
Battery Pack Desiccant Replacement - EV



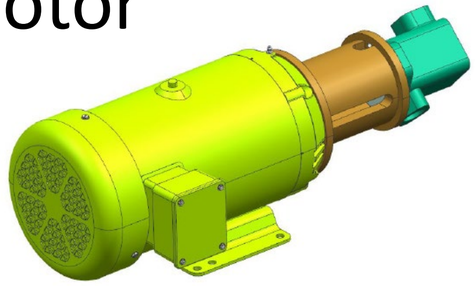
Maintenance 5 (M5) – Every 48,000 Miles or 36 Months

Air Compressor Filter Replacement - EV



Ancillary Bay Desiccant Plug Inspection and Replacement - EV

Power Steering Motor Lubrication - EV



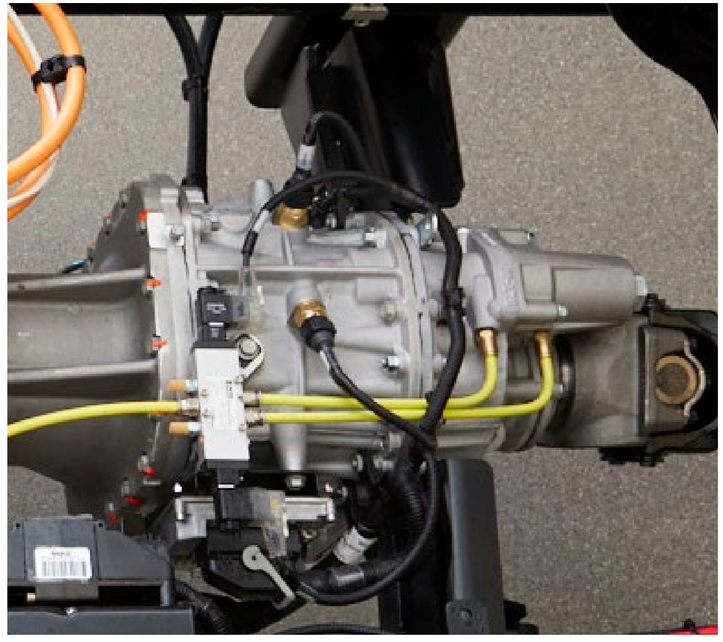
Additional EV-Specific PM Examples

Every 60,000 Miles:

- Air Compressor Oil Separator Element and Main Seal Replacement - EV

Every 36 Months:

- Transmission Fluid Changing - EV



PM Schedule Overview – EV Specific

Title of Maintenance Operation	Maintenance Intervals					
	IM - 4Kmi/6mo	M1 - 4Kmi/6mo	M2 - 8Kmi/6mo	M3 - 16Kmi/12mo	M4 - 32Kmi/24mo	M5 - 48Kmi/30mo
Torque Mark Inspection - EV			•		•	
Electric Motor Inspection - EV			•		•	
Transmission Inspection - EV			•		•	
Air Compressor Oil Separator Element and Main Seal Replacement - EV	**Every 60,000 miles**					
Air Compressor Filter Replacement - EV		•	•	•	•	•
Coolant System Maintenance - EV			•		•	
Transmission Fluid Level Checking - EV			•		•	
Transmission Fluid Changing - EV	**Every 36 months**					
Power Steering Motor Lubrication - EV		•	•	•	•	•
Charge Port Inspection, Electric Vehicle			•		•	
Ancillary Bay Desiccant Plug Inspection and Replacement - EV		•	•	•	•	•
Battery Pack Desiccant Replacement - EV			•		•	

