Bus & Truck Charging Group Meeting Presentations

June 12, 2018

Columbus, OH

BUS AND TRUCK CHARGING INTERFACE GROUP

Hosted by American Electric Power (AEP)
1 Riverside Plaza, Columbus, Ohio 43215

Tuesday, June 12, 2018

Agenda

	Room Location: PODS ABCD	
1:00 PM	Welcome and Introductions	Mark Kosowski, EPRI
1:15 PM	Lessons Learned for Transit and High Power	Paul Stith, Black and Veatch
1:45 PM	Cutric Project Overview	Josipa Petrunic, Cutric
2:15 PM	Review and Status of J-3105 Automatic Charging	Mark Kosowski, EPRI
2:30 PM	Bus Depot Charging in Amsterdam	Greg Scearce, Schunk
3:00 PM	**Break**	
3:30 PM	BYD Electric Bus and Charging	Jason Yan, BYD
4:00 PM	APTA Overview and Update	Lisa Jerram, APTA
4:30 PM	Discussion and Review next meeting	All
5:00 PM	Adjourn	All
6:00 PM	Casual Dinner Reception	***Buca di Beppo*** *343 N Front St* *Columbus, OH 43215* (614) 621-3287

The minutes and presentations from the meetings are located at the link below for your reference.

https://www.epri.com/#/busandtruck

Lessons Learned:
Transit & High Power Charging

EPRI IWC Bus & Truck – June 12,2018

Paul Stith
Director, Strategy & Innovation
Transformative Technologies

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BLACK & VEATCH

Lessons Learned: Transit & High Power Charging

- About Black & Veatch
- Electric Vehicle Infrastructure Projects

- Stakeholder Alignment & Project Goals
- Project Approaches & Risk Models
- Paperwork, Process & Permissions
- Project Scope & Schedule Management
- Equipment, Equipment, Equipment
- Rocks, Water, Trees, Traffic & Other Discoveries
- Utility Interconnection & Power Delivery Schedule

> Clients: Vehicle OEMs, Transit Agencies, Fleet Operators, Hardware OEMs, EV Network Service Providers & Utilities

About Black & Veatch

Power Infrastructure / Clean Energy

Transformative Technologies

Mission Critical Facilities

11,000+ Professionals

110+ offices

Six continents

7,000 active projects worldwide

$3.4 Billion

in revenue in 2017

Safety Performance

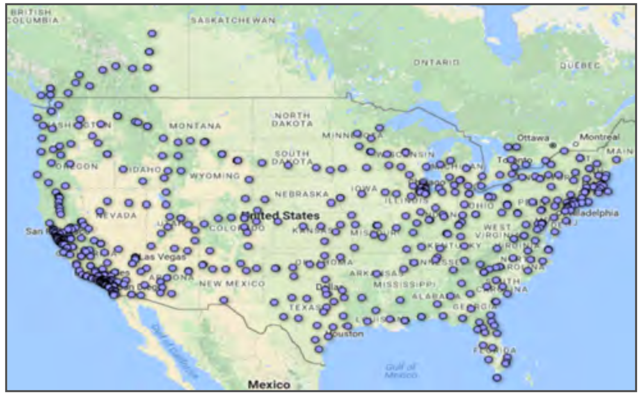
0.37

Recordable Incident Rate

0.06

Lost Time Incident Rate

Transformative Technologies



Over 1,000 250KW+ High-Power Sites

Scaling Distributed Clean Energy Infrastructure

Electric Vehicle Infrastructure

Hydrogen Infrastructure

Energy Storage Networks

Emerging Distributed Technology

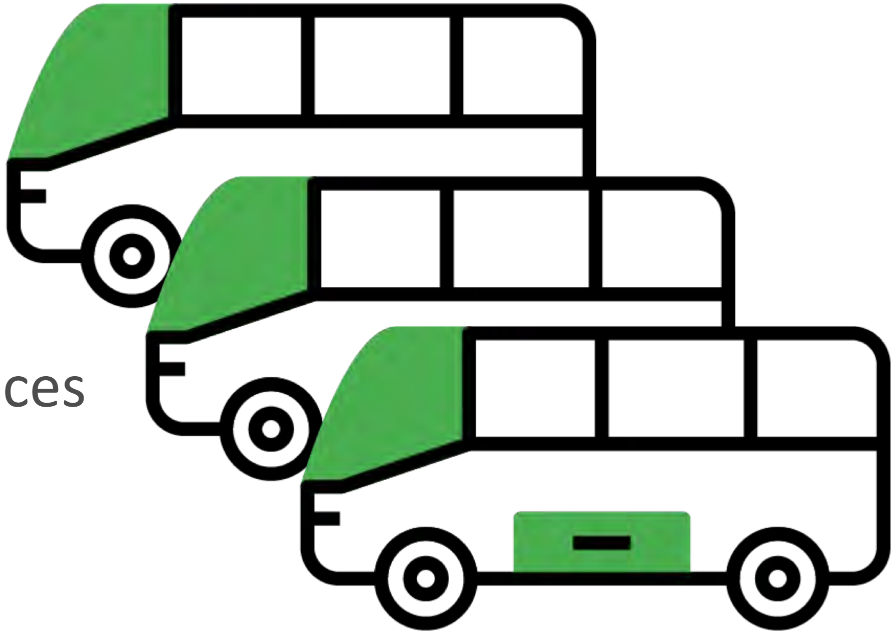
Autonomous, Connected Vehicle Infrastructure

We build complex networks faster

Electric Transit & School Bus Infrastructure Projects

- Multiple Technologies, School Districts & Transit Agencies
- Over-Head 350-500 KW On-Route
- Plug-In 25-150KW Depot Charging

- Turn-Key Engineering, Permitting, Construction
- Roadmap Development, Capacity Planning
- Owner's Engineer, Construction Administration Services
- Technology & Site Feasibility Assessments
- Energy Storage & Renewables Integration



> 30+ Megawatts Charging Capacity in Projects

Electric Vehicle Fleet Infrastructure Projects

- High-Density Charging Facilities
- 10s to 100s of Charging Stations
- 2 – 20+ Megawatt Power Requirements

- Energy and Communications Infrastructure
- Site Criteria Development & Selection
- Utility Planning & Coordination
- Vendor / Equipment Selection
- Operations Space and Workflow Planning
- Energy Storage, Distributed Generation, Microgrids

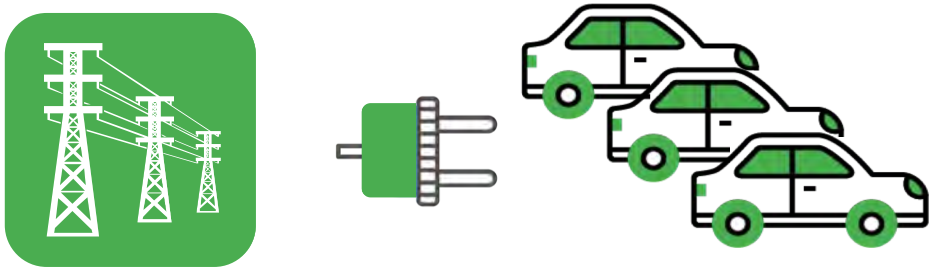
Logistics, Transportation Service Providers, Fleet Operators, Facility Owners

Utility Electric Vehicle Projects

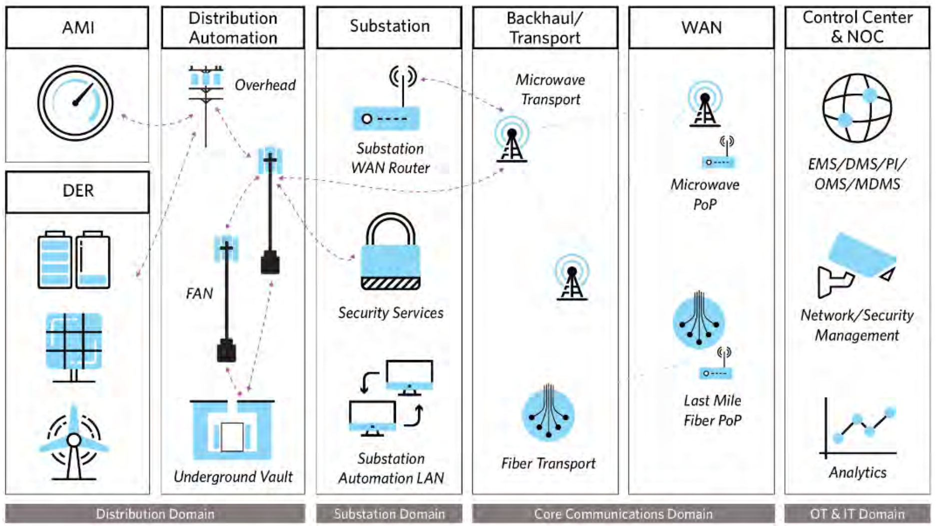
- Utility Innovation & Business Case Development
- EV Program Development & Design
- Distributed Energy Resource Portfolio Analysis

- Service Territory Fleet Adoption Analysis
- Utility Service Design, Engineering
- Right of Way, Land Use Services

- EV Infrastructure Make Ready / Station Engineering, Design, Permitting & Construction



Grid Modernization: Adjacent Projects



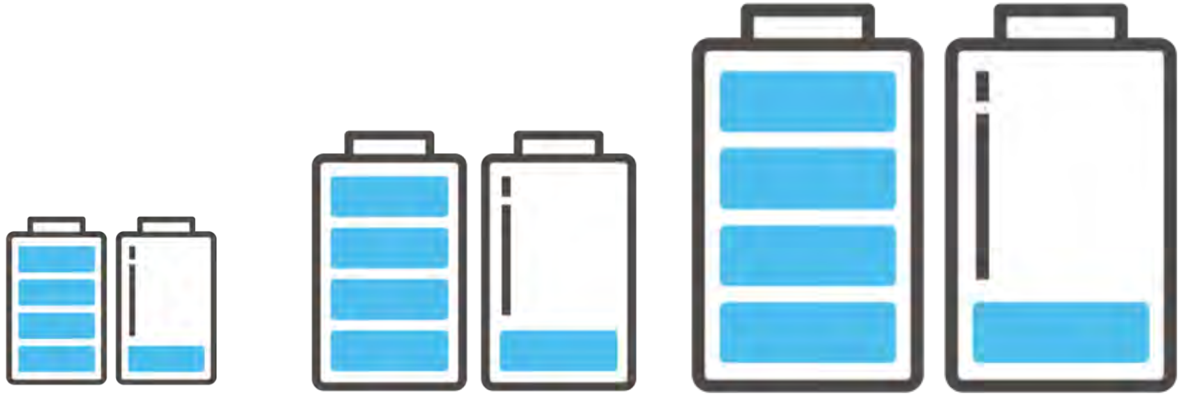
> Investor Owned, Municipal, Independent Power Providers, Domestic & International

Step Change in Charging Infrastructure Requirements

- Larger Batteries
- Higher Power Charging
- Higher Utilization Vehicles
- Higher Voltages, Conductive, Inductive
- New Applications and Venues

High-Power Corridors
Urban Charging Hubs & Depots
Freight Movement Facilities
Autonomous
Aviation

- Larger Capital Requirements
- Power Delivery Requirements
- Schedule Risk Management
- Least Regret Investments



> Energy Procurement, Power Delivery, Infrastructure Deployment Strategy

Stakeholder Alignment & Project Goals

- Existing Project History
- Concurrent, Future Projects

- Building Load Integration
- Cost of Energy, Renewable Content
- Resilience
- Future Proofing Infrastructure

- Project Timeline
- Project Budget
- Total Cost of Operation

> Agencies & Fleets, Utilities, Cities, Vehicle OEMs, Clean Energy, Community Interests, Project Execution Team, Funding & ROI

Project Approaches & Risk Management

- Evolving Procurement Landscape
  - Bundling Infrastructure with Vehicles
  - Separate Infrastructure and Vehicle RFPs
  - Turn-Key or Separate Hardware, Software, Deployment Services, Operations & Maint.
- Alternative Contracting Methods & Tools
  - Public Contracting Rules Vary
  - Design-Build
  - Design-Bid-Build
  - Owners Engineer, Construction Administration
  - Fixed Price, Cost Plus, Open Book
  - Engineering “Bench” Services
  - Internal Engineering and Construction Services

Project Delivery/Risk Models: Different Levels of Scope Clarity & Cost Certainty

Paperwork, Process & Permissions

- Start EARLY on EVERYTHING

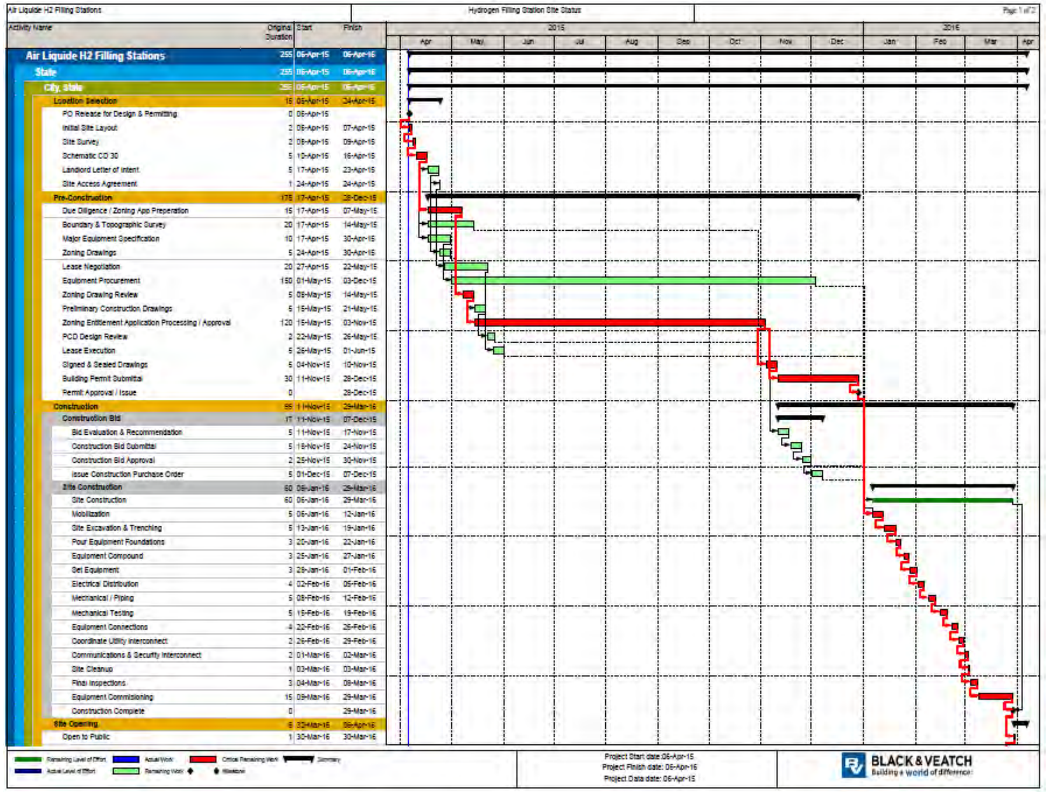
- Inter-Agency Agreements & Approvals
- State Environmental Impact Filings
- Sorting out Applicable Terms & Conditions
- Differences between Vehicles, Infrastructure & Deployment Services

- Utility Load Letters, Right of Way & Service Agreements
- DOT & City Approvals & Special Permits
- Building & Electrical Permits (Can expire!)

> Patience & Persistence

Project Scope & Schedule Management

- Roles & Responsibility Matrix
    - Project Management
    - Design / Layout Acceptance
    - Engineering
    - Permitting
    - Utility Coordination
    - Construction Management
    - Construction
    - Safety
    - Equipment Storage



- Milestones & Deliverables (All Parties)

> Schedules: Utility, Vehicle, Equipment, Commissioning/Test, Political

Equipment, Equipment, Equipment

- Chargers
- UL Listings & Field Certification
- Compatibility / Interoperability

- Switch Gear
- Transformers
- Cable & Special Connectors

- Manufacturing Slots, Lead Times
- Specification Changes

- Site Delivery / Storage / Laydown Areas

> Changes Impact Schedule and Cost

Rocks, Water, Trees, Traffic & Other Discoveries

- Rocks, Asphalt, Compaction Ratios
- Walls, Floors, Roofs
- Environmental Conditions

- Water

- Utilities, Hidden Obstructions
- Abandoned Conduits & Structures
- Underground Hazards & Discoveries
- Traffic Control & Security

- Re-Mobilization, Hand Digging

> Re-Engineering, Schedule and Cost Impacts

Utility Interconnection & Power Delivery Schedule

- Evolving charging loads

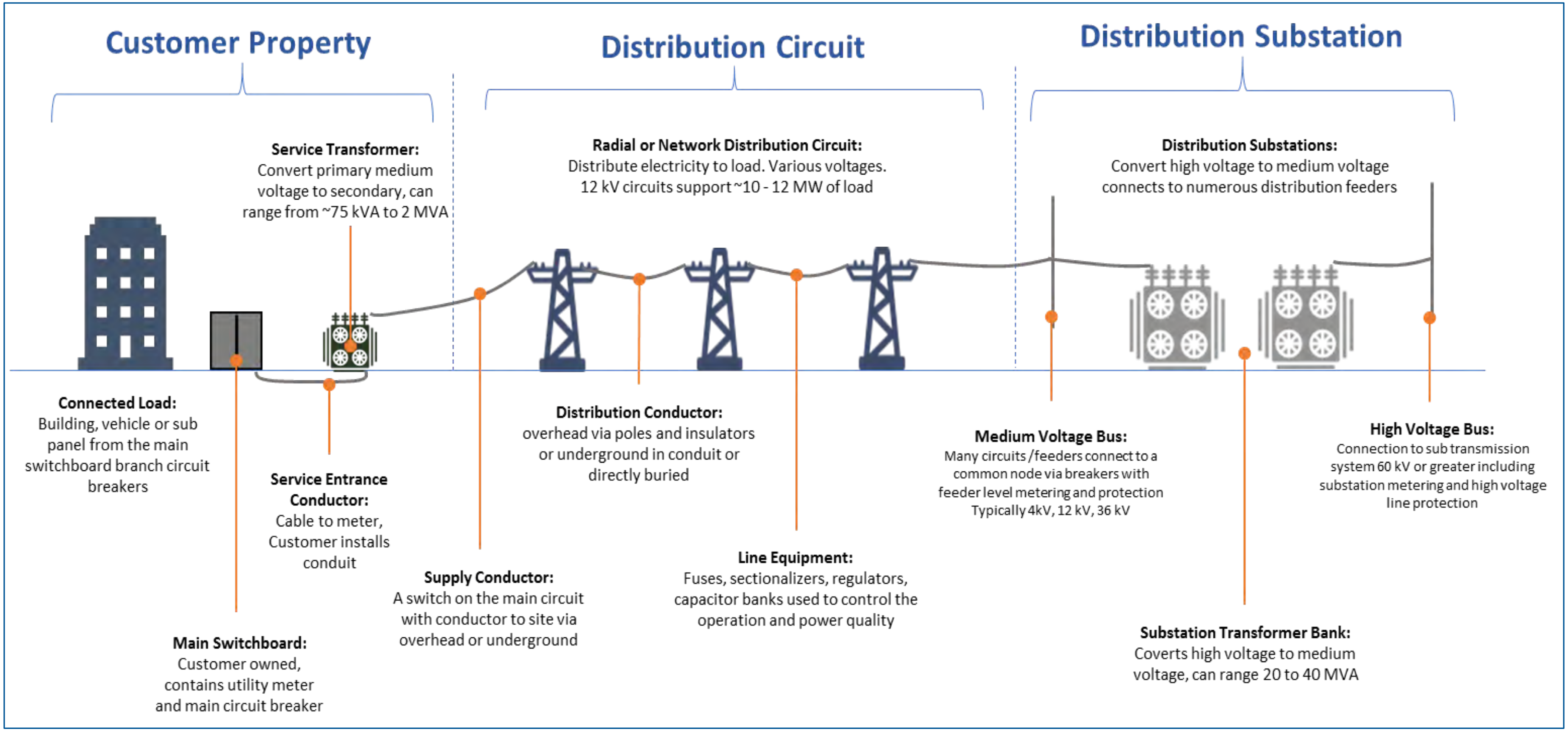
- Service upgrade
- Existing building Loads
- Metering location
- Switchgear sizing

- Power levels & voltage
- Lead times for increasing power
- Distribution grid upgrades

- Re-Mobilization

> Race is on for Real Estate and access to Power

Power Delivery



High-Power Site Development Schedules

Base Case Power Delivery Schedule: No Grid Upgrades Required

Project Phase	Typical Ranges (Months)		
Engineering / Design	0.50	-	2.00
Permitting / Land Use	0.50	-	3.00
Construction	1.75	-	2.50
Commissioning	0.25	-	0.50
Total Project Schedule	**3.00**	**-**	**8.00**

Assumes 1-2 megawatt load, power is available on site, new utility service and transformer, 480v supply, existing utility right of way, limited to no building load integration. May include service extension.

