BATTERY ELECTRIC BUS FAMILIARIZATION

Session 3
BEB Charging Considerations

March 23, 2021

TRANSPORTATION LEARNING CENTER

Last updated by Amri, 03/24/2021
Includes updates from CTE sent after Zoom webinar on 03/23/2021

Welcome

- Who are we?
- Why this course?
- What’s next?

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Welcome to final session on BEB Familiarization, Thanks for Attending

I’m John Schiavone – Transportation Learning Center
Our Mission: Advance frontline worker training on Joint L-M basis

We know BEB procurements are growing, we also know that technicians will need new skills to keep pace with the technology.

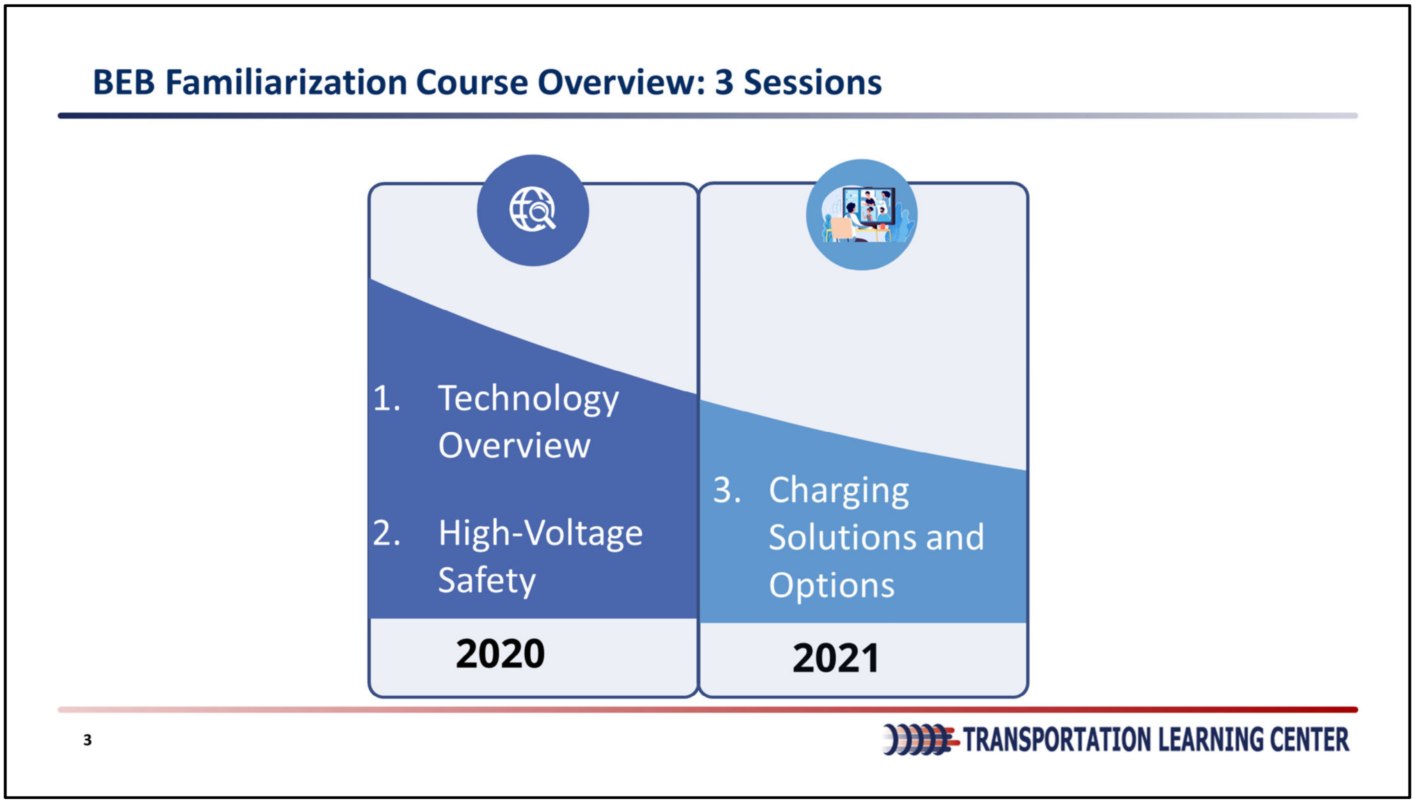
Familiarization Course is designed for techs, instructors & others with no/limited BEB Experience. Intent is to make them feel more comfortable about BEBs in advance of more in-depth training

Thanks to all OEMs who participated – BYD, Eldorado, Gillig, New Flyer, NovaBus, Proterra

Also thanks for Center for Transportation & the Environment

All Volunteered their time & resources = strong indication that we can all work together to advance training

We hope to take this course to next level – make it a full course that engages students to learn more through advanced training techniques and hands-on exercises



This BEB Familiarization Course is being delivered in three sessions:

1. General Technology Overview
   Was Delivered in June 2020
1. High-Voltage Safety Considerations
   Was Delivered in October 2020
3. Charging Solutions and Options
   Today’s Session (March 2021)

Today's Presenters

1. Charging Overview
2. Charging Considerations and Technology
3. Charging Standards, Maintenance and Safety
4. Facility and Operations Considerations

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Today we have four Presenters

1. Charging Overview
   - Delivered by Randy Premo, BYD
2. Charging Considerations & Technology
   - By David Warren, New Flyer
3. Charging Standards, Maintenance & Safety
   - By James Hall, Proterra
4. Facility & Operations Considerations for BEBs
   - Amy Posner, Center for Transportation & the Environment

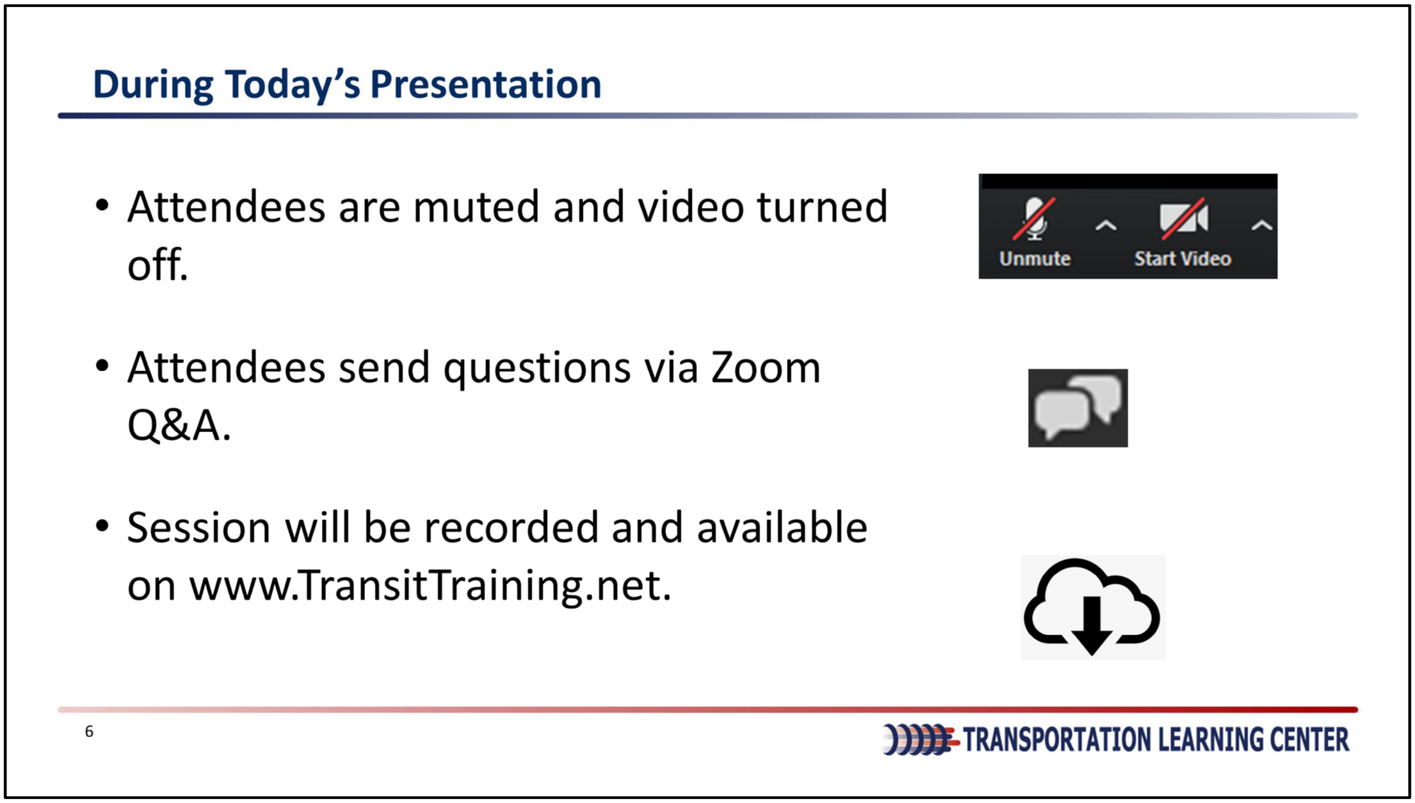
Thanks again for their cooperation and participation

Learning Outcomes

1. Describe charging options, battery management systems, & charger-bus communication.
2. Identify existing and future battery charging technologies.
3. Recognize charging standards & charger maintenance and safety.
4. Evaluate up-front planning needed for BEB facilities and operations.

Upon Completion of today's BEB Overview Session, you will be able to:

1. Describe various charging options, battery management systems, & charger-to-bus communication.
2. Identify existing and future battery charging technologies.
3. Recognize charging standards and charger maintenance and safety considerations.
4. Evaluate up-front planning needed for BEB facilities and operations.



Some housekeeping notes:

All Attendees will be muted & web cams turned off .

Encourage attendees to type their questions during the presentations using the "Q&A" in the Zoom Webinar controls.

I'll moderate all questions & present them after each presentation.

Session will be recorded – download from Transportation Learning Center website: www.TrainsitTraining.net

Download materials will include full recorded session and slides with presenter's written notes.

Final Notes

- Use downloaded versions for further training
  - Instructor-Led
  - Self-directed
- Complete BEB familiarization course in future

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In Closing:

We understand material is new and we move through it quickly

But Instructors can downloaded these materials and use them as basis for an instructor-led course

Or you can use the materials as a refresher

As mentioned earlier, our hope is to take this material and develop a more engaging course with interactive & hands-on exercises

And with that I'll introduce first speaker, Randy Premo, BYD who will provide an overview of battery charging

Fundamentals Of BATTERY ELECTRIC BUSES

Charging Overview

March 2021

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Source: https://new.abb.com/about/our-businesses/electrification/e-mobilitysolutions/ebus-depot

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Thanks John, Amri and the staff @ TLC!