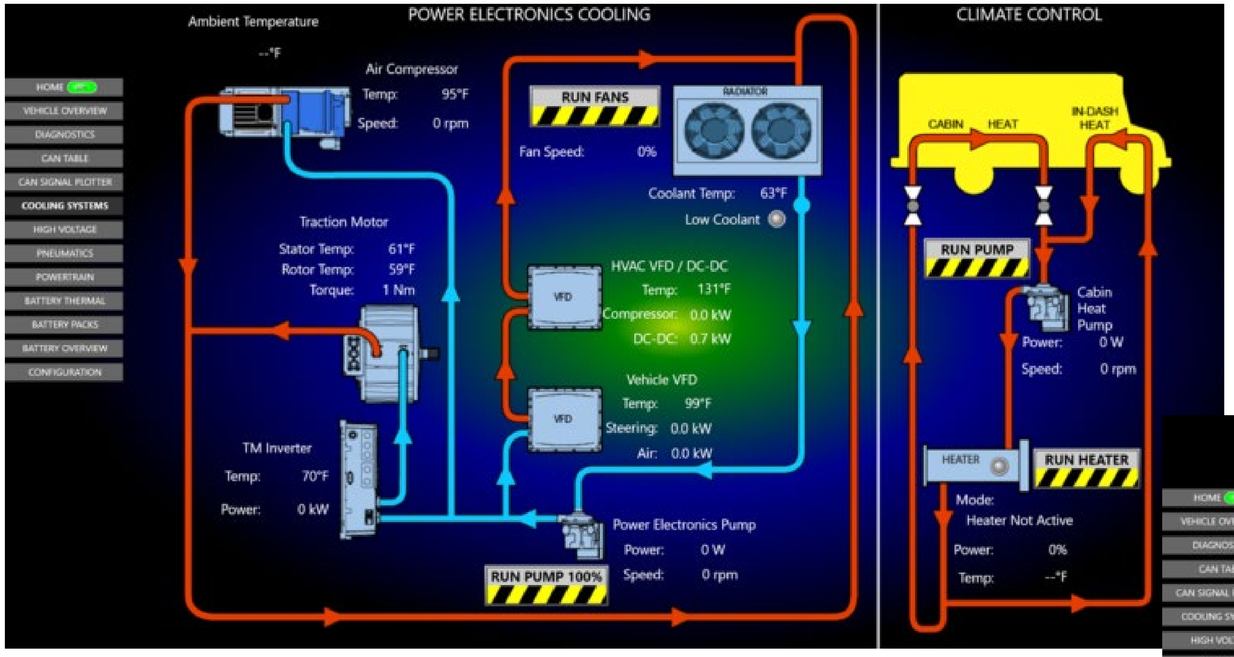
Diagnostic Troubleshooting

- ✓ **Powertrain Diagnostic Software**
  - Requires OEM specific program & software
- ✓ **Battery Diagnostic Software**
  - Requires OEM specific program & software
- ✓ **Typical Fault & Troubleshooting Approach**
  - Confirm compliant, diagnose fault, apply Corrective Action
- ✓ **Data Logging**