High-Power Site Development – Grid Upgrades

Potential Grid Upgrades Required, Typical Scenarios & Land Use

Power Delivery, Trigger MW, Upgrade Locations	MW	Customer	Right of Way	Utility
Supply Conductor (Service Extension)	0 - 1	■	■	
Medium Voltage (Service Provisioning)	3 - 5	■	■	
Feeder Re-Conductor	1 - 5		■	
Feeder Additional Conductor	3 - 5		■	
New Feeder	5 - 10		■	
Substation Upgrade Required	5 - 10			■
New Substation Required	10 - 20			■

Example ranges – all power delivery scenarios are specific to a location, feeder access, existing, in queue projects and utility operating / power provisioning standards.

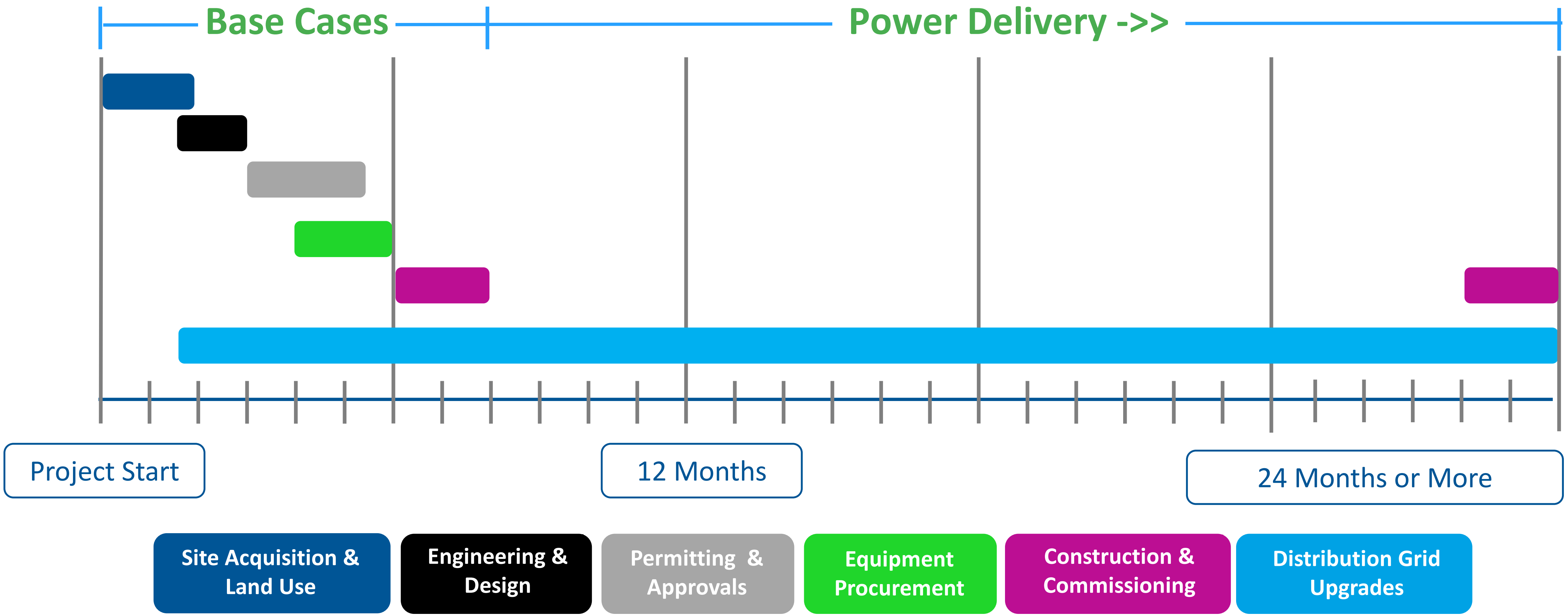
Power Delivery, Grid Upgrade Schedules

Potential Grid Upgrades Required, Schedule Impacts

Potential Power Delivery Upgrades	Typical Ranges (Months)		
Supply Conductor (Service Extension)	0	-	2
Medium Voltage (Service Provisioning)	0	-	5
Feeder Re-Conductor	6	-	36
Feeder Additional Conductor	6	-	36
New Feeder	9	-	48
Substation Upgrade Required	18	-	36
New Substation Required	24	-	48

Example ranges – Power delivery scenarios are specific to a location, feeder access, existing, in queue projects and utility operating / power provisioning standards.

Distribution Grid Upgrade Schedule Impacts



Example Schedules – Power delivery scenarios are specific to a location, feeder access, existing, in queue projects and utility operating / power provisioning standards.

Additional Electrification Resources

REPORTS & BRIEFINGS:

To request whitepapers "Priming the U.S. Grid for High-Power Charging" and "Understanding and De-Risking Power Delivery" email StithP@bv.com.

PRESENTATIONS:

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SAE J-3105 Heavy-Duty Conductive Automatic Charging Recommended Practice

Presenter: Mark Kosowski, EPRI

SAE J-3105 Committee Chairperson

June 12, 2018

SAE Automatic Charging Recommended Practice

Article has been published in this months SAE Automotive Engineering Magazine

SAE STANDARDS NEWS

Conductive Automatic Charging Recommended Practice nears completion

SAE's Medium and Heavy-Duty Vehicle Conductive Charging Task Force committee has been working to develop a Recommended Practice (RP) for heavy-duty conductive automatic charging, and the document is now close to the publication stage. SAE J3105, which is slated for publication in first quarter 2019, covers the physical, electrical, functional, testing, and performance requirements for conductive DC power transfer primarily to electrified transit vehicles.

"The document is for buses or heavy-duty vehicles in general," Mark Kosowski, SAE J3105 Committee Chairperson and long-time SAE member, told *Automotive Engineering*.

For the past two years, the task force has been meeting twice monthly via WebEx as well as in person, with the next one scheduled for July in Troy, Mich. "The group has worked to define conductive power transfer methods for the RP," Kosowski said. The methods include the infrastructure electrical contact and vehicle connection interfaces, the electrical characteristics of the DC supply and the communication system.

J3105 also covers the functional and dimensional requirements for the vehicle connection and supply equipment interfaces.

Kosowski recently shared information about the forthcoming new RP in a presentation at the **APTA** (American Public Transit Association) 2018 Bus & Paratransit Conference last month. The technical, educational program is held for bus and paratransit system employees and managers, board members, contractors, suppliers, manufacturers and consultants.

"J3105 will ensure that each connection type is safe and interoperable among manufacturers," said Kosowski, who is Technical Executive for the **Electric Power Research Institute** (EPRI).

The RP will be produced as a family of documents connected by a main document. J3105, the main document, will contain the significant common parts of the system (about 90%), which include the electrical interface, power flow (voltage and currents), communications, safety and systems.

The four subdocuments of the RP—J-3105-1, J3105-2, J3105-3, and J3105-4—will detail the different connections and the unique parts, including connection locations and alignment. All connections will use the common requirements established in the overall document J3105.

- J3105-1 Infrastructure-Mounted Pantograph (Cross rail), figure 1;
- J3105-2 Infrastructure-Mounted Blade (Blade), figure 2;
- J3105-3 Vehicle-Mounted Pantograph (Bus-up), figure 3;
- J3105-4 Enclosed Pin and Socket, figure 4.

When an infrastructure is selected, then all vehicles independent of the manufacturer will be able to use the system.

Many individuals have been involved in the standard development work with approximately 20-25 experts in regular attendance at meetings. Participants involved include major bus manufacturers (**GILLIG, New Flyer, Nova Bus, Opbrid, Proterra**), charger manufacturers (**ABB, Heliox, Siemens, Toshiba**), pantograph and connector manufacturers (**Furrer+Frey, SCHUNK, Stäubli, STEMMANN**), utilities (EPRI, **Sacramento Municipal Utility District** (SMUD), **Southern California Edison**), transit fleets (APTA, **Chicago Transit Authority, King County Metro, Los Angeles County Metropolitan Transportation Authority, NY City Transit**) and other interested parties (**ANL, CalStart, CEC,** and **CTE**).

For more information on J3105, contact Mark Kosowski at mkosowski@epri.com.

Jennifer Shuttleworth
Associate Editor
Jennifer.Shuttleworth@sae.org

Fig. 1 - J3105-1 Infrastructure-Mounted Pantograph (Cross Rail).

Fig. 2 - J3105-2 Infrastructure-Mounted Blade (Blade).

Fig. 3 - J3105-3 Vehicle-Mounted Pantograph (Bus-up).

Fig. 4 - J3105-4 Enclosed Pin and Socket.

4 June 2018

AUTOMOTIVE ENGINEERING

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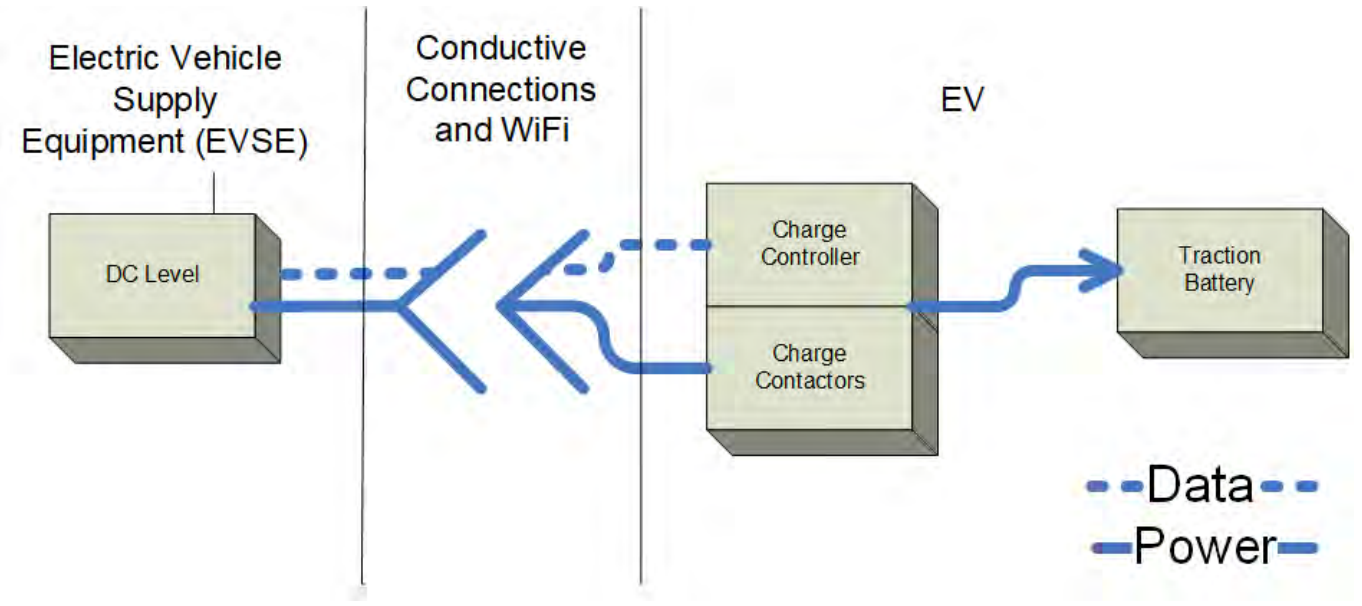
SAE Automatic Charging Recommended Practice

- Automatic Charging Connection at High Power- SAE J-3105
  - Documents are "Recommended Practices" that define the interface electrically and physically between the infrastructure and the vehicle
  - The document is for buses or heavy-duty vehicles, in general.



Requirements include:

Power Levels

Power Configurations

Communications

Safety

Connection Points

Alignment Protocol

J-3105 Meetings and Timing

- The committee meets twice a month on the 2nd and 4th Thursday at 11 am ET by WebEx
- Regular attendance is about 20 to 25 experts
- The committee has had four 2-day Face to Face meetings over two years- the latest was in March
- The committee has a two-day Face to Face meeting at the SAE Headquarters in Troy, Michigan in late July
- Assuming the SAE First Ballot begins in September 2018, the final published version should occur in the 1st Quarter 2019

J-3105 Regular Participants include:

Major Bus Manufacturers

Gillig
New Flyer
Nova Bus
Opbrid
Proterra

Pantograph and Connector Manufacturers

Furrer-Frey
Proterra
Schunk
Staubli
Stemmann

Transit Fleets

APTA
Chicago Transit
King County Metro
LA Transit
New York City Transit

Charger Manufacturers

ABB
Heliox
Siemens
Toshiba

Utilities

EPRI
Sacramento (SMUD)
Southern Cal Edison (SCE)

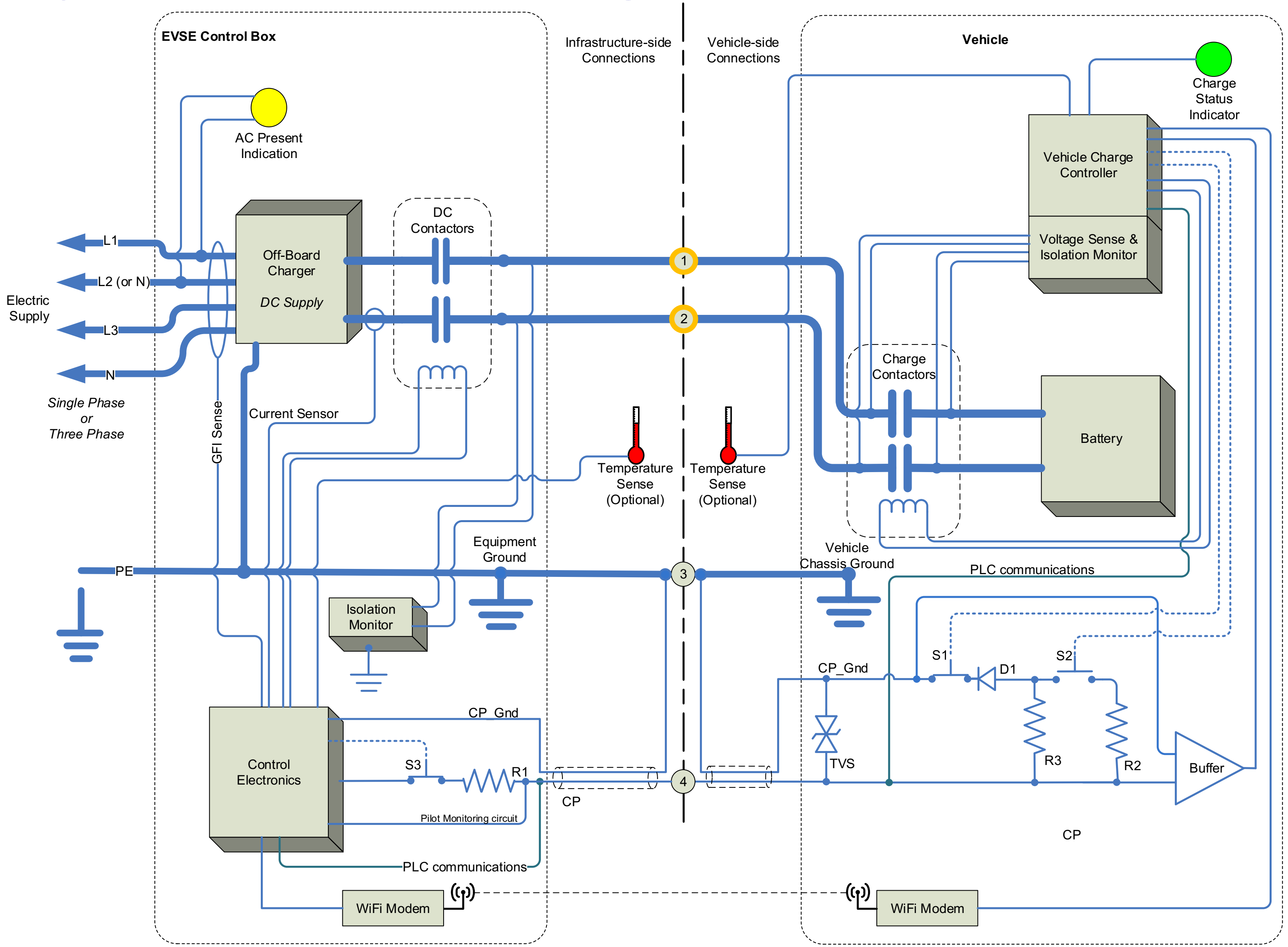
Others

ANL
CalStart
CEC
CTE

J3105 Recommended Practice

- The Recommended Practice will be produced as a family of documents connected together by a main document.
- The main document J-3105 will contain the significant common parts of the system (about 90%). It will include:
  - Electrical Interface
  - Power Flow (Voltage and Currents)
  - Communications
  - Safety
  - Systems
- The 4 sub-documents J-3105-1, J3105-2, etc. will detail the different connections and the unique parts including connection locations and alignment.

