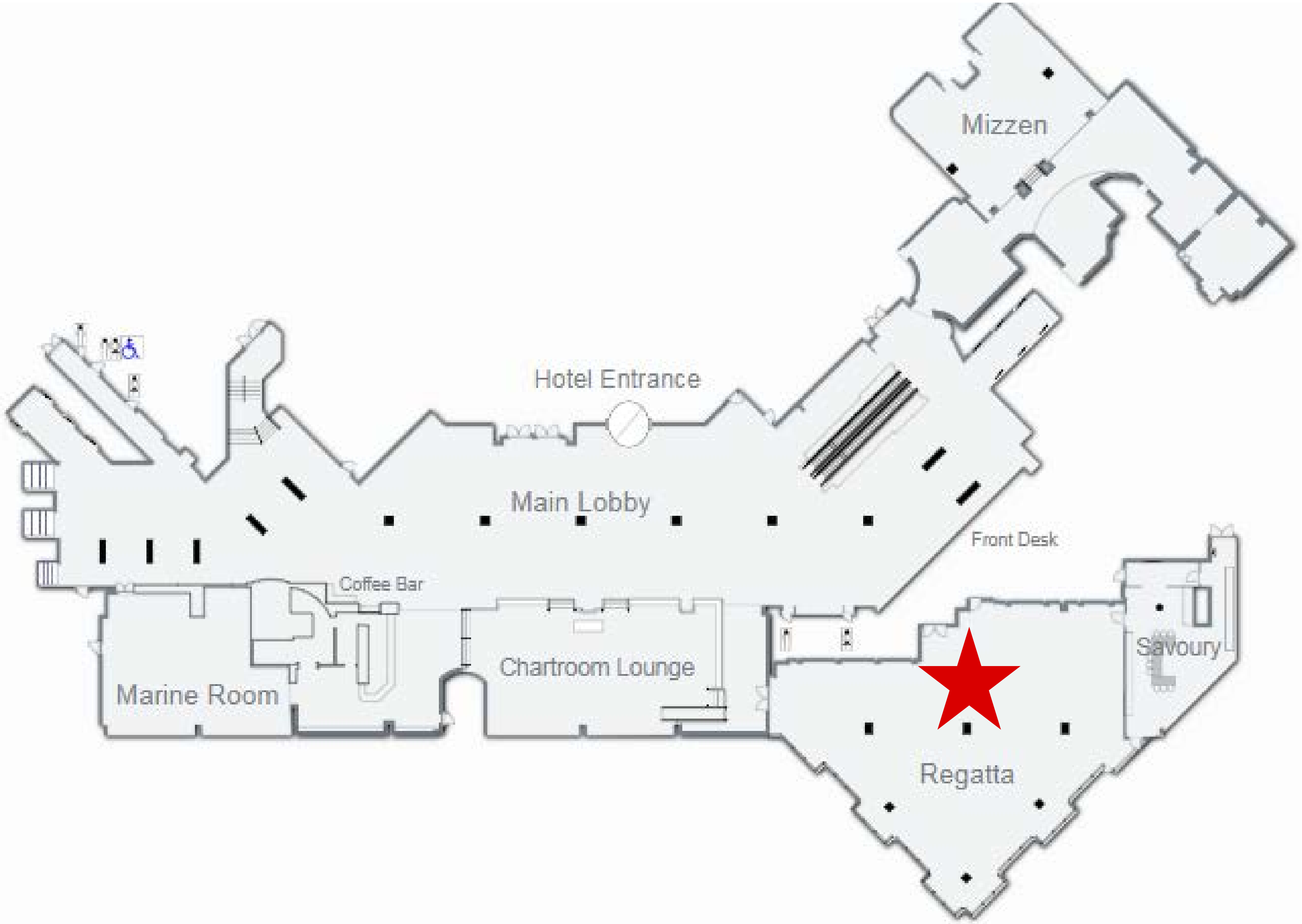
APRIL 10, 2018

Transportation expert day

Electrification of public transport

Safety Moment



Let’s write the future.

Together.

ABB: pioneering technology leader in power and automation

What *(Offering)*	**Pioneering technology**		
	Products 59%	Systems 24%	Services & software 17%
For whom *(Customers)*	**Utilities**	**Industry**	**Transport & Infrastructure**
	~35% of revenue	~40% of revenue	~25% of revenue
Where *(Geographies)*	**Globally**		
	Asia, Middle East, Africa 37%	Americas 30%	Europe 33%

~$35 bn revenue	~100 countries	~135,000 employees

ABB in Canada

Investment and growth

Region headquarters
Montreal, Quebec

~ **4,000 employees**
in Canada

~ **$2.1** billion
revenue

55 locations
coast to coast

Over 100 years of
technological
innovation in Canada

~ **26**
sales & service
locations

~ **29**
Manufacturing
& assembly
locations

Canadian market leader in power
transmission and
distribution

Ranked in top 20
Canada's Best Employers
2016 & 2017

~ **600** Safety
Observation Tours in
2016

North American
Center of Excellence for E-Mobility

Close to $1 million
given to Canadian
communities in 2016

Top 20 Canada's best employers ranking by Forbes: https://www.forbes.com/companies/abb/

ABB Campus Montreal

A strong investment in Canada

- 300 000 ²ft located in the Technoparc of Saint-Laurent
- Headquarter, R&D, manufacturing and testing
- Represent an investment of 90 millions $
- LEED certification

North American Center of excellence in electro-mobility

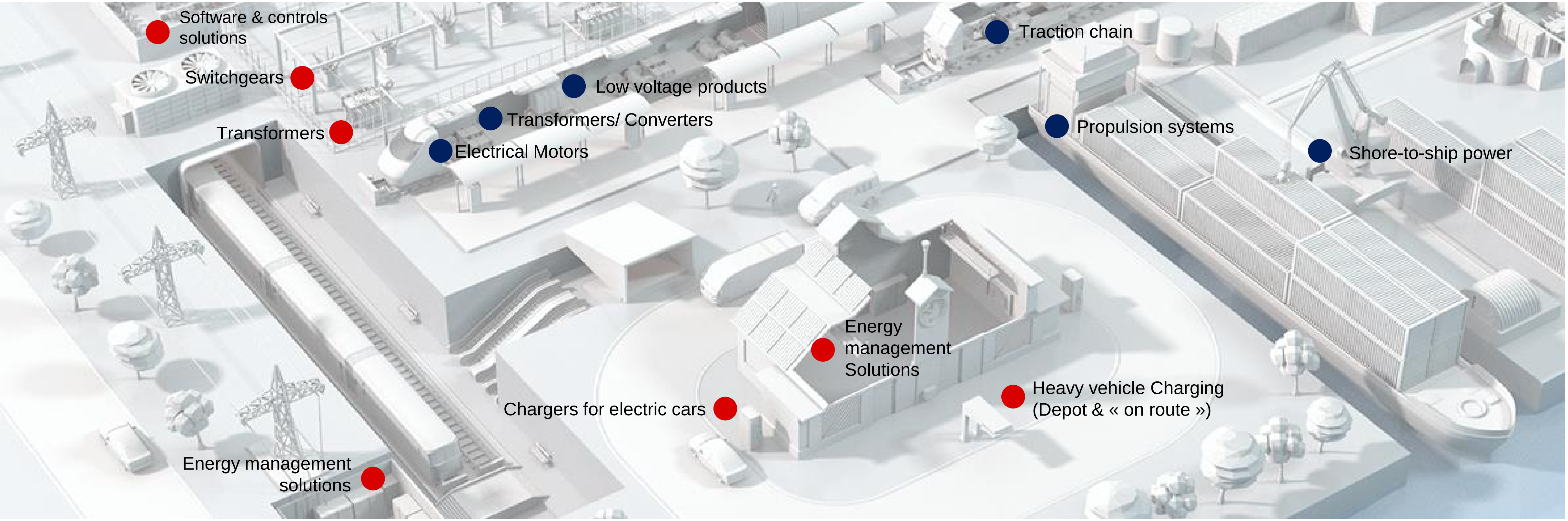
In the new ABB campus Montréal

- The CoE in e-mobility, inaugurated in **may 2017**, will help accelerate the conception and the deployment of innovative infrastructure technologies for the powering and charging of **cars, buses, trucks and trains.**

- The CoE will enable stronger collaboration with **cities, transit authorities, universities, OEMs, and power utilities** with the objective to cooperate in the realization of concrete projects in North America

Mandate

Electrical power and charging infrastructure for land transportation



R&D Collaboration

Local and regional

Collaborative projects

Ex. Pan-canadian e-bus demonstration project

- **Demonstration** project of automatic fast charging for electric buses at terminals
- Based on « OppCharge » connection standard **(https://www.oppcharge.org/)**
- **World premier** for a demonstration project involving few cities with different bus and chargers OEMs
- Under the leadership of **CUTRIC**, project with 18 members including 3 cities (**Brampton, Newmarket & Vancouver**) in 2 provinces, 2 electric bus manufacturers (**New Flyer & Nova Bus**) and 2 charging equipment manufacturers (**ABB & Siemens**) and **research and universities org.**

Collaborative projects

Ex. project « Alfred Nobel »

- **MOU signed on June 13** 2017, between FP Innovation, Technoparc Montréal, Motrec International Inc., ABB Inc. and Ericsson Canada Inc.
- Evaluation of a **new mobility service, on demand,** for the first/last mile. Concept around an **autonomous shuttle, fully electric, connected,** and adapted to Canadian **winter conditions**.
- The SMART shuttle wil de
- Local collaborative project with **the desire** to involve world class companies and act as **incubator** for local & regional « **startups** »
- First phase of the project will be in the **Technoparc MTL**
- **« Living lab »** to see and live the experience.

Agenda

TIME	TOPIC	SPEAKERS
8:00	Breafast & Check in	
9:00	Welcome & Introductions	Daniel Simounet
9:15	Keynote Speaker: Connecting People: The 2041 Regional Transportation Plan	Peter Paz, Manger of regional partners, Metrolinx
	E-mobility 101: The roadmap to electric transportation. As cities drive to become cleaner, transit authories and transportation providers are expected to go electric. Each city‘s journey to electrification looks different.	
9:45	Building a roadmap to e-mobility	Naeem Farooqi, Principal Consultant, WSP
10:15	Break	
10:30	Energy storage backed railway traction chain	Elvis Dzindo, ABB
11:00	eBus: Mix of fleet and design considerations	Stephanie Medeiros, EV charging infrastructure, ABB
11:30	Digitalization strategies for electric fleets	Pat Egan, Enterprise Software, ABB
12:00	Networking & Lunch	
	Impact of electrified transport on the grid: The collaboration between transit operators and utilities is imperative. Prepare for the future with design strategies that account for intelligent grid connection, minimized demand charges, and optimized reliability.	
1:30	A utility perspective: Insights on electrified transport's grid impacts, and best practices for utility partnership	Neetika Sathe, VP, Advanced Planning, Alectra
2:30	Electrification of bus fleets: Grid impacts and solutions	Stephanie Medeiros, EV charging infrastructure, ABB
3:00	Break	
3:15	Generating positive cashflow through Rail Energy Storage Systems	Patrick Savoie, Wayside Energy Storage Systems, ABB
3:45	Rail electrification design considerations	Imtiyaz Mashraqi, Grid Integration, ABB
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4:30	Reception	

METROLINX

Connecting People: 2041 Regional Transportation Plan

Peter Paz Manager, Regional Partnerships
Metrolinx

WHO IS METROLINX?

Metrolinx was created in 2006 by the Province of Ontario with a mandate to create greater connection between the communities of the Greater Toronto and Hamilton Area, and now beyond to the Greater Golden Horseshoe

Vision: Getting you there, better, faster, easier.
Mission: We connect our communities.

PLAN

BUILD

OPERATE

CONNECT

METROLINX'S GEOGRAPHIC MANDATE

Complex

Working with thirty municipalities, four levels of government and nine municipal transit agencies