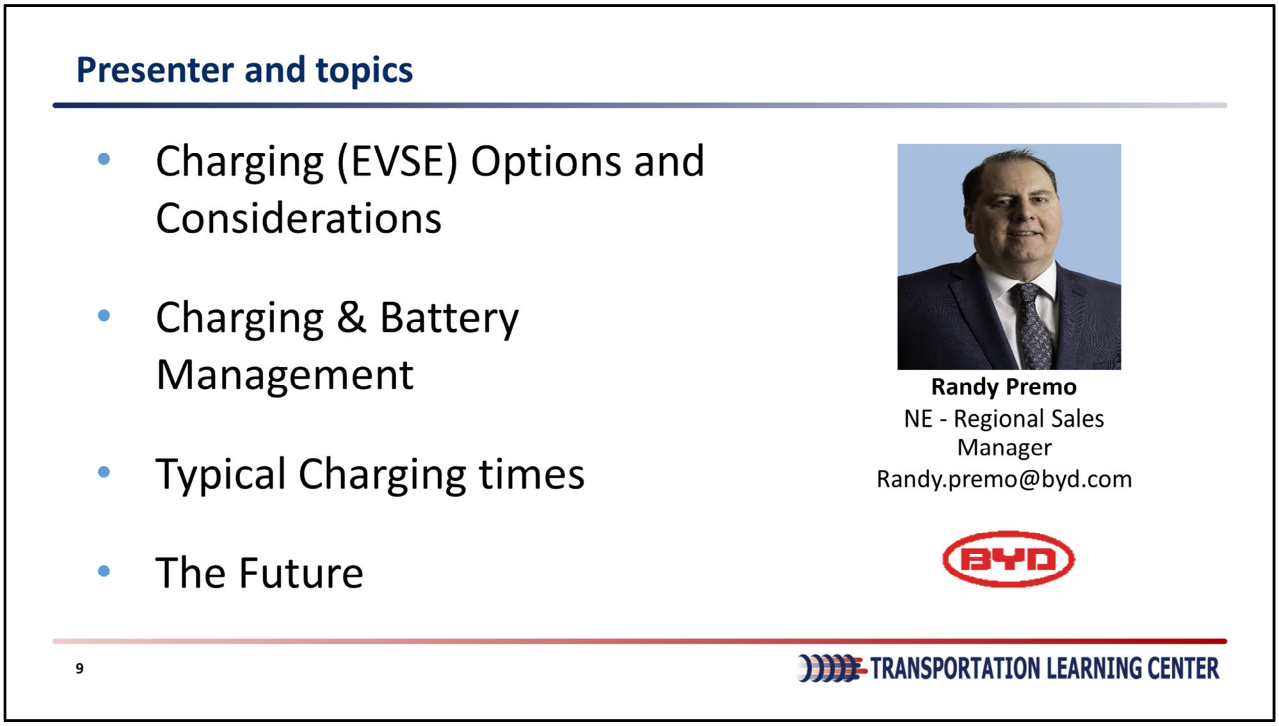
Hello All! Randy Premo here from BYD. A little background on myself; Regional Sales Manager-NE (little over 2 yrs now) – Previous to that I had 26 years in PT – having worked my way up through all maint. Positions and when I left I was the Supt. Of Fleet Maint. PT was a very rewarding and good job, I left because I wanted to be part of the change I thought was needed (away from fossil fuels and towards alternative energy and electric buses).

Happy to be part of TLC's BEB Training Program – Session 3 Charging Options!

I just wanted to start with a preface: There are many charging options & solutions available to BEB users and these options/solutions should be discussed and considered well before the purchase & implementation of BEB's. Many things to consider with regards to; maintaining & meeting service needs, power capabilities, infrastructure, etc. Amy from CTE will go over much of this in her presentation!

Where able plan and implement with an eye on the future!

Let's get into an overview of BEB Charging!



Today I will cover four topics:

1. Charging Options & considerations
2. Charging & Battery Management
3. Typical Charging Times
4. The Future

The Learning Objectives for this presentation are:

- Understanding the different charging options available
- Learning about charging and battery management options and the benefits of these
- Getting an idea on how long it will take to charge your batteries dependent on charging type/methodology and per charger power ratings
- A glimpse into the future?

My esteemed colleagues from NFI (David), Proterra (James) & CTE (Amy) will further discuss and expand on charging options!

Acronyms and Terminology

- BMS –Battery Management System
- AC – Alternating Current
- AC Charger – Inverter on vehicle
- CCS – Combined Charging System
- Conductive Charging
- DC – Direct Current
- DCFC – DC Fast Charging
- Depot charging
- ESS – Energy Storage System
- EVSE – electric vehicle supply equipment
- Inductive charging
- Kw – kilo-watt
- kWh – kilo-watt hour
- Opportunity or on-route charging
- Overnight charging
- Smart charging

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Some terminologies and acronyms used for Zero Emission & Battery Electric Buses and charging:
EVSE – Chargers
CCS – Connectors

- Type 1 – AC Connectors – largely used in Europe and Asia
- Type 2 – DC Connectors – new – interoperable connectors

- EVSE – electric vehicle supply equipment
- Depot charging – charging @ property
- Opportunity or on-route charging – charging in-service
- Overnight charging – Method of charging (slow)
- AC – Alternating Current – think home service
- DC – Direct Current – think batteries
- AC Charger – Inverter is on vehicle
- DCFC – DC Fast Charging – inverter is in charger
- Inductive Charging (wireless) – transfer of energy
- Conductive Charging – Physical connection
- Kw – kilo-watt think power (hp)
- kWh – kilo-watt hour – think energy (GE)
- Smart Charging – charging control / intelligence
- CCS – Combined Charging System (connectors)

[Image used with creative commons license]

Charging Options & Considerations

Depot Charging

- Plug-In – AC
- Plug-In – DC
- Others

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Depot Charging – A means of charging at the depot (or facility) – Initially this was technology was used to replace the diesel fuel nozzle.

AC Chargers – Widely used overseas and in particular in Asia – Inverter is on the bus and the “interface”/charger is tapped into existing AC service.

DC (Fast) Chargers – Offer interoperability and are UL Listed. DCFC’s have the inverter in the charger and therefore are bigger and more expensive than AC Chargers. DCFC’s are becoming the norm or standard as they offer interoperability for all users/manufacturers.

Others - As properties are starting to realize and consider some of the “new” challenges with charging and the need to look at complete “fleet” conversions depot charging is now utilizing technologies that are being used On-Route. Such as inductive charging pads and Overhead charging as well as variations to these technologies (Plug-in chargers mounted high, charging strips above, etc.).

These other methods and charger types have been considered for several reasons;

- Facility ease of maintenance, use and space
- Charging needs
- Etc.

Charging Options & Considerations

- Overhead Pantograph
- Power Distribution box and means of charging

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In-Route or On-Route – terms are actually derived from the French term En-Route which meant; “along the way”. In-Route has come to mean “in-transit” in English/America.

Pantograph or Overhead opportunity charging was the other “initial” method of charging buses introduced along side depot charging. It’s intent was to provide a means of keeping BEB’s in service or to meet service requirements for range.

Overhead chargers can be of the pantograph up or down type.

This charging method usually requires less battery capacity as charging occurs more frequently or the route is shorter (loop, shuttle service, etc.).

Charging Options

On-route or Opportunity Charging

- Inductive or wireless charging.
- Newer and evolving technology
- Power Distribution box and means of charging (pads on street and bus)

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Source: https://thedriven.io/2020/06/23/washington-e-buses-get-300kw-wireless-charging-system/

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Inductive or wireless charging (electro-magnetic induction) is a relatively newer/emerging technology that has been gaining popularity and there are several solutions being used and considered for now and the future. This technology consists of a wireless charging station/in-ground pads (on-route) and pads installed on buses. We are familiar to this technology with our home charging pads for our phones.

This technology had some challenges and concerns early on; mainly efficiency. Most of these challenges and concerns have been addresses (efficiencies of the transfer of power (90% and better) and the increase of available charging Kw rates; 75kW -150kW-300kW (and 600kW is being explored/tested)) and this technology is starting to be utilized more.

Opportunity chargers present some benefits and mainly these are; 1-1 fleet replacement and no concerns for range!

Of note: As the demand and increase of BEB’s grows there is much conversation and innovation going on and primarily in battery advancements and charging solutions.

Charging & Battery Management

Communication Between Bus Batteries and Charger

- **Battery Management Systems (BMS)** – keeps ESS or battery packs thermally conditioned and safe.
- **Charging Management** – manages vehicle charging.
- **Smart Charging Technology** – allows the ability to monitor and control charging.
- **Charging & Infrastructure Management** – OEMs offer solutions and services.

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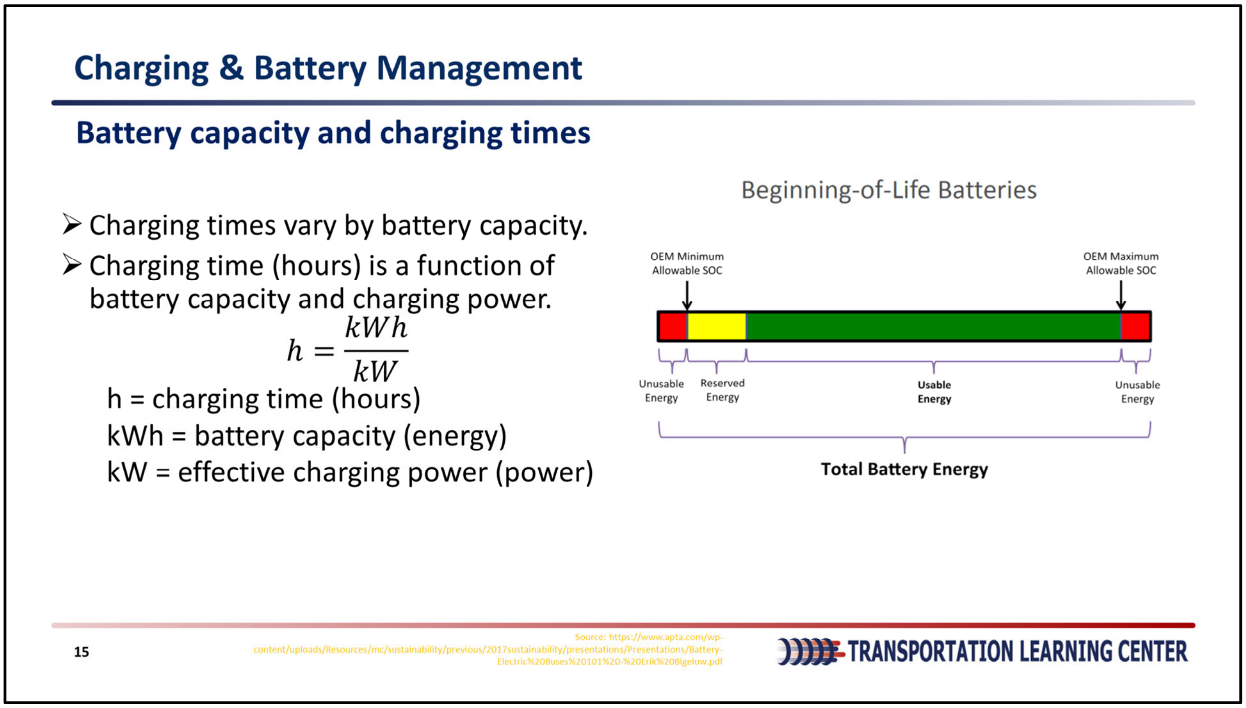
BMS – Battery Management System – This system allows the batteries to not only be monitored but also conditioned and controlled both thermally and during charging. Crucial that battery packs are operating and functioning properly and safely and kept at the best temps for optimum life.