Typical Circuit Diagram



Four Interface Connections are defined:

1. DC Power (Plus)
2. DC Power (Negative)
3. Ground
4. Control Pilot

Automatic Charging Requirements

- The Voltage Range is 250 to 1000 V
- Two Power Levels are being considered-
  - Level 1: up to 600 A (350 kW)
  - Level 2: up to 1200 A (1200 kW)
  - Level 1 and Level 2 need to be compatible and interoperable
- Wireless communications will be used to pair the vehicle with the charger- IEEE 802.11n
- The Control Pilot will be used for communications once the vehicle is connected to the infrastructure

J-3105 Sub-Document Definition

J-3105-1 - Infrastructure-mounted Cross Rail Connection

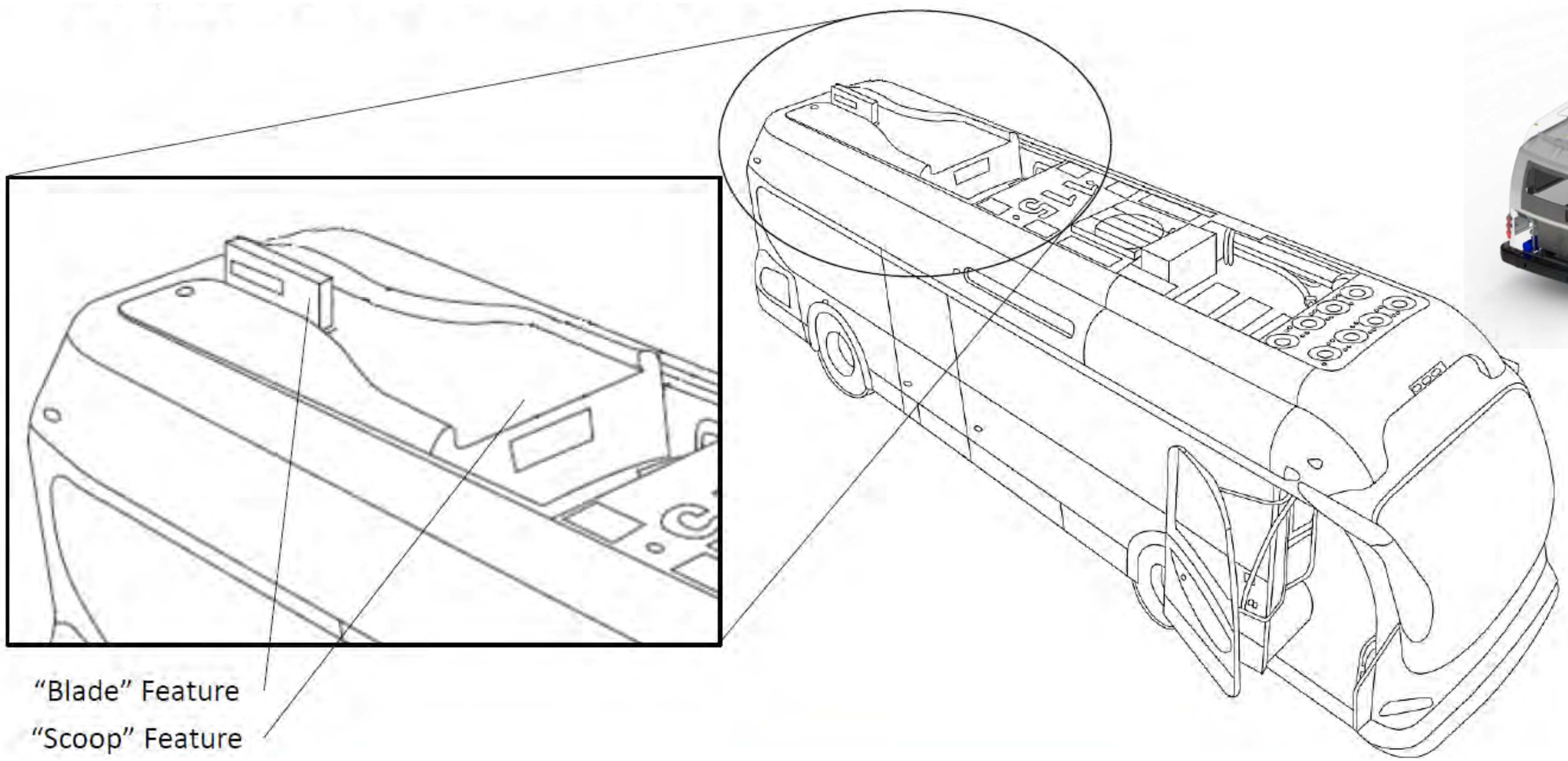
J-3105-1 Infrastructure-mounted Cross Rail Connection

J-3105 Sub-Document Definition

J-3105-1 - Infrastructure-mounted Cross Rail Connection

J-3105-2 - Infrastructure-mounted Blade Connection

J-3105-2 Infrastructure-mounted Blade Connection

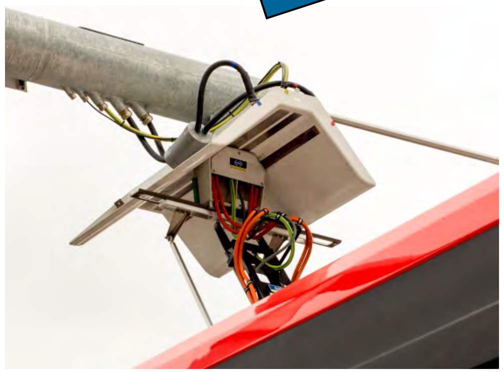


J-3105 Sub-Document Definition

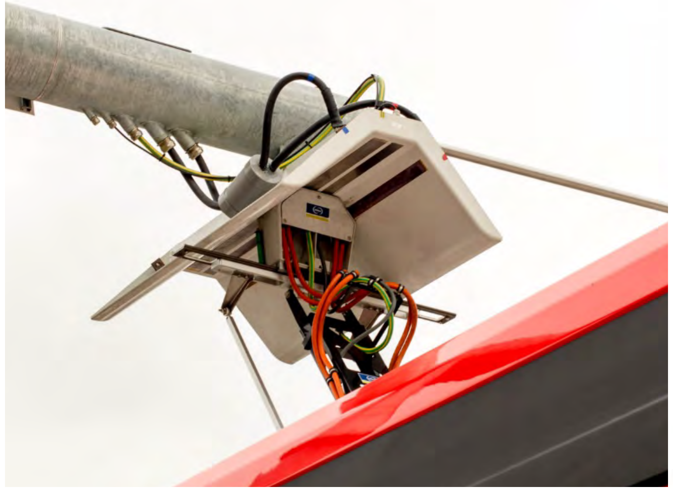
J-3105-1 - Infrastructure-mounted Cross Rail Connection

J-3105-2 - Infrastructure-mounted Blade Connection

J-3105-3 - Vehicle-mounted Pantograph Connection



J-3105-3 Vehicle-Mounted Pantograph Connection



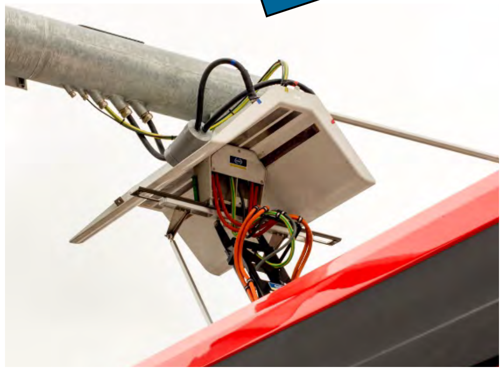
J-3105 Sub-Document Definition

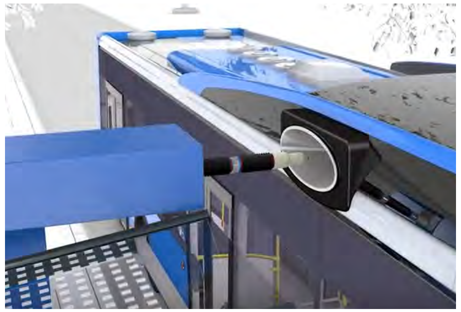
J-3105-1 - Infrastructure-mounted Cross Rail Connection

J-3105-2 - Infrastructure-mounted Blade Connection

J-3105-3 - Vehicle-mounted Pantograph Connection

J-3105-4 - Enclosed Pin and Socket Connection





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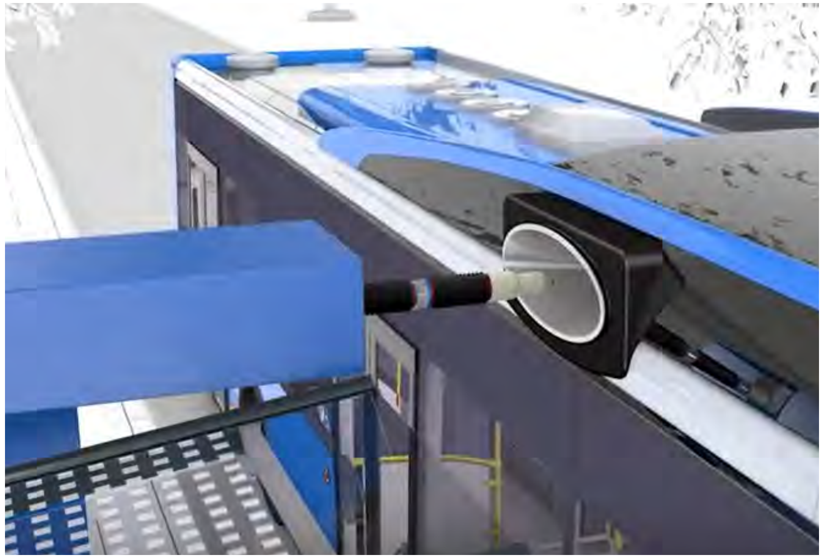
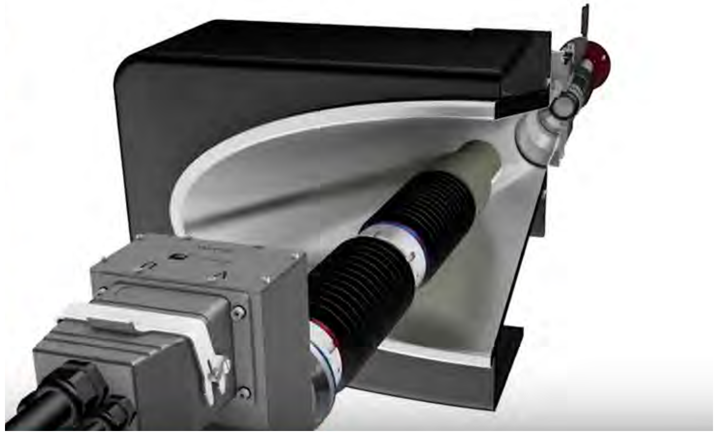
J-3105-4 Enclosed Pin and Socket Connection





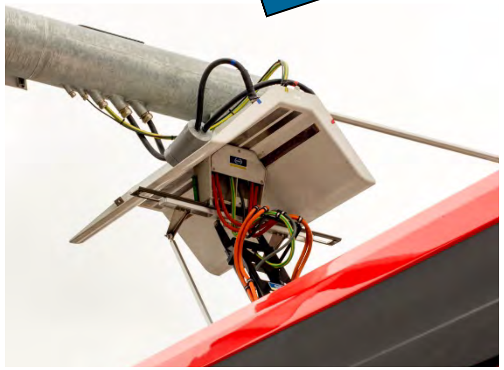
J-3105 Sub-Document Definition

J-3105-1 - Infrastructure-mounted Cross Rail Connection

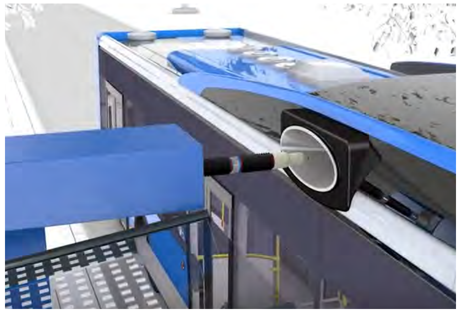
J-3105-2 - Infrastructure-mounted Blade Connection

J-3105-3 - Vehicle-mounted Pantograph Connection

J-3105-4 - Enclosed Pin and Socket Connection



1. Scope
2. Conductor Dimensions and Spacing
3. Alignment Procedure



Summary

- The SAE Recommended Practice is planned to be published in the 1st Qtr of 2019
- A family of documents will be published
  - J-3105 Main Document- including most requirements
  - 4 Sub-documents
    - J-3105-1 - Infrastructure-mounted Cross Rail Connection
    - J-3105-2 - Infrastructure-mounted Blade Connection
    - J-3105-3 - Vehicle-mounted Pantograph Connection
    - J-3105-4 - Enclosed Pin and Socket Connection
- SAE planning on publishing article in SAE Magazine in June

Thank You

Mark Kosowski

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Together…Shaping the Future of Electricity

For Your Information

http://www.electrification2018.com/

SAE Charging Status

Presenter: Mark Kosowski,
EPRI

SAE J-3105 Committee
Chairperson

May 6, 2018

SAE High Power Charging Documents

Manual DC connection at high power- SAE J-1772 CCS

An existing document that will make provisions for the higher power (1000V, 350A, 350 kW) needs of the buses

Manual 3 phase AC at high power- SAE J-3068

Recently published document that is getting good acceptance

Wireless connection at high power- SAE J-2954-2

A developing document that will make provisions for the higher power needs of the buses

Automatic Charging at high power- SAE J-3105

Document planned to be published in early 2019

J-1772 CCS- 7th Revision

CURRENT REVISED 2017-10-13

SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

J1772_201710

This SAE Standard covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America. This document defines a common EV/PHEV and supply equipment vehicle conductive charging method including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector.

Revision History   Related Info

J1772_201710	**2017-10-13**	**Latest**	**Revised**
J1772_201602	2016-02-03	Historical	Revised

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What's New with J1772?

- Described State B1 (EVSE Not Ready to Supply Power)
- Removed current tolerance (offset and % error) from pilot description

- DC Pin Current capacity raised to 400A
- DC Pin Voltage capacity now 50V to 1000V

- Updated Appendix H (Draft coupler performance certification test procedure)

J-3068 3 Phase AC Charging Connector

CURRENT ISSUED 2018-04-25

Electric Vehicle Power Transfer System Using a Three-Phase Capable Coupler J3068_201804

This document covers the general physical, electrical, functional, testing, and performance requirements for conductive power transfer to an Electric Vehicle using a Coupler capable of, but not limited to, transferring three-phase AC power. It defines a conductive power transfer method including the digital communication system. It also covers the functional and dimensional requirements for the Electric Vehicle Inlet, Supply Equipment Connector, and mating housings and contacts. Moveable charging equipment such as a service truck with charging facilities are within scope. Charging while moving (or in-route-charging) is not in scope.

Revision History Related Info

J3068_201804	2018-04-25	Latest	Issued

J-2954-2 High Power Wireless Charging

SAE TIR J2954/2 HEAVY DUTY Power Classes

WPT5	WPT6	WPT7	WPT8
60kW	180kW	295kW	590kW

- 85% efficiency is used as a basis for the calculation of power class.
- Future revisions of J2954-2 may extend WPT power classes up to 1MW

- Recommended Practice to be published in 2020

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Heliox
charging urban life

heliox

PUBLIC TRANSPORT

Global Market Leader in opportunity & depot charging

Source: OV magazine

Amstelland Meerlanden (AML) Operating Concession

transdev
MOBILITY INSPIRED BY YOU

connexxion

VDL
BUS & COACH

heliox

schunk

Key facts and figures about AML

Largest opportunity charge / depot charge installation in the world, ten year concession 2017 – 2027

Covers Amsterdam, Schiphol, Amstelveen and surrounding region (Schipholnet and R-Net)

24/7/365 operation with 100 VDL Citea articulated electric buses 18m (60’) of total 260 buses, 11 million km/year

Remaining 160 diesel buses will be replaced with electric by 2021

Connexxion purchases all green energy for this operation

Grid connection is 13MW

Four charge points distributed around the region with a mix of opportunity and depot charging

86 depot chargers 30kW and 23 opportunity chargers 450 kW

Fast opportunity charging from depleted 180 kWh battery in 22 minutes at 450kW

heliox

100 VDL Citea 18m electric bus, 180 kWh batteries

VDL
BUS & COACH

heliox

5.7 MW grid connection at Schiphol depot

heliox

Heliox 450kW opportunity charger

Schunk roof-mounted pantograph

Schunk roof-mounted pantograph

heliox

Schunk SLS 102 roof mounted pantograph

Specifications

- Charging system for electric buses
- Enables charging: „bus-up“
- High power transmission in only a few seconds
- Charging possibilities
  - Pulse charge: 1.000A / 30s (750kW)
  - Opportunity Charging: 600A / 15min (450kW)
  - Depot Charging: 150A (100-150kW)
- 4-pole Design according to CCS – Mode 4 communication
- Contact sequence – “First make, last break” / Handshake

Advantage of pantograph:

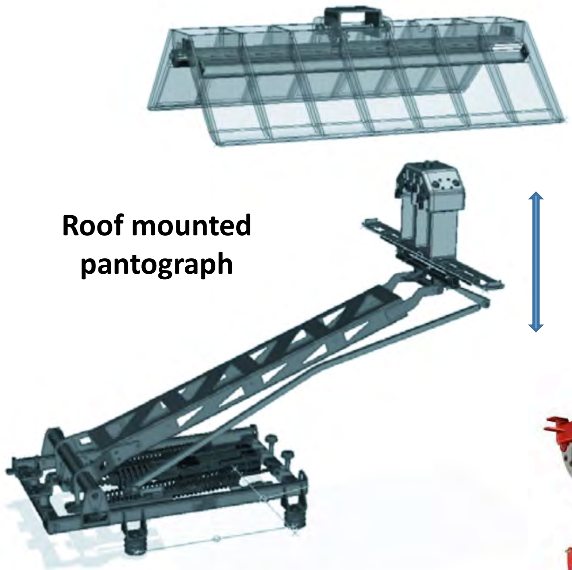
- All charging strategies possible with one solution
- High compensation of parking tolerance – also Kneeling
- Mounting on each bus possible

Customer and projects:

- VDL – AML, Eindhoven, Köln, Heerenveen, IXION
- Solaris – Oberhausen, Dresden, Jaworzno, Krakau, Barcelona etc.
- Linkker, Hess, IRIZAR, BYD…
- Special vehicles for ariport, harbor and mining