Greater Toronto and Hamilton Area

- Full Metrolinx mandate

GO Transit Service Area

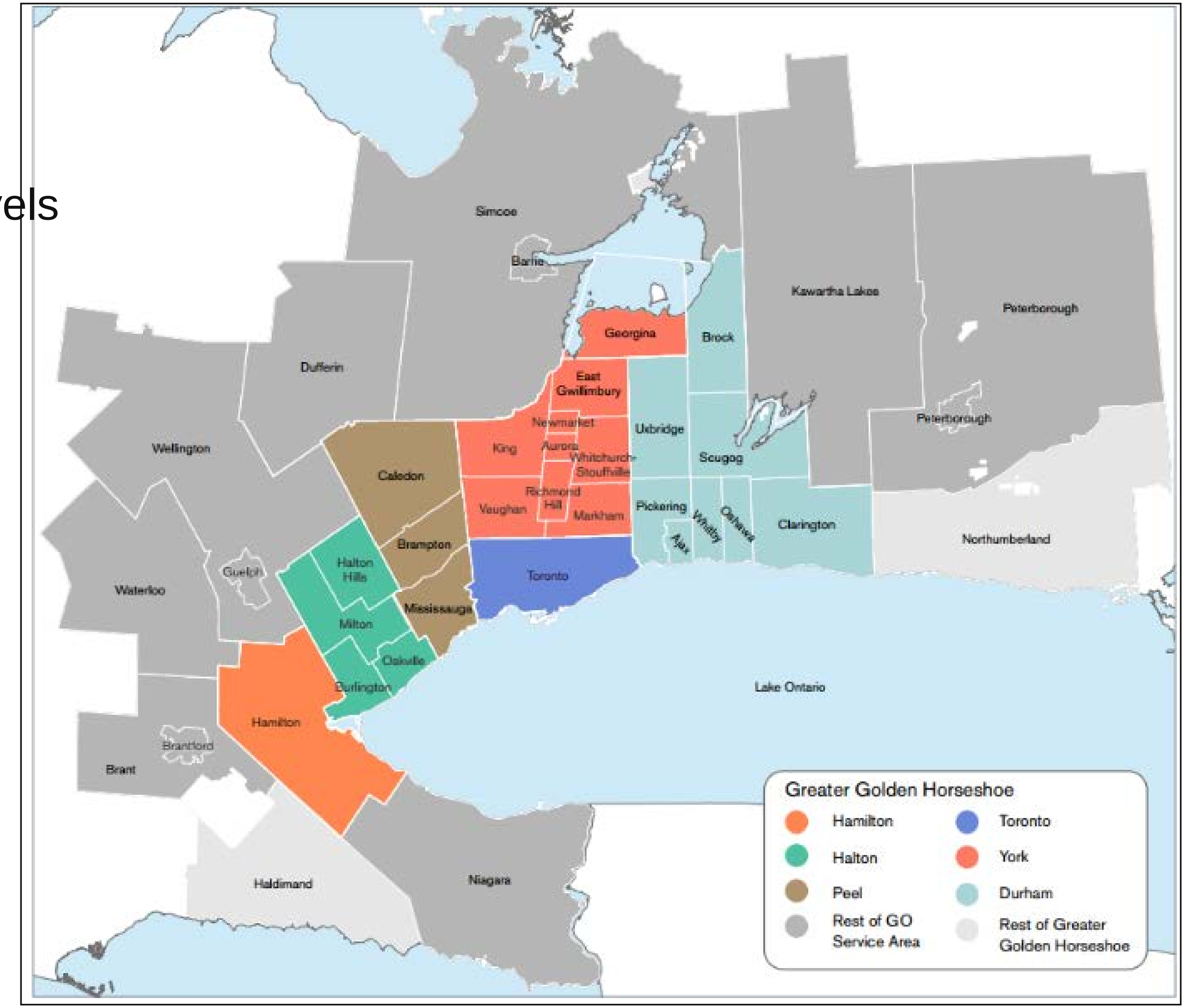
- Build and operate GO Transit

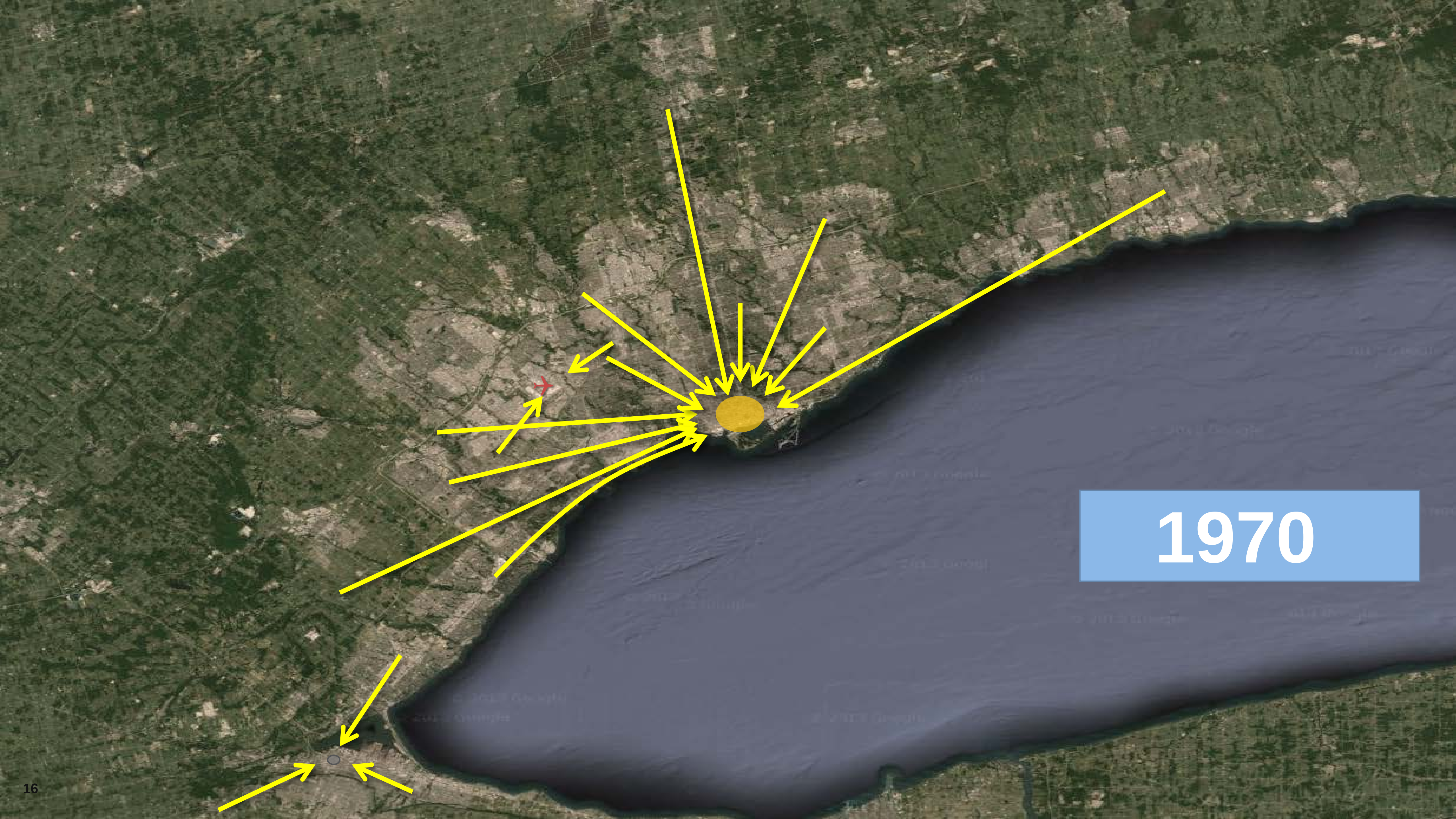
Ottawa

- PRESTO

Other Ontario Communities

- Transit Procurement Initiative




1970

THEN & NOW: HIGHWAY 401 IN TORONTO

1958

2015

THEN & NOW: GO TRANSIT

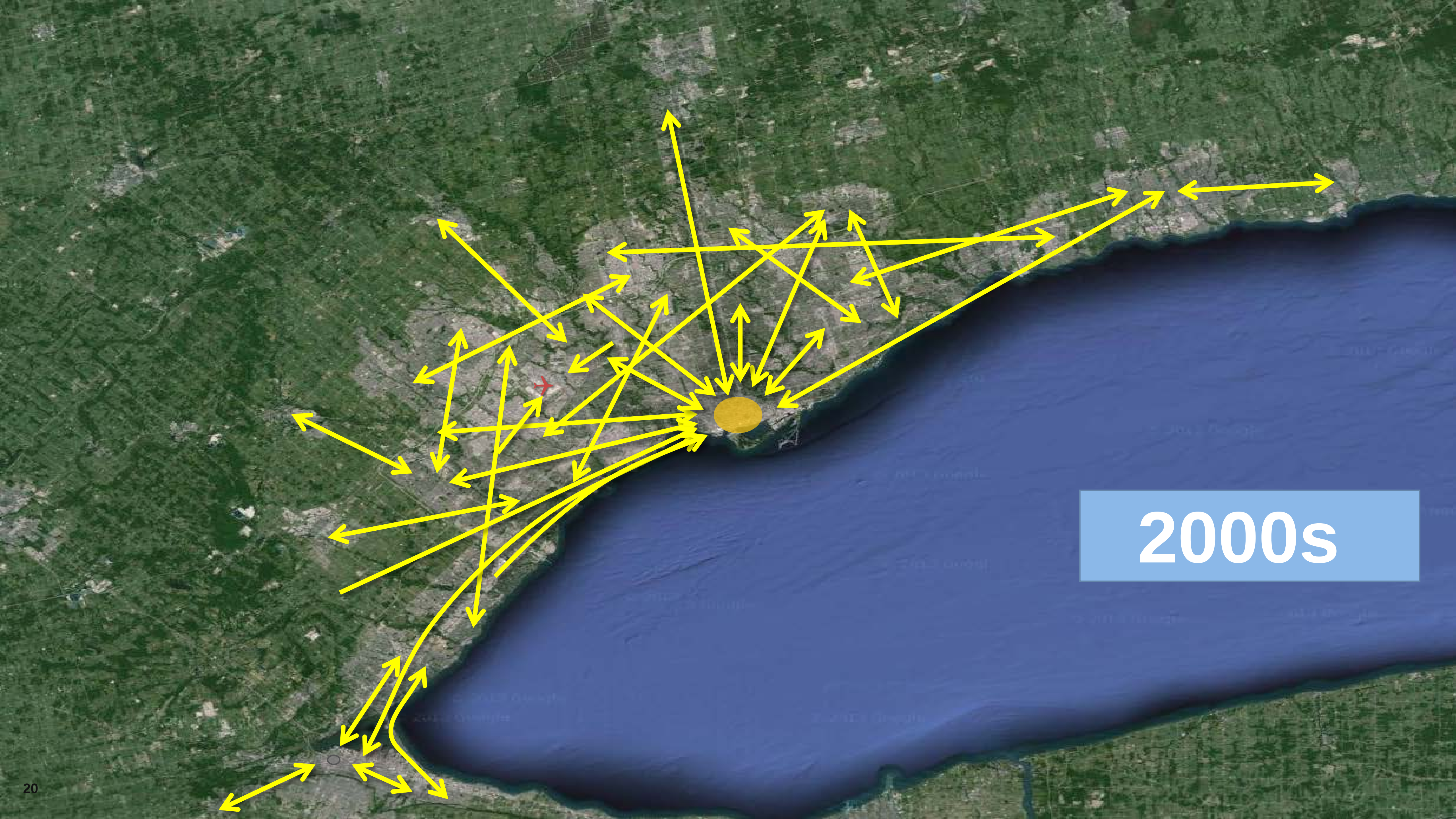
1967

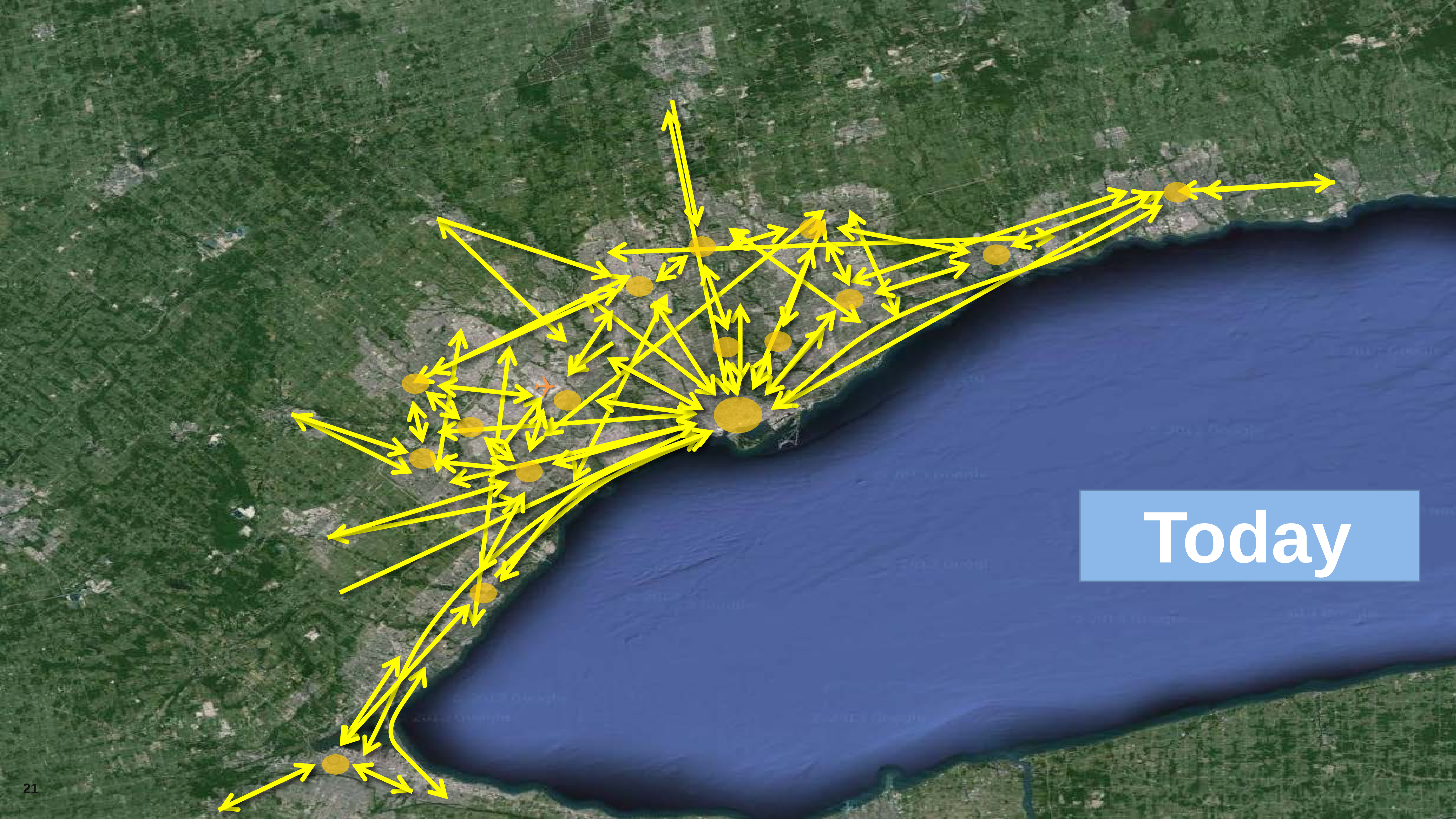
2012

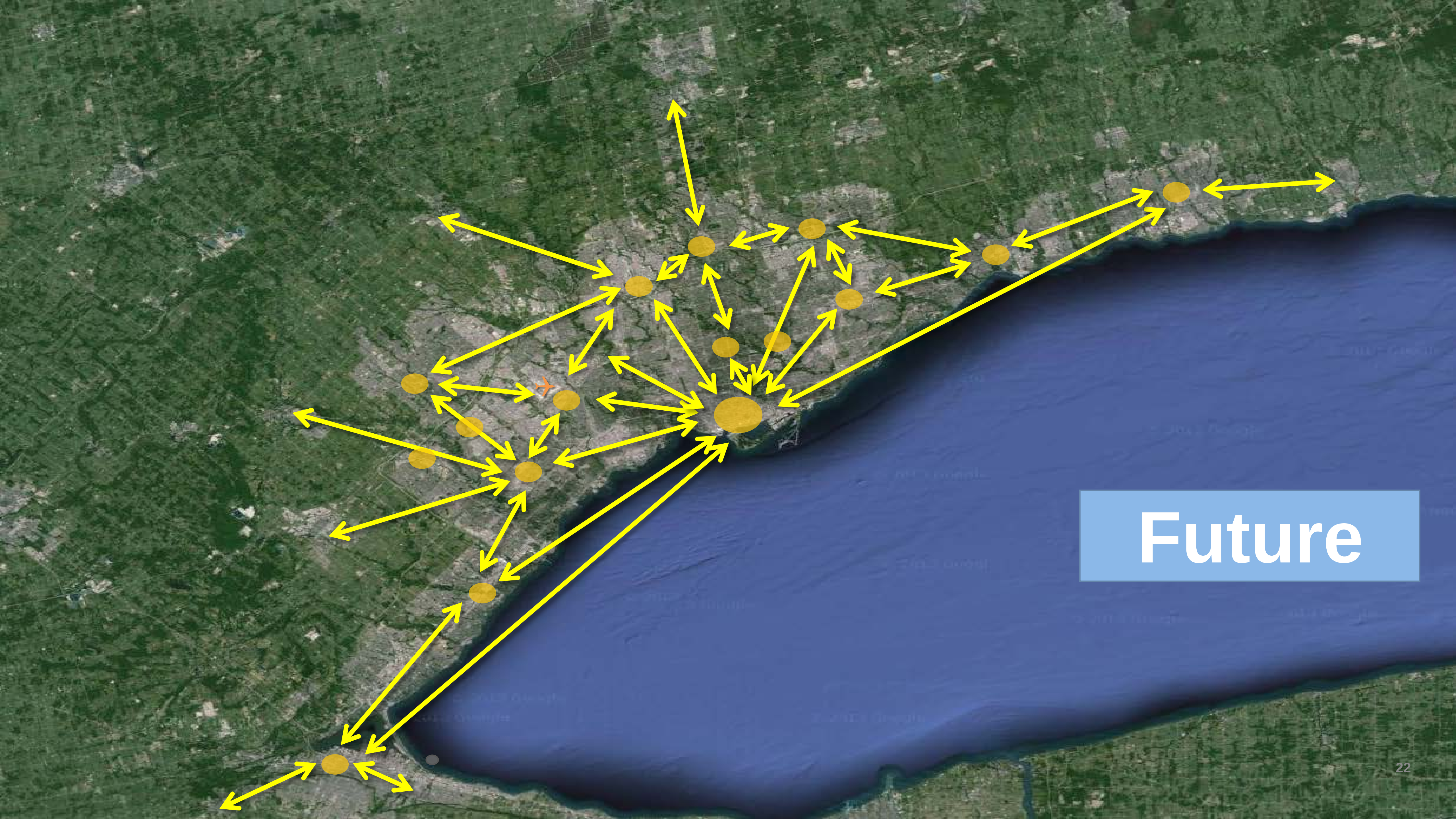
THEN & NOW: TTC YONGE SUBWAY LINE

1958

2017


2000s


Today


Future

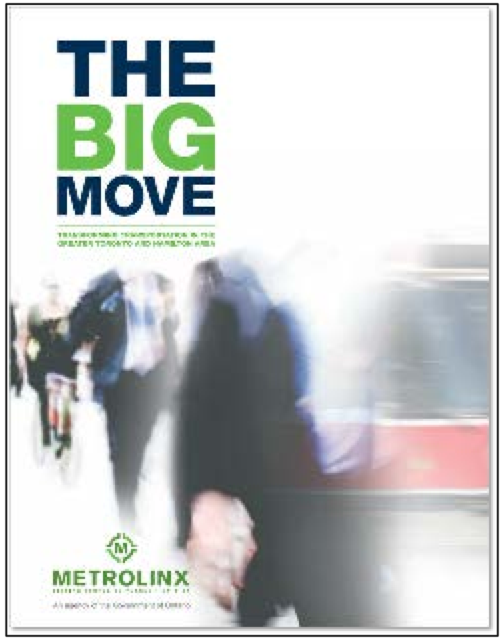
HAVE A COMPLETE PLAN!