Charging Management – Done during charging but also can be enhanced as smart charging and per facility desires.

Smart Charging allows for the user to control when charging occurs and to avoid “peak” demand charging rates that were not necessary by charging accordingly. It also allows a level of vehicle and charging monitoring.

Charging & Infrastructure Management Solutions & Services– Smart Charging & Fleet Charging & Monitoring Management are exciting solutions to ensuring your fleet is charged and available for service, monitoring your fleets SOC, while also optimizing charging rates and fees. Services range from assessments/support to installation – to complete turn-key solutions where the whole charging solution and bus availability is managed and provided as a service. ***The slide you see to the right is a snap-shot of a Charging Management Solution dashboard.***

New advancements now allow the charging & battery management systems to work in unison to condition the buses batteries as well as the buses coach temperature.



So here we are showing the relationships between battery (energy) capacity (size), charging rates (power) and charging times.

Not only will battery pack size impact charging times but also the charger type/size will impact charging times.

All batteries are rated per battery (energy) capacity (size – example 400kWh battery) and have reserve energy and useable and unusable energy available (as the image shows).

So a 400kWh battery pack will typically only have a usable capacity (energy) of 320 to 360kWh of usable energy.

All batteries deteriorate over time and charging has an impact on this.

Beginning of life and end of life are terms used to describe beginning and expected capacities of batteries; example a battery can start with 360kWh's of energy and over the life of the bus this battery pack will lose capacity which will directly impact range. Therefore it is crucial to understand battery (energy) capacity and expected lose of battery (energy) capacity over time.

Formula for establishing charging times:
Charging Time [h] = Battery Capacity [kWh] / Effective Charging Power [kW]

Charging & Battery Management

Battery capacity and charging times

- Charging times also vary by charging method.
- With formula:
  - DCFC depot plug-in charger with 320 kWh and 80 kW = 4 hours
  - Pantograph charger with 320 kWh and 300 kW = 1 hour.
  - Wireless with 320 kWh and 150 kW = 2 hours

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Below are some *rough charging times per charging types (Formula for establishing charging times:
Charging Time [h] = Battery Capacity [kWh] / Effective Charging Power [kW]):
:
AC Depot Plug-In Charger (80 kW) x = 320kWh/80kW Therefore x = 4 hrs

DCFC Depot Plug-In Charger (150 kW) x = 320kWh/150kW Therefore x = 2.5 hrs

Pantograph Charger (300 kW) x = 320kWh/300kW Therefore x = Roughly 1 hr – but since this method of charging is for “topping-off” or extending range a 6 minute charge will put roughly 30kWh’s back into the battery pack which should be roughly 15 miles – so in theory if you were utilizing an on-route charger every 20 miles or so you should see long range/use or you can also look at hours miles per hour travelled and factor this way. The best case is an opportunity charger being used on a “loop-service” which would allow for less battery pack (kWh) requirement

Wireless Charging (150 kW) x = 320kWh/150kW Therefore x = Roughly 2 hrs or (using factors above) adding roughly 15kWh’s of power back into the battery pack

*We are assuming a new 400 kWh battery pack and charging from 20% SOC to 100% SOC (80kWh to 400kWh Capacity) – Of course each battery (chemistry) may have different charging requirements and per charging rate of allowed power

*The above numbers are “rough” numbers as each battery type and EVSE manufacturers charge rates will impact charging times. These numbers provided for estimations only.

Charging technologies down the road…

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https://ucrtoday.ucr.edu/22485
https://d346xxcyottdqx.cloudfront.net/wp-content/uploads/2021/02/ebus-charging-station_00001.jpg

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So what will the future hold for EV's & BEB's particularly with continued growth, charging, batteries and range?
Some things being used, worked on and considered:

- Overhead Cabling (existing) like previously used for electric trolleys
- Solar Panels on Roof (of bus) to OFFSET OR ASSIST w/electric demand from HVAC
- Hot button topic – V2G – for emergency power
- Wireless Routes/Electrified Roads – Sweden (has started and plans to expand to the whole country), South Korea (since 2017_ has been testing (7.2 miles) as well as Tel-Aviv (1.2 miles)
- Remote Wireless Charging?
- Solid-State Batteries
- Ultra-Fast Carbon Electrode Technology (NAWA Technologies) – uses a (VACANT) vertically-aligned carbon nanotube designed to; boost battery power ten-fold, increase energy storage by a factor of three, and increase the lifecycle of a battery five times
- Semi-Conductors
- Ultrafast Charging – will allow for less downtime and make ev use more appealable and manageable
- Nonowire Battery Technology – for faster charging and longer life

My personal thoughts - We need to address;

- First and foremost charging solutions for facilities and the large scale implementation of BEB's
- Range
- Large Scale Implementations
- Battery chemistry and rare minerals
- Ability to meet power needs and have back-up abilities (V2G)

Summary

- Explain charging options and considerations
- Explain BMS/CMS and Charging & Infrastructure offerings
- Calculate charge times per charger types.
- Recognize the future and innovations in BEBs, their charging infrastructure, and technologies.

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- You should now…
  - Know more about charging options and considerations.
  - Understand Battery Management Systems, Charging Management & Charging & Infrastructure offerings.
  - Better understand charge times per charger rating (kW).
  - Be looking forward and seeing that BEB's are a viable and present solution today and tomorrow.

Questions and Answers

Randy Premo
Regional Sales Manager NE
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BYD

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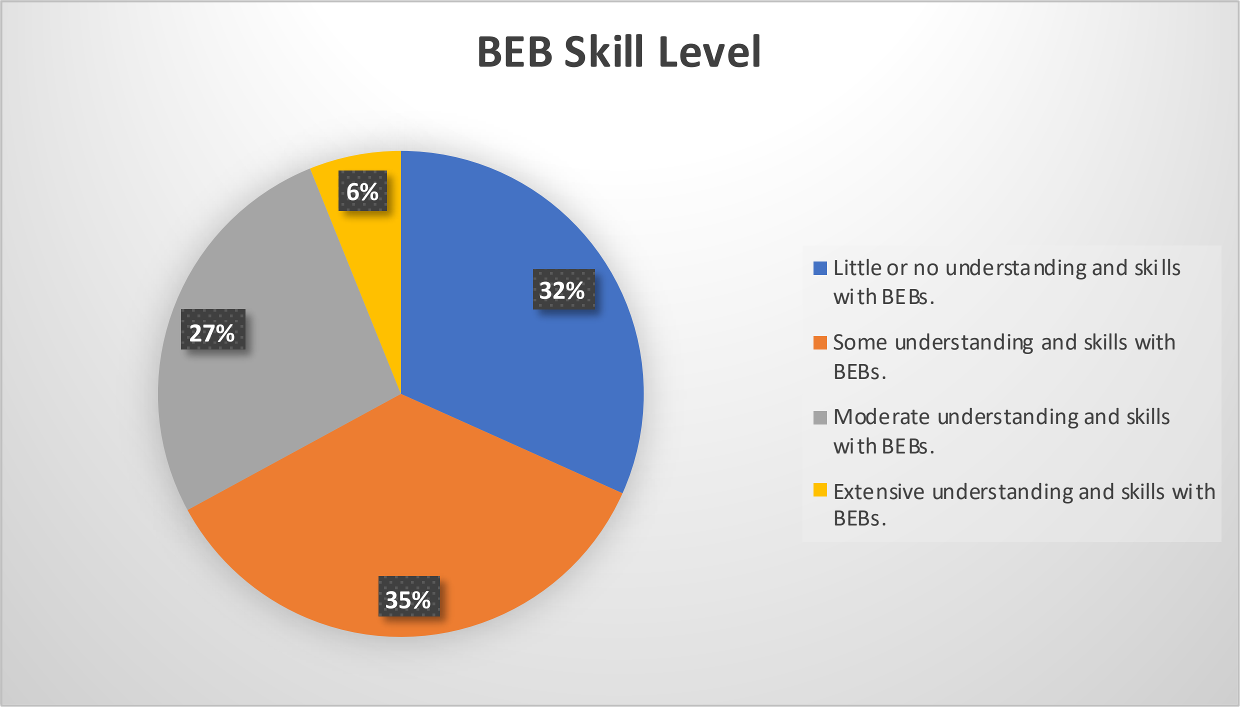
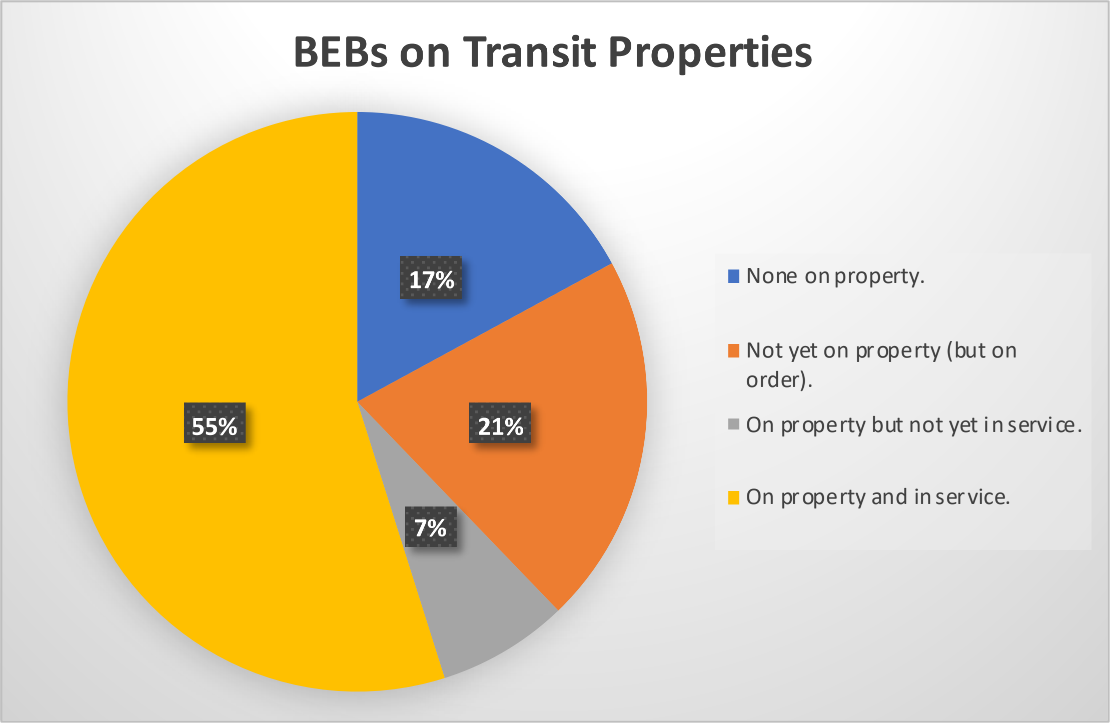
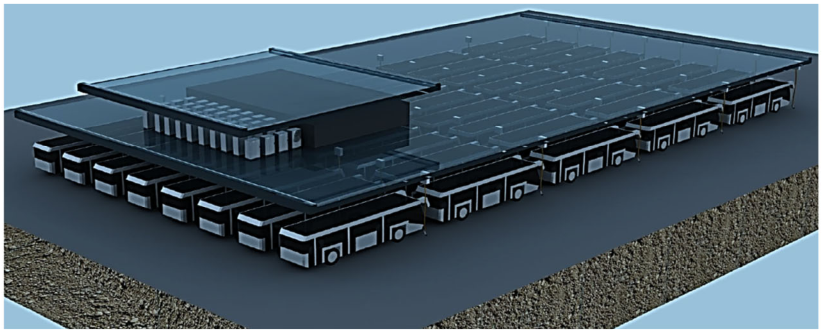
Thank you, I'll take questions now.