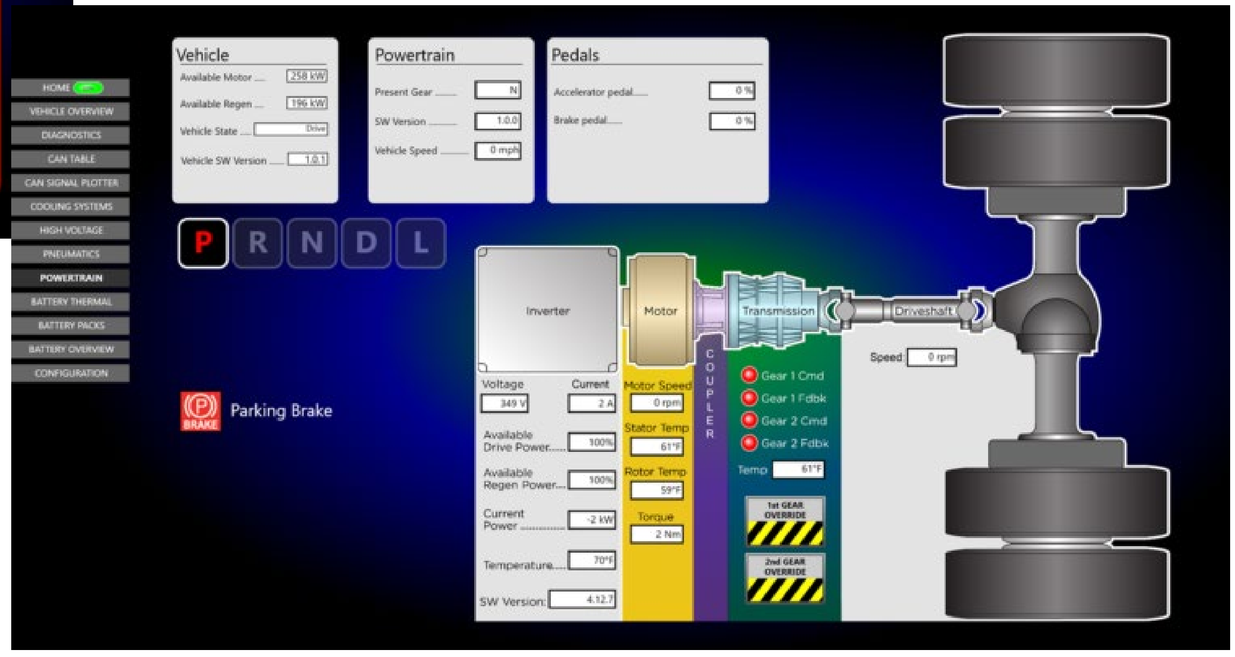
Diagnostic Troubleshooting

- Powertrain Dongle
- Laptop

ESB Diagnostic Tool



System Requirements	
Operating System	Win 10 - 64 bit or >
CPU	Intel Core i5 or >
Memory	8 GB RAM



System Requirements	
Hard Drive	500MB Free Space
Graphics Hardware	Intel 5000 IG or >

PDT is compatible with Nexiq USB-Link 2

Questions and Answers

Presentation 3

ESB ESS Overview and Battery Management

GreenPower MOTOR COMPANY

Sean Ashcraft

Learning Outcomes

- Define E.S.B. Energy Storage System (E.S.S.)
- Define cells, modules, and pack(s)
- Describe why a Battery Management System (BMS) is needed
- Describe why a Battery Thermal Management System (BTMS) is needed

ESB Energy Storage System

Energy Storage System (ESS)

- Used in various forms, but generally means the complete battery pack system
- ESS is a combination of cells that mechanically and electrically connected, along with appropriate thermal, electronics, and mechanical structure to house the entire unit

Single Pack

=

ICE Diesel Fuel Tank

Cells, Modules, Pack(s)

Commonly battery cell chemistry is Lithium Iron Phosphate (LFP).

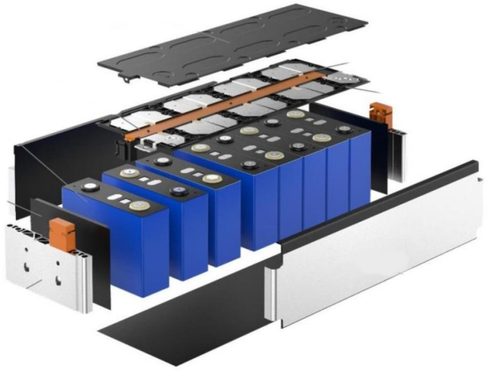
A single cell has a nominal voltage of 3.2VDC

Some design factors that dictate the capacity (kWh) of the ESS are:

- Range
- Voltage
- Performance
- Weight constraints

Prismatic LFP Cell

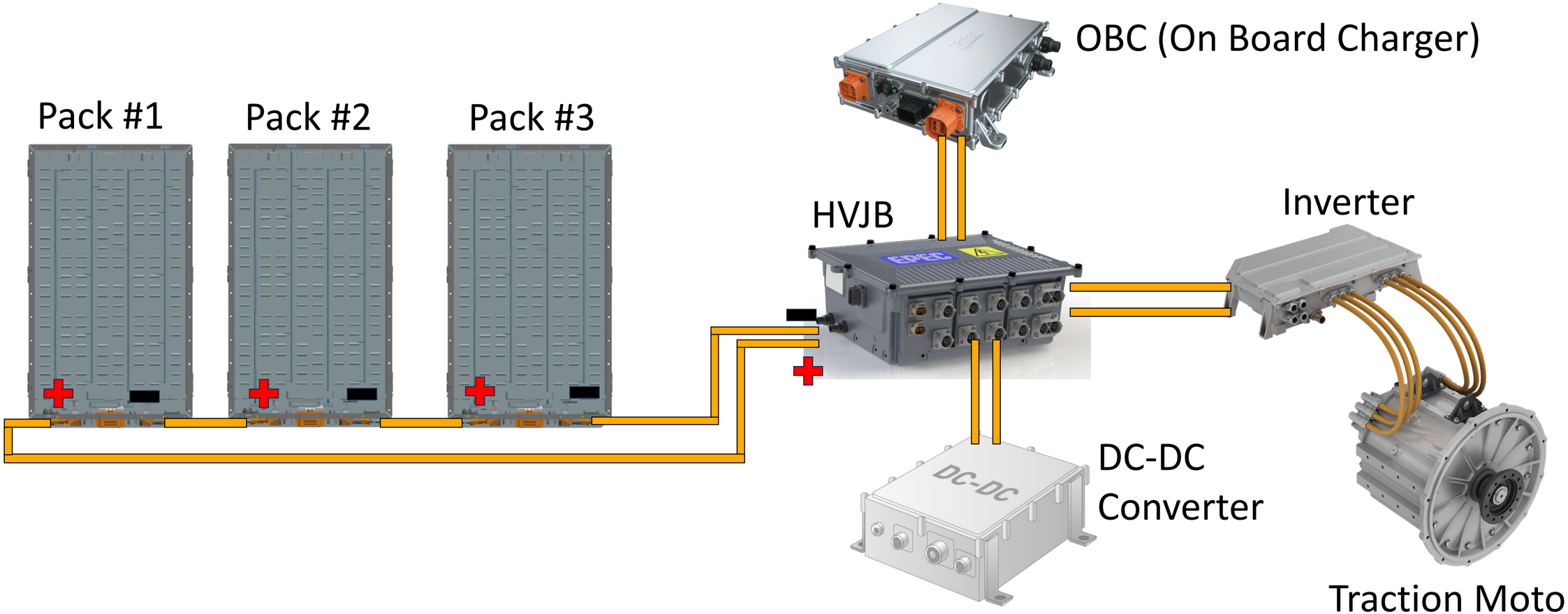
Module with 8 Cells connected in series



- Individual Cells are connected in a series/parallel arrangement
- This forms a Module
- Modules are connected in a series/parallel arrangement
- This forms a Pack
- There may be multiple packs connected in series

Cells, Modules, Pack(s) Cont.

Total number of packs installed on a vehicle will vary between OEMs



Battery Management System (BMS)

What is it and why is it needed?

The BMS ensures the safety and life of the ESS by:

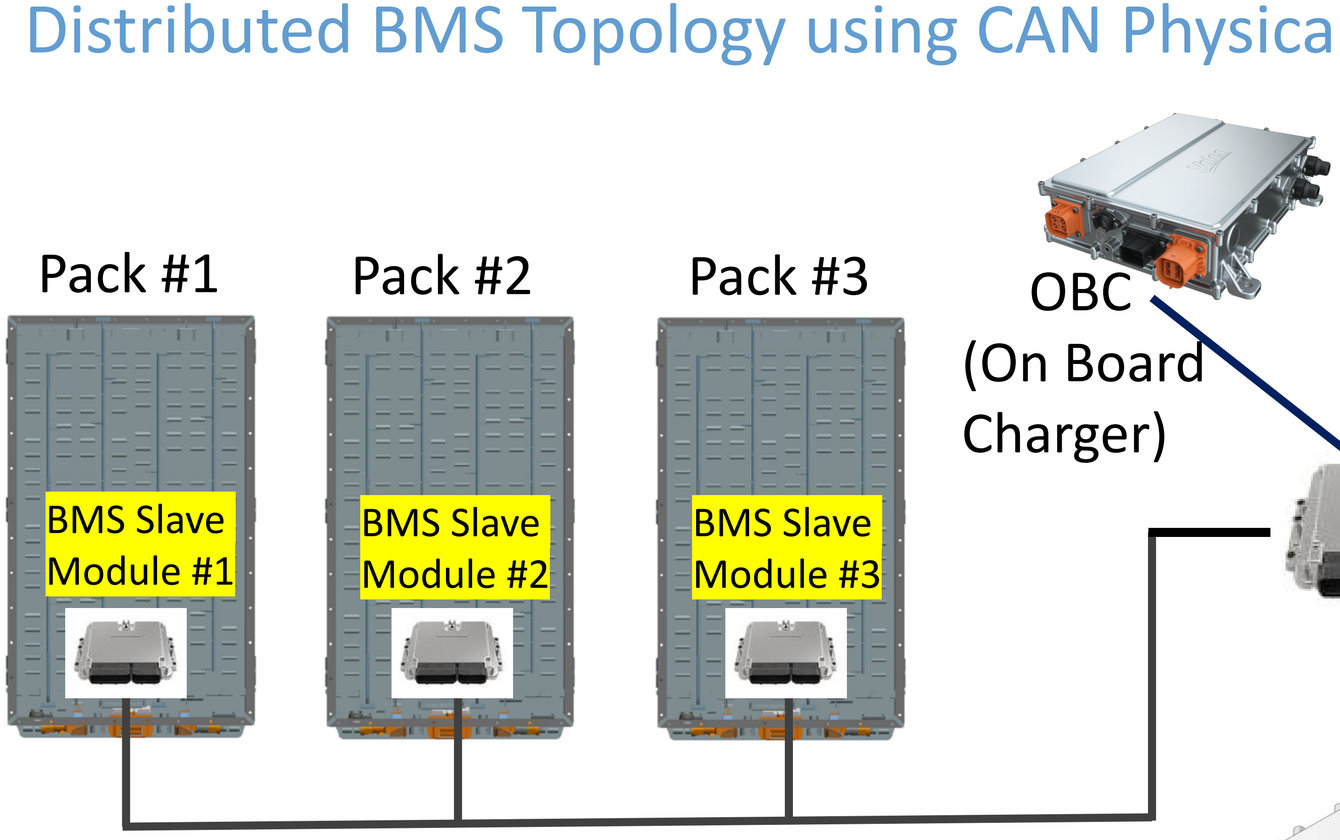
- Measuring cell voltage and temperature
- Measuring ESS current, isolation resistance
- Dictates charging/discharging limits
- Calculating SOC & remaining range
- Control ancillary HV loads
- HVIL (High Voltage Inter-Lock) Monitoring

2.5V ☹ ⟷ 😎 ⟷ 3.65V ☹

Examples of Prismatic LFP Cells that were overcharged, and as a result are permanently damaged.

Battery Management System (BMS)

Distributed BMS Topology using CAN Physical Layer

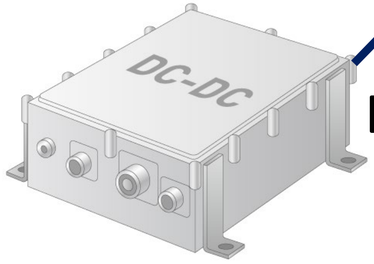


OBC (On Board Charger)

HVJB

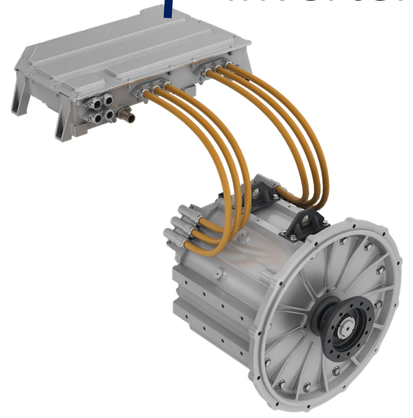
VCU (Vehicle Control Unit)