2008

“In 25 years, the GTHA will have an integrated transportation system that enhances our quality of life, our environment and our prosperity”

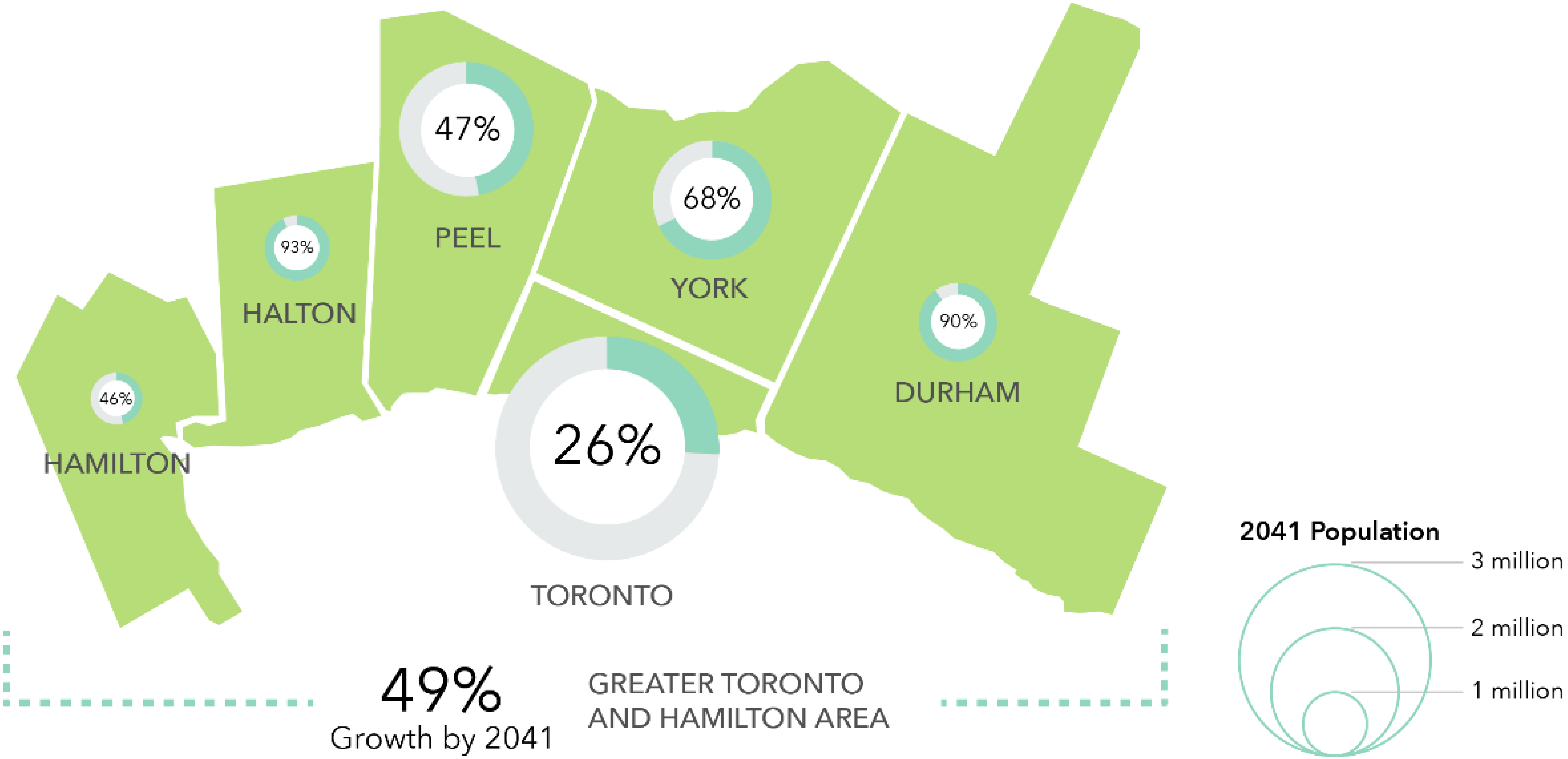
THE BIG MOVE'S LEGACY:

$36 BILLION IN INFRASTRUCTURE INVESTMENT



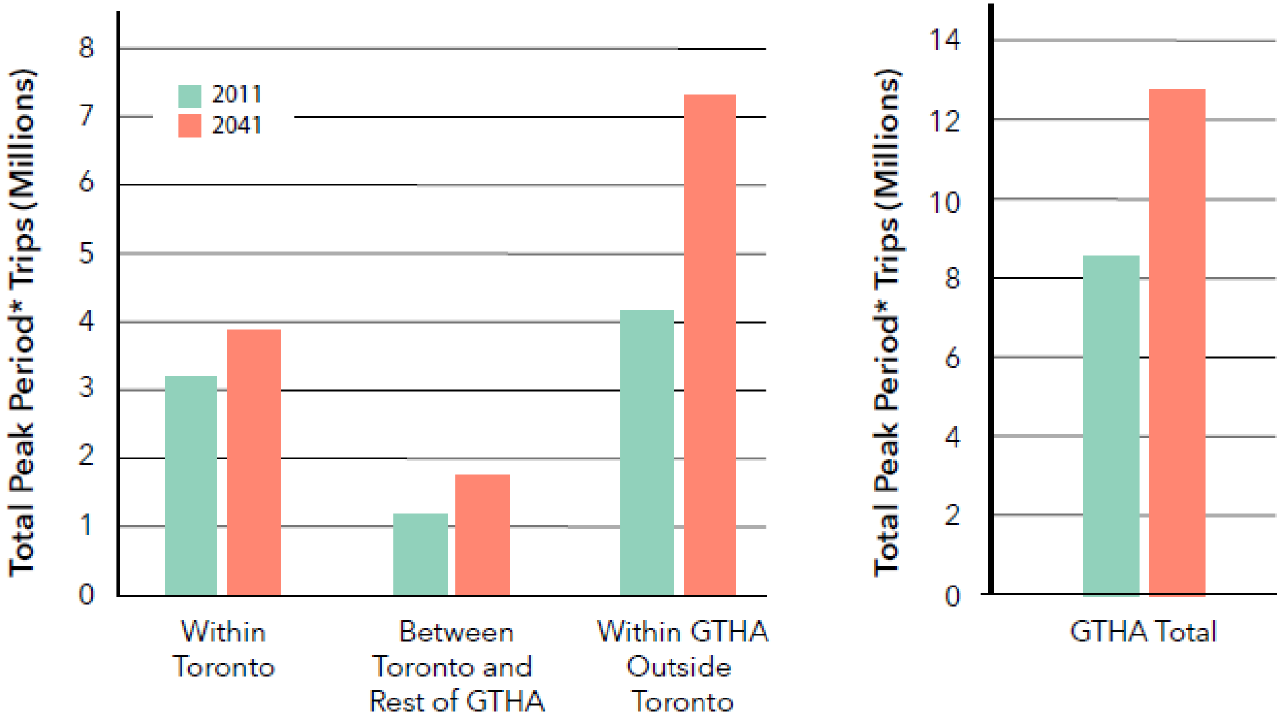
METROLINX

POPULATION GROWTH 2011 - 2041

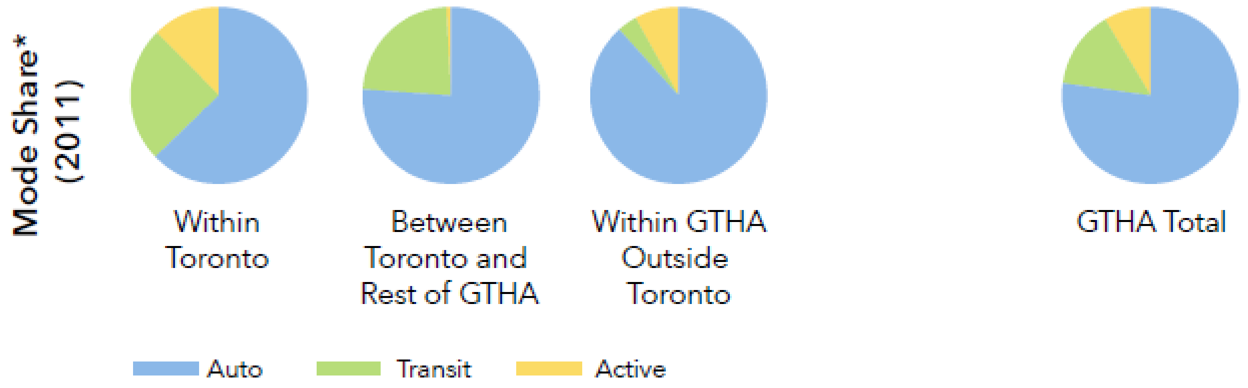


TRAVEL DEMAND AND MODE SHARE (PEAK PERIODS)*

Current and Future Total Trips



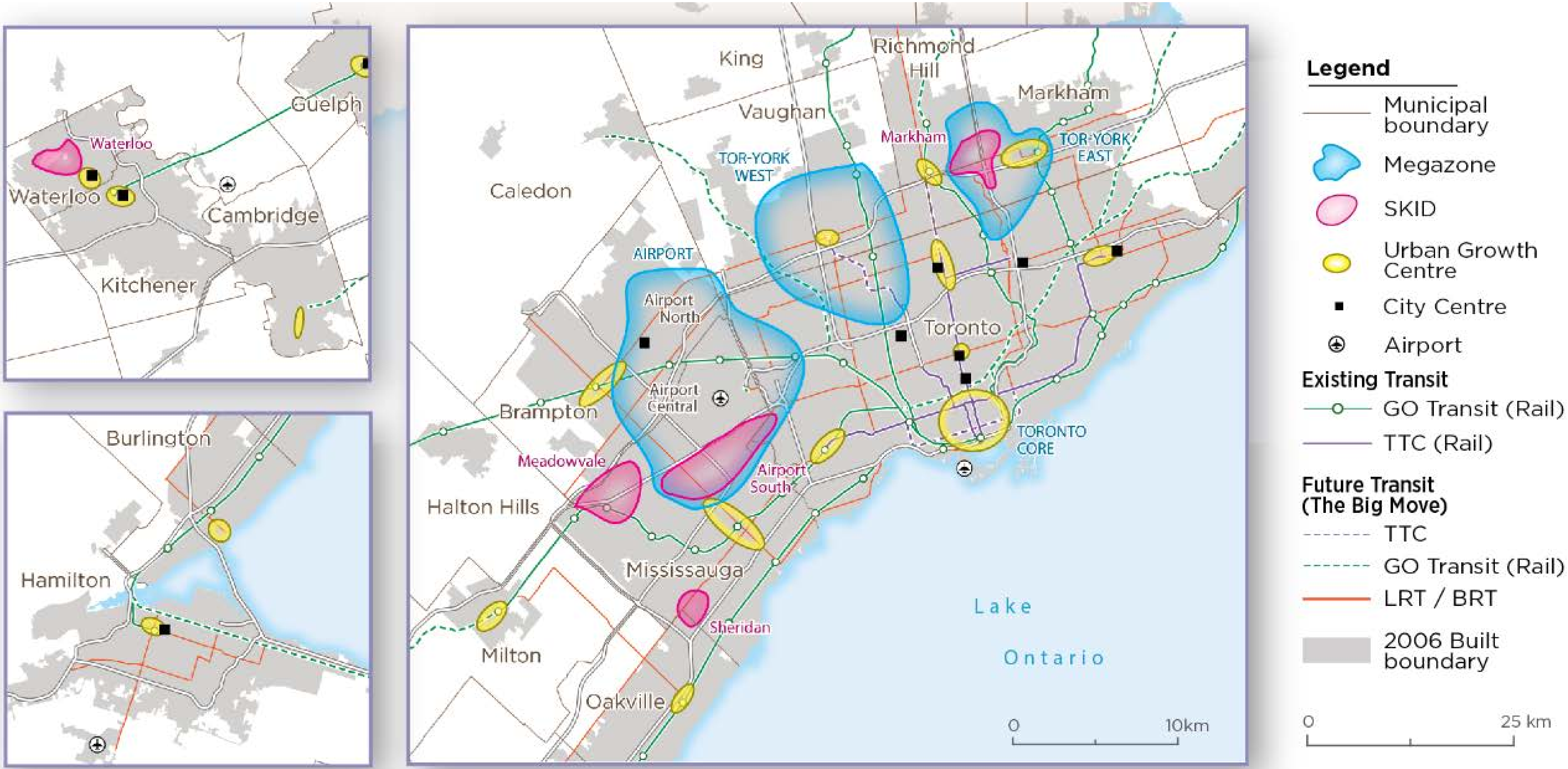
Current Mode Share



METROLINX

*6:00 - 9:00 a.m. and 3:00 - 7:00 p.m.

ECONOMIC LANDSCAPE



SOURCE: NEPTIS FOUNDATION

EMERGENCE OF NEW MOBILITY

AUTONOMOUS VEHICLES

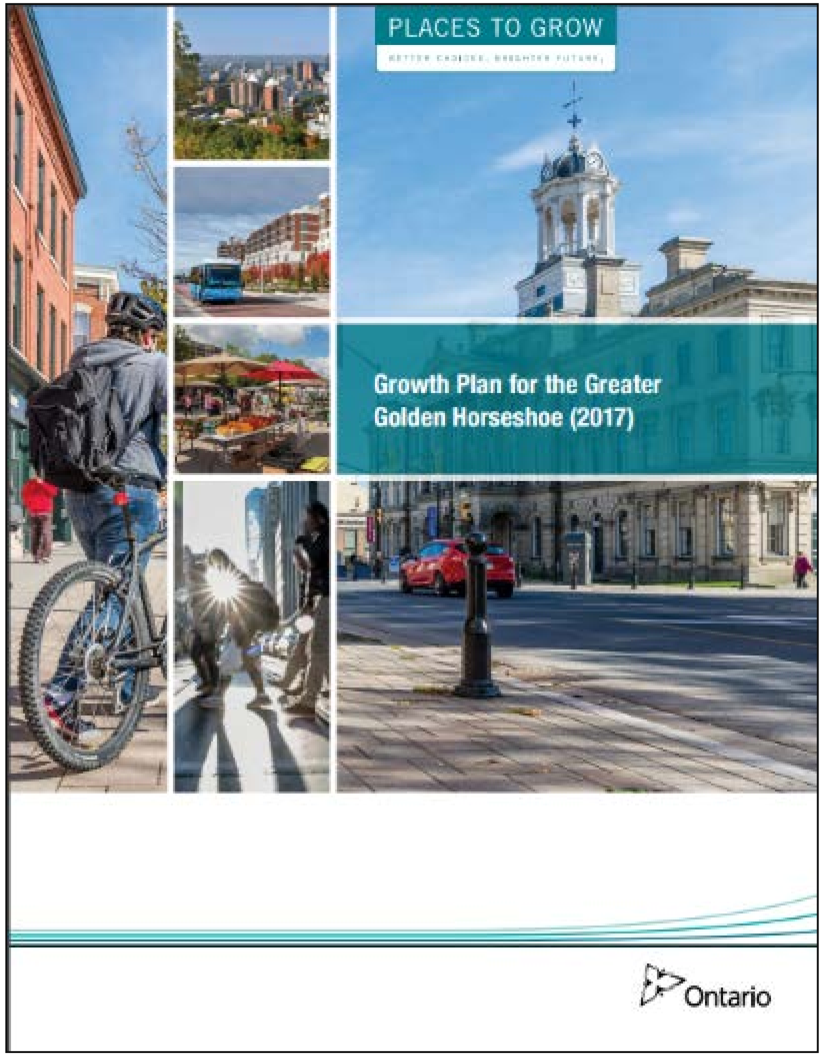
IMAGE CREDIT: WAYMO

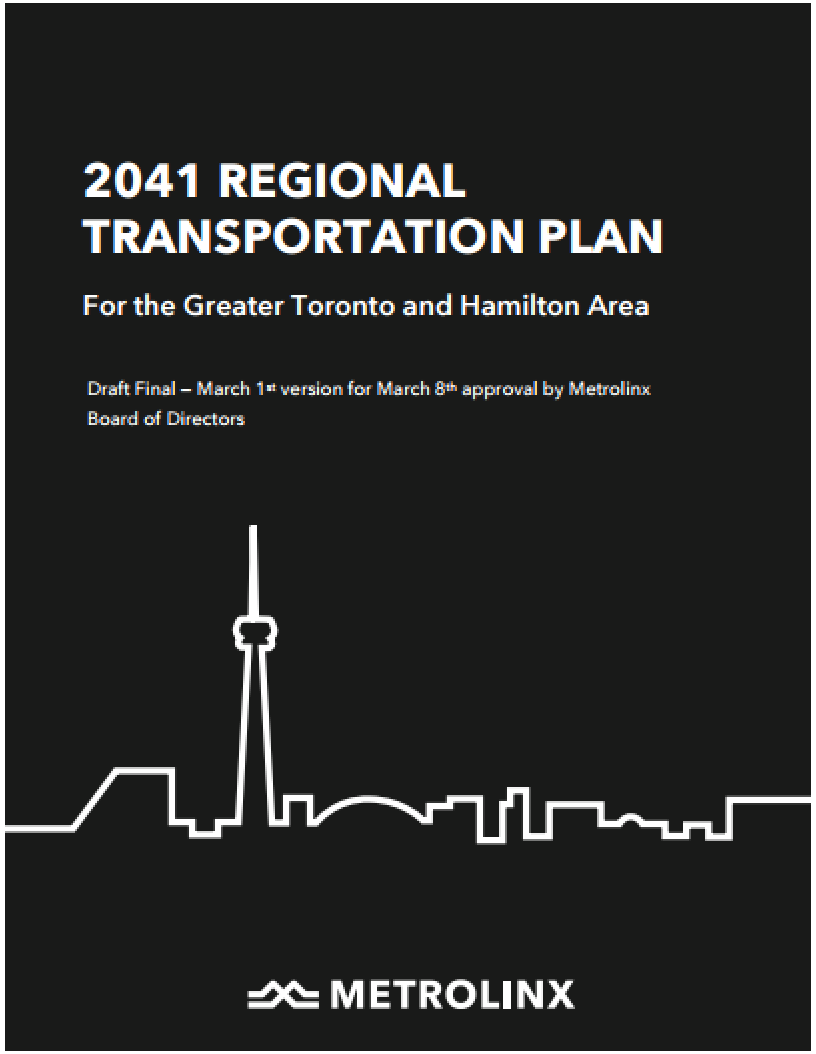
CLIMATE CHANGE

IMAGE CREDIT: KAREN CLEVELAND

2041
DRAFT PLAN!

COORDINATION WITH THE GROWTH PLAN



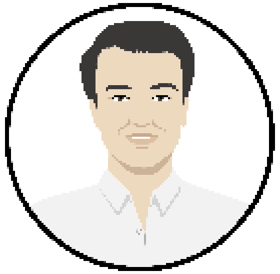


PARTICIPATORY ENGAGEMENT FOR DEVELOPING THE NEXT PLAN

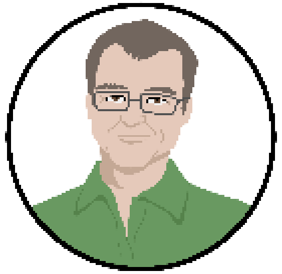
GTHA REGIONAL TRAVELLER PERSONAS—UNDERSTANDING KEY DIFFERENTIATORS

- GTHA traveller personas were developed through focus groups and a survey of 8,500 residents.