John moderates questions and answers. **[Launch poll]**


BEB Skill Level
6%
32%
27%
35%
Little or no understanding and skills with BEBs.
Some understanding and skills with BEBs.
Moderate understanding and skills with BEBs.
Extensive understanding and skills with BEBs.


BEBs on Transit Properties
17%
21%
7%
55%
None on property.
Not yet on property (but on order).
On property but not yet in service.
On property and in service.



Fundamentals Of BATTERY ELECTRIC BUSES

Charging Considerations and Technology

March 2021

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Presenter and Topics

In this presentation, we will:

- Identify transformers and switchgear
- Discuss charger manufacturers
- Explain communications to chargers
- Examine smart charging

David Warren
Director of Sustainable Transportation
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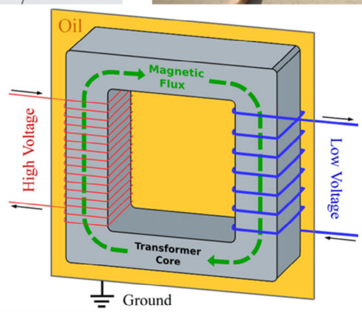
In this presentation, we will:

- Examine transformers and switchgear
- Chargers Manufacturers
- Explain communications to chargers
- Examine smart charging

Transformers

- Transfers electrical energy from one electrical circuit to another.
- Isolates the primary electrical grid from the secondary service to customers.
- Core and wire windings.
- Utility typically proves transformer and meter.



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- A transformer is a passive electrical device that transfers electrical energy from one electrical circuit to another.
- A transformer isolates the primary electrical grid from the secondary service to customers.
- Transformers are made up primarily of a core and wire windings.
- The Transformer and Meter are typically provided by the Utility.

Switchgear

- Composed of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.
- Used to de-energize equipment to allow work to be done and to clear faults downstream.

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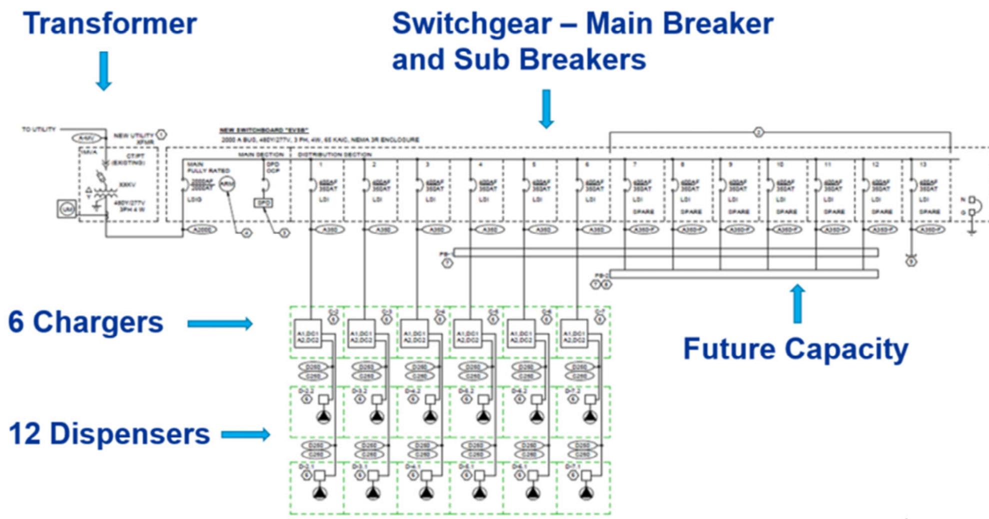
- In an electric power system, switchgear is composed of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.
- Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream.

Transformer and Switchgear Wiring to Chargers

Example



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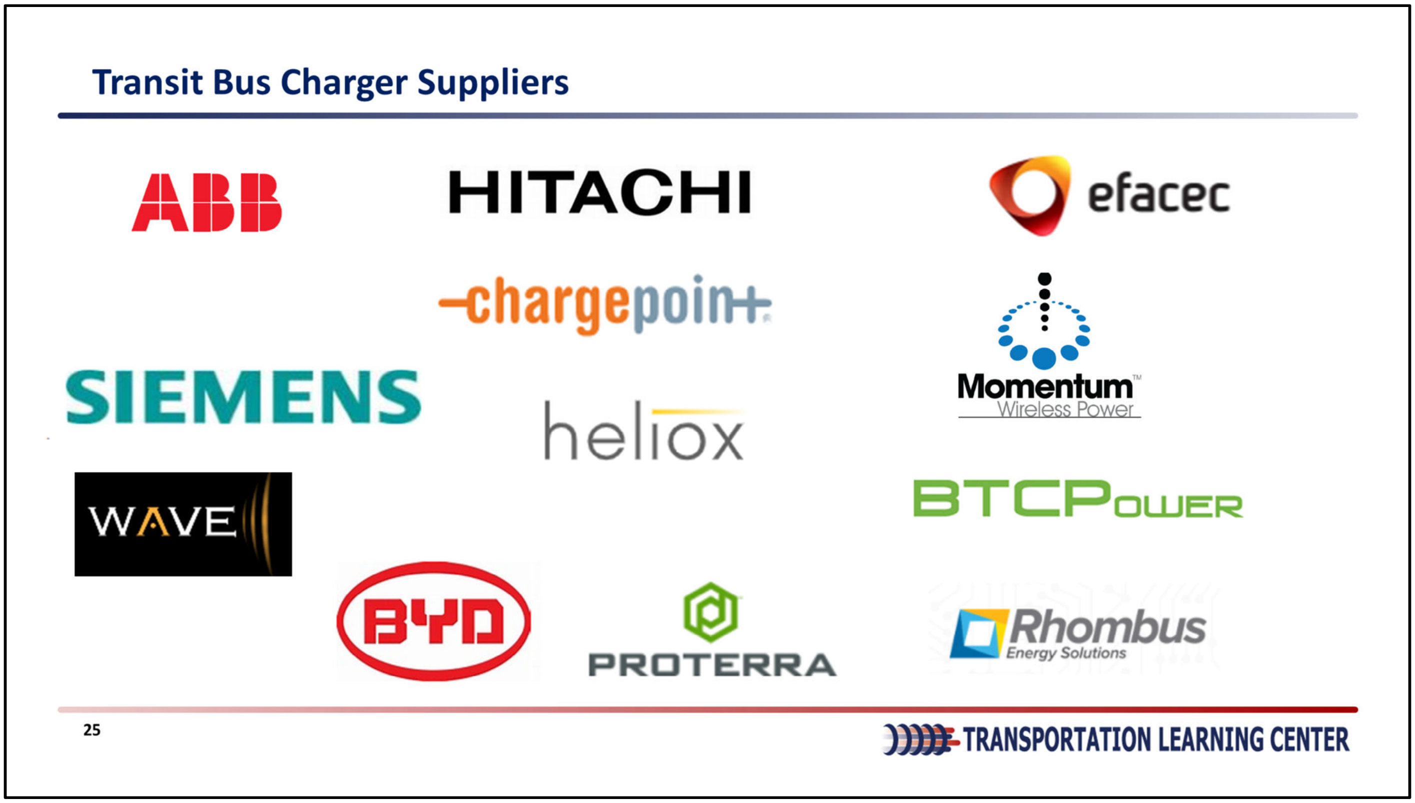
Example of transformer and switchgear wiring to chargers



Bus charger suppliers

Overhead On-Route Charging Process

Pantograph down (charge rails on bus)

Arrival: 0 min

- Driver stops at parking reference.
- Parking brake is activated.
- Safety checks.
- Pantograph lowered onto bus rails.
- If the bus is in the correct position, wireless communication between the bus and the charging station begins.
- Bus then Initiates charging.

Charging

- Driver notified that charging session started.
- Main circuit of charger switched on.
- Bus batteries are connected to charger.
- Continuous monitoring of charging begins.
- At the end of the charging session the driver releases the parking brake to stop power transfer.

Departure: 6 min

- The pantograph is raised and charger notifies bus when complete.
- The bus is able to depart the parking zone.

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Overhead on-route charging process
– Pantograph Down (Charge Rails on Bus)

Depot Charger Installation Example

Source ABB

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Example of depot charger installation

Depot Charger Technical Spec Example

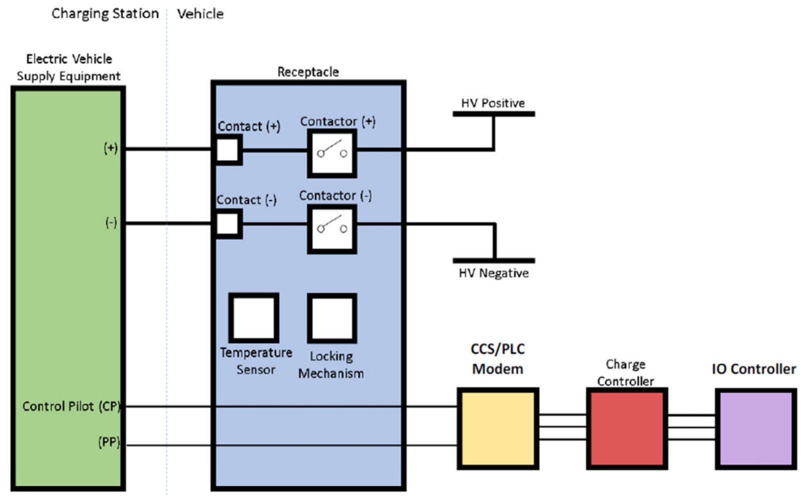
Technical specifications			
Configurations		HVC 100C	HVC 150C
Maximum output power		100 kW	150 kW
AC input voltage		UL: 3-phase, 480Y/277 VAC +/- 10% (60 Hz) CSA: 3-phase, 600Y/347 VAC +/-10% (60 Hz)	
AC input connection		L1, L2, L3, GND (no neutral)	
Rated input power		117 kVA	170 kVA
Rated input current		UL: 132 A / CSA: 108 A	UL: 198 A / CSA: 168 A
Recommended upstream circuit breaker(s)		UL: 1 x 200 A / CSA: 1 x 150 A	UL: 1 x 250 A / CSA: 1 x 250 A
Output voltage range		150 – 850 VDC	
Maximum DC output current		166 A	200 A
Vehicle connection interface		CCS/Combo Type 1 Connector	
Cable length		3.5 m (11.5 ft) standard; 7 m (23 ft) optional	
DC connection standard		SAE J1772 - IEC 61851-23 / DIN 70121 - ISO 15118	
Environment		Indoor/Outdoor	
Operating temperature		Standard: -10 °C to +50 °C (de-rating characteristic applies) Optional: -35 °C to +50 °C	
Protection		Power Cabinet: IP54 – IK10 (equivalent to NEMA 3R) Depot Charge Box: IP65 - IK10	
Network connection		GSM/3G modem | 10/100 base-T Ethernet	
Compliance and Safety		CSA No. 107.1-16 and UL 2202 certified by TUV BA Rule 49 CFR Part 661.5 (Optional)	
Dimensions			
Power Cabinet	Dimensions (H x W x D)	2030 x 1170 x 770 mm / 79.9 x 46.1 x 30.3 in	
	Weight	1340 kg / 2954 lbs	
Depot Charge Box (without pedestal)	Dimensions (H x W x D)	800 x 600 x 210 mm / 31.5 x 23.6 x 8.3 in	
	Weight	61 kg / 134.5 lbs (with 7 m / 23 ft cable)	
Depot Charge Box (with pedestal)	Dimensions (H x W x D)	1914 x 600 x 400 mm / 75.4 x 23.6 x 16.3 in	
	Weight	181 kg / 398 lbs (with 7 m / 23 ft cable)	