BMS Master Module



DC-DC

Inverter



Traction Motor

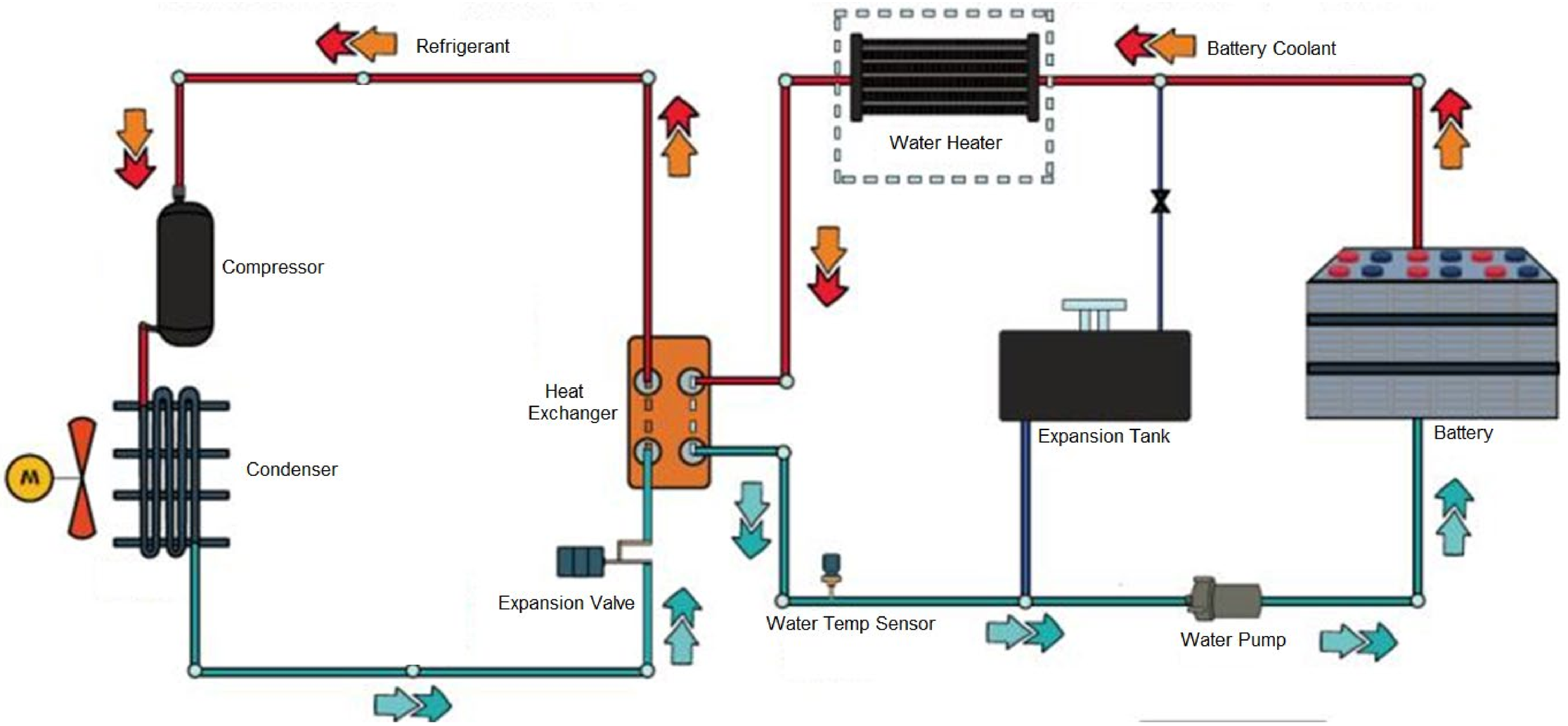
Each slave module reports temperature and voltage readings of cells/modules inside each pack to BMS Master module

Why is a Battery Thermal Management System Needed?

When the ESS is required to charge or discharge, a chemical process takes place within the battery cells, allowing electrons to move