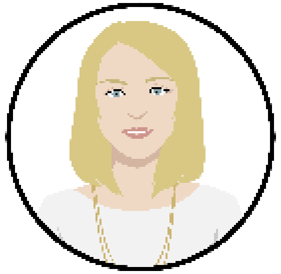
- The personas are a tool to formulating an RTP that responds to the needs, preferences and behaviours of GTHA travellers of today and tomorrow



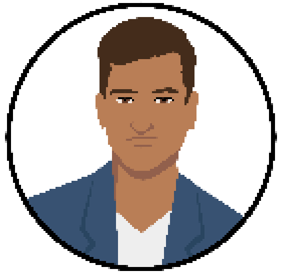
19%
Time & Balance Seekers (RAYMOND)



15%
Traditional Suburban Travellers (JOHN)

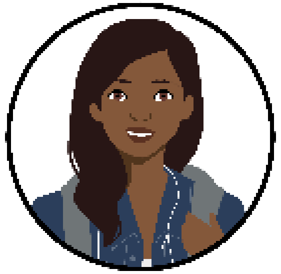


15%
Frustrated Solution Seekers (SUSAN)



22%
Connected Optimizing Urbanites (DEV)

11%
Satisfied Mature Urbanites (BARBARA)



18%
Aspiring Young Travellers (CAMILLE)

VISION FOR 2041

THE GTHA URBAN REGION WILL HAVE A TRANSPORTATION SYSTEM THAT SUPPORTS COMPLETE COMMUNITIES BY FIRMLY ALIGNING THE TRANSPORTATION NETWORK WITH LAND USE.

THE SYSTEM WILL PROVIDE TRAVELLERS WITH CONVENIENT AND RELIABLE CONNECTIONS AND SUPPORT A HIGH QUALITY OF LIFE, A PROSPEROUS AND COMPETITIVE ECONOMY AND A PROTECTED ENVIRONMENT.

STRATEGIES

Strategy 1: Complete Delivery of Current Regional Transit Projects

Strategy 2: Connect more of the Region with Frequent Rapid Transit

Strategy 3: Optimize the Transportation System

Strategy 4: Integrate Land Use and Transportation

Strategy 5: Prepare for an Uncertain Future

31 Priority Actions to Support the 5 Strategies*

Strategy 1: Complete Delivery of Current Regional Transit Projects

GO EXPANSION AND LIGHT RAPID TRANSIT BY THE NUMBERS

52 New Train Sets
faster service

New GO Tracks
150 km

23 New/Proposed
GO Stations

Bridge Upgrades
45+

6000 Trips / Week: 300% increase

15 Minute Service
or better

10 rail/road grade separations
1 rail/rail grade separation

GO Extensions to Kitchener, Niagara, and Bowmanville

New LRT Stops & Stations
16 Stations
65 Stops

New LRT tracks
64 km

WE ARE INVESTING TO MEET FUTURE NEEDS

METROLINX ASSETS TODAY

$19.5 Billion*

**March 2017, Audited*

PLANNED CAPITAL SPEND OVER 10 YEAR PROGRAM

over $43 Billion**

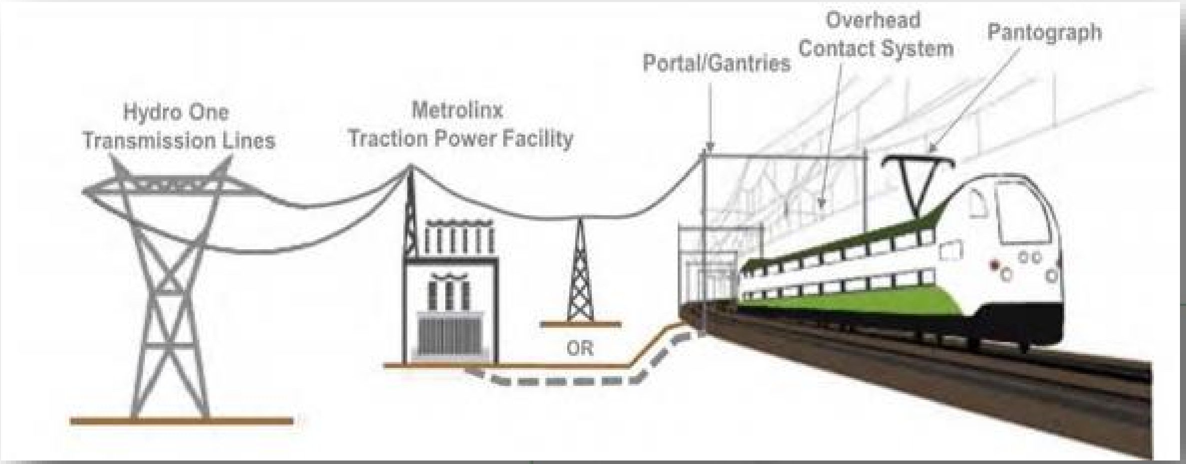
***Metrolinx 17/18 Business Plan*

Concrete Ties on the Stouffville Corridor, August 2017.

CURRENT STATE	REGIONAL EXPRESS RAIL
30-60 MINUTES, LIMITED WEEKEND SERVICE, MIXED FREIGHT AND PASSENGER	EVERY 15 MIN
PEAK DIRECTION ONLY	TWO WAY
RUSH HOUR	ALL DAY, EVERYDAY
A COMMUTER SYSTEM	CONNECTING COMMUNITIES
DIESEL SERVICE	FASTER, CLEAN, ELECTRIFIED SERVICE

INCREASED GO TRAIN SERVICE

ELECTRIFICATION

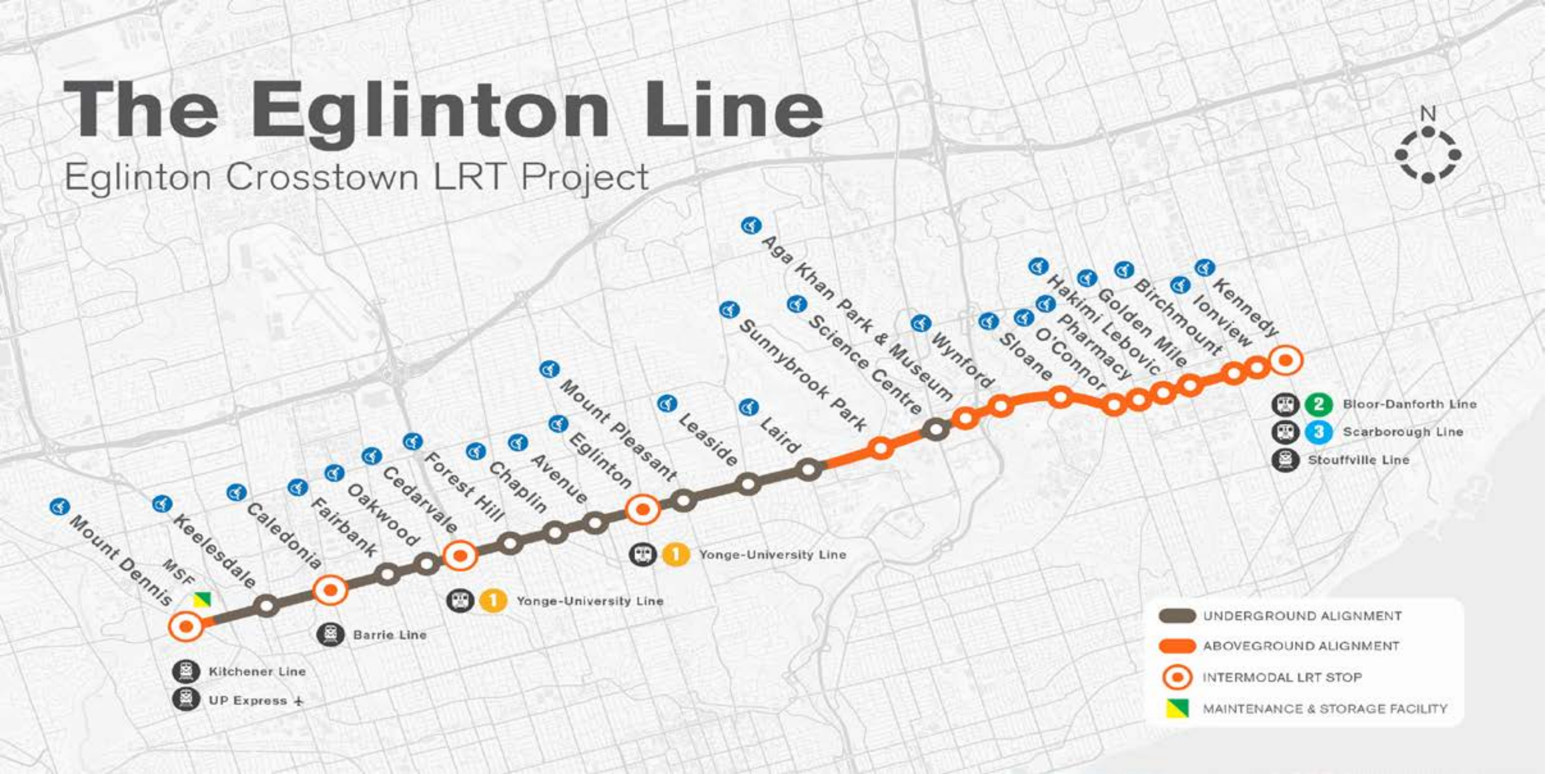


Electrification will allow Metrolinx to deliver faster, more frequent GO service.

In order to electrify, we need to build extensive new infrastructure like switching stations, an overhead contact system and safety modifications.

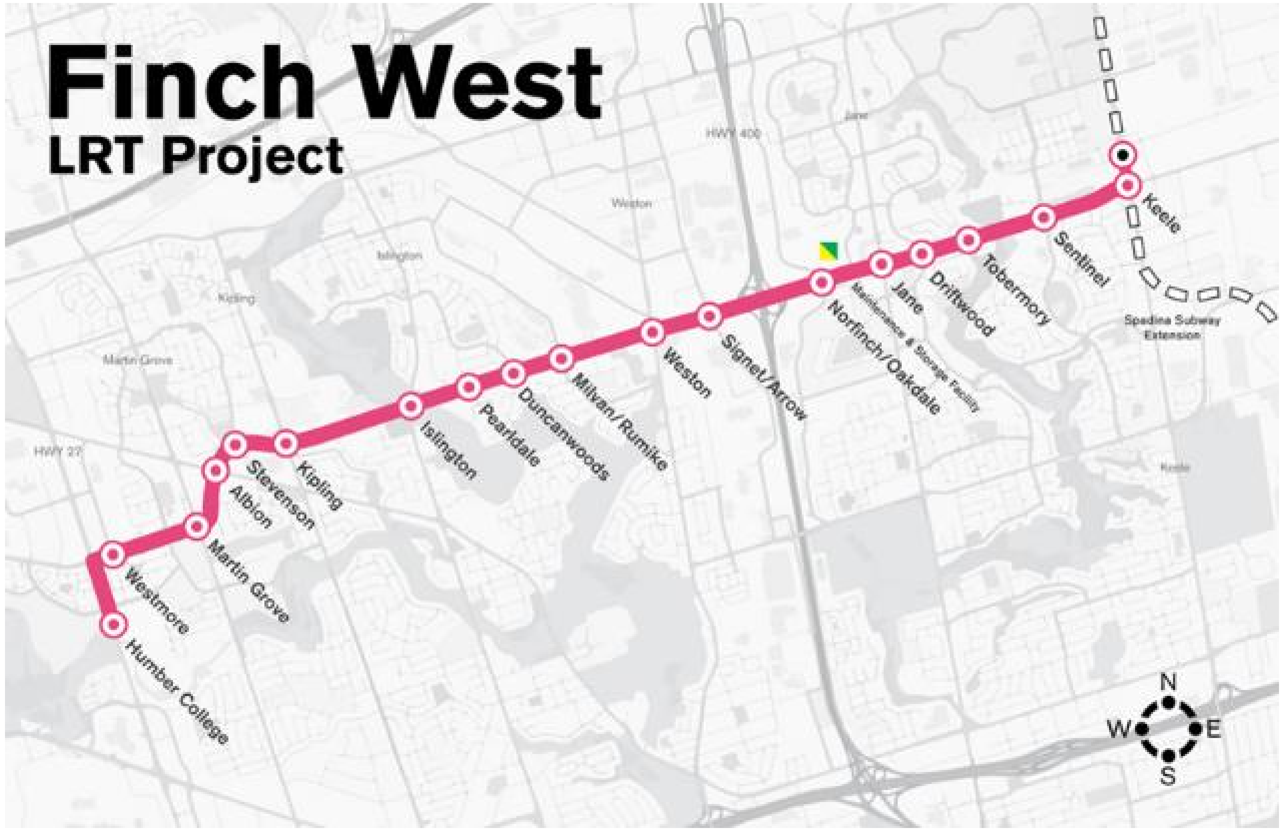
EGLINTON CROSSTOWN LRT

- 19 km line from Mount Dennis to Kennedy Station. Work includes:
  - 25 stops and stations (15 underground)
  - 10 km twin tunnels between Keele Street and Laird Drive
  - Maintenance and storage facility for the vehicle fleet
- Completion 2021
- Design Build Finance Maintain contract with Crosslinx (CTS) – consortium of Ellis Don, Aecon, ACS Dragados and SNC Lavalin