Source ABB

Technical spec example of depot charger spec

Charging Sequence between Bus and Charger

Charging Seq
Unmated
Mated
Initialize
Cable Check
Precharge
Charge
Power Down
Unmated

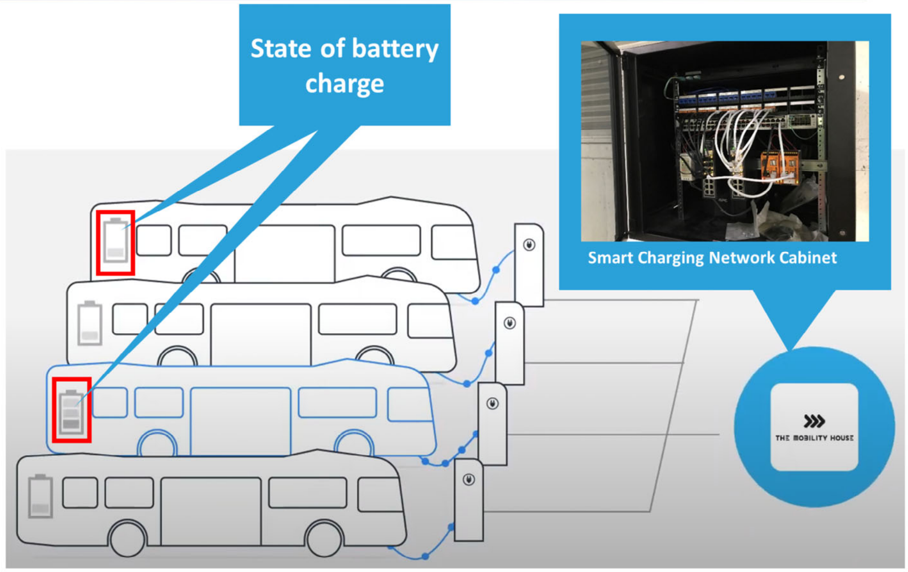


Plug-in Charging System Diagram

Charging sequence between bus and charger

Smart Charging

- Ensures that all vehicles are charged.
- Limits grid power usage based on user inputs.
- Prioritizes specific vehicles.
- Reports charging data and vehicle status.
- Provides alerts in case of charge failure



What is Smart Charging?

- Ensures that all vehicles are charged
- Limits grid power usage based on user inputs (Time, peak load, etc)
- Prioritizes specific vehicles based on user inputs and vehicle ID’s
- Reports charging data and vehicle status (SOC, power utilization, rates of charge, etc.)
- Provides alerts in case of charge failure

Questions and Answers

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NEW FLYER

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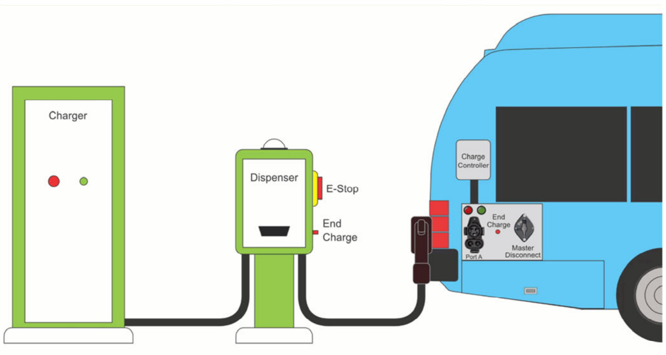
John moderates questions and answers.
[Poll results displayed]



Fundamentals Of BATTERY ELECTRIC BUSES

Charging Standards, Maintenance & Safety

March 2021

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Image courtesy of Proterra

Presenter and Topics

In this presentation, we will:

- Discuss charger / vehicle communications
- Examine current charging standards.
- List typical charging equipment maintenance procedures.
- Review charger safety precautions.

James Hall
Manager of Training
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PROTERRA

James Hall
Manager of Training, Proterra

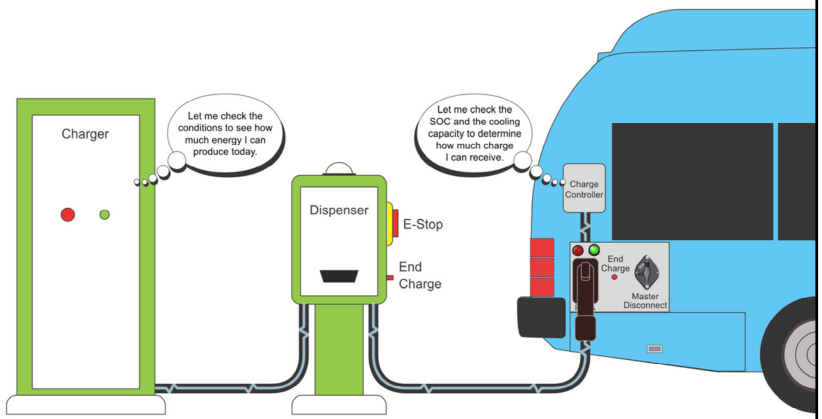
In this discussion, we will:

- Discuss charger / vehicle communications
- Examine current charging standards.
- List typical charging equipment maintenance procedures.
- Review charger safety precautions.

Charger / Vehicle Communication

How does it work?

- LV sensing circuit in built into charge port and cable.
- Plugging the charge cable into the vehicle's charge port completes the circuit.
- The charge controller on the vehicle and the charger to initiate a "handshake."



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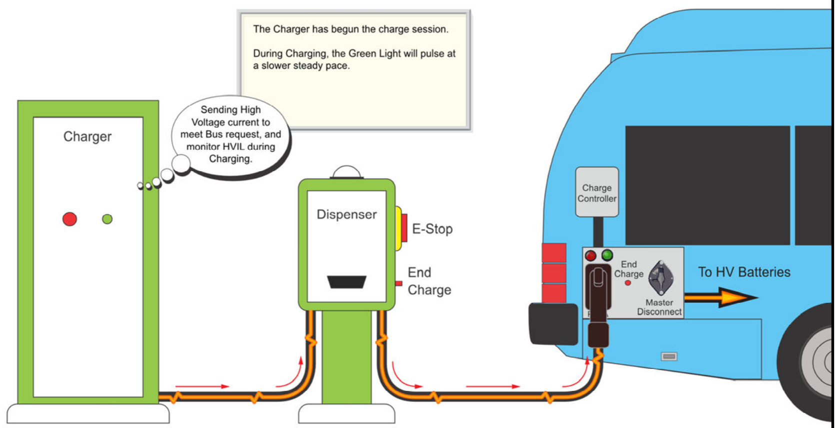
- How does it work?
  - A LV sensing circuit in built into both the vehicle port, and the charge cable.
  - Plugging the charge cable into the vehicle's charge port completes the circuit, prompting the charge controller on the vehicle and the charger to initiate a "handshake"
    - Tests isolation
    - Communicates SOC, allowable charge current, charger output capabilities
  - Supply equipment signals presence of AC input power
  - Vehicle detects plug via proximity circuit (thus the vehicle can prevent driving away while connected) and can detect when latch is pressed in anticipation of plug removal.
  - Control Pilot (CP) functions begin
    - Supply equipment detects plug-in electric vehicle (PEV)
    - Supply equipment indicates to PEV readiness to supply energy
    - PEV ventilation requirements are determined
    - Supply equipment current capacity provided to PEV
  - PEV commands energy flow
  - PEV and supply equipment continuously monitor continuity of safety ground
  - Charge continues as determined by PEV
  - Charge may be interrupted by disconnecting the plug from the vehicle, using end charge pushbuttons, and e-stops.

Charger / Vehicle Communication

- If all tests fall into acceptable parameters:
  - LV signal closes the HV output contactor(s) in the charger enabling HV charging.
  - **No HV is present until this point**
- HV isolation and other parameters are continuously monitored.



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Compare to GFCI.

- If all tests fall into acceptable parameters, a LV signal is sent to the HV output contactor(s) in the charger, closing the contacts to enable HV charging.
  - No HV is present at the charge cable until this point
- During the charging process, HV isolation and other parameters are continuously monitored. If at any point, a parameter exceeds the specified limits, the charge sequence is ended.

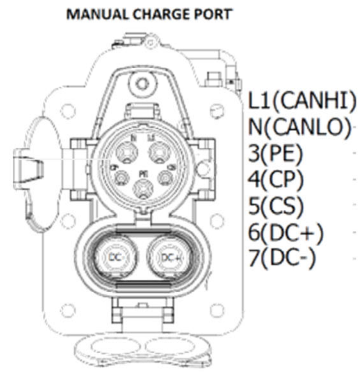
Charging Standards

- J-1772
  - Plug-in
- J-3068
  - AC / DC
- J-3105
  - Overhead
  - 3 versions
- J-2954-2
  - Inductive

Charging Standards

J-1772
Plug-in

- Most common depot application in North America.
- Provides communication and charging connections in one form
- AC / DC Charging



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- Provides communication and charging connections in one form
- AC / DC Charging
  - AC Level 1 – 1.44 to 1.92 kW
  - AC Level 2 – 19.2 kW
  - DC Level 1 – 80 kW
  - DC Level 2 – 400 kW
- Most common depot application in North America
- The J1772 standard includes several levels of shock protection, ensuring the safety of charging even in wet conditions. Physically, the connection pins are isolated on the interior of the connector when mated, ensuring no physical access to those pins. When not mated, J1772 connectors have no power voltages at the pins, and charging power does not flow until commanded by the vehicle.
- The ground pin is of the first-make, last-break variety.
  - If the plug is in the charging port of the vehicle and charging, and it is removed, the shorter control pilot pin will break first causing the power relay to open, stopping current flow. This prevents any arcing on the power pins.

Charging Standards

J-3068
AC/DC

- Not common in heavy-duty and/or transit applications.
- Considered CCS, Type 2
- Centered around AC charging
- Single-phase up to 277VAC
- Three-phase up to 600VAC

- Considered CCS, Type 2
- Centered around AC charging
    - Single-phase up to 277VAC
    - Three-phase up to 600VAC
- Not common in North American heavy-duty and/or transit applications.
- Mostly found in Europe and South America

Charging Standards

J-3105
Overhead

- Two pantograph options:
  - Roof-mounted (bus-up)
  - Inverted (bus-down)
- Both on-route and depot charging options.
- Roof-mounted allows option to install more powerful chargers for a faster charge time.