Commonly applied coupling systems

Roof mounted pantograph

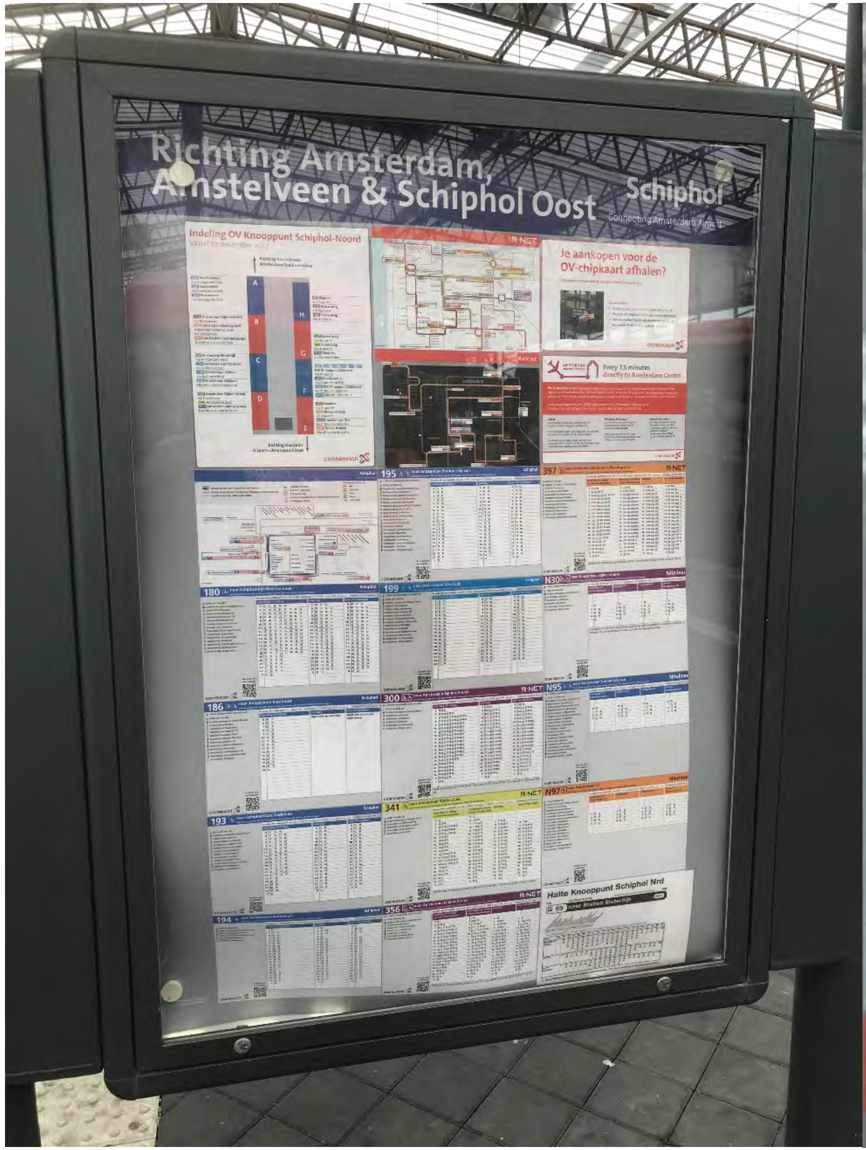


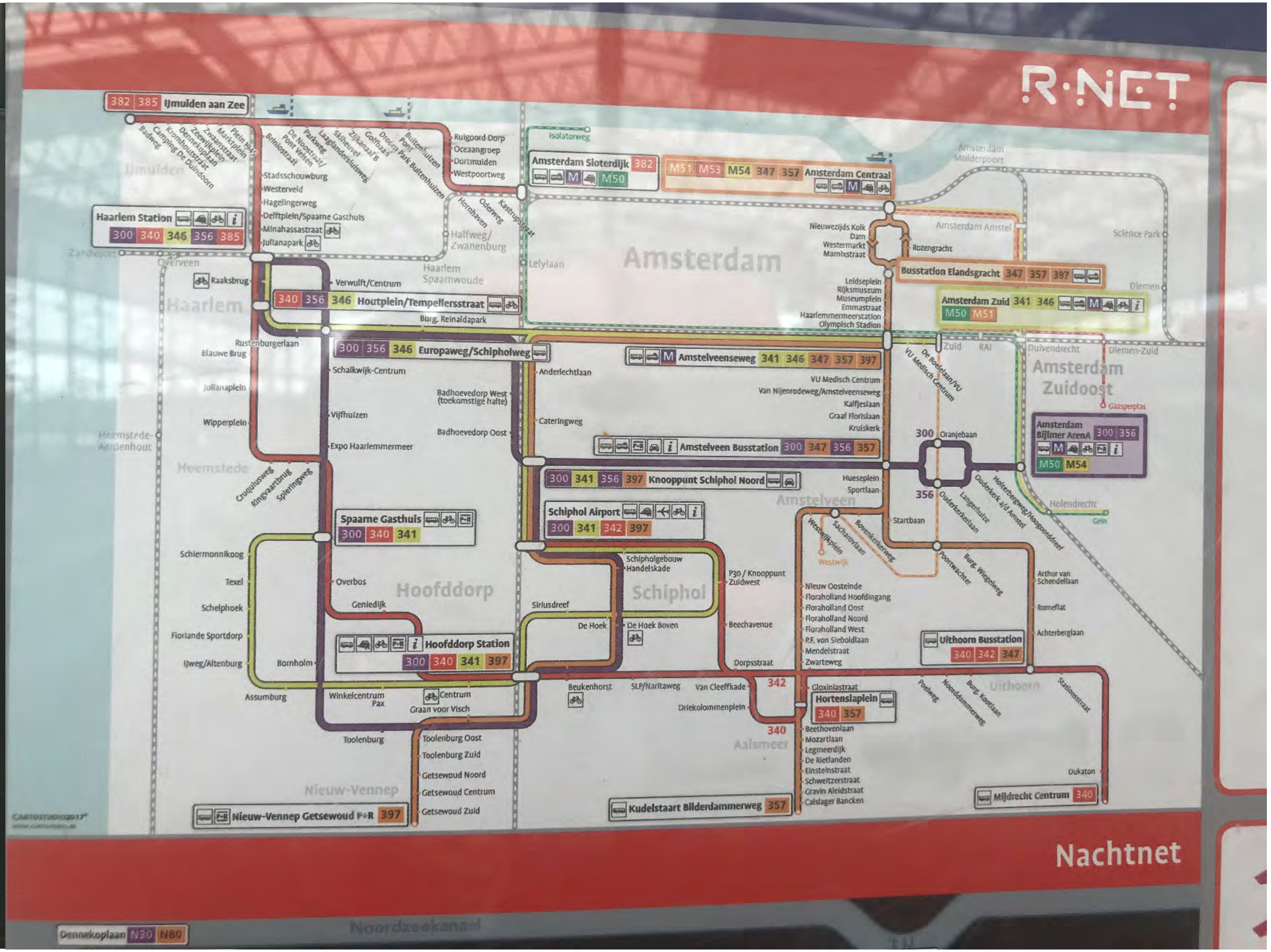
Inverted pantograph

CCS Plug

heliox

Service area Schiphol and the region





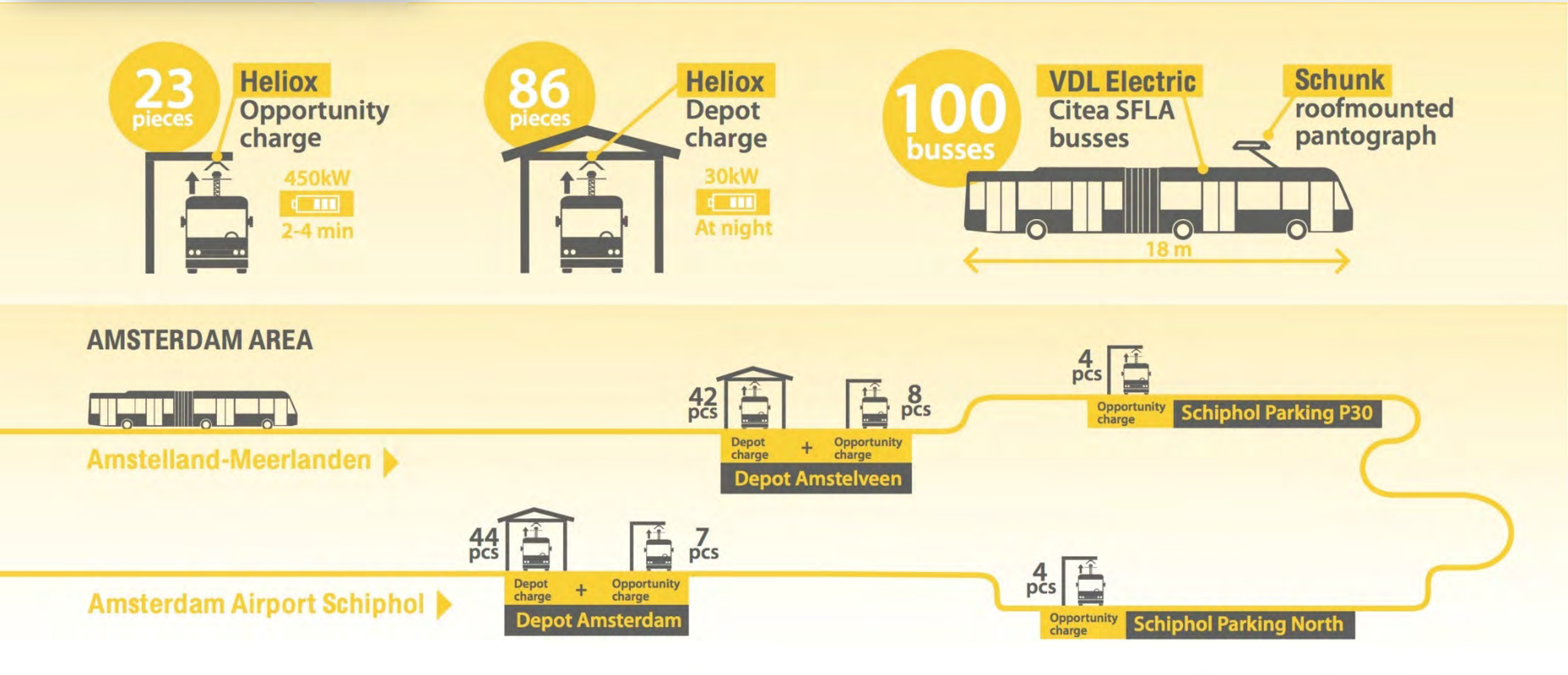
heliox

[VIDEO – Amsterdam Airport Schiphol – Largest opportunity and depot charge network]

heliox

13 MW
Charging Infrastructure

World's largest Opportunity and Depot Charge network



transdev
MOBILITY INSPIRED BY YOU

VDL
BUS & COACH

heliox

Supports all Charging Strategies

Depot Charging

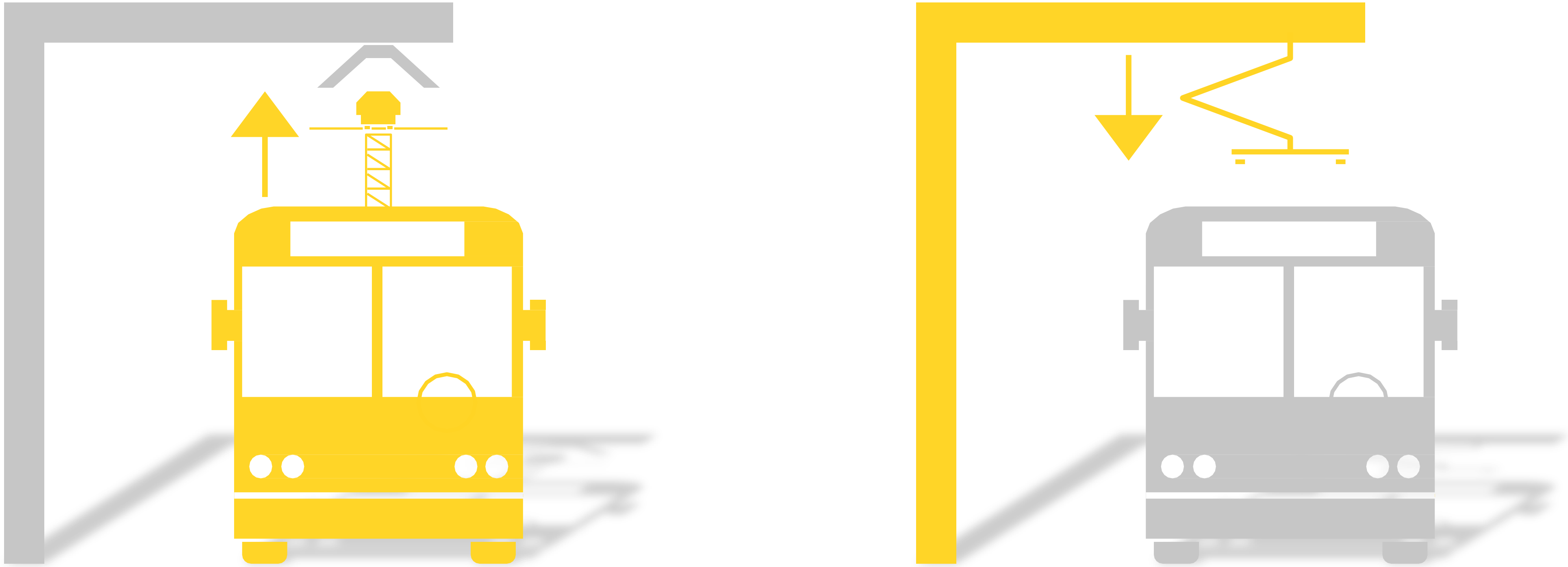
Opportunity Charging

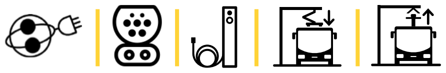
Combination of both

heliox

Opportunity Charging

150kW | 300kW | 450kW | 600kW





LIQUID COOLING | BI-DIRECTIONAL | CONSTANT POWER

Efficiency	>96%	**Cos ϕ**	Unity	**Output Voltage Range**	460-800Vdc
Protection	IP54	**Temp.**	-30 to 50 °C optional	**Operational noise level**	<55 dBA

Depot Charging

2x30kW | 50kW | 150kW

BI-DIRECTIONAL | CONSTANT POWER

Efficiency	>96%	**Cos ϕ**	Unity	**Output Voltage Range**	460-800Vdc
Protection	IP54	**Temp.**	-20 to 40 °C	**Operational noise level**	<55 dBA

heliox

heliox

heliox

Opportunity chargers on left, depot chargers on right

heliox

Schiphol North Parking Station: 4 opportunity chargers 450 kW

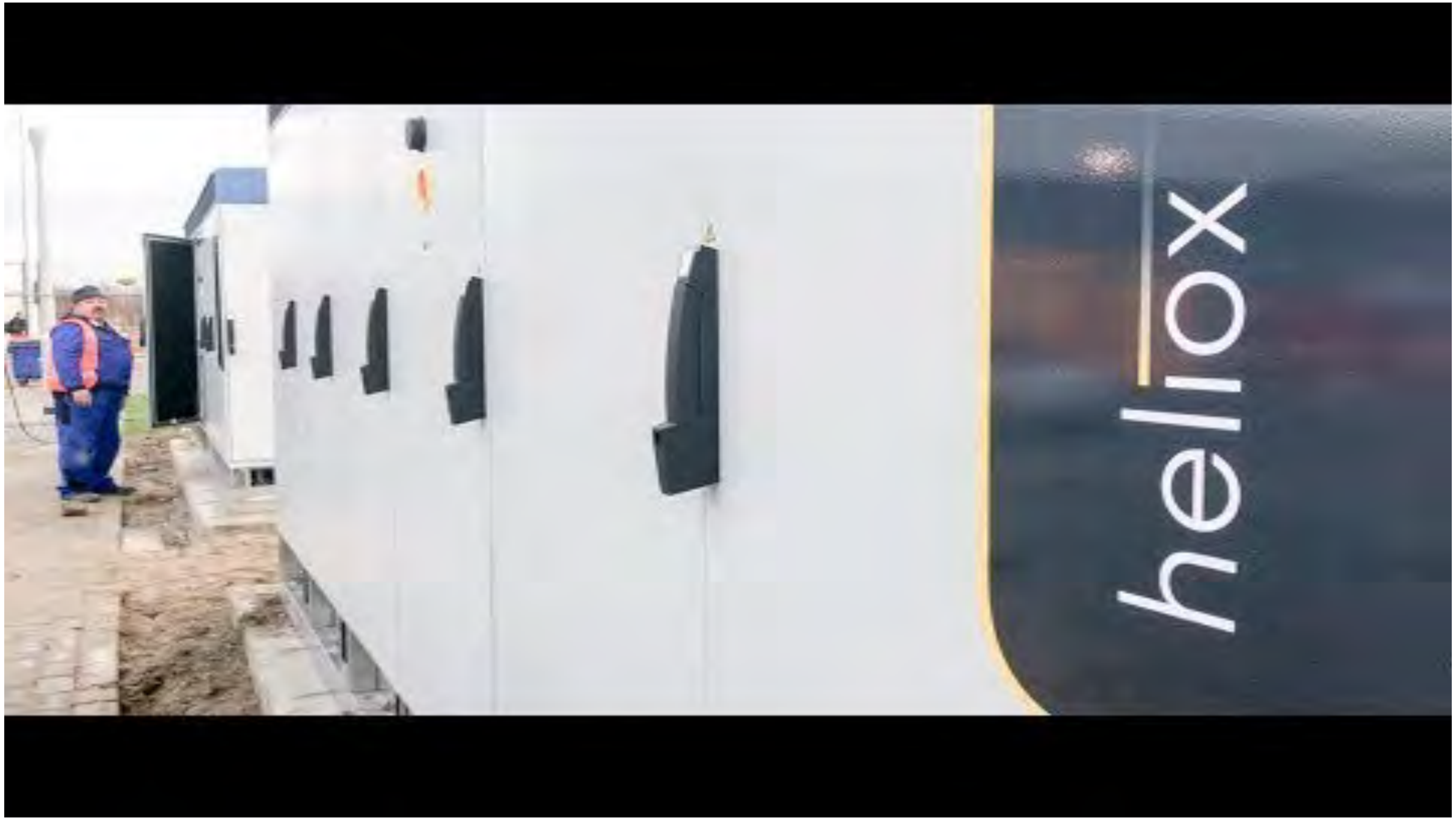
heliox


Main Schiphol depot: 44 depot and 8 opportunity chargers
Schiphol
9746
34-BKF-8

2x30 kW depot chargers

heliox

VIDEO – Amsterdam Airport Schiphol – Installation of 450kW Chargers and Charging Portals



Thanks for your attention!

heliox

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schunk

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INTRODUCTION TO BYD BUSES & TRUCKS

| Bus & Truck Charging Interface Group |

June 12, 2018

A pioneer in providing a new energy ecosystem: from **Power Generation** to **Energy Storage** to **Electrified Transportation**