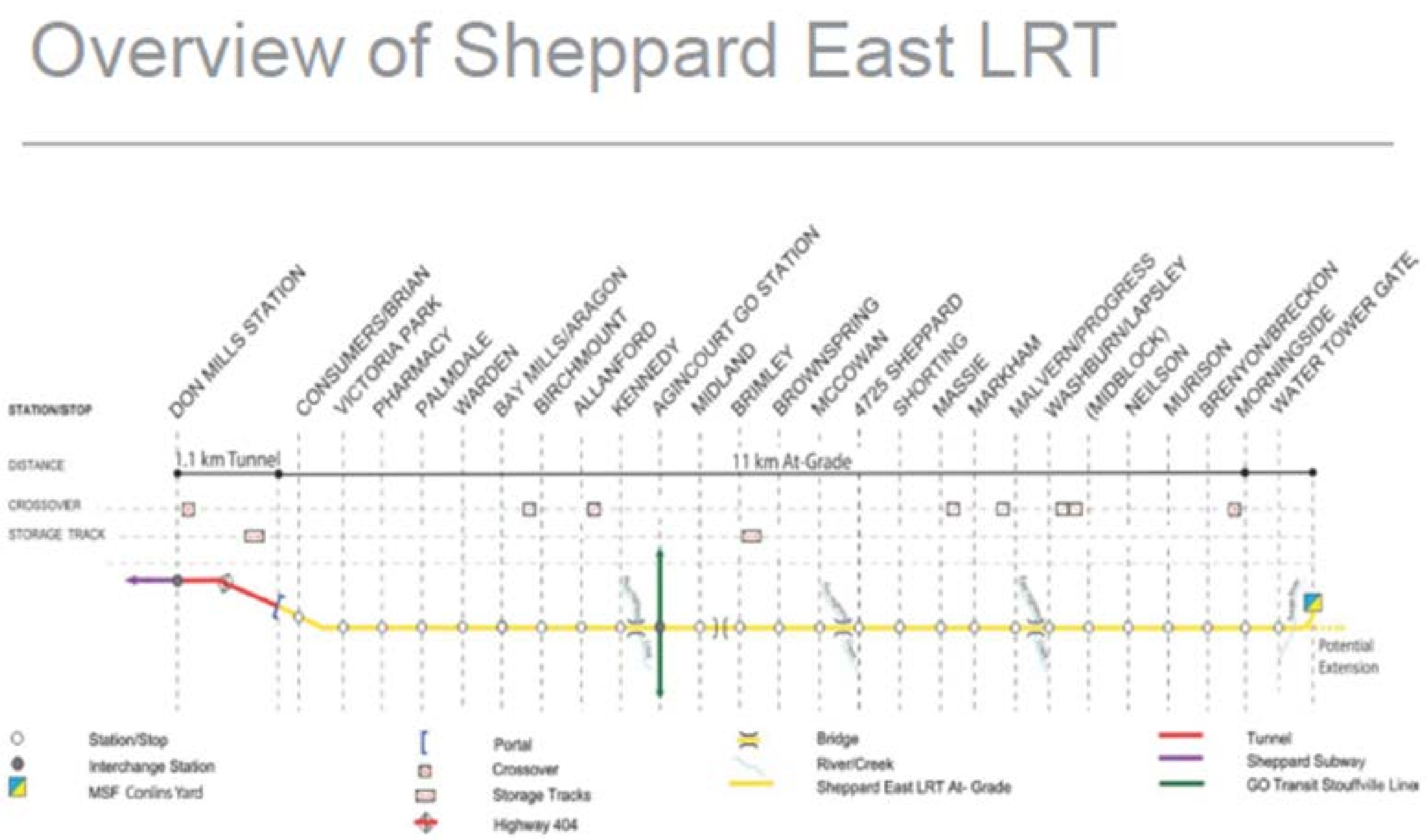
FINCH WEST LRT

- 11 km line from Humber College to Keele Street. Work includes:
  - ➢ 16 surface stops and 1 underground stop at Humber College
  - ➢ 1 TTC interchange station at Keele Street (TYSSE)
  - ➢ Maintenance storage facility for the vehicle fleet
- Completion 2022
- RFP for Design Build Finance Maintain project closed December 2017



SHEPPARD EAST LRT

- 12.8 km line from Don Mills Subway station to the Sheppard Maintenance and Storage Facility on Conlins Road:
  - Up to 25 surface stops.
  - 1 underground connection to the subway (Don Mills station)
- The project will start after the Finch West LRT project has been completed



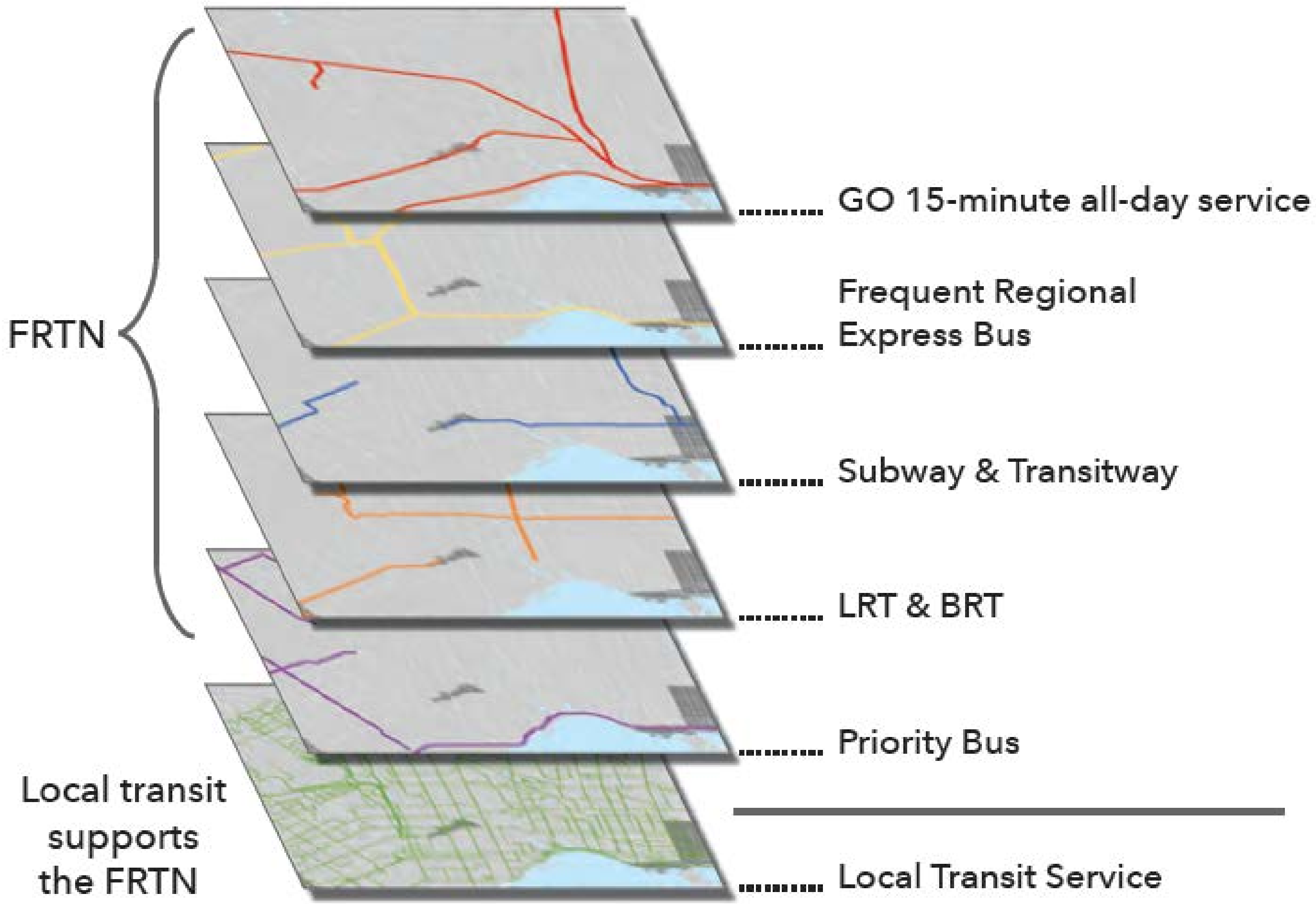
HURONTARIO AND HAMILTON LRTS

- 20 km line from Port Credit GO Station to Steeles Avenue:
  - ➢ 22 stops
  - ➢ LRT connects to 2 GO Transit rail lines, GO Bus, the Mississauga Transitway, as well as Mississauga MiWay and Brampton Züm Bus Rapid Transit
  - ➢ Maintenance Storage Facility for the vehicle fleet
  - ➢ Completion 2022

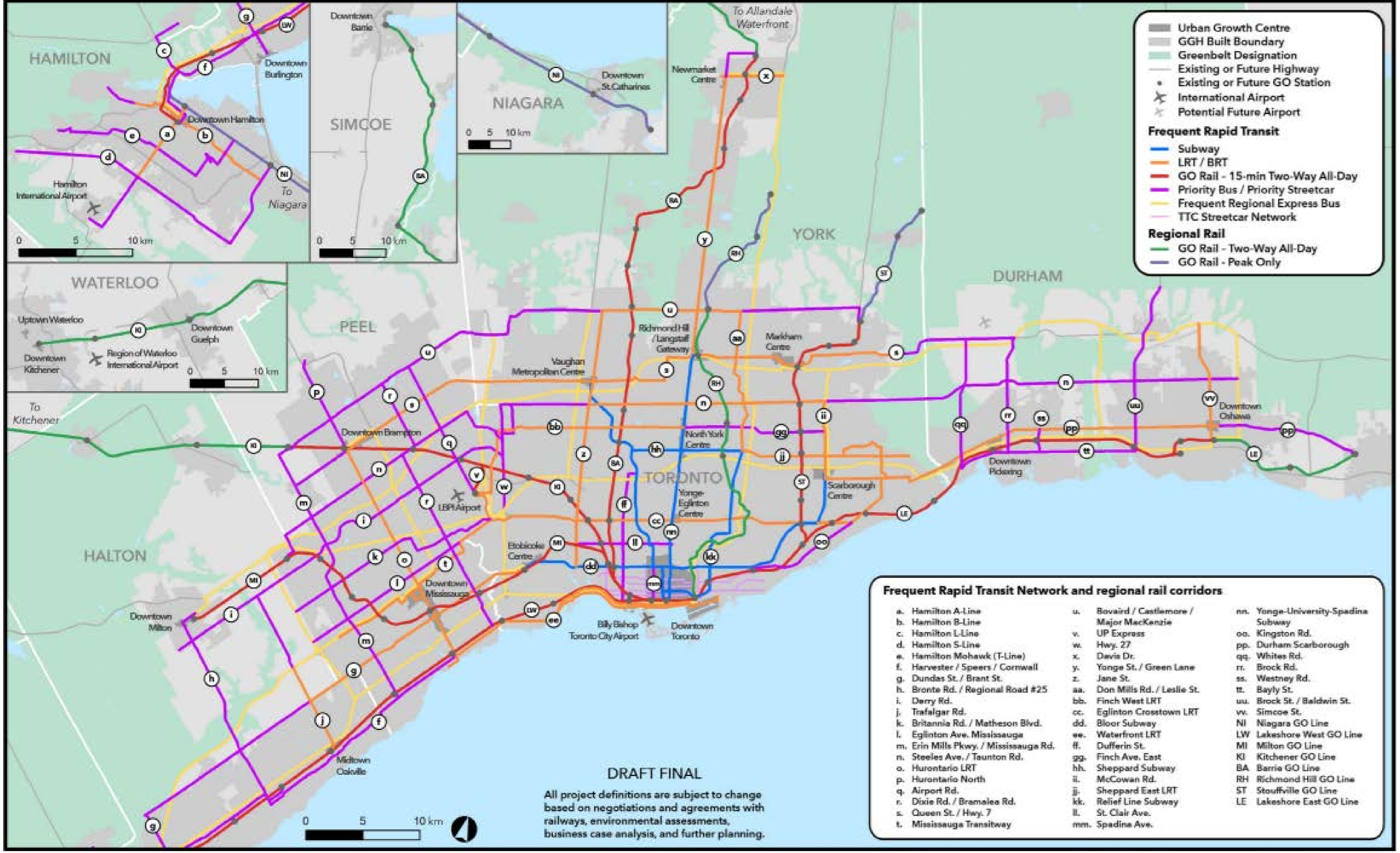
- 14 km line from McMaster University to Eastgate Square along Main and King streets. Work includes:
  - ➢ 17 surface stops
  - ➢ Maintenance Storage Facility for the vehicle fleet
  - ➢ Completion 2024