Roof mounted

Inverted

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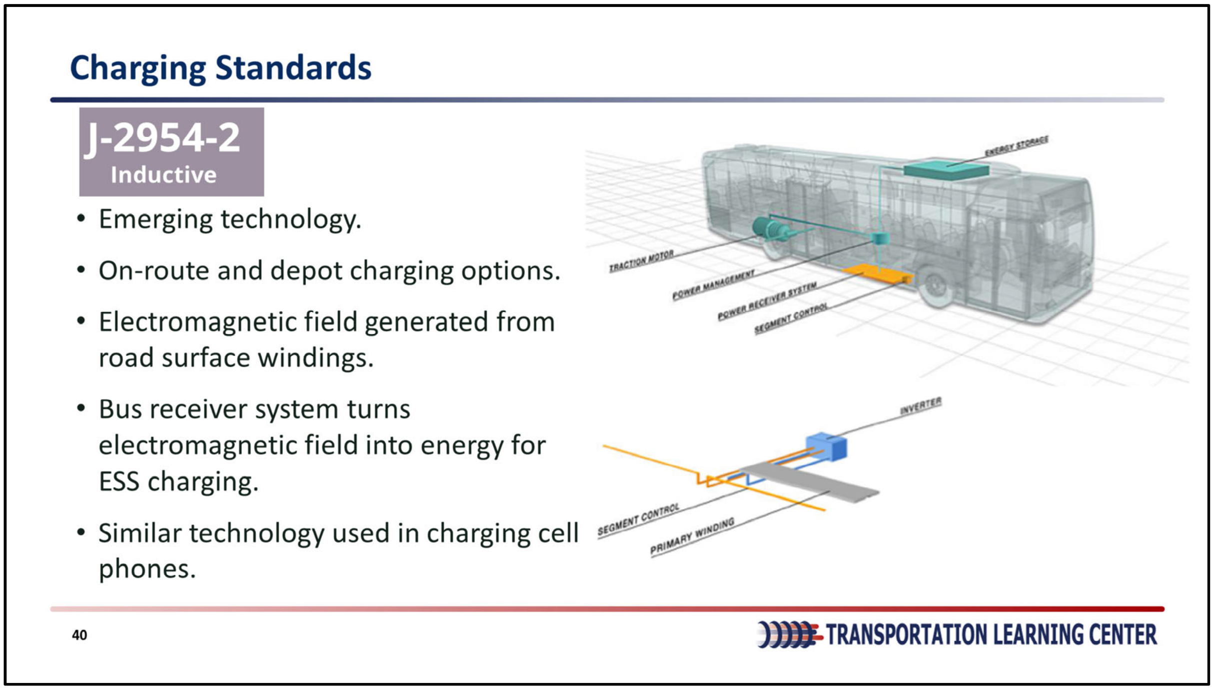
- 2 options currently available: roof-mounted pantograph (bus-up), and inverted pantograph (bus-down)
- Allows for both on-route and depot charging options.
- Roof-mounted overhead charging options allow for the option to install more powerful chargers for a faster charge time.
- Both options utilize SAE standard J3105
- Up to 600kW



https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0060.pdf
FTA Research: Review and Evaluation of Wireless Power Transfer (WPT) for Electric Transit Applications – FTA Report No. 0060

- Currently an emerging technology that is continuing to be refined.
- Allows for both on-route and depot charging options.
- Windings built into the road surface generate an electromagnetic field.
- A receiver system under the floor of the bus turns the electromagnetic field into energy that can be supplied to charge the ESS.
- Similar to the inductive charging technology used to charge most modern cell phones.
- Not common in current transit applications.

Charger Safety Precautions

Basics

- Disconnect **ALL** input/output sources, and use proper caution before opening or working on equipment.
- **Verify the absence of voltage with a proper measuring instrument before servicing equipment.**
- DC-link capacitors can hold a charge after being disconnected from grid and DC input load.

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Now, let’s take a look at the safety precautions associated with chargers, prior to examining the maintenance procedures.

- Disconnect **ALL** input/output sources, and use proper caution before opening or working on equipment.
- **Verify the absence of voltage with a proper instrument before servicing equipment.**
- DC-link capacitors can hold a charge after being disconnected from grid and DC input load.
- Be sure to wait the appropriate amount of time before servicing.

Charger Safety Precautions

Basics

- Remove jewelry, watches, rings, and metal objects from your person
- Use anti-static wristbands when servicing electronic components.
- Be sure that all electrical connections and connectors are properly installed and torqued.

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- Remove jewelry, watches, rings, and metal objects from your person
- Use anti-static wristbands when servicing electronic components.
- Be sure that all electrical connections and connectors are properly installed and torqued.

Charger Safety Precautions

PPE to service charging equipment

- Arc-flash suit
- Arc-flash face shield and hard hat
- Balaclava or arc-flash hood
- Safety glasses
- Ear plugs
- Rubber insulating gloves with leather overlays
- EH-rated safety shoes

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- To properly service charging equipment, you will need:
  - Arc-flash suit
  - Arc-flash face shield and hard hat
  - Balaclava or arc-flash hood
  - Safety glasses
  - Ear plugs (arc-flashes can generate sound waves equivalent to a sonic boom, which can damage or destroy your eardrums)
  - Rubber insulating gloves with leather overlays
  - EH-rated safety shoes

Charger Safety Precautions

Tools and equipment

- Appropriately rated DMM
- Lock-out devices for:
  - Breakers / switchgear
  - Charger
  - Dispenser
  - Charge cable(s)
- Anti-static wrist strap

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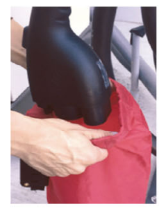
Note: In session 2 we discussed these tools and LOTO procedures, and this information can be found on the TLC website.

- Tools and equipment for charger service:
  - Appropriately rated DMM
  - Lock-out devices for:
    - Breakers / switchgear
    - Charger
    - Dispenser
    - Charge cable(s)
  - Anti-static wrist strap
- Remember: while not necessarily considered tools or equipment, you will also need a safety observer with the same level of PPE.

Charger Safety Precautions

Lockout/Tagout

1. Disconnect the input AC source.
    - Apply lock and tag
2. Disconnect the load (vehicle) from the charger.
    - Place charge cable in a lock-out bag, and apply lock and tag
3. Inspect PPE and tools, then “gear-up”.
4. Confirm the recommended amount of time has passed prior to opening charging equipment.



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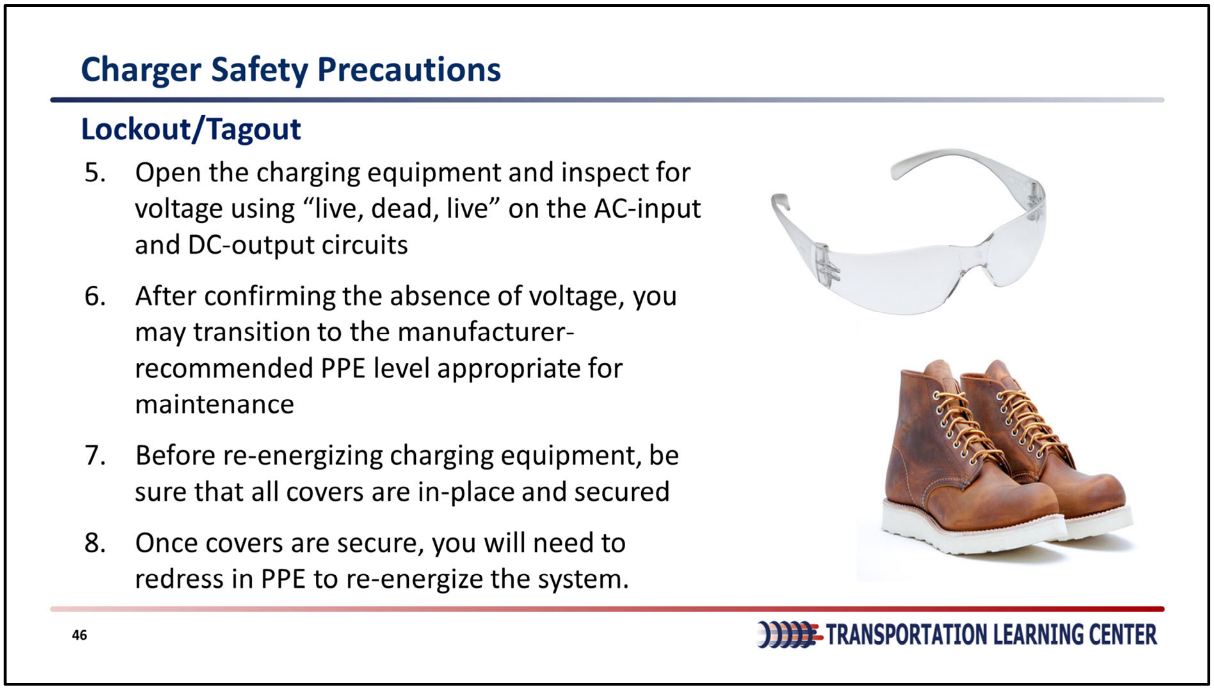
These are general LOTO procedures and you should always follow manufacturer and facility procedures.

1. Disconnect the input AC source
    - Apply lock and tag
2. Disconnect the load (vehicle) from the charger
    - Place charge cable in a lock-out bag, and apply lock and tag
3. Inspect PPE and tools, then “gear-up”
4. Confirm the recommended amount of time has passed prior to opening charging equipment



5. Open the charging equipment and inspect for voltage using “live, dead, live” on the AC-input and DC-output circuits
    - Remember: you will need to change the meter setting to the appropriate voltage-type
6. After confirming the absence of voltage, you may transition to the manufacturer-recommended PPE level appropriate for maintenance
    - In most cases, this will include a minimum of EH-rated safety shoes and safety glasses, however you should always refer back to the maintenance procedures for the most accurate information
7. Before re-energizing charging equipment, be sure that all covers are in-place and secured
8. Once covers are secure, you will need to redress in PPE to re-energize the system.

Charging Equipment Maintenance

Monthly Inspection Procedures	
Overall	Confirm no indications of failure.
Cables	Perform a visual inspection. Look for discoloration or chaffing of visible cables.
Lugs	Perform a visual inspection. Check for looseness. Note: Torque putty on lugs will provide an indicator.
High Voltage Wiring	Perform a visual inspection of all the high voltage wiring.
Control Wiring	Perform a visual inspection. Check that wiring moves freely with actuation and that wires are not chaffing.
Intake/Exhaust Fans And/or Blowers	Inspect for proper operation, and clear dust/debris.

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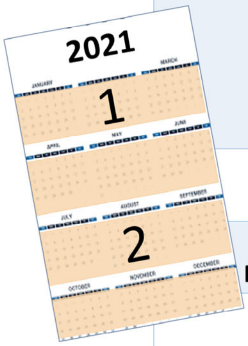
Now, let’s take a look at some of the general maintenance procedures you will need to perform prior to following the steps to re-energize the system.