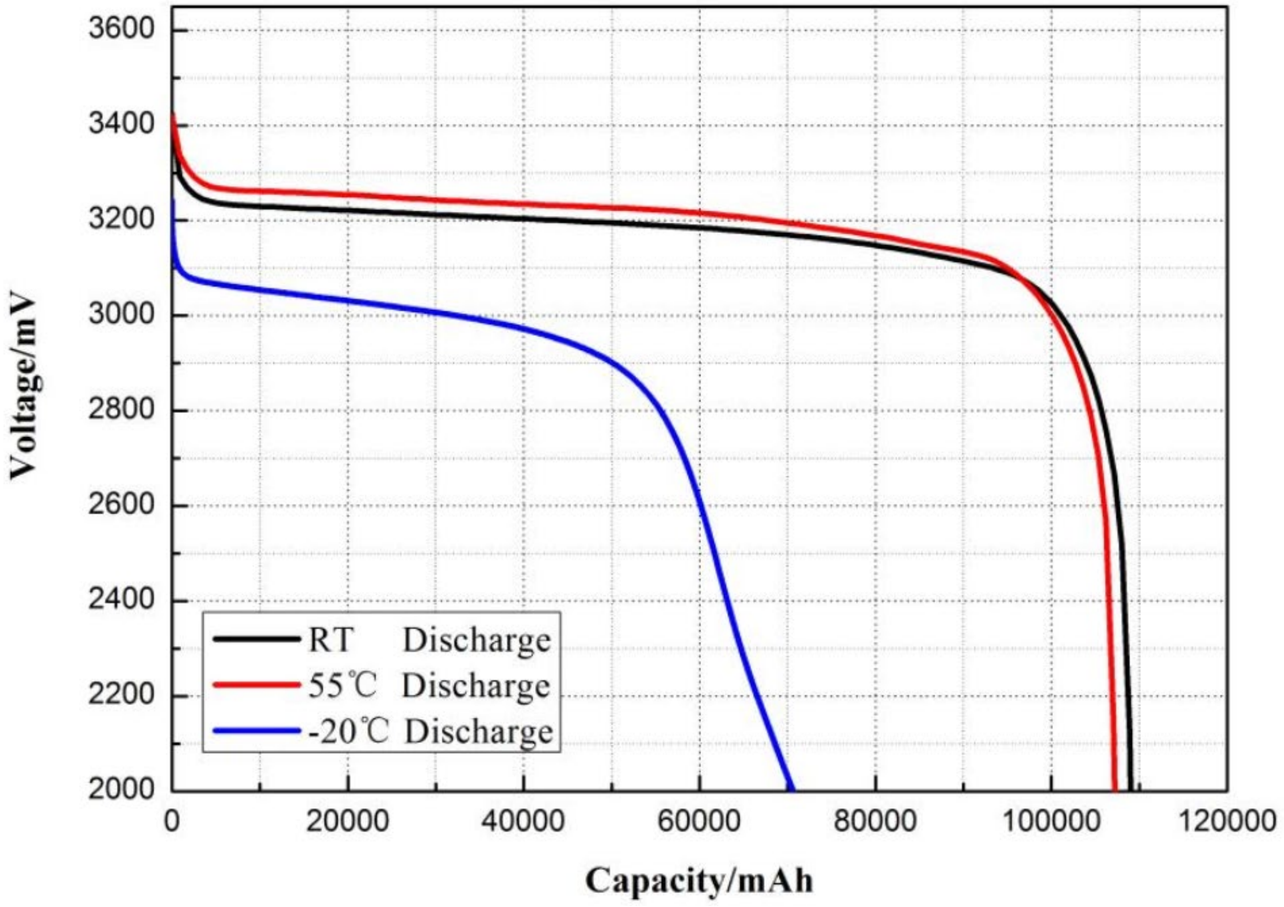
- Chemical process can be negatively effected by extreme ambient temperatures
- Cannot be charged when LFP cell temps are < 0°C, and >55°C
- BTMS is a system incorporated into the ESS by the OEM to mitigate these extreme temperatures within the battery packs
- Common BTMS components: Refrigerant, Compressors, Pumps, Heat Exchangers, Valves, Fans
- All automatically controlled by the BMS system

Why is a Battery Thermal Management System Needed?



Why is a Battery Thermal Management System Needed?

How Temperature Effects LFP Discharge Performance



The cells useable capacity is reduced as a result of the extreme temperatures

Cell performance and longevity will also be reduced

Questions and Answers

Register for ESB Familiarization Webinars

Webinar topics:

- Module 1: Operator Overview (April 10)
- Module 2: Electric School Bus Technology Overview (August 7)
- *Module 3: High Voltage Safety Considerations
- *Module 4: Charging Considerations

Register at:
driveelectric.gov/webinars

Registration for Modules 3 and 4 coming soon!

Thank you!

Today's Presentation:
Module 2: ESB Technical Overview

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