Strategy 2: Connect more of the Region with Frequent Rapid Transit

THE FREQUENT RAPID TRANSIT NETWORK



Map 6: Complete 2041 Frequent Rapid Transit Network

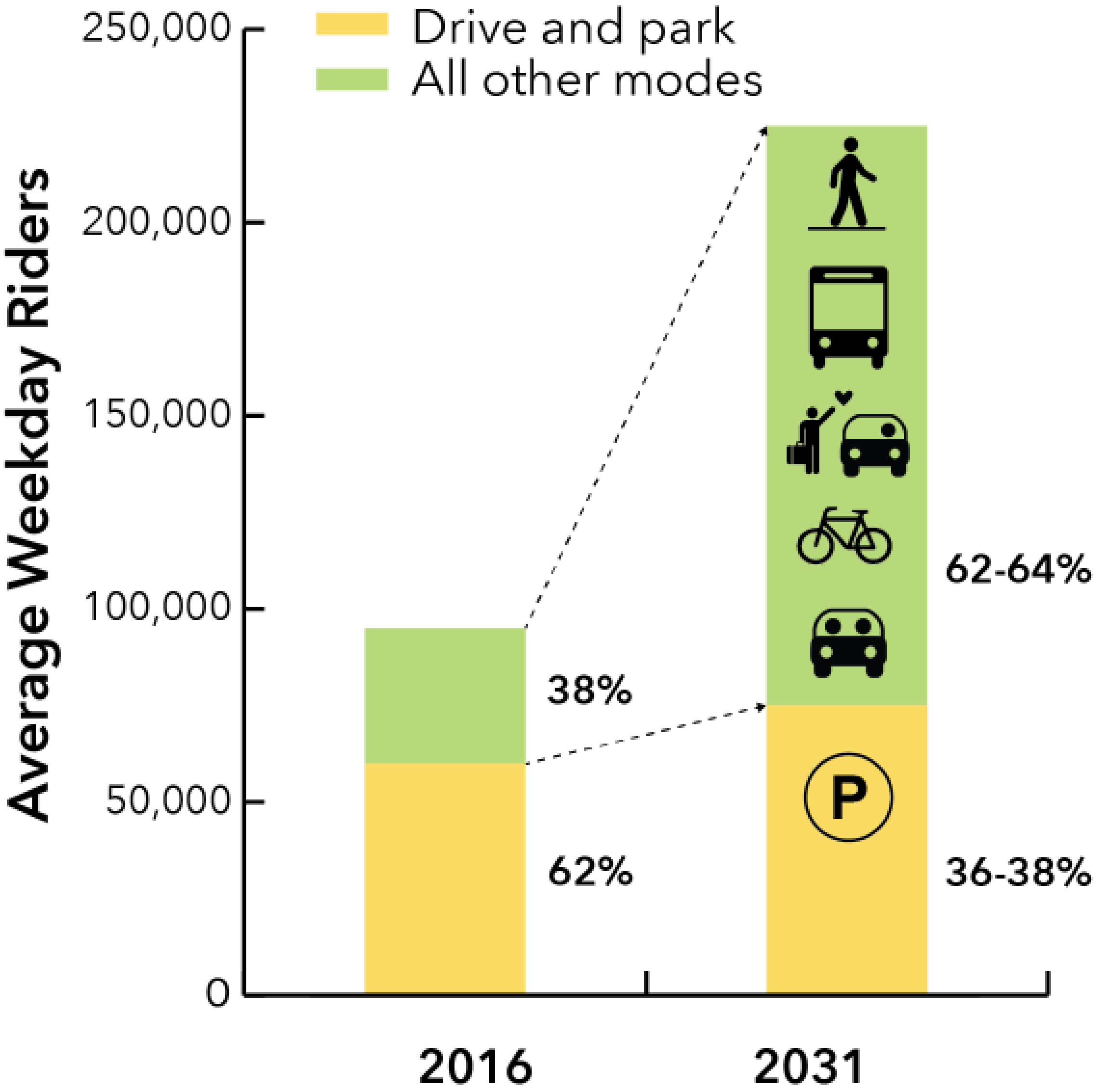


Strategy 3: Optimize the Transportation System

DESIGN EXCELLENCE

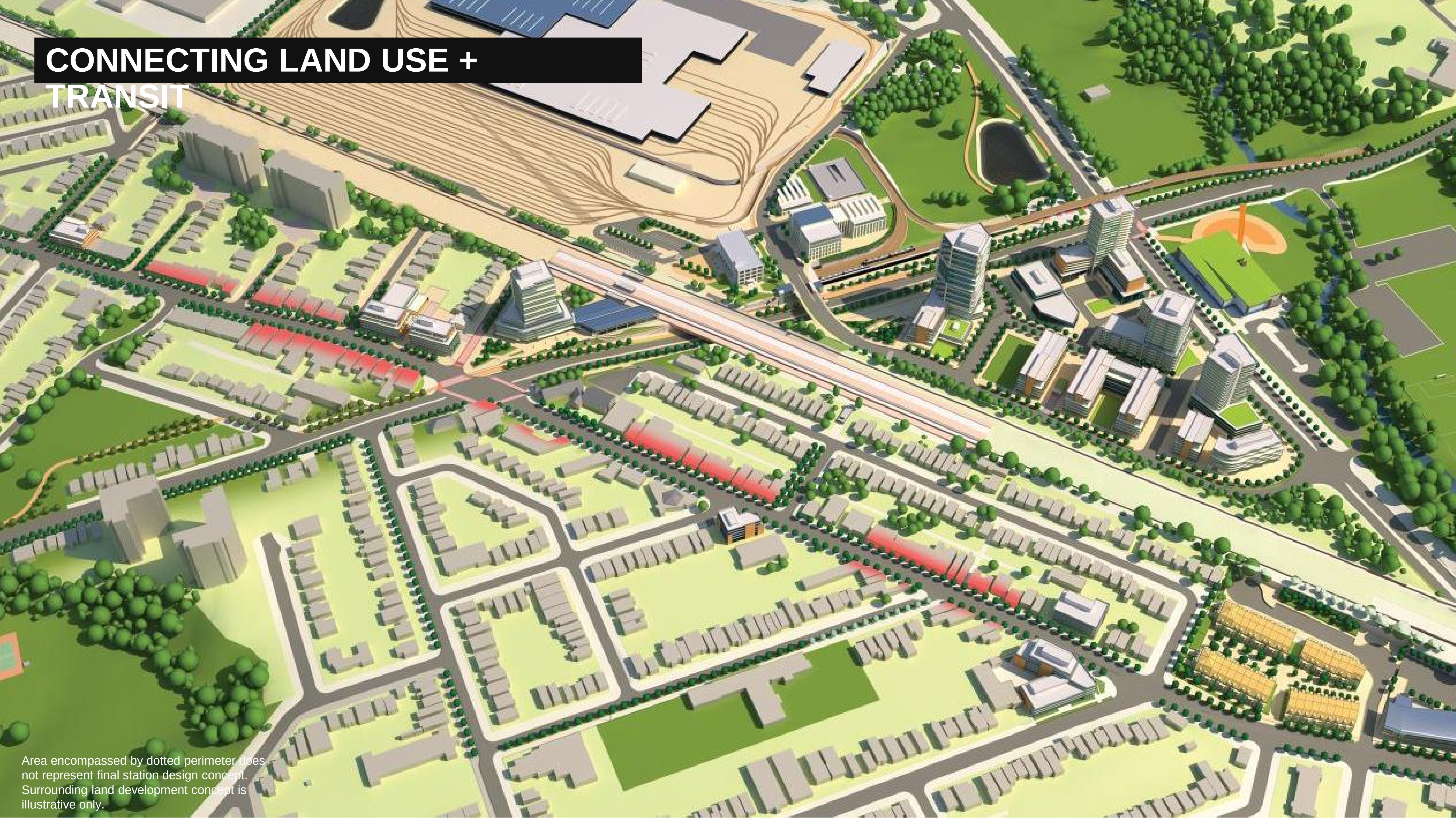
STATION ACCESS: MOVING PEOPLE, NOT CARS

PLAN FOR FIRST AND LAST MILE TO AND FROM GO STATIONS



Strategy 4: Integrate Land Use and Transportation

CONNECTING LAND USE + TRANSIT



Area encompassed by dotted perimeter does not represent final station design concept. Surrounding land development concept is illustrative only.

Strategy 5: Prepare for an Uncertain Future

REDUCING EMISSIONS AND CLIMATE CHANGE ADAPTATION

READ THE 2041 RTP

E-mobility 101

The roadmap to electric transportation

Agenda

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4:30	Reception	

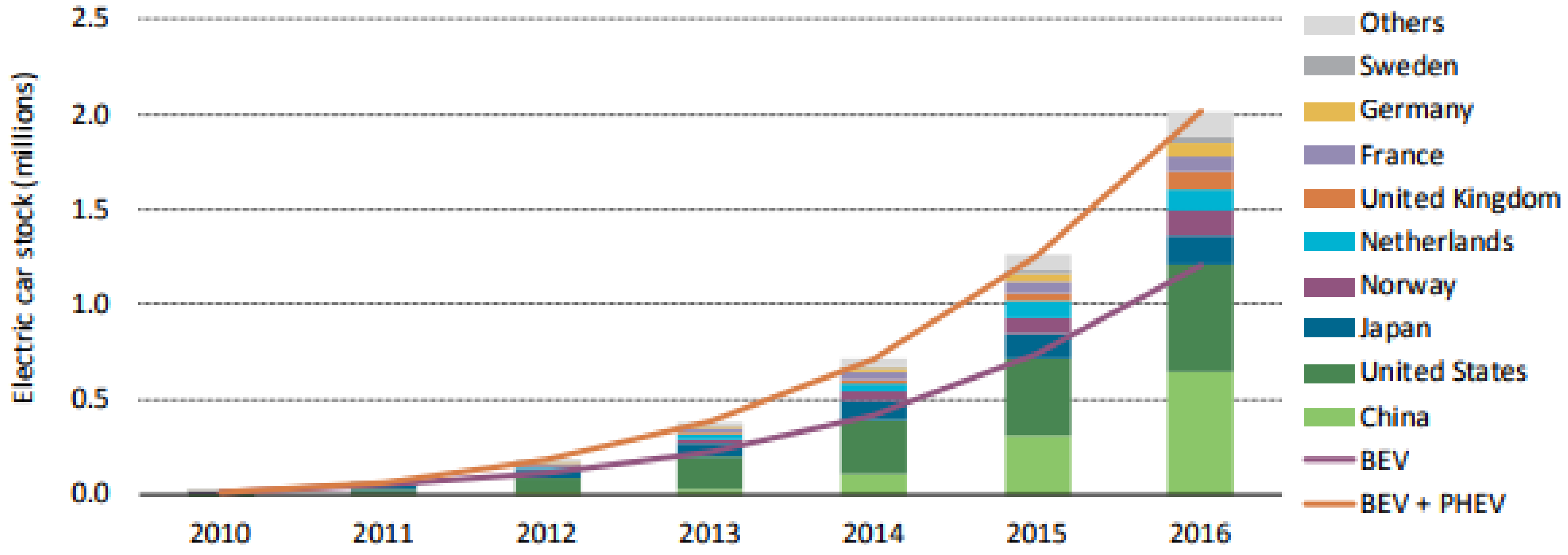
The Journey to E-Mobility

Naeem Farooqi, Principal Consultant
Advisory Services Canada

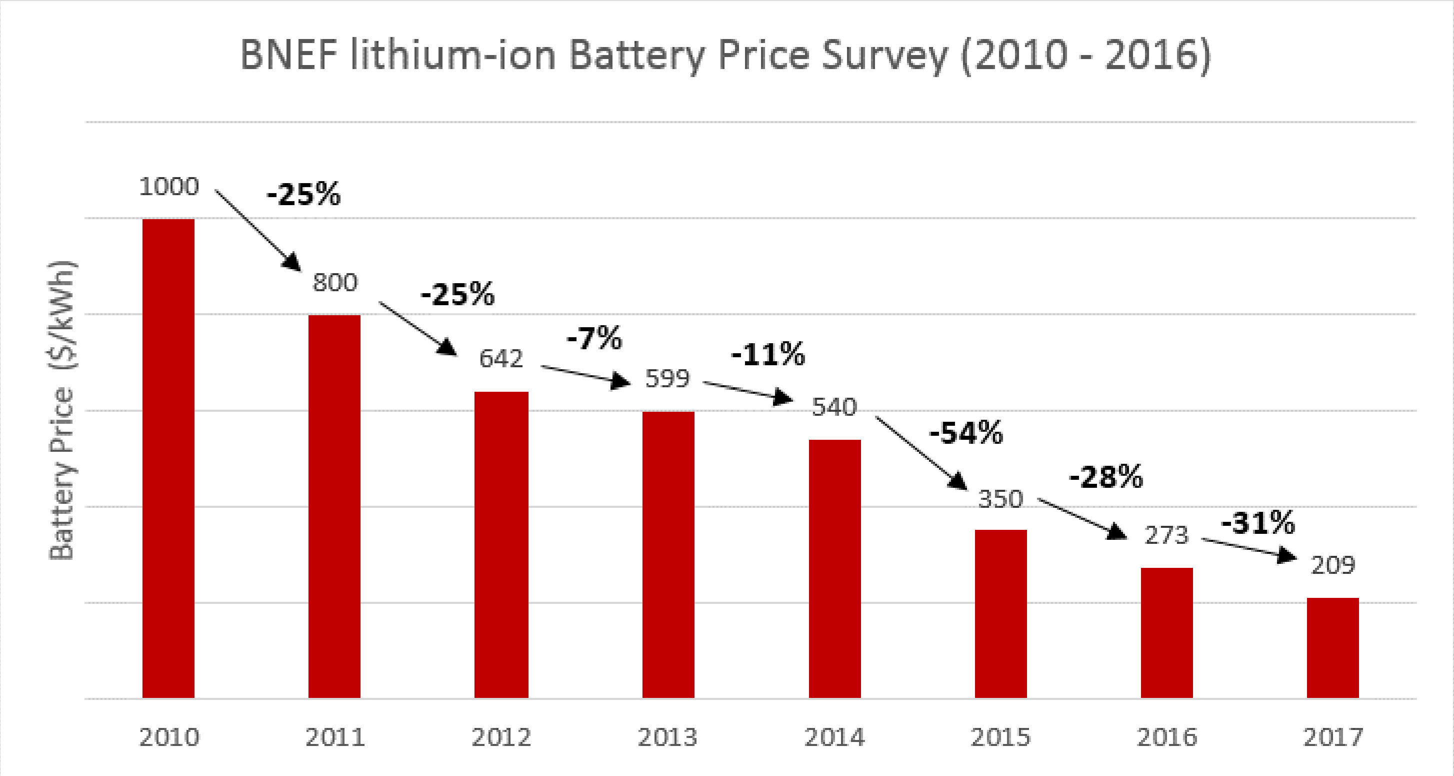
Outline

- Introduction
  - *Industry Trend*
- Electric Adoption Globe to Globe
  - *Public Transportation*
- Transition to Electric Vehicles Road Map
  - *Urban Transit Buses*
- The Future is Electric

Global Electric Vehicle Adoption



Battery Pricing Trend



*Source Bloomberg New Energy Finance

Tipping Point for EV adoption $100/kWh (est. 2025)
Breakeven energy density with gasoline/diesel

Today's Pricing:
GM's LG Chem battery cells $145/kWh

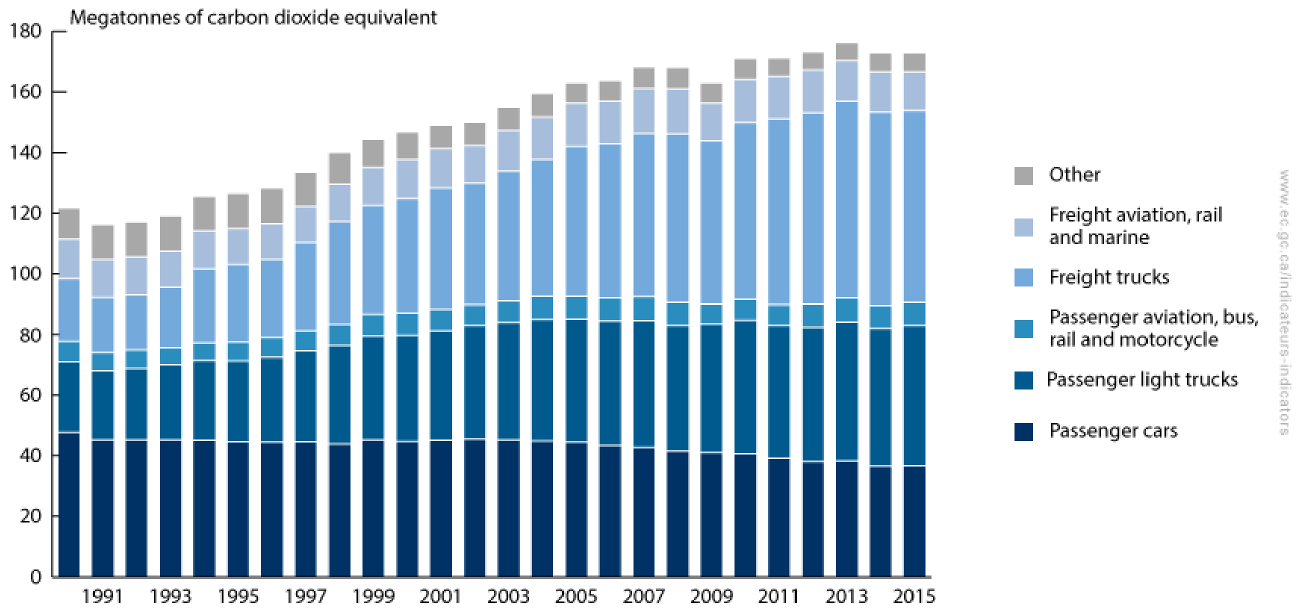
Tesla Li-Ion around $150/kWh today

Average lithium-ion $209/kWh

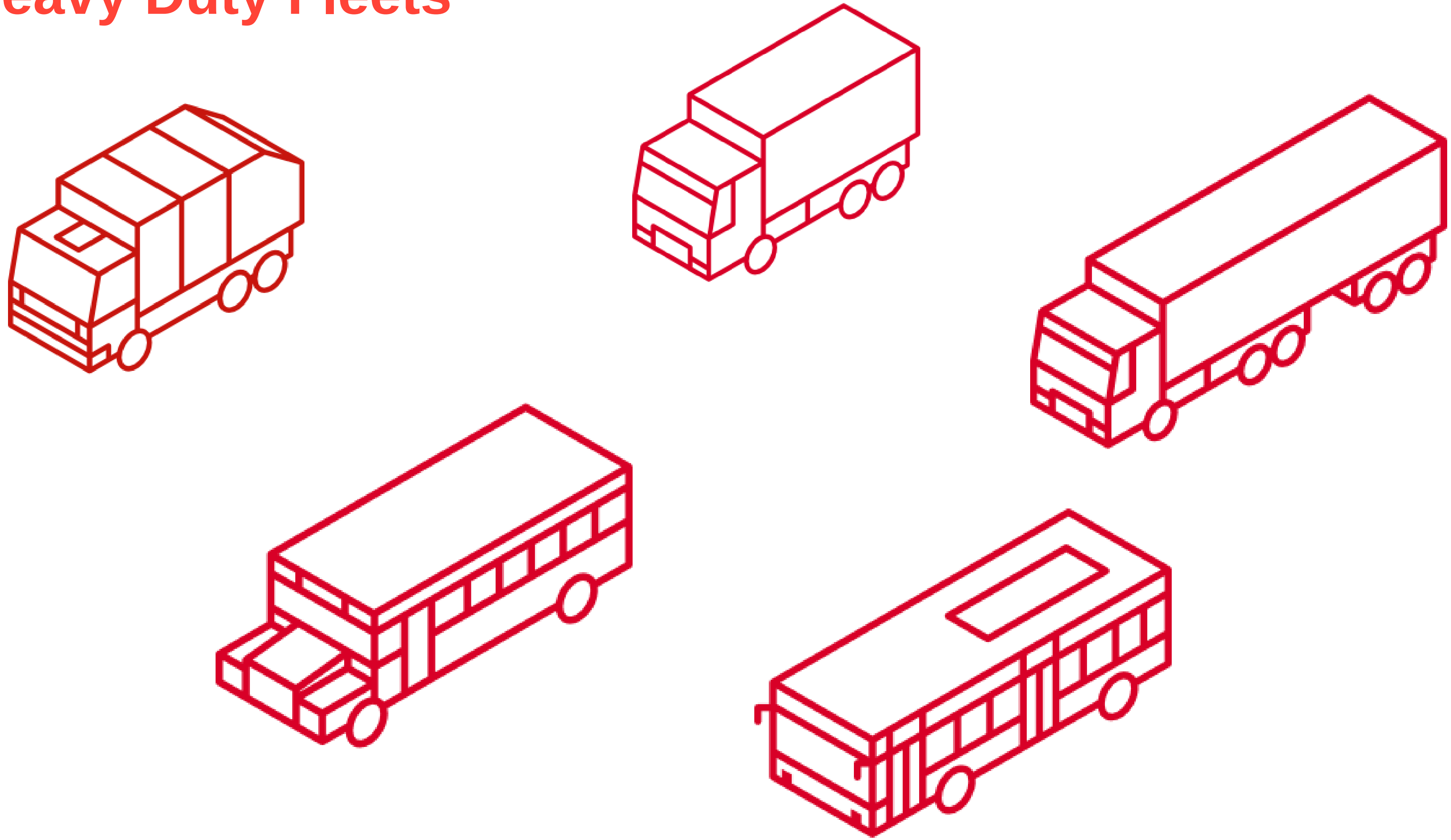
Weight of 20 kWh Battery	
Lead acid	550 kg
Nickel Cadmium	500 kg
Nickel Metal Hydride	350 kg
Lithium Ion	180 kg