- Overall – During inspection, confirm there are no indications of failure
- Cable Inspection - Perform a visual inspection and look for discoloration or chaffing of visible cables.
- Lug Inspection - Perform a visual inspection and look for indications that any lugs are loose.
    - Note: Torque putty on lugs will provide an indicator.
- High Voltage Wiring - Perform a visual inspection of all the High Voltage wiring.
- Control Wiring - Perform a visual inspection and ensure that the control wiring is allowed to move freely with actuation and that wires are not chaffing.
- Intake/Exhaust Fans and/or Blowers – Inspect for proper operation, and clear dust/debris. Include information about inspecting for vermin and other animals (nests)

Charging Equipment Maintenance



Bi-annual Inspection Procedures	
Intake Filters	Perform a visual inspection and clean or replace as needed. Note: Depending on the environment intake filters may need to be cleaned or replaced more frequently than 6-month intervals
Intake and Exhaust Vents	Perform a visual inspection and clean vents of debris that may reduce or obstruct air flow
Charger and/or Dispenser Cabinet	Vacuum interior of accumulated dust and/or and inspect for infestations of bugs, rodents, etc.
AC/DC Terminals	Inspect and re-torque as needed. Be sure to re-torque according to the appropriate maintenance and repair manual.

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- On top of monthly inspection procedures, you will also…
- Intake Filters – Perform a visual inspection and clean or replace as needed.
  - Note: Depending on the environment intake filters may need to be cleaned or replaced more frequently than 6-month intervals
- Intake and Exhaust Vents – Perform a visual inspection and clean vents of debris that may reduce or obstruct air flow
- Charger and/or Dispenser Cabinet - Vacuum interior of accumulated dust and/or and inspect for infestations of bugs, rodents, etc.
- AC/DC Terminals – Inspect and re-torque as needed. Be sure to re-torque according to the appropriate maintenance and repair manual.

Summary

You should now be able to…

- Explain charger / vehicle communication.
- Identify the various charging standards.
- List basic charger maintenance steps.
- Review generic charger safety precautions.

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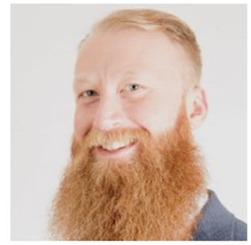
- You should now…
  - Understand charger / vehicle communication.
  - Be able to identify the various charging standards.
  - List basic charger maintenance steps.
  - Be familiar with generic charger safety precautions.

Questions and Answers



James Hall
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PROTERRA

John moderates questions.

Fundamentals Of BATTERY ELECTRIC BUSES

Facility and Operations

March 2021

https://new.abb.com/about/our-businesses/electrification/e-mobilitysolutions/ebus-depot

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Facility and Operations

In this presentation we will:

- Examine charger selection and specification.
- Discuss scaling up charging for large fleets.
- Discuss managed charging to control fuel costs.

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cte

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About CTE

WHO WE ARE

501(c)(3) nonprofit engineering and planning firm

OUR MISSION

Improve the health of our climate and communities by bringing people together to develop and commercialize clean, efficient, and sustainable transportation technologies

PORTFOLIO

$600+ million

- *Research, demonstration, deployment*
- *90 Active Projects totaling over $316 million*

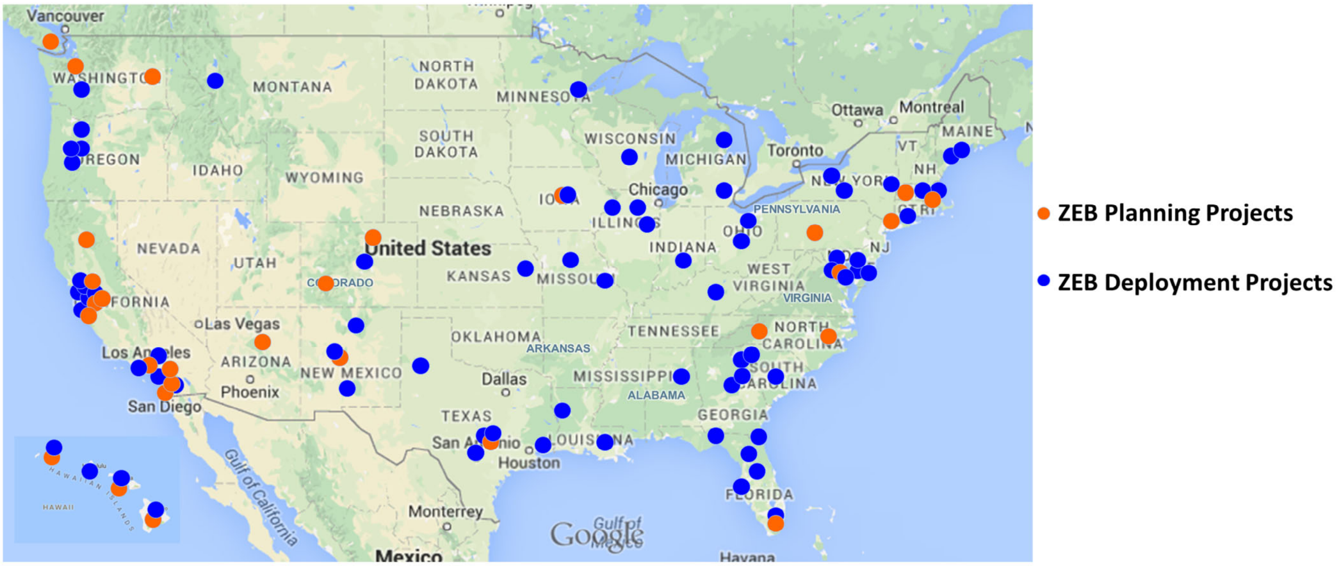
OUR FOCUS

Zero-Emission Transportation Technologies

NATIONAL PRESENCE

Atlanta, Berkeley, Los Angeles, St. Paul

CTE's Zero-Emission Bus Projects



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CTE has supported over 70 transit agencies across the country to deploy zero-emission buses, and has supported over 25 transit agencies to develop full fleet transition plans.

Charger Selection

Fueling infrastructure must "fit" your planned ZEB service

- **Up front planning**:
  - ***Where?*** *At the depot or on-route?*
  - ***How?*** *With plug-in chargers, overhead chargers, inductive chargers?*
  - ***How?*** *At low or high power?*
  - ***When?*** *Overnight, mid-day, both?*
- With more BEB deployments, your transit agency will probably use a mix of bus OEMs, charger OEMs, and charging approaches.

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- A lot of up front planning is required to make sure that the charging approaches will allow transit agencies to meet their planned service needs
- There were a few questions in the Q&A about selecting the correct size of the vehicle, and vehicle range. Because there are so many factors that can impact BEB efficiency and range, we conduct route modeling with the transit agencies that we work with to make sure the buses can complete the planned service, but its equally as important to model charging to make sure that your buses will charge either in the depot or on route in enough time to make service
- As you've seen from the other presentations, there are a lot of options when it comes to charging. There are chargers that you can have 1 charger for each bus. Other chargers are higher power and have multiple dispensers that can charge multiple buses sequentially or simultaneously.
- All of these factors go into the decision-making about how the buses will be operated and what types of chargers will be deployed.
- The BEB market is still maturing, but it probably won't be unusual for a transit agency to operate a mix of bus and chargers from different OEMs.

Technical Specifications

- ➢Charger type and installation location
- ➢Compliance with standards
- ➢Compatibility with buses
- ➢Charging rate and charging window
- ➢Alignment guides
- ➢Power distribution requirements
- ➢Data availability and monitoring
- ➢Charger management and backup systems

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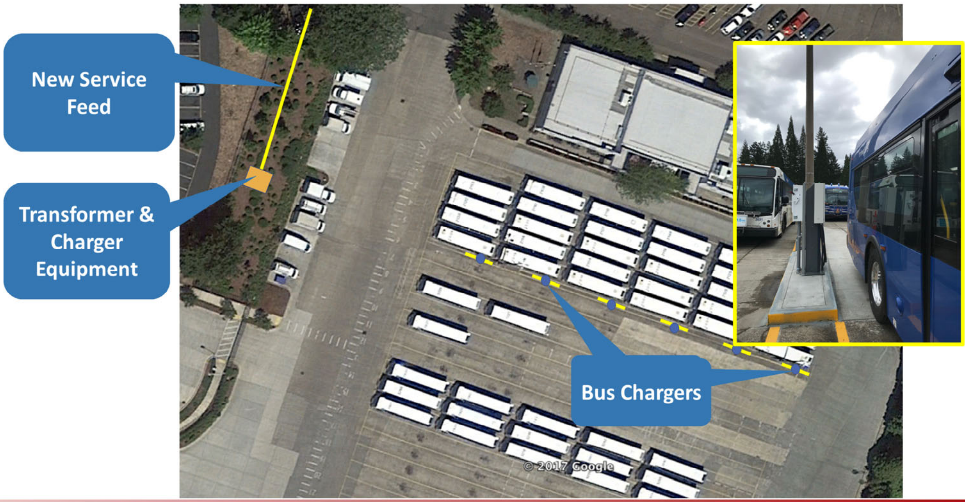
- Some considerations for technical specifications for chargers are shown here. To describe a few:
- Specify charger types, and as much information about the proposed installation location as possible
- Make sure that the chargers are compliant with the standards that James described
- You'll want to describe the charging rate – it might be the time that you have available to fully charge your bus overnight, or with on-route charging, you might indicate how many minutes per hour your bus will charge
    - Depot chargers: time available to fully recharge from the minimum SOC
    - On-route: Available time to charge per hour per bus (including time to dock and undock) and energy consumption of each "loop"
- You'll also want to work with your utility to describe the current available power and distribution assets (e.g., transformers, switchgear, metering) at the planned charge location, and any required upgrades.
- You'll also want to think about your data monitoring needs. There's a lot of data available for buses and charging. Some transit agencies like to have charger faults or errors be emailed or texted to facility staff so they can stay on top of any buses that aren't charging when they should be.

Infrastructure Considerations

Charging infrastructure must "fit" your planned BEB service, but it must also "fit" your available space.

Infrastructure Considerations



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This is an example bus yard for a transit agency that procured 6 battery electric buses. Most bus yards have limited space available, and buses are parked nose to tail, so it can be challenging to figure out where to put the charging equipment. In this situation, there was a space between parking rows where there were some light poles, so the dispensers were able to be put next to the buses on this row, without compromising any other space.

Usually with your first few buses, you're able to come up with a solution where you can throw the equipment. But it gets harder when you're looking at full fleets.

Where do the chargers go?

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This is an overhead view of a garage at King County Transit; all of these buses are parked nose to tail, there is no extra space for chargers right next to the buses. There aren't any examples of full large fleets of ZEBs in the U.S. so we don't know what the best practices are yet.

Better?

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At the Schiphol airport in Amsterdam uses these fast overhead chargers as depot chargers for their buses. This certainly saves space, but is this better? We really don't know yet. It's really important to be thinking about what your infrastructure needs will be at the end of your ZEB fleet transition to make the best decisions possible for your earlier deployments.

Understanding and Managing Electricity Costs

Transit agencies with BEB fleets may become one of their electric utility's largest customers.

Managing fuel costs is as important as ever, but it is different with electricity than it is with diesel or gas.