BATTERY FOCUSED

BYD Business Divisions

Commercial Vehicles

Consumer Vehicles

SkyRail

IT

Other Components

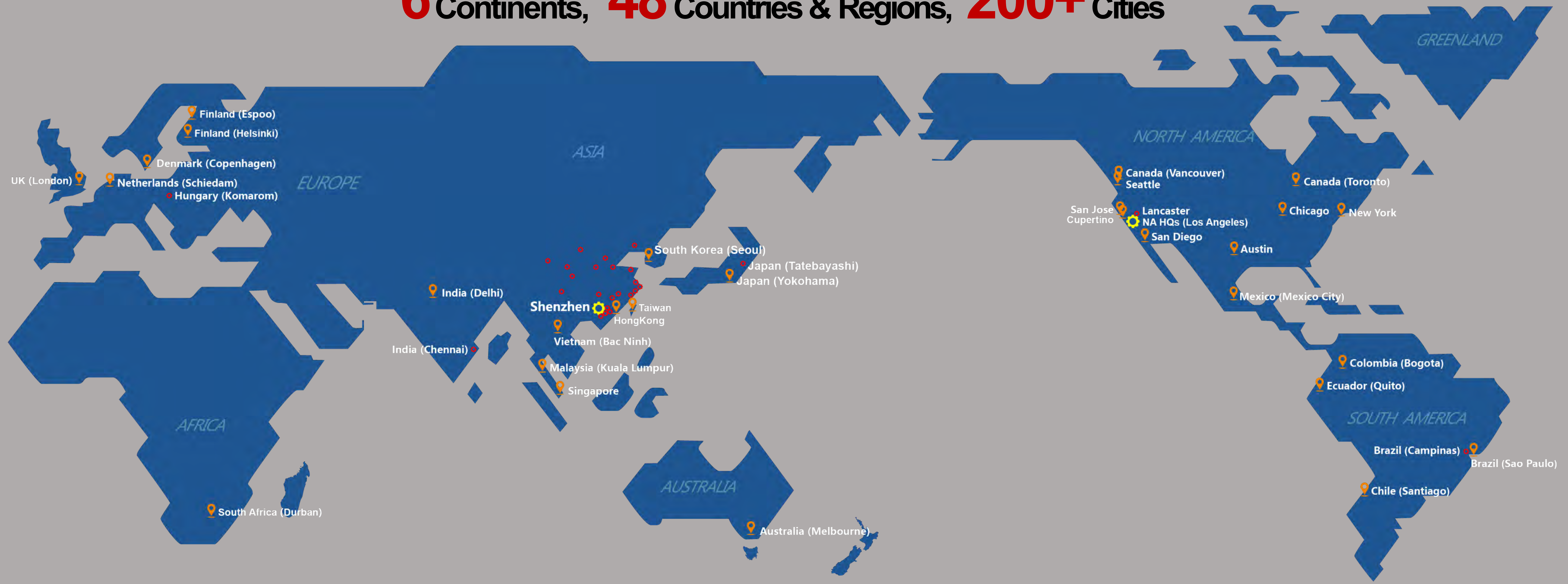
Battery

BYD AT A GLANCE

- World's **largest electric vehicle & rechargeable battery manufacturer**
- 220,000 employees, 32 manufacturing sites in 15 countries:
  - North American HQ in DTLA, with manufacturing in Los Angeles County
- Four areas of focus: **electric vehicles, clean energy (solar & ESS), consumer electronics, and SkyRail**
- $16.5B USD revenue in 2017
- International recognition:
  - Sustainia Award: top 10 global innovator in clean tech
  - Bloomberg: BYD the world's 8th most innovative company
  - Fortune Magazine: One of the top companies changing the world 2015
  - Fast Company: #2 Most Innovative Company in the World, Energy

GLOBAL REACH

6 Continents, 48 Countries & Regions, 200+ Cities



Beijing	Qingdao	Ningbo	Shanwei	Haidong	Shangluo	Fenghua
Shanghai	Dalian	Chengde	Shantou	Wuhan	Changsha	Xining
Xi'an	Hangzhou	Huizhou	Shaoguan	Taiyuan	Nanjing	Baotou

32 Manufacturing Sites , **27** Branches

- Global Headquarters
- Manufacturing Sites
- Branches

US BASED MANUFACTURING

446,000 Square-Foot EV Manufacturing Space

Lancaster, CA


BYD
EMERGENCY EXIT

LOCAL JOB CREATION

More than 700 manufacturing jobs

Over 900 US employees

ZERO IS TODAY

ZERO IS TODAY

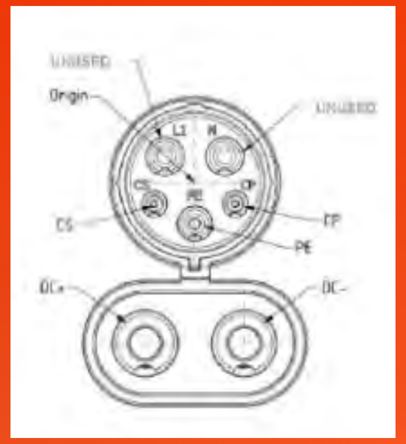
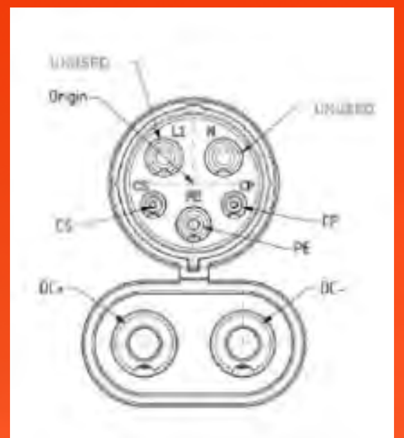
ZERO EMISSION GOODS MOVEMENT

ELECTRIC IN OUR COMMUNITIES

CHARGING ROADMAP – AC & DC






- Short-circuit protection
- Overheat Protection
- Lightning Protection
- Next gen AC Charger to be J3068 compliant

Charger	40 kW	80 kW	100 kW	200 kW	150 kW DC	300 kW DC
Charging Mode	AC	AC	AC	AC	DC	DC
Input Voltage	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase
Operating Voltage Range	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	456V-504V 3-phase	456V-504V 3-phase
Continuous Input Current	48A	96A	120A	240A	180A	360A
Input Power	40kW	80kW	100kW	200kW	150 kW	300 kW
Frequency	60Hz	60Hz	60Hz	60Hz	60Hz	60Hz
Output Voltage	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	400VDC - 850 VDC	400VDC - 850 VDC
Output Current	48A	48A per coupler	120A	120A per coupler	200A	200A per coupler
Output Power	40kW	40kW per coupler	100kW	100kW per coupler	150 kW	150 kW per coupler
Charging Coupler Type	IEC62196-2	IEC62196-2	IEC62196-2	IEC62196-2	CCS Combo 1	CCS Combo 1 *2
Wires	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground
Width	15.8 x 7.9 x 27.2 in	15.8 x 7.9 x 27.2 in	19.7 x 15.8 x 78.8 in	19.7 x 15.8 x 78.8 in	31.5 x 39.4 x 87.8 in	27.6 x 63 x 78.7 in
Charging Cable Length	10 ft	10 ft	10 ft	10 ft	10 ft	10 ft
Reference Standard	IEC61851/IEC62196	IEC61851/IEC62196	IEC61851/IEC62196	IEC61851/IEC62196	SAE J1772	SAE J1772
Enclosure Protection	IP55	IP55	IP54	IP54	IP54	IP54
Operating Temperature	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F
Operating Humidity	5-95%	5-95%	5-95%	5-95%	5-95%	5-95%

CHARGING ROADMAP – Inductive

Getting more powerful, while getting cheaper

CHARGING ROADMAP – Overhead

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APTA Overview and Update

EPRI Bus and Truck Charging Interface Group

June 12, 2018

Lisa Jerram

Director-Bus, Paratransit and Surface Transit

American Public Transportation Association

AMERICAN PUBLIC TRANSPORTATION ASSOCIATION

About APTA

- Established in 1882
- ~81 full-time employees
- Represents all modes of public transit
- More than 1,500 member organizations

Ninety-five percent of those using public transit in the U.S. are carried by APTA members

Public Transportation in the U.S.

- 34 million boardings every weekday
- 10.1 billion annual boardings in 2017
- Approximately 6,700 transit providers in U.S.
- 48% of trips on bus; 48% taken on rail (4% other)
- $68 billion / yr. industry; directly employs 400,000 and supports 1.4 million jobs

Sustainability Trends in Transit

- Agencies are reducing their energy consumption and GHG emissions through:
  - Utility data tracking to evaluate areas for improvement
  - Identifying opportunities to reduce energy consumption through behavioral change
  - Upgrades to more efficient products
  - Switching to less carbon intensive energy sources (i.e. solar, other renewables, etc.)
- Agencies are promoting greenhouse gas savings through:
  - Operating transit service and providing a less energy-intensive mode of transportation
  - Creating opportunities for transit-oriented development
  - Increasing bicycle and pedestrian access to transit stations through first/last mile initiatives

Factors Driving Zero Emission Buses

EXTERNAL

- Government (federal, state, local) policies and regulations
- Higher fuel cost/dependence on foreign oil

INTERNAL

- Lower operational and maintenance cost
- Noise reduction

The U.S. has over 300 zero emission buses operating in transit fleets.

But Agencies Facing Challenges with ZEBs

- At its May 2018 Bus Conference, APTA held a Maintenance Managers Workshop. In the ZEB breakout sessions, the top issues were:
  - Choosing infrastructure
    - Understanding the various options and how they will work with the agency's operations
    - Challenges around the RFP for infrastructure
  - Energy management
    - Demand charges, off peak rates, energy storage
  - Utility engagement
  - Need to understand true operating costs and comparative fuel costs

APTA Standards Program

- One area where APTA is engaged in supporting members regarding ZEBs is through its Standards Program
- The APTA Bus Transit Standards Program has development activities in the following topic areas:
  - Brake & Chassis
  - Bus Maintenance Facility
  - Bus Operations
  - Bus Rapid Transit
  - Bus Safety
  - In-Plant Inspection
  - Maintenance Training
  - **Standard Bus Procurement Guidelines**

- Documents are performance based and are designed to be a resource for all agencies, big and small.

Bus Procurement Guidelines Activity

- APTA's Bus Procurement Guidelines are being updated to include ZEB language
- APTA currently working to complete technical specification of the Standard Bus Procurement Guidelines with language ***specific to battery electric buses***
- Next – APTA looking to develop procurement guidelines for battery electric bus ***infrastructure***
- APTA staff will be managing this effort over the next several months
- Could be other areas for Standards development relating to ZEBs, including maintenance or training

Education, Outreach and Membership Engagement

- APTA Conferences
  - 2018 Bus Conference featured two sessions on Zero Emission Buses; Maintenance Managers Workshop included ZEB breakout discussion
  - Next - Annual EXPO/Meeting, September 2018
- Webinars
  - 2017 "Lessons Learned" webinar on European ZEB experiences
- Other membership education opportunities could be around evaluating infrastructure, determining fueling costs, how to work effectively with utilities

Further Engagement

- While capital costs of ZEBs still need to come down, infrastructure is quickly becoming a top priority/challenge for transit agencies
- Key issues include understanding and assessing infrastructure options; uncertainty around fuel costs; energy management strategies, especially when ramping up ZEB deployments
- Thus, APTA staff see engagement with the utility industry and organizations such as EPRI as a key priority to support agencies’ successful ZEB adoption

THANK YOU

Lisa Jerram
Director-Bus, Paratransit and
Surface Transit
ljerram@apta.com

DC as a Service Update

Mike Rowand, Duke

Watson Collins, EPRI

06/13/2018

Update

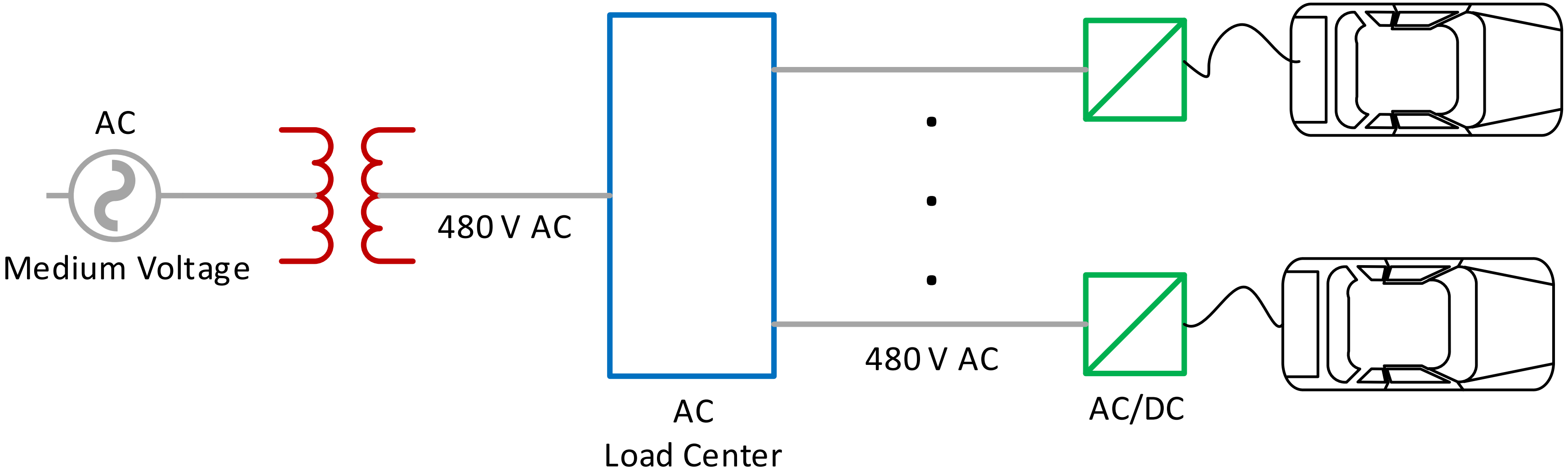
Current Activities

- Proof-of-Concept project at Duke
- Seeking collaboration partners with National Labs, equipment vendors, utilities and others
- Project Concept Paper submitted to U. S. Department of Energy: DE-FOA-0001919
  - Subtopic Area – 1b: Plug-in Electric Drive Vehicle Extreme Fast Charging Research
- Potential subcontractor to U. S. Department of Energy: Vehicle Technologies Office AOP Lab Call
  - Subtopic Area - 3E: Beyond Extreme Fast Charging for MD/HD Electric Vehicles

Next Steps

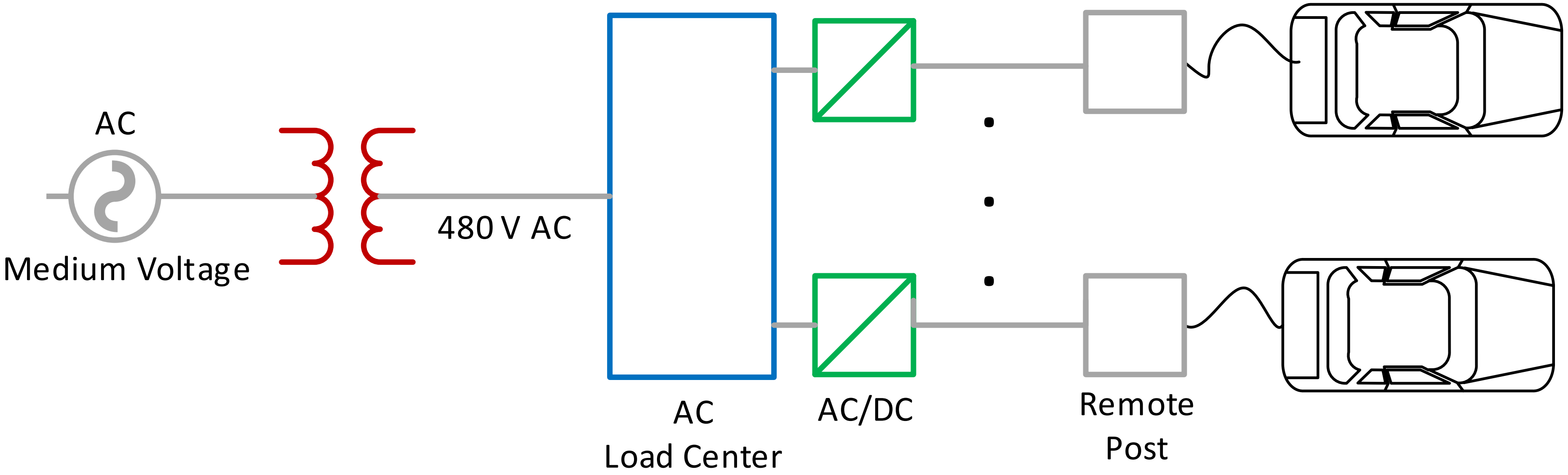
- Develop proposal for DE-FOA-0001919, if selected (Plan A)
- Set up a functional stakeholder process – bi-monthly meetings
  - Building email distribution list for stakeholders
- Identify technology gaps, opportunities and economics
- EPRI is committed to the topic and will seek alternative engagements

Original Approach to 50kW DC Fast Charging



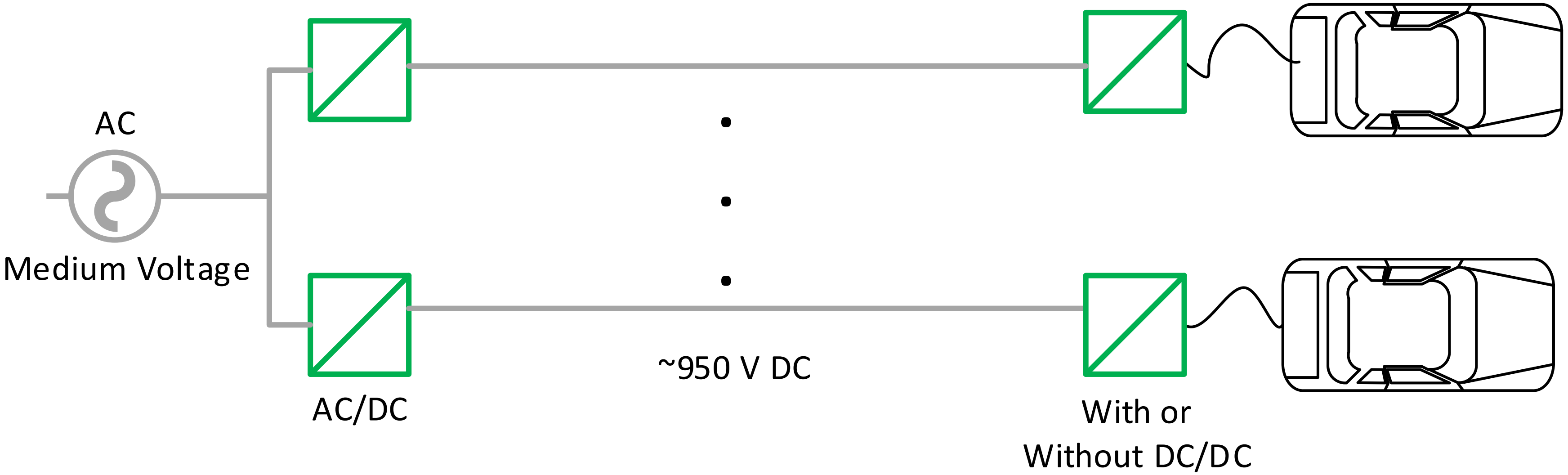
- 480 V AC distribution equipment is interoperable and well established