Current Climate

- Canadian Target: reduce GHG emissions by 30% of 2005 emissions level by 2030
- Transportation approx. 24% of Canada's total GHG emissions
- Municipal fleets can make up 20-30% of CO2 and GHG of carbon footprint of municipalities



Heavy Duty Fleets



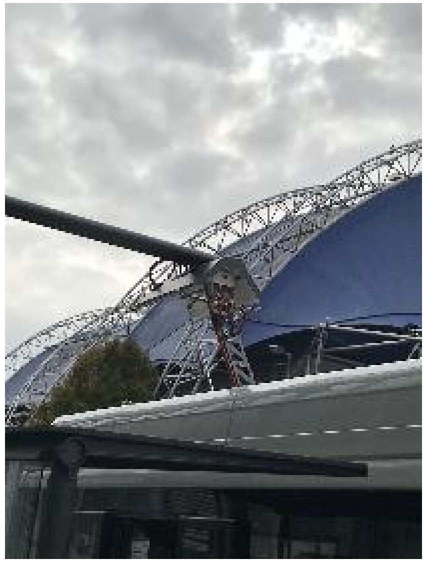
Electric Bus Revolution

- Global estimates of Bus fleet size are over 1.3 million units in operation around the world
- Currently, the #1 propulsion is Diesel, followed by CNG
- Electric Bus Technology has made huge advancements in the past decade
- Electric Bus Pilots are underway in every corner of the world
- BRT service is a prime contender for electrification
- Industry Experts predict by 2030 globally 40% of the worlds buses will be electric

Our Experience - Electric Bus

69

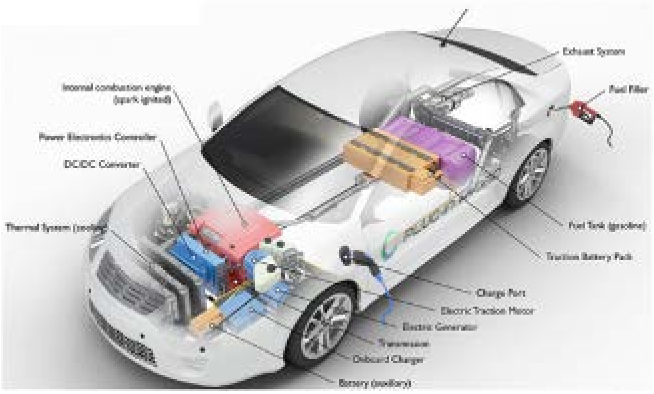
Electric Bus Projects & Research

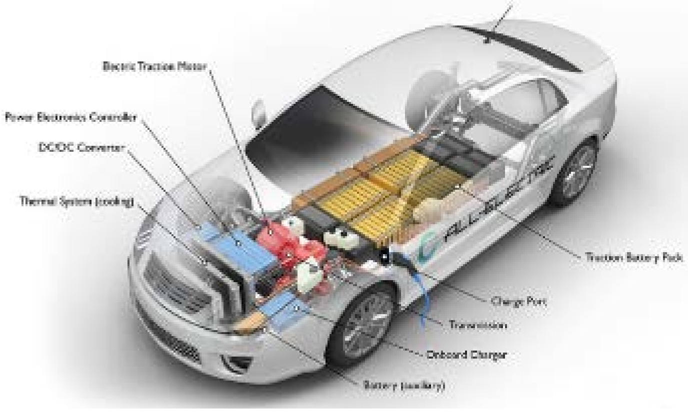


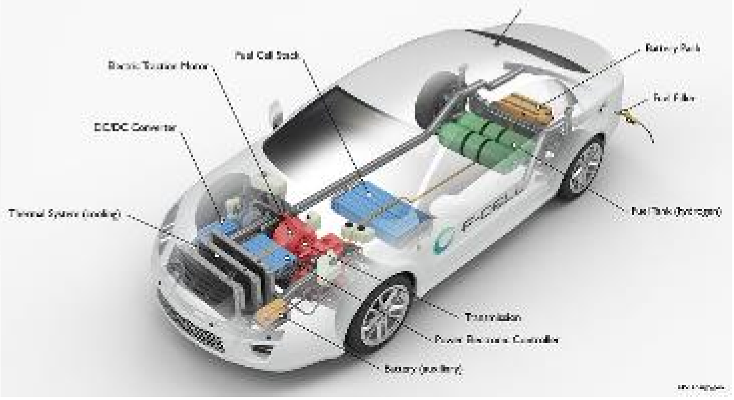
Path to Electric Vehicles

Not One Size Fits all Fuel Solution

— Operating conditions of user groups might limit technology options
— Weigh the Pros and Cons
— Consider impact to facility modifications and fueling infrastructure cost
— Consider impact to labor force and supply chain







Opportunities to Transit Agencies

Why are transit agencies going electric?

Requirements for transit agencies to reduce GHG emissions of their fleet.

Electric buses are a main GHG mitigation initiative supported by government funded programs and policies.

The electric bus market is experiencing considerable growth with much interest and investment in electric bus technology and advancements in battery innovation.

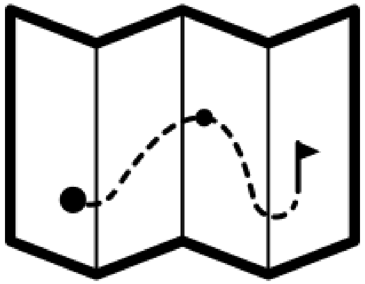
Main questions transit agencies have for electric bus adoption:

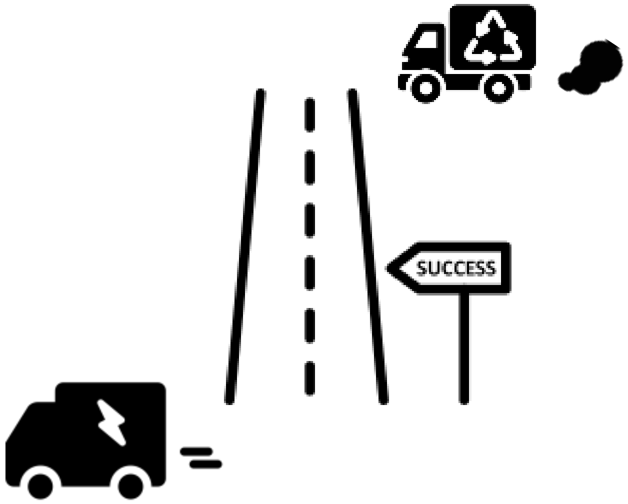
1. *How much will an electric bus and supporting infrastructure cost me?*
2. *How will my current operations and facilities be disrupted by introducing electric buses?*
3. *What kind of training will be required for drivers and personnel working with high voltage electrical infrastructure and batteries?*

Road Map (Stages)

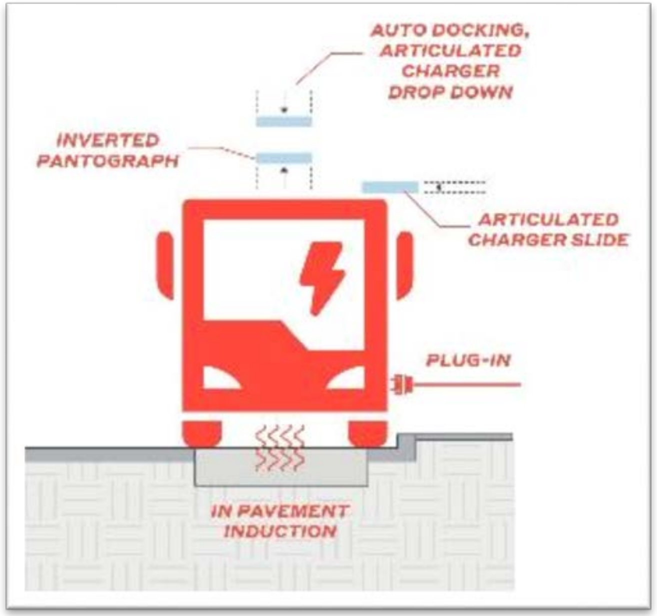
Stage 1: Understanding
- User group and vehicle needs (operations)
- GHG Reduction Targets

Stage 2: Exploratory
- Market research on alt. propulsion technologies
- Impact of green tech on GHG reduction
- Grants and funding opportunities
- Utility Partnerships



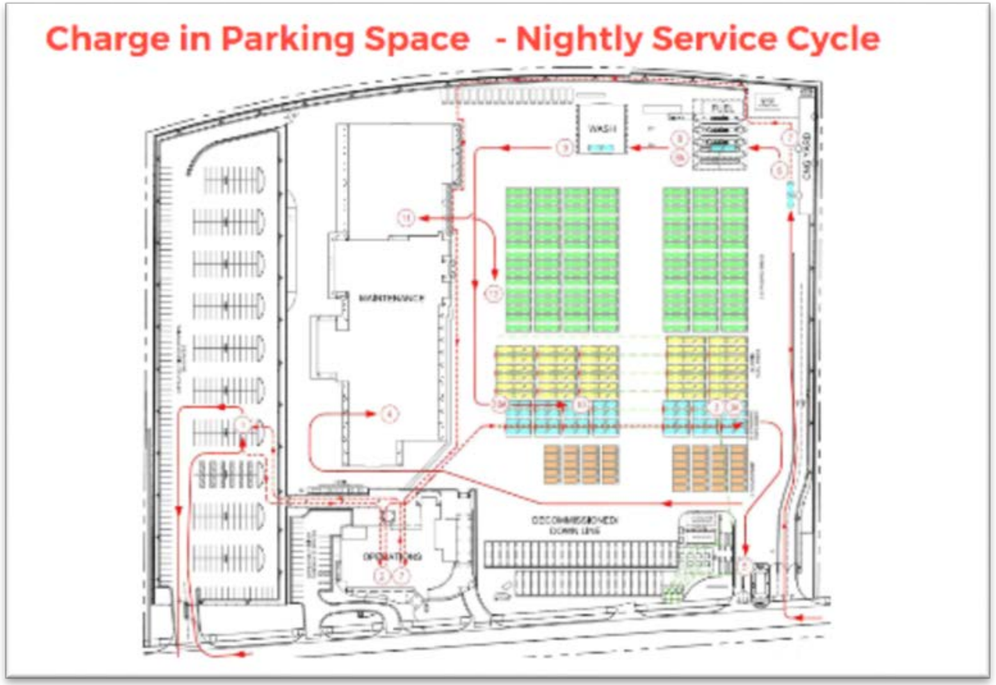


Road Map (Stages)



Stage 3: Implementation
- Change management plan
- Maintenance & facility modifications
- Buy-in from stakeholders & senior management

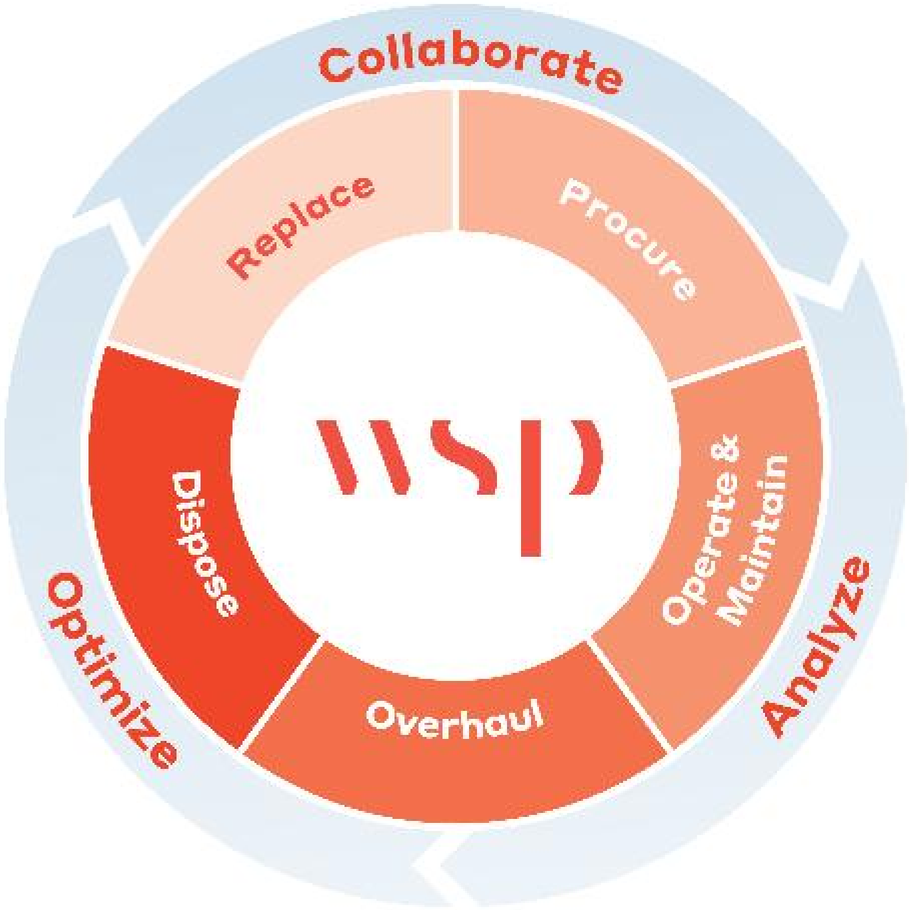
Stage 4: Execution & Monitoring
- Pilot vehicle program
- Review of pilot data & user feedback



Road Map (Stages)

Stage 5: Business Case (CBA)

- Total lifecycle of ownership of fleet
- Triple bottom line



Road Map

Develop a GHG inventory & Reduction Targets

Understand User Group & Vehicle Daily operations

Conduct market research for alternative propulsion that meets operating needs

Understand technology impact on user group, maintenance (staff/equipment), and Facility (modifications/fueling)

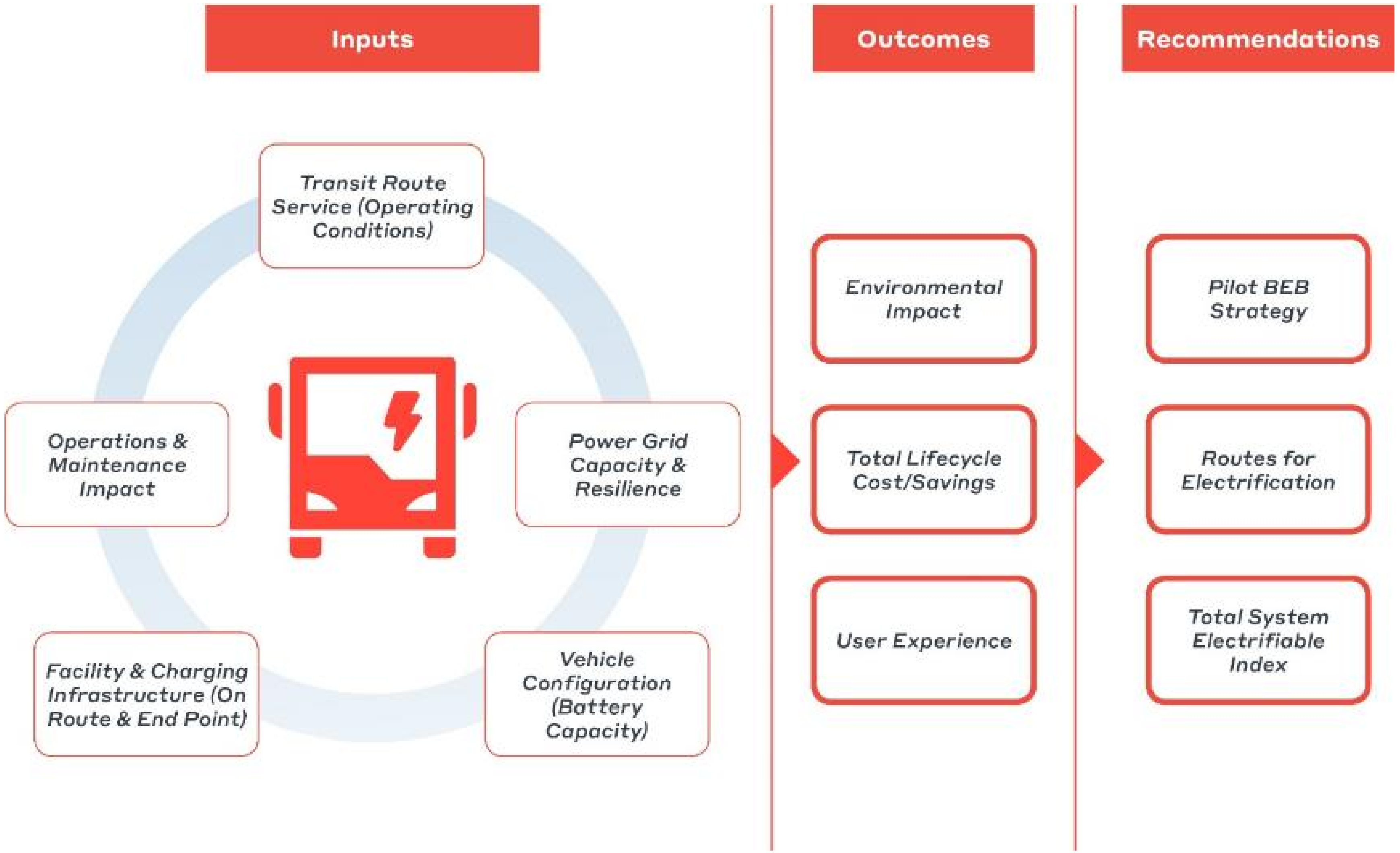
Explore grants & Incentives to complete business case (triple bottom line)