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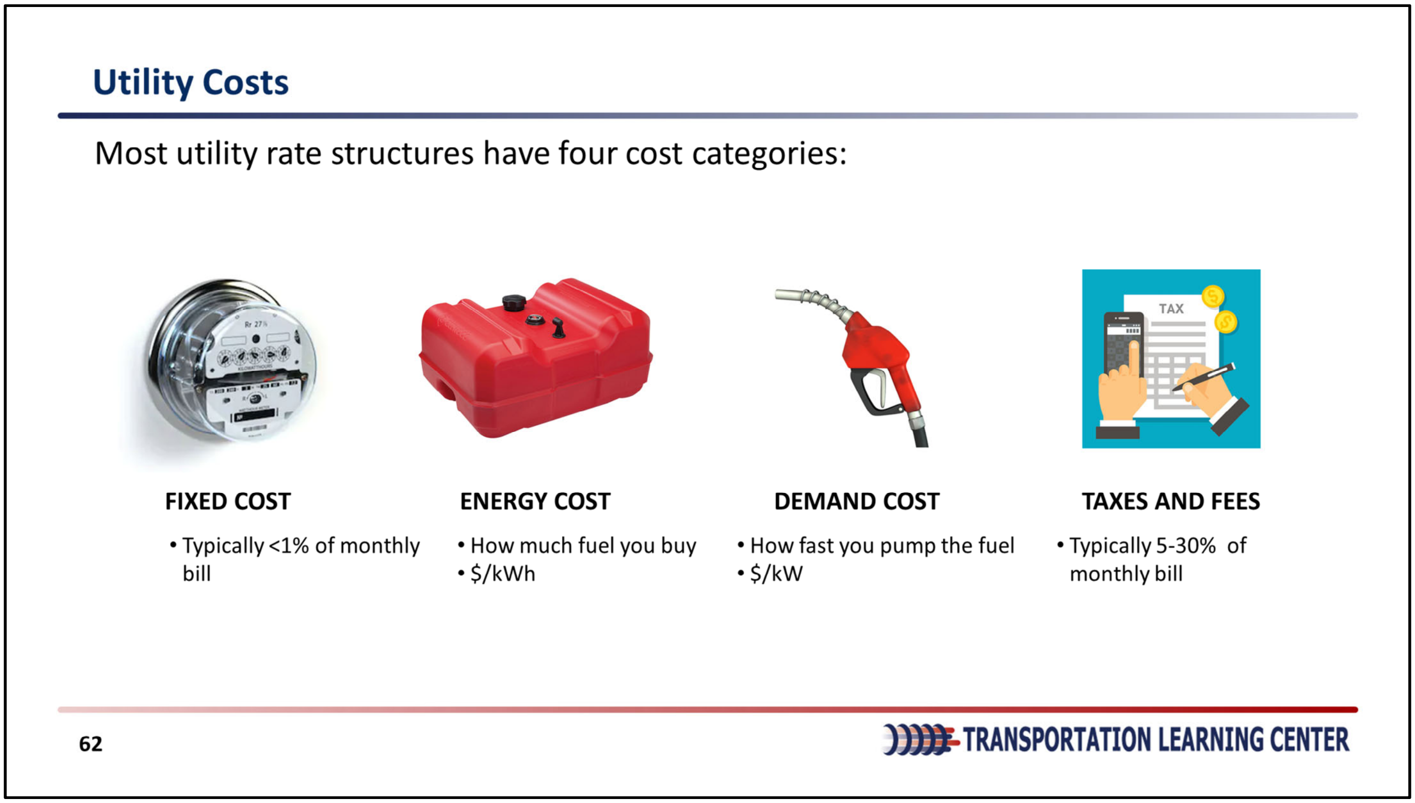
Transit agencies haven't historically been big electricity users – usually the bus wash and lights are the biggest drivers. But a transit agency with BEBs will likely become one of the largest users in a utility's service area.

Managing fuel costs is always really important, and it's especially important for ZEBs, because the capital costs are higher than diesel buses. But it is a different approach with electricity, and will require a lot of coordination with your electric utility.



I want to cover the basic cost categories of an electricity bill, in order to talk about the things that we can manage.

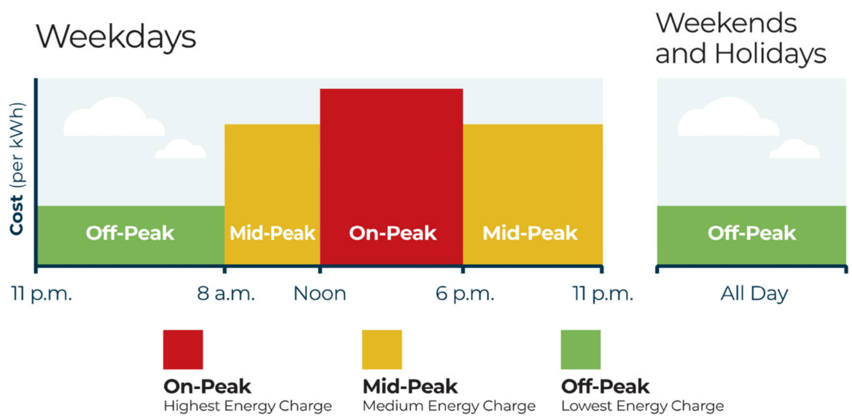
- Fixed costs are monthly fee for having a meter, and are typically a small portion of the bill
- Energy costs is a fee per unit of energy that you buy, think about how many gallons of diesel you buy, but it's now kWh
- Demand costs is a charge for how fast you fuel. This is a charge by kW, and is driven by how many chargers are running at the same time, and the power of those chargers. The catch with demand charges is that it's usually based on the highest 15-30 minute demand in the billing period. So you can have a really good plan to manage charging to keep your overall demand low, but if you have one really bad day you need to charge more buses, that can blow up your bill for the entire month.
- Taxes and fees vary by region or utility and can range anywhere from 5-30% of your monthly bill.

We're going to focus on the energy and demand costs as what we can manage with BEB charging.

Common Electricity Rate Structure

Rates may vary by:

- Day of week
- Time of day



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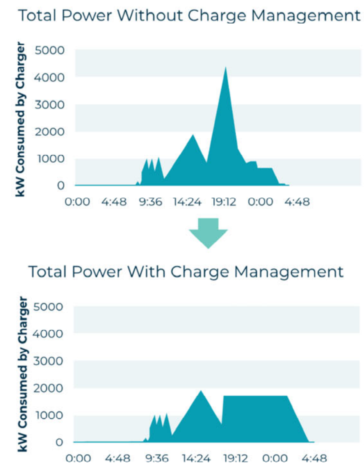
Time of use rates are a common electricity rate structure that we see with transit agencies, and can be hard to manage.

How these rates work are that electricity might be more expensive during the utility's peak times, and less expensive during off-peak times. So if you're able to charge in only those off-peak times, you can save a lot of money.

But the priorities of your electric utility and your transit agency aren't always aligned. Utilities want to manage their grid assets and lower their peaks, but transit buses have to be ready at a specific time for service, so it may not be possible for you to avoid charging at those peak times.

Charge Management

- **Operational procedures – Manually plug/unplug buses**
- **Third-party software – Automatically control chargers**
  - Limit peak overall demand
  - Optimize charger power and timing based on bus scheduling
  - Prioritize buses/chargers
  - Open Charge Point Protocol (OCPP) compliance to manage chargers from different OEMs



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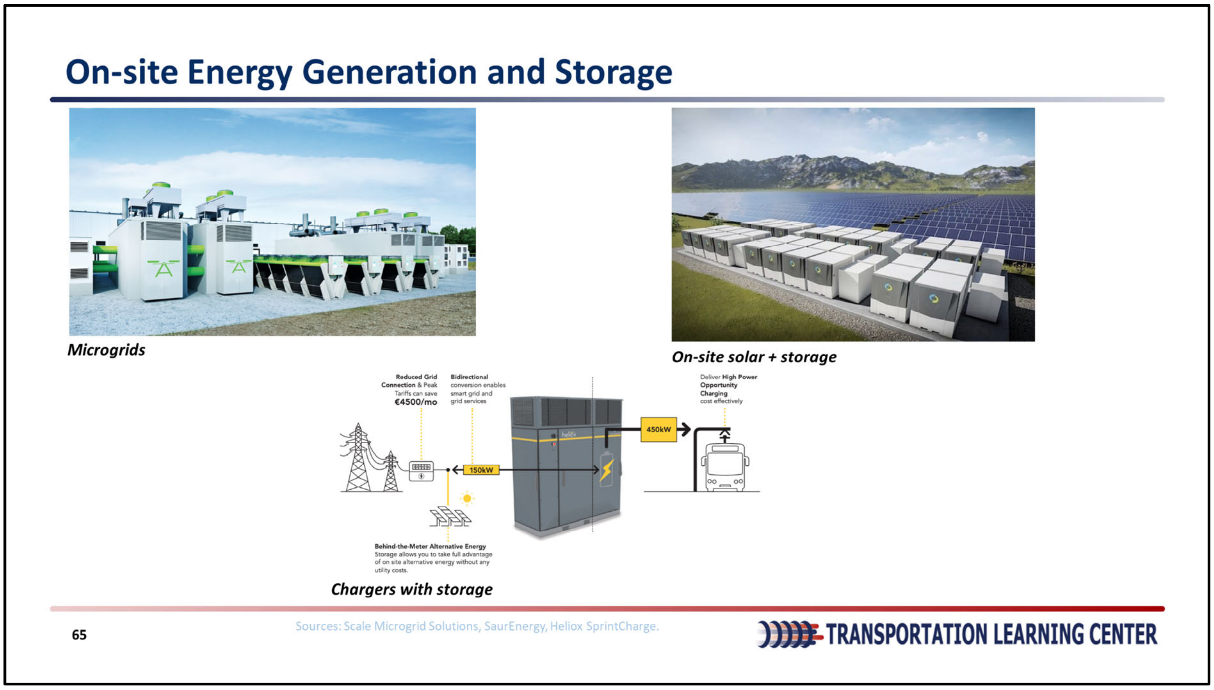
You've heard about charge management or smart charging a few times today, but this is your best bet to help you manage your operational costs. The goal of charge management is to limit peak demand at your facility but still meet all service requirements.

Charge management can be operational procedures – it could be waiting to plug in buses until the peak period is over.

Or you can use a third-party software to automatically control groups of chargers, based on your service needs and electricity rate schedule. Like I mentioned at the beginning of my presentation, it might not be uncommon for a transit agency to have multiple types of chargers, so there is this open charge point protocol that most chargers are compliant with, which would allow a third party vendor to talk to and control different types of chargers.

The chart on this slide shows the before and after of charge management. The top image shows a scenario where buses go out in the morning, some come back throughout the morning and afternoon for a mid-day charge, and then around 7pm, a lot of buses come back in, they're immediately plugged in, and you get this big peak.

The bottom image shows the same mid-day charge scenario, but having some controls on the chargers to limit that evening peak in half. But in both scenarios, the buses complete charging at the same time.



Some transit agencies are interested in having on-site power generation or storage – these options can provide a few benefits:

- Shave peak demand
- Reduce the carbon intensity of your electricity consumption
- Ensuring that you have the electrical capacity for all of your buses – we've heard from transit agencies that their utility can't give them the grid power available to run all of their chargers at once.
- Resilience during a power outage

Summary

•You should now understand that:

- Up-front planning is critical to select the right chargers for your application
- Charging for a full fleet is challenging – keep your end goals in mind during early deployments
- Effective charge management can lower operational costs without impacting service

Questions and Answers

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John moderates questions and answers.

Wrap Up

- Session available for download.
- Evaluate today's session.
- Thanks to all attendees and presenters!