Today’s Approach to +50 kW DC Fast Charging



- Eliminates need for sizeable curbside AC to DC conversion equipment

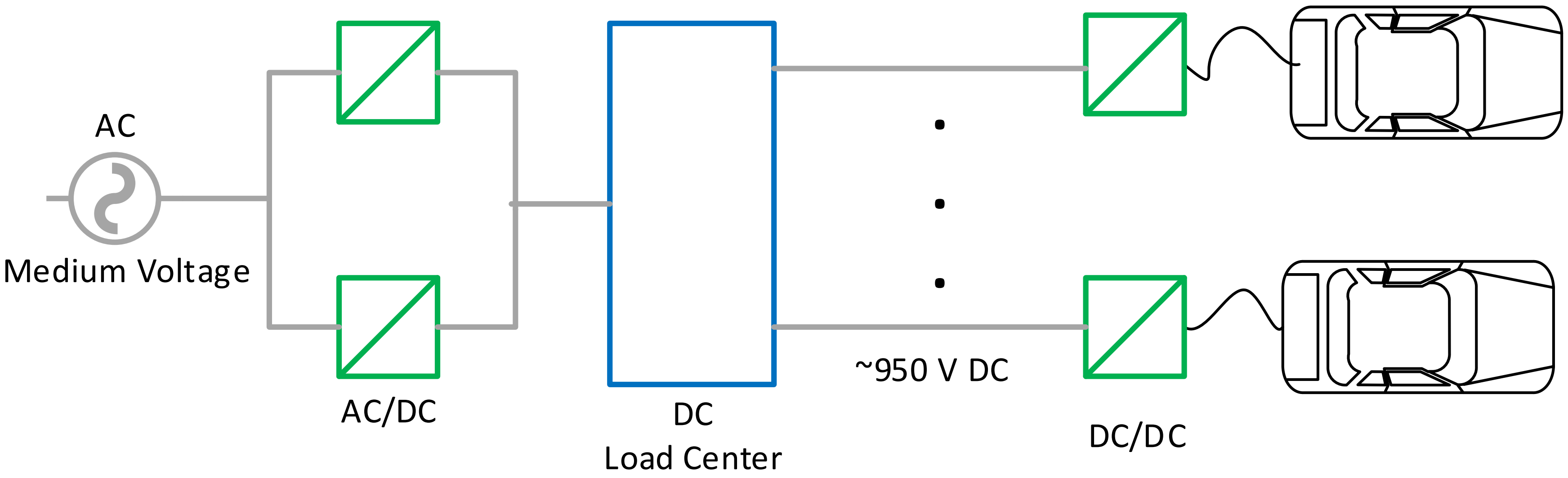
Option A – Approach to Solid State Medium Voltage Connection



- Potential for reduced capital costs, losses and other operating costs
- Simpler approach to galvanic isolation

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Option B – Approach to Solid State Medium Voltage Connection



- DC Load Center can be used for integration of other Distributed Energy Resources
- Potential to size upstream equipment to a diversified peak, instead of a connected peak
- Complications with galvanic isolation

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Together…Shaping the Future of Electricity

Tops-Down, Theoretical Estimate of Charging Infrastructure Sizing

(Working Draft of Connecticut)

Segment	100% Electrification MWH / Day	Est. Number of charging sites	Charging Hours per day at site	Average MWh per Site	Average MW per Site	Estimated Peak MW Demand (@ 50% DF)	Estimated Peak MW Demand (@ 25% DF)	Comments
Combination Long-haul Truck	2,141.75	10	12	214.17	17.85	35.70	71.39	Vehicles to fast charge but queuing to charge occurs during a 12 hour period (comprable to a 50% utilization rate)
Combination Short-haul Truck	702.13	30	12	23.40	1.95	3.90	7.80	Depot based overnight charging routine
Intercity Bus	64.87	8	8	8.11	1.01	2.03	4.05	Depot based overnight charging routine
Light Commercial Truck	1,789.16	100	8	17.89	2.24	4.47	8.95	Depot based overnight charging routine
Motor Home	14.24					-	-	
Motorcycle	158.58	400	8	0.04	0.00	0.01	0.02	10% occurs away from home
Passenger Car	15,692.98	400	8	5.88	0.74	1.47	2.94	15% occurs away from home
Passenger Truck	15,636.29	400	8	5.86	0.73	1.47	2.93	15% occurs away from home
Refueling	3.77					-	-	
Refuse Truck	32.53	100	8	0.33	0.04	0.08	0.16	Depot based overnight charging routine
School Bus	38.47	125	12	0.31	0.03	0.05	0.10	Depot based overnight charging routine
Single Unit Long-haul Truck	38.53	30	8	1.28	0.16	0.32	0.64	Depot based overnight charging routine
Single Unit Short-haul Truck	456.00	300	8	1.52	0.19	0.38	0.76	Depot based overnight charging routine
Transit Bus	19.48	6	8	3.25	0.41	0.81	1.62	Depot based overnight charging routine

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I
Integrated, inter-operable high-powered charging systems

Canadian Urban Transit Research & Innovation Consortium (CUTRIC)
Consortium de recherche et d'innovation en transport urbain au Canada (CRITUC)

@JosipaPetrunic
@CUTRIC_CRITUC
www.cutric-crituc.org

CUTRIC
CRITUC

Canadian Urban Transit Research & Innovation Consortium (CUTRIC)

Vision

To make Canada a global leader in **low-carbon smart mobility** technology innovation across all modes of ground transportation.

Mission

To support the commercialization of technologies through industry-led collaborative demonstration and integration trials and technology development initiatives that support the global exposure of innovative designs by Canadian companies, and the domestic growth of a globally relevant low-carbon smart mobility eco-system.

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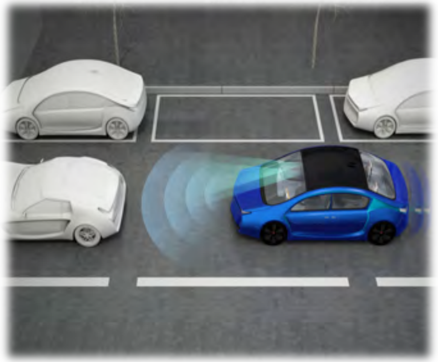
Canadian Urban Transit Research & Innovation Consortium (CUTRIC)

To make Canada a **global leader** in **low-carbon smart mobility technology innovation** across light-duty and heavy-duty platforms, including advanced transit, transportation, and integrated mobility applications.

Pillar #1

Zero-emissions & low-carbon propulsion systems with fueling & charging system integration

Pillar #2



"Smart" vehicles and "smart" infrastructure

Pillar #3

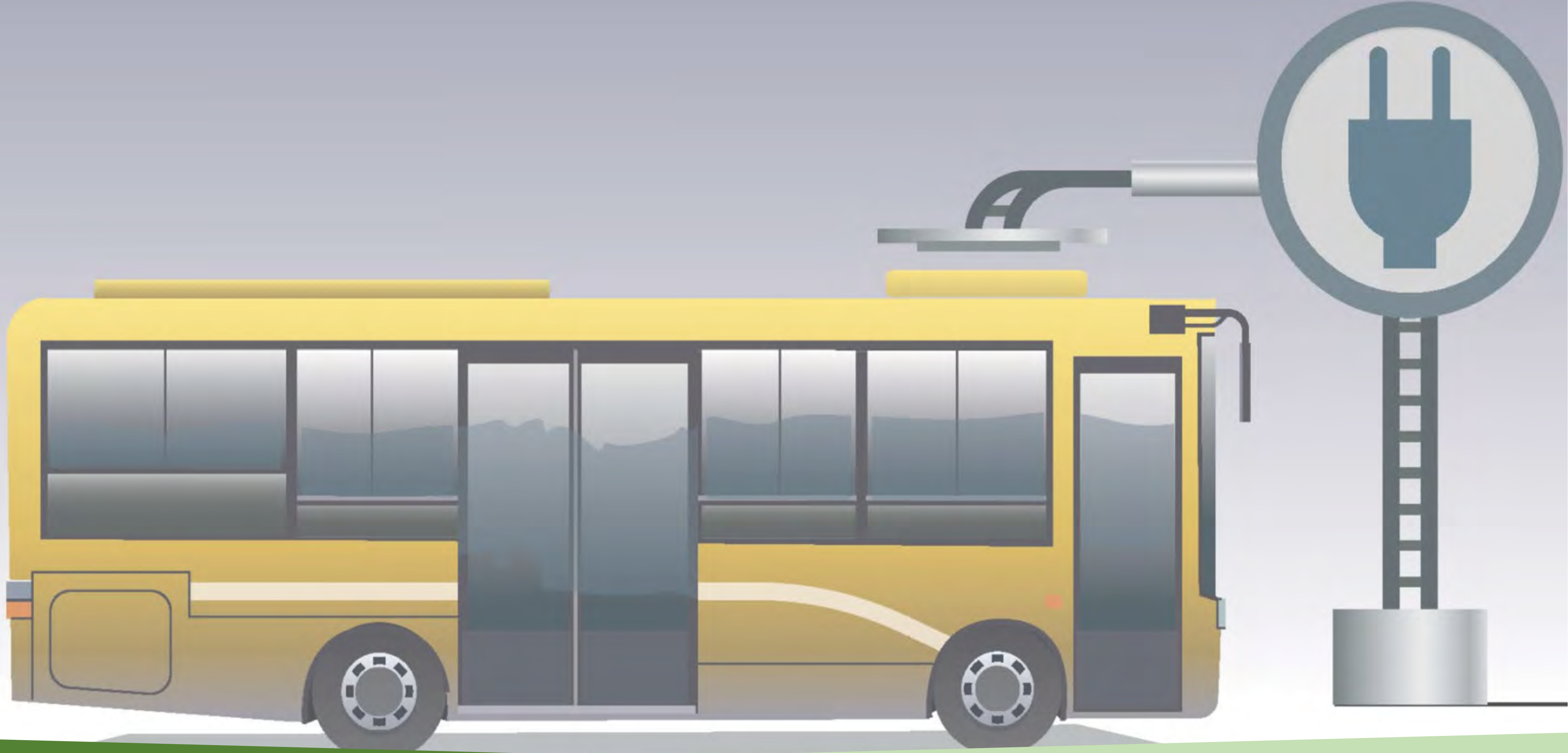
Big data advanced mobility

Pillar #4

Cybersecurity in mobility

CUTRIC CRITUC

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I, II



Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I

Phase 1 ($45M)

Standardization

Interoperability

OppCharge Protocol

3 Transit: TransLink, Brampton, YRT

18 electric buses

7 overhead 450kW chargers

5 routes

Utility business innovation

Charger cybersecurity

Phase 2 ($110M)

Standardization

Interoperability

J3105 SAE (North America)

Smart-enabled "throttled" charging

8 Transit: Winnipeg, Burlington, London, Halifax, Charlottetown

60 electric buses

12 overhead 450 -> 600kW chargers

4+ energy storage units integrated

P3 funding options (financing, operations, maintenance)

Phase 3

Full automation of charging

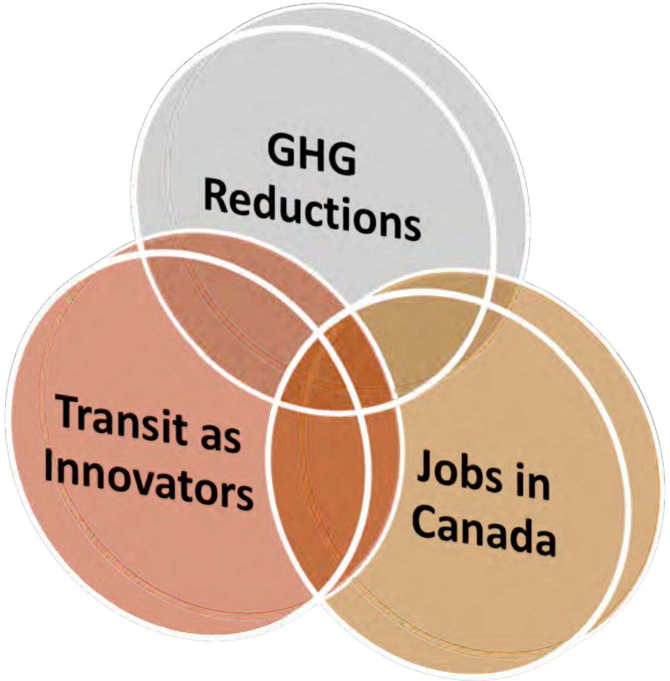
Partial automation of connected platoons on rapid transitways

NAFTA grid cybersecurity protocol

Utility & P3 business innovation

CUTRIC CRITUC

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I



Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I

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Green Car Congress

Energy, technologies, issues and policies for sustainable mobility

CUTRIC launches $40M Pan-Canadian electric bus trial

13 April 2018

The Pan-Canadian Electric Bus Demonstration and Integration Trial: Phase I was launched at TransLink in Vancouver as part of a national coordinated effort to advance zero emissions transit technology, spear-headed by the Canadian Urban Transit Research and Innovation Consortium (CUTRIC).

The $40-million project encompasses 18 standardized and interoperable electric buses, seven standardized and interoperable overhead chargers, and five routes in three cities, said CUTRIC Executive Director & CEO Josipa Petrunic.

CUTRIC brought together manufacturers, transit agencies, utilities, funding partners, research teams, and technology development capacities for the demonstration trial that is launching first in TransLink's system in Vancouver, B.C. TransLink is joined by Brampton Transit and the Regional Municipality of York as sites for the trial, with Brampton Transit having spearheaded the trial planning process back in 2016.

> *This funding investment will support the first global trial to integrate competitive bus manufacturers with competitive charging station manufacturers—all of whom are designing and delivering interoperable high-powered charging systems for on-route charged electric buses—across multiple*

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I

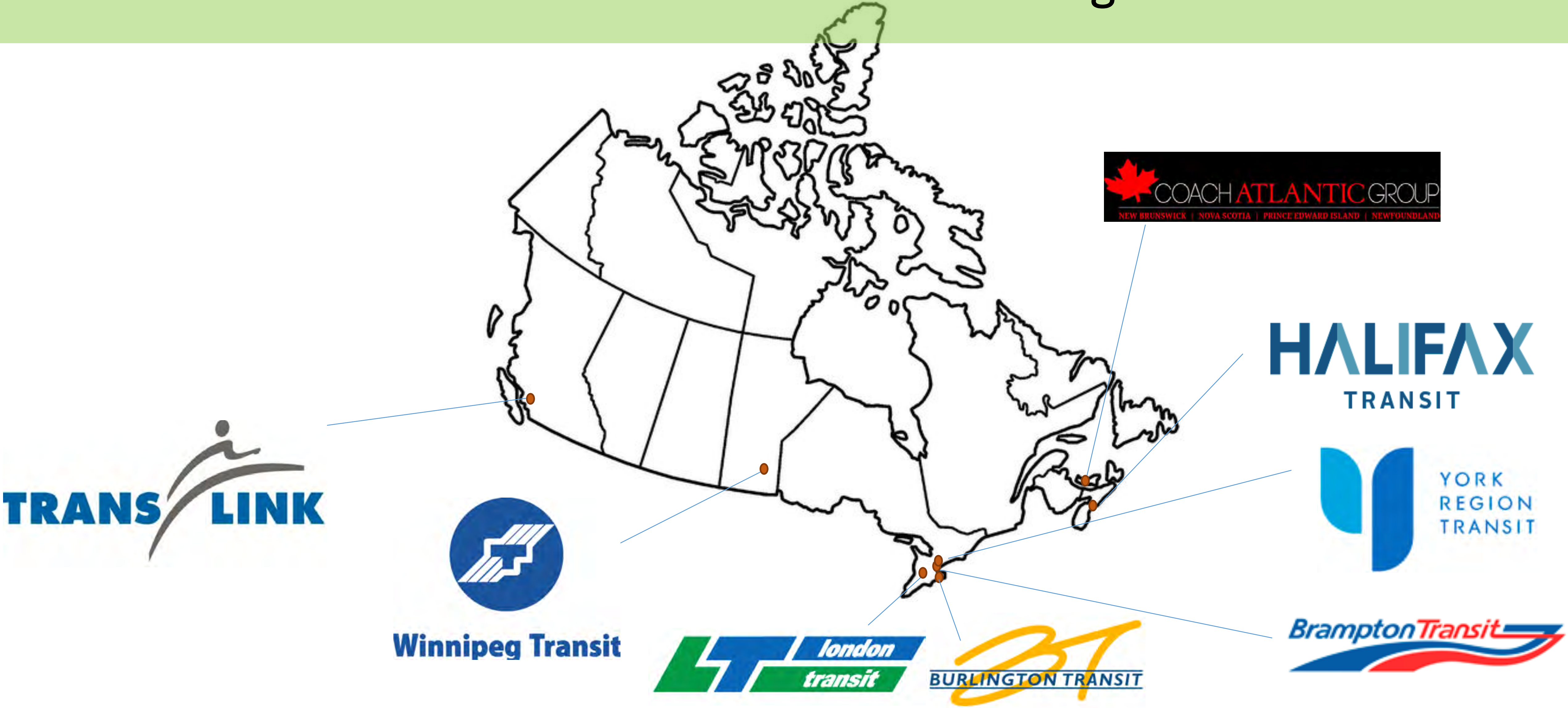
Buses

High power charger

Energy storage media

CUTRIC CRITUC

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I



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Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I

NEW FLYER

ABB

ecamion
POWER OVER ENERGY

NOVA BUS

SIEMENS

BAE SYSTEMS

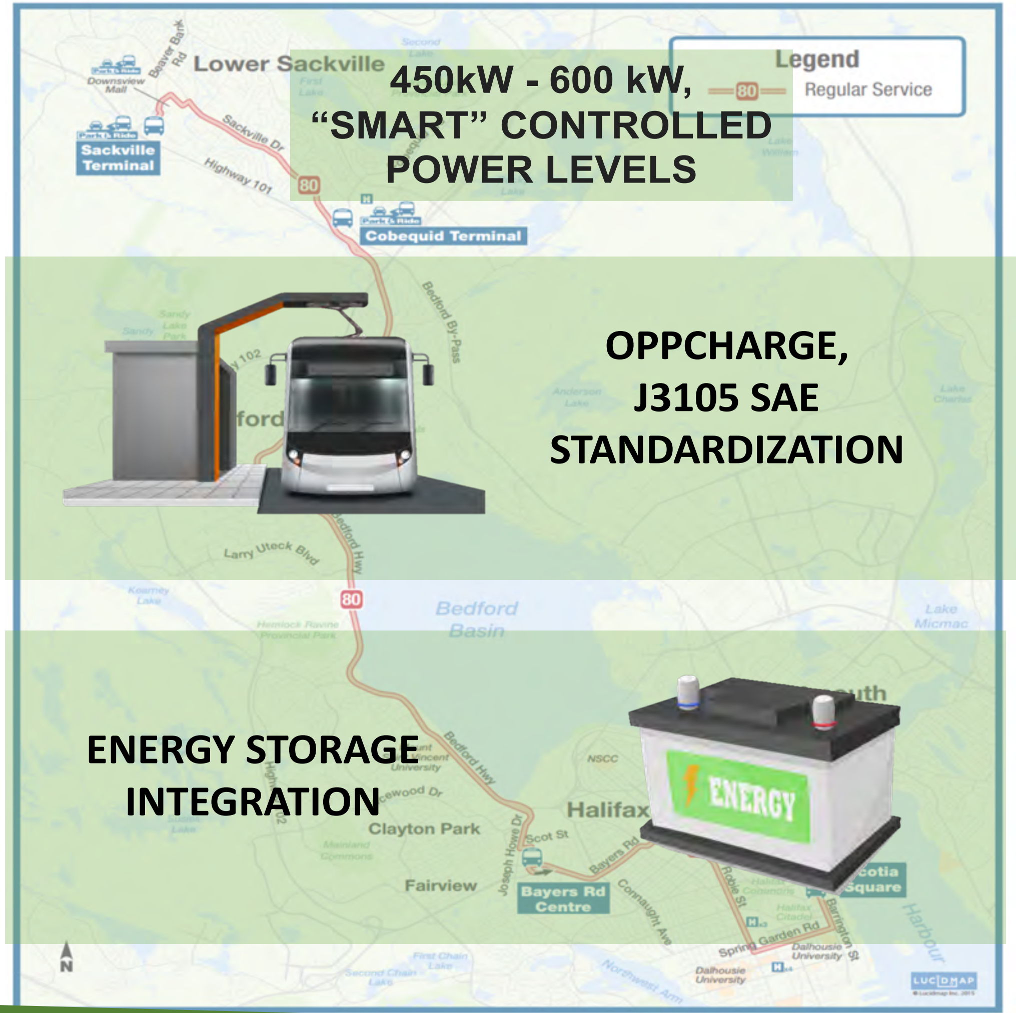
PROTERRA

STORNETIC
The Energy Storage Company

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I

CITY OF WINNIPEG TRANSIT SYSTEM

HALIFAX TRANSIT



stm

CUTRIC CRITUC

Pan-Canadian Electric Bus Demonstration & Integration Trial: Phase I
Financing & business gaps

Private Capital financing

- 12 year financing
- 18 year financing
- 20 year financing
- ($1M per charging system, 450-600KW, smart-enabled)

Transit Ownership

- Electronic & Smart Digital Fleet ownership
- Civil works co-financing
- Modular design requirements

Operations & Maintenance

- Monthly/annual fees
- Preventative maintenance
- Corrective maintenance
- ($6,000/mo)

CUTRIC CRITUC

National Smart Vehicle Demonstration & Integration Project: Phase I

CUTRIC CRITUC

National Smart Vehicle Demonstration & Integration Project: Phase I

NAVYA - COGNITIV

Computer that merges data from sensor architecture:

- Lidar
- Cameras
- Radar
- GPS RTK
- IMU
- Odometry

EASYMILE Fleet Management Software

- Drives up to 45 km/h
- Carries up to 15 passengers
- In-built access ramp
- Fixed or on-demand route
- Supervised by EasyMile’s fleet management software
- Requires no additional road infrastructure

National Smart Vehicle Demonstration & Integration Project: Phase I

2GetThere – Automated People Mover Shuttle

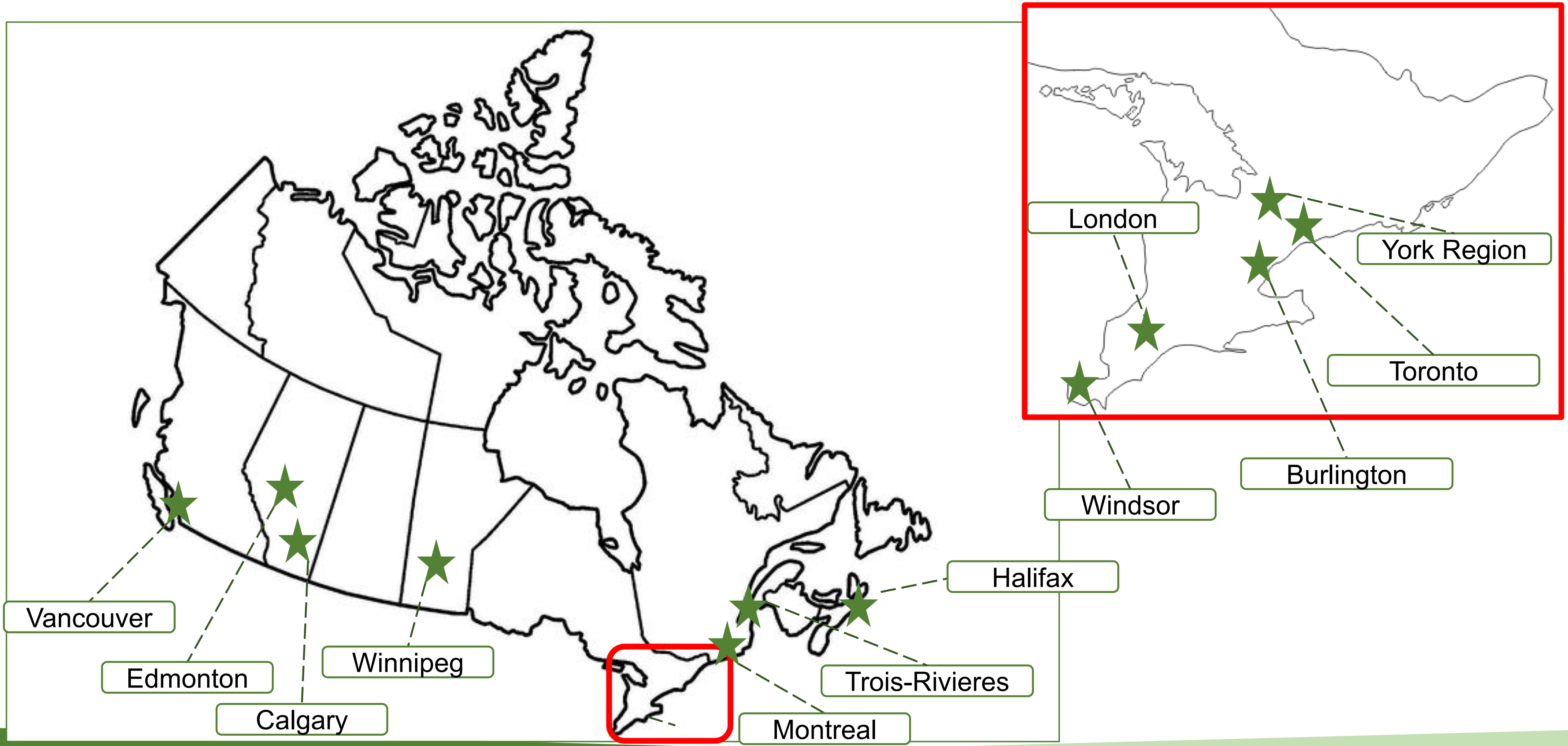
- 24 passengers
- Speeds of 60 km/h
- Can serve short connections (<1.5 km) or long connections (<12 km)
- Costs 50-70% of traditional APM systems

FP Innovations – PIT Group

- Developed a four season mini-transit autonomous shuttle
- Opportunity charging system
- Fully integrated with mass transit
- V2V & V2I communication

CUTRIC CRITUC

National Smart Vehicle Demonstration & Integration Project: Phase I



CUTRIC CRITUC

National Smart Vehicle Demonstration & Integration Project: Phase I

Private Capital financing

- 12 year financing, digital infrastructure & road infrastructure
- $400K (vehicle, charger)
- $TBD sensors, controls on roads
- $TBD Road barriers/pathways

City Ownership & Sharing Model

- *Shuttle fleet, charging systems, digital infrastructure & data*
- *Civil works co-financing*

Operations & Maintenance

- Monthly/annual fees
- Preventative maintenance
- Corrective maintenance
- Upgrading to emergent digital infrastructure standards
- ($TBD/mo.)


JOIN US IN MONTREAL ON JUNE 21-22 2018
CUTRIC 2nd Biennial Technology Innovation Forum
Building Low-Carbon Smart Mobility Projects Across Canada
Generously sponsored in-part by:
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Techno-economic modelling of an electric bus demonstration project in Ontario York Route #55&55B full electrification

Anaissia Franca,
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Dr. Josipa Petrunic,
Executive Director & CEO (CUTRIC)
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V1.5

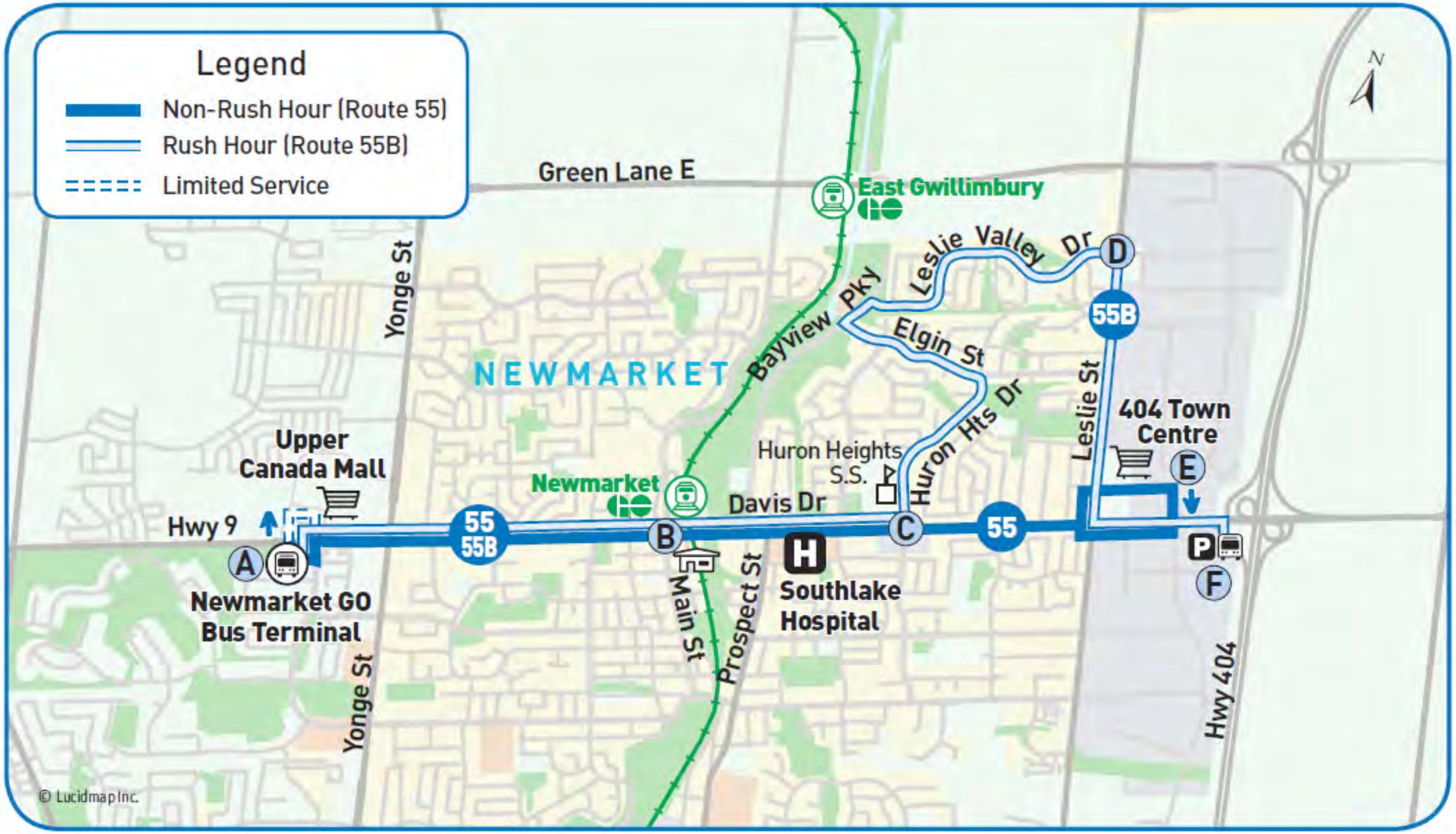
FASTER • SMARTER • GREENER
RAPIDE•INTELLIGENT•VERT

Outline

- Routes and duty cycles
- E-bus energy consumption and SOC calculations
- Charging infrastructure simulation
- Comparative simulation of diesel bus fuel consumption
- Electricity costs estimations, simulation results and emissions calculation for each route
- GHG emission savings

Routes and duty cycles

Route 55/55B map



Route statistics

Name of route	Length of the route one way (km)	Estimated time to complete the route (min)
York bus # 55 (East – West)	5	13
York bus # 55B (East – West)	10	28

Route topography

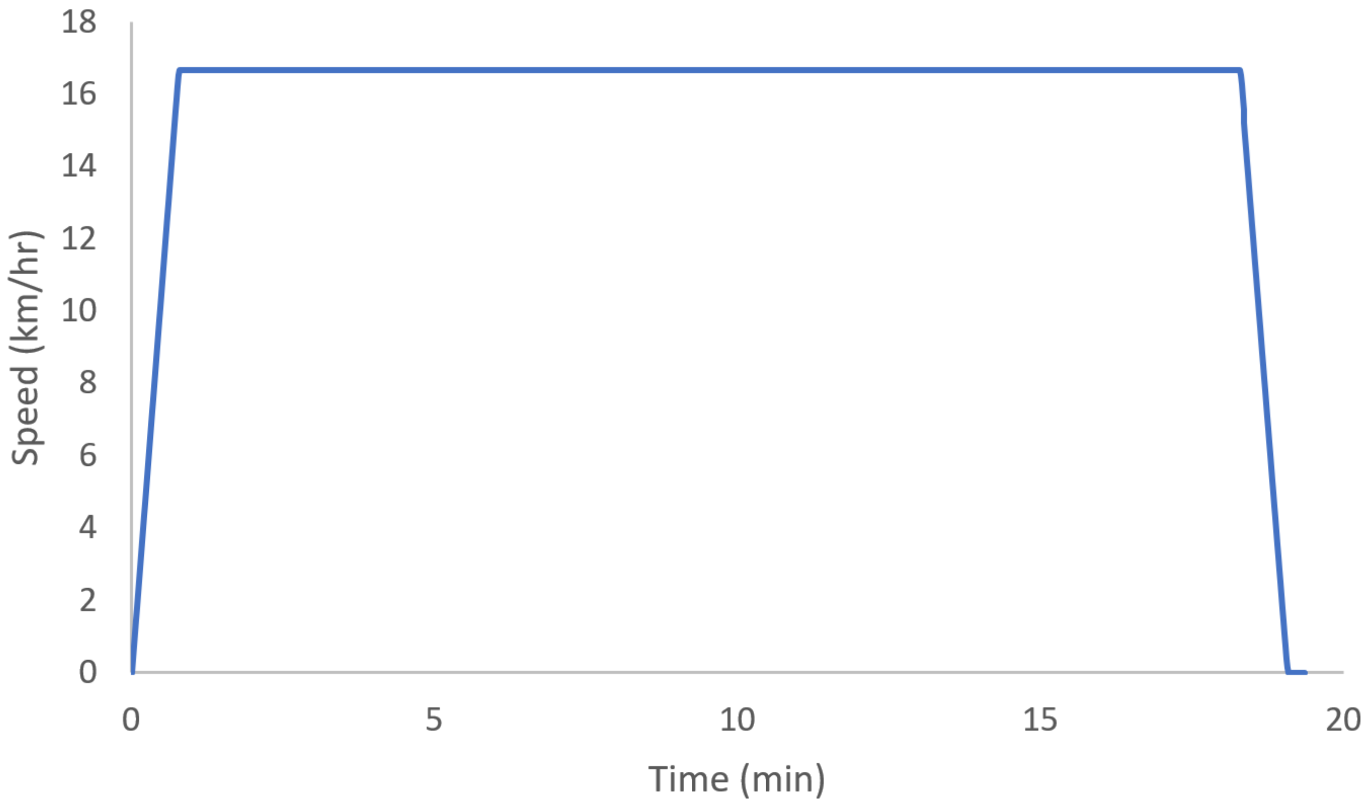
- Used Google Earth to define the path (.kml files)
- Calculated the distances between the nodes

Elevation profile

- Used DEM database[1] to obtain the raw data for elevations
- Used filtration/smoothing to obtain realistic road grades (multiple steps of Savittzky-Golay filter)

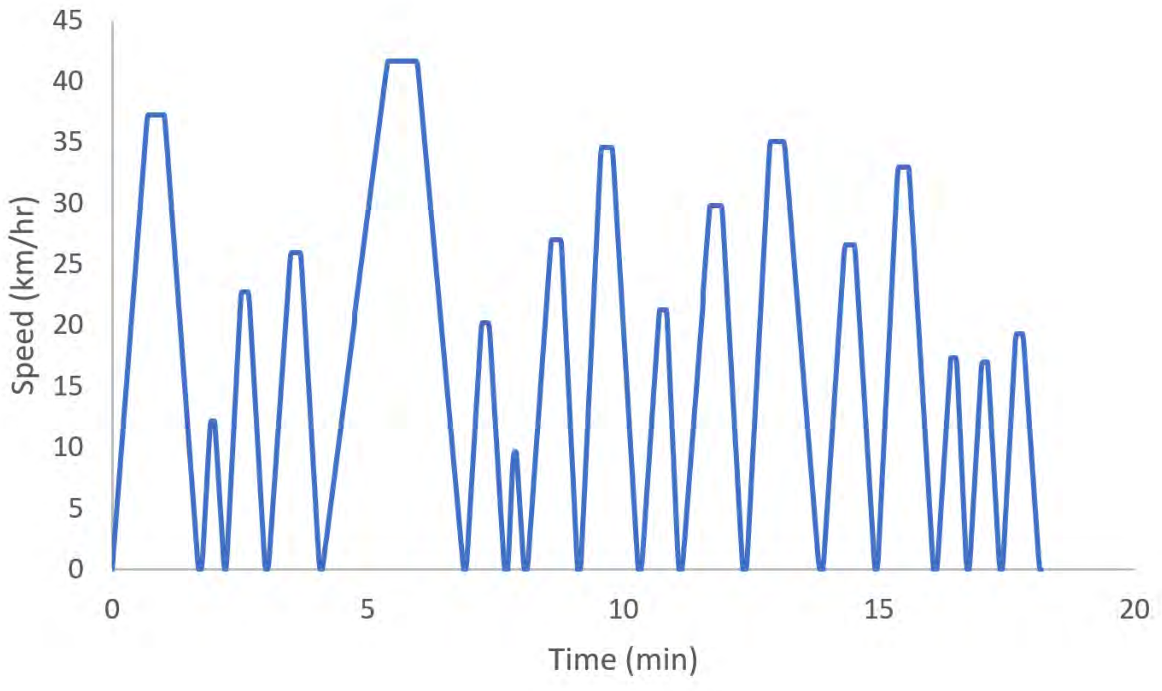
Duty cycles development – example route 55 East

- Light duty cycle
  - Constant velocity, no stop



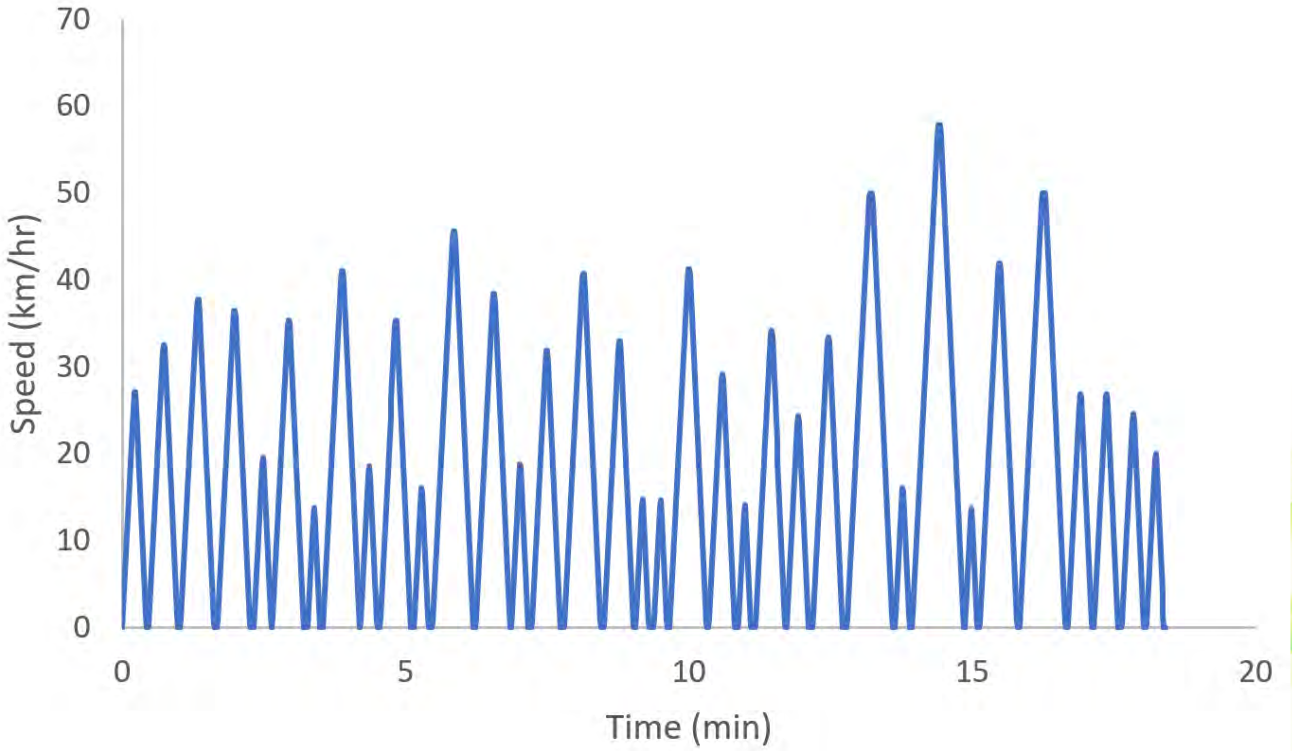
Duty cycles development - example route 55 East

- Medium duty cycle
  - Stop for all scheduled (major) bus stops
  - Additional stops at 50 % of other stops: randomly selected from all the traffic lights, stops signs, passenger walks and other (unscheduled) bus stops



Duty cycles development - example route 55 East

- Heavy duty cycle
  - Stop for all bus stops (scheduled/unscheduled), traffic lights, stop signs and additional stopping for pedestrians



E-bus energy consumption and SOC calculations

Ebus energy consumption and charging power calculations

- Used in-house Matlab and Python code
- Physical characteristics of 12m New Flyer XE40 and a 12m Nova Bus LFSE
- Accounted for variation in topography
- Regenerative braking power split: 35%
- Constant accessory draw
  - Heavy duty cycle: 10,000 W
  - Medium duty cycle: 5,000 W
  - Light duty cycle: 0 W

Vehicle parameters

Parameter	76 kWh NB LFSE	200 kWh NFXE40	Unit
Weight	13,782	14,864	kg
Frontal area (assumed if *)	7.67	8.48*	m^2
Battery chemistry	LiFePO4	NMC	
Drag coefficient (assumed)	0.65		
Rolling coefficients	R0 = 0.006		
Gear Ratio	7.38	5.67	
Tire radius		0.485	m
Transmission efficiency (assumed)	95		%
Converter efficiency (assumed)	97		%
Maximum motor torque	2700	2500	Nm
Charger efficiency	91		%
Efficiency map	Provided		
Maximum passengers	71	76	

Key variables affecting the energy consumption

- Weight of the vehicle
- Auxiliary load
- Tire rolling coefficient
- Regenerative braking usage
- Gear ratio

Energy consumption Route 55 (10 km RT) with Nova Bus (76 kWh)

	East direction					West direction				
	kWh per km	Total kWh used	SOC at route end			kWh per km	Total kWh used	SOC at route end		
			Ideal	5 % buffer	10% buffer			Ideal	5 % buffer	10 % buffer
Light duty	0.57	2.87	96.0%	91.0%	86.0%	0.51	2.6	96.4%	91.4%	86.4%
Medium duty	1.09	5.56	92.3%	87.3%	82.3%	1.01	5.15	92.9%	87.9%	82.9%
Heavy duty	1.98	10.05	86.1%	81.1%	76.1%	2.0	10.15	85.9%	80.9%	75.9%

Note: Ideal battery initial SOC = 100%, 5 % buffer initial SOC = 95%, 10 % buffer initial SOC = 90 %

Energy consumption Route 55 (10 km RT) with New Flyer (200 kWh)

	East direction					West direction				
	kWh per km	Total kWh used	SOC at route end			kWh per km	Total kWh used	SOC at route end		
			Ideal	5 % buffer	10% buffer			Ideal	5 % buffer	10 % buffer
Light duty	0.58	2.95	98.4%	93.4%	88.4%	0.53	2.68	98.6%	93.6%	88.6%
Medium duty	1.12	5.7	97.0%	92.0%	87.0%	1.04	5.27	97.2%	92.2%	87.2%
Heavy duty	2.02	10.25	94.6%	89.6%	**84.6%**	2.04	10.38	94.5%	89.5%	**84.5%**

Note: Ideal battery initial SOC = 100%, 5 % buffer initial SOC = 95%, 10 % buffer initial SOC = 90 %

Energy consumption Route 55B (20 km RT) with Nova Bus (76 kWh)

	East direction					West direction				
	kWh per km	Total kWh used	SOC at route end			kWh per km	Total kWh used	SOC at route end		
			Ideal	5 % buffer	10% buffer			Ideal	5 % buffer	10 % buffer
Light duty	0.54	5.41	92.5%	87.5%	82.5%	0.49	4.96	93.1%	88.1%	83.1%
Medium duty	1.16	11.63	83.9%	78.9%	73.9%	1.08	10.89	84.9%	79.9%	74.9%
Heavy duty	1.85	18.66	74.1%	69.1%	**64.1%**	1.8	18.11	74.9%	69.9%	**64.9%**

Note: Ideal battery initial SOC = 100%, 5 % buffer initial SOC = 95%, 10 % buffer initial SOC = 90 %

Energy consumption Route 55B (20 km RT) with New Flyer (200 kWh)

	East direction					West direction				
	kWh per km	Total kWh used	SOC at route end			kWh per km	Total kWh used	SOC at route end		
			Ideal	5 % buffer	10% buffer			Ideal	5 % buffer	10 % buffer
Light duty	0.56	5.62	97.0%	92.0%	87.0%	0.51	5.11	97.3%	92.3%	87.3%
Medium duty	1.19	11.96	93.7%	88.7%	83.7%	1.11	11.19	94.1%	89.1%	84.1%
Heavy duty	1.88	18.97	90.0%	85.0%	80.0%	1.81	18.21	90.4%	85.4%	80.4%

Note: Ideal battery initial SOC = 100%, 5 % buffer initial SOC = 95%, 10 % buffer initial SOC = 90 %

Charging infrastructure simulation

Electricity demand – Route 55 (10 km RT) Nova Bus (76 kWh) 450 kW charger

	East direction						West direction					
	Ideal charging 100 %		**Typical efficiency 86 %**		**Worst case efficiency 71%**		**Ideal charging 100 %**		**Typical efficiency 86 %**		**Worst case efficiency 71%**	
	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Endpoint charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)
Light duty	0.38	2.87	0.44	3.33	0.54	4.05	0.35	2.61	0.4	3.01	0.49	3.67
Medium duty	0.74	5.57	0.86	6.44	1.05	7.84	0.69	5.16	0.8	5.96	0.97	7.26
Heavy duty	1.34	10.07	**1.55**	11.64	1.89	14.18	1.36	10.18	1.57	11.78	1.91	14.34

Note: Ideal charging: the energy from the grid goes straight to the battery
Typical efficiency: 86% of the energy from the grid goes to the battery (91% charger efficiency, 95 % battery management system efficiency)
Worst case efficiency: 71% of the energy from the grid goes to the battery

Electricity demand – Route 55 (10 km RT) New Flyer (200 kWh) 450 kW charger

	East direction						West direction					
	Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%		Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%	
	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Endpoint charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)
Light duty	0.39	2.95	0.45	3.41	0.55	4.15	0.36	2.68	0.41	3.1	0.5	3.77
Medium duty	0.76	5.71	0.88	6.61	1.07	8.05	0.7	5.27	0.81	6.1	0.99	7.43
Heavy duty	1.37	10.27	**1.58**	11.87	1.93	14.46	1.39	10.41	**1.6**	12.04	1.95	14.66

Note: Ideal charging: the energy from the grid goes straight to the battery
Typical efficiency: 86% of the energy from the grid goes to the battery (91% charger efficiency, 95 % battery management system efficiency)
Worst case efficiency: 71% of the energy from the grid goes to the battery

Electricity demand – Route 55B (20 km RT) Nova Bus (76 kWh) 450 kW charger

	East direction						West direction					
	Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%		Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%	
	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Endpoint charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)
Light duty	0.72	5.41	0.83	6.26	1.02	7.62	0.66	4.97	0.77	5.75	0.93	7.0
Medium duty	1.55	11.65	1.8	13.47	2.19	16.4	1.45	10.9	1.68	12.61	2.05	15.35
Heavy duty	2.5	18.71	**2.89**	21.65	3.51	26.36	2.42	18.13	**2.8**	20.97	3.41	25.54

Note: Ideal charging: the energy from the grid goes straight to the battery
Typical efficiency: 86% of the energy from the grid goes to the battery (91% charger efficiency, 95 % battery management system efficiency)
Worst case efficiency: 71% of the energy from the grid goes to the battery

Electricity demand – Route 55B (20 km RT) New Flyer (200 kWh) 450 kW charger

	East direction						West direction					
	Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%		Ideal charging 100 %		Typical efficiency 86 %		Worst case efficiency 71%	
	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Endpoint charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)	Charging time (min)	Energy from the grid (kWh)
Light duty	0.75	5.62	0.87	6.51	1.06	7.92	0.68	5.12	0.79	5.92	0.96	7.21
Medium duty	1.6	11.97	1.85	13.85	2.25	16.87	1.49	11.2	1.73	12.96	2.1	15.77
Heavy duty	2.54	19.01	**2.93**	21.99	3.57	26.78	2.43	18.23	**2.81**	21.09	3.42	25.67

Note: Ideal charging: the energy from the grid goes straight to the battery
Typical efficiency: 86% of the energy from the grid goes to the battery (91% charger efficiency, 95 % battery management system efficiency)
Worst case efficiency: 71% of the energy from the grid goes to the battery

Comparative simulation of diesel bus fuel consumption

Comparative simulation of diesel bus fuel consumption

Fuel consumption simulation – New Flyer 2013 XD35

- Used Python code developed in-house, based on work from [1]

Vehicle parameters	Value	Unit
Vehicle curb weight	11,113	kg
Mean passenger weight	75	kg
Maximum passengers	65	-
Engine maximum power	209	kW
Drivetrain efficiency	95	%
Rolling coefficient	Provided by OEM	-

Fuel parameters	Value	Unit
LHV of low sulfur diesel	42.6	MJ/kg
Diesel density	850	kg/m^3
CO_2 content of fuel *	2.630	kg CO_{2e}/L fuel

*Note: emission factors for mobile fuel combustion of diesel in heavy-duty vehicles, see [2]

[1] W. Edwardes and H. Rakha "Modeling Diesel and Hybrid Bus Fuel Consumption with Virginia Tech Comprehensive Power-Based Fuel Consumption: Model Enhancements and Calibration Issues Model". Transportation Research Record: Journal of the Transportation Research Board, No. 2533
[2] BC Ministry of Environment "2016/17 B.C. Best practices Methodology for quantifying greenhouse gas emissions" Victoria, May 2016

Fuel consumption – Route 55 (10 km RT)

- Runs per week to compare with fast charging: 122

	Light-Duty	Medium-Duty	Heavy-Duty
Fuel used per run (round trip) per bus (L)	3.2	4.2	7.2
Fuel efficiency of diesel equivalent (L/100km)	31.9	41.3	71.1
Emitted CO_2e per year (kg)	54,338	70,304	121,086
Cost of diesel per year @$1.00/L ($)	$20,661	$26,732	$46,040

Fuel consumption – Route 55B (20 km RT)

- Runs per week to compare with fast charging: 75

	Light-Duty	Medium-Duty	Heavy-Duty
Fuel used per run (round trip) per bus (L)	5.6	8.7	14.7
Fuel efficiency of diesel equivalent (L/100km)	27.6	43.4	73.1
Emitted CO2e per year (kg)	57,289	89,854	151,454
Cost of diesel per year @$1.00/L ($)	$21,783	$34,165	$57,587

Electricity costs estimations, emission reduction and simulation results for each route

Fully electrifying the route is possible

- Based on the current schedule provided by York Region Transit, 4 buses are currently running on route 55 and 55B
- There is always enough downtime at the terminal stations to charge the buses, one charger is required at each terminal

Newmarket – Tay Power rates

Jurisdictional Hydro Company	York Hydro for General Service (50 to 4,999 kW)
Monthly service charge (CAD $)	138.54
Distribution rate ($/kW)	4.7791
Transmission rate network ($/kW)	2.876
Transmission rate connection ($/kW)	2.2806
Rate Rider ($/kW)	-0.0146

- Debt Retirement Charge ($/kWh): 0.007
- Wholesale Market Services Charge and regulatory charges ($/kWh): $0.0032 + 0.0021 + 0.0004$
- Monthly administration charge ($/month): 0.25

Cost of electricity

- Used hourly 2016 HOEP prices, added global adjustment rate that changes monthly ($\$/kWh$)
- Accounted for 13 % HST
- Cost of electricity for each route, at hour h calculated as:

$$Cost_{elec}(h) = (HOEP(h) + GA) \times E(h) \times (1+\text{HST})$$

$E(h)$: Energy required to charge the bus (kWh)
GA: global adjustment rate ($\$/kWh$)

Regulatory cost

- Regulatory cost calculated as:

$$C_{reg} = E_{total} * (r + r_d + r1) + 12 * r2$$

E_{total}= total energy consumption for a week
r = regulatory charges ($\$/kWh$)
r_d= debt retirement charge
$r1$= support program charge
$r2$= administration charge

Delivery cost

- Monthly service charge (MSC) are different for each jurisdiction

$$C_{deliv} = 12 * (MSC + 450kW \times r_d \times \frac{t_{charge}}{15min})$$

r_d= Monthly demand charge ($/kW)

Charging costs – Full Route 55 and 55B with Nova Bus (76 kWh)

	Light	Medium	Heavy
Yearly MWh estimated	85	175	304
Electricity cost (CAD $)	$8,584	$17,838	$30,838
Regulatory cost (CAD $)	$2,165	$4,451	$7,728
Delivery cost (CAD $)	$9,040	$15,754	$23,647
Total charging cost for a year (CAD $)	**$22,361**	**$42,989**	**$70,301**
Diesel cost for a year (CAD $)*	$42,444	$60,897	$103,627
Benefits (CAD $)	**$20,083**	**$17,908**	**$33,327**
Carbon cost of fuel (CAD$) **	$2,009	$2,883	$4,906
Benefits if carbon price included (CAD$)	**$22,092**	**$20,791**	**$38,233**

* : Price of diesel : $1/L

**: Price of carbon: $18/tCO2

Charging costs – Full Route 55 and 55B with New Flyer (200 kWh)

	Light	Medium	Heavy
Yearly MWh estimated	87	180	310
Electricity cost (CAD $)	$ 8,854	$18,291	$31,283
Regulatory cost (CAD $)	$2,216	$ 4,578	$ 7,880
Delivery cost (CAD $)	$9,254	$16,111	$23,826
Total charging cost for a year (CAD $)	**$22,966**	**$44,048**	**$71,177**
Diesel cost for a year (CAD $)*	$42,444	$60,897	$103,627
Benefits (CAD $)	**$19,478**	**$16,849**	**$32,450**
Carbon cost of fuel (CAD$) **	$2,009	$2,883	$4,906
Benefits if carbon price included (CAD$)	**$21,487**	**$19,732**	**$37,356**

* : Price of diesel : $1/L

**: Price of carbon: $18/tCO2

Ontario 2015 Grid Emissions [2]

	Solar / Wind / Bioenergy	Natural Gas	Nuclear	Coal	Waterpower
Electricity production (TWh)	14.2	15.9	92.3	0	37.3
Percentage of the grid use (%)	8.89	9.96	57.80	0.00	23.36

- Total electricity production (2015): 159.7 TWh
- Total emission (2015): 7.1 MT CO_2e
- The emission is calculated as 0.044 Tonne CO_2e/MWh

[2]: IESO " MODULE 1: State of the Electricity System: 10-Year Review ", August 2016

Emission reduction – Route 55 and 55B with Nova Bus (76 kWh)

	Light	Medium	Heavy
Yearly electricity estimated (MWh)	85	175	304
Yearly diesel use (L)	42,444	60,897	103,627
CO2e from electricity (Tonne)	3.74	7.7	13.376
CO2e from diesel (Tonne)*	111.63	160.16	272.54
CO2e reduction for a year (Tonne)	107.89	**152.46**	**259.16**

* : Mobile emission factor for mobile fuel combustion of diesel in heavy-duty vehicles is 2.63 kg CO2e/L

Emission reduction – Route 55 and 55B with New Flyer (200 kWh)

	Light	Medium	Heavy
Yearly electricity estimated (MWh)	87	180	310
Yearly diesel use (L)	42,444	60,897	103,627
CO2e from electricity (Tonne)	3.82	7.92	13.64
CO2e from diesel (Tonne)*	111.63	160.16	272.54
CO2e reduction for a year (Tonne)	107.80	**152.24**	**258.90**

* : Mobile emission factor for mobile fuel combustion of diesel in heavy-duty vehicles is 2.63 kg CO2e/L