Get buy-in from senior staff, council, and other departments to proceed

Develop a Pilot program with establish performance parameters for vehicles and purchase/lease units

Develop a change management plan addressing all the impacted stakeholders and facility

BOLT – Electric CBA Tool



Funding opportunities

FCM

- Incentives for purchasing green fleet vehicles for pilot
- Funding for Green fleet studies

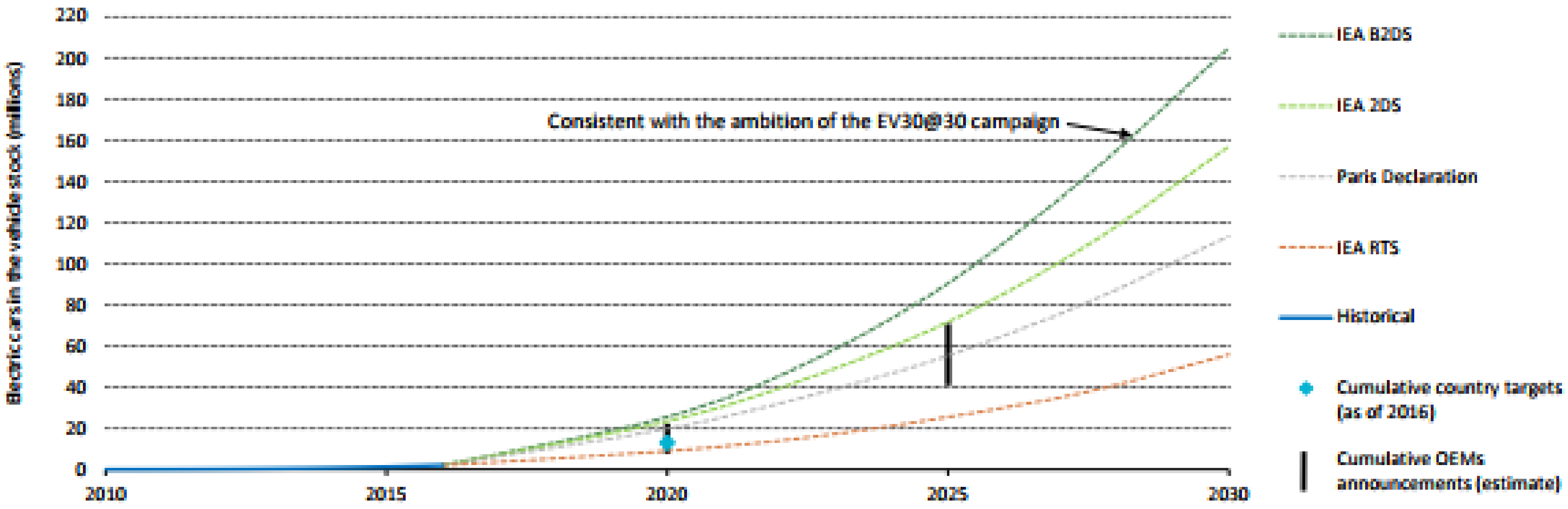
Green Commercial Vehicle Program

- Ontario Ministry of Transportation
- Incentives for vehicle purchase
- Fuel saving devices (anti-idling)

Green Ontario Fund 2018

- Rebates for electric vehicle purchases
- Charging stations incentives

Future is Sustainable



Thank you!

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APRIL 10, 2018

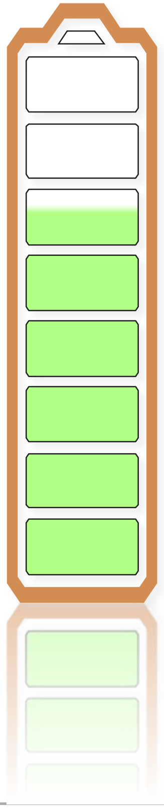
Rail: Energy storage backed traction chain

Elvis Dzindo & Daniel Simounet, ABB

Energy Storage Integration in Mass Transit
Key Drivers

Electric Vehicles

- Catenary Free Operation
- Energy Savings
- Peak Power Reduction
- Enhance Drive Performance
- Traction Power Supply Optimization



Diesel-Electric Vehicles

- Engine Downsizing
- Fuel Economy
- Local Emission Reduction
- Regulatory Environment

Electric Vehicles

Key Drivers

Catenary free operation

- Lowering of aesthetic impact in cities
- Reduced cost of electrification
- Operational benefits like range extension, Last mile operation, shunting inside depots & washing yards

Energy Savings

- Possibility to reduce energy consumption by up to 30%

Peak power optimization

- Reduced peak power demand (30… 50%)
- Reduced energy cost, because billing is according to peak load

Enhance Drive Performance

- No Interruption of traction power supply, this means no reduced performance because of rail gaps or iced line
- No interruption of auxiliary power supply for HVAC, lights, ….

Traction Power Supply Optimization

- Increase in frequency of operation or use of longer vehicles
- Increase in distance between substations → Less sub-stations
- Reduction in line losses

Diesel-Electric Vehicles

Key drivers

Engine Downsizing

– Reduced engine size, due to additional power from energy storage system during acceleration

Fuel Economy

– Optimal power point operation of diesel engine

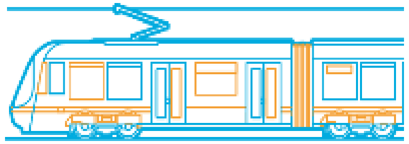
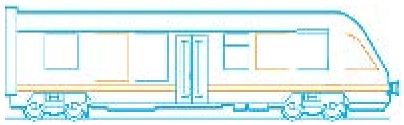
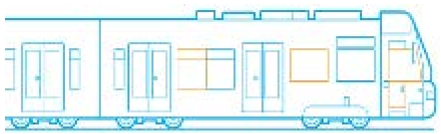
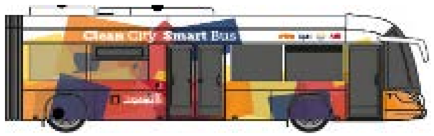
Local Emission Reduction & Regulatory Environment

– Switching off diesel engine and powering auxiliaries from energy storage

– Noise & emission reduction at stations

Energy Storage in Mass Transit

Application Vs Solution

Light Rail Vehicle	Diesel Electric Multiple Unit	Metro	Electric Bus
			
Catenary free operation Braking energy recovery & re-use Peak power reduction Line voltage stabilization	Diesel engine downsizing Fuel consumption reduction Emission reduction	Braking energy recovery & re-use Line voltage stabilization Grid ancillary services	Catenary free full-electric bus Reduced total cost of ownership “Zero” Emissions Aesthetic appeal
Storage Technology			
Electric double-layer capacitor Lithium-ion battery	Electric double-layer capacitor	Electric double-layer capacitor Lithium-ion battery	Electric double-layer capacitor Lithium-ion battery
Location of Storage Device			
On-board storage	On-board storage	Way-side storage	On-board storage
Alternative Solutions			
		Active rectifier in substation Meshed supply network	

Braking Energy Re-Use

Solution

- Energy storage integration in LRVs is quite common with multiple installations worldwide by almost all vehicle manufacturers.
- Electric Double Layers Capacitors (ELDCs) are the preferred choice in braking energy reuse and peak shaving applications
- In most cases energy storage chopper is part of the traction converter.
- Solution with chopper as part of storage unit or as a separate standalone unit gaining focus (retrofit market)
- Most vehicle builders buy cells or modules and build the storage system in-house

Catenary Free Operation

Solution

- There is no standard solutions in the market for catenary free operation. In general available solutions can be classified into,
- Solutions based on onboard energy storage
  - charging at stations or charging during catenary operation for partly catenary free lines
  - partial autonomy with reduced performance, if there are no charging stations at stops
  - combined with storage required for braking energy re-use
  - choice of storage : Battery or in combination with ELDCs
- Solutions based on ground based supply systems
  - based on proprietary technologies
  - Bombardier “Primove”, ALSTOM “APS” & Ansaldo “TramWave”

Energy Storage in Mass Transit

Key Requirements

Key requirements for energy storage devices

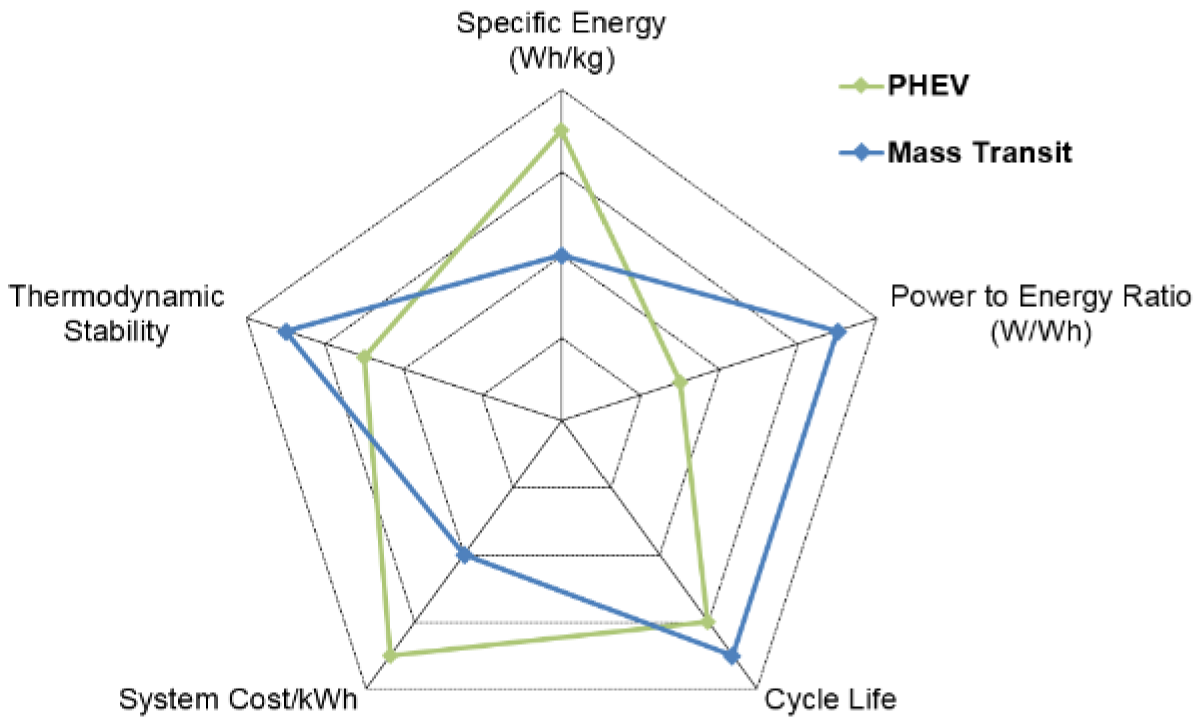
Moderate to high energy density

Medium to high power to energy ratio

Best in class thermodynamic stability

High cycle life

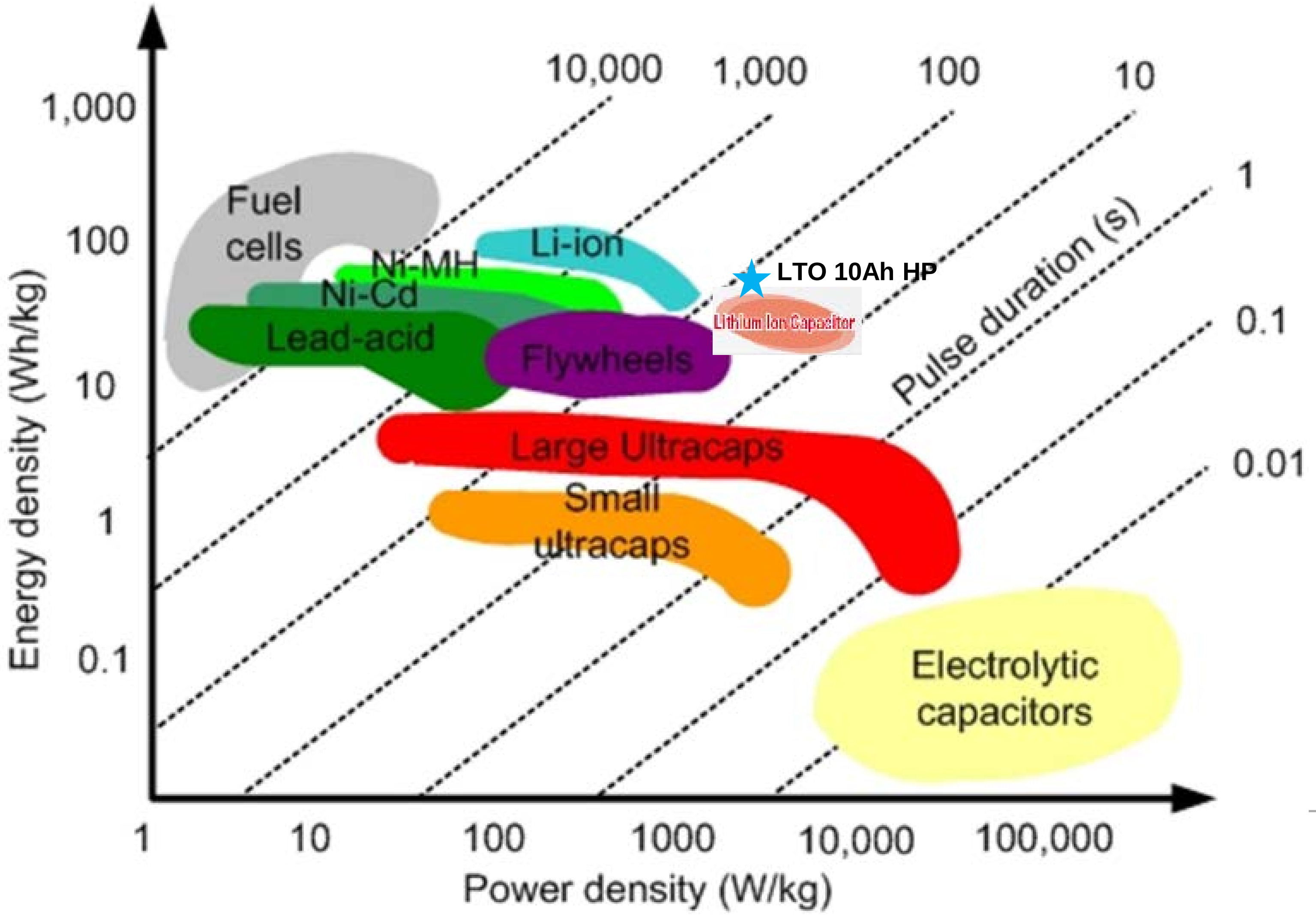
Suitability for harsh operating environments



Benefits from automobile EV battery research..but some key differences in operational requirements

Storage Comparison

Key Requirements



Storage Comparison

Key Requirements

	ELDC	LIB	LIC	ELDC	LIB	LIC
Gravimetric Energy Density (Wh/kg)[1]	3…6	50…200	10…12	🔴	🟢	🟢
Volumetric Energy Density (Wh/l)[1]	6 to 8	50 to 400	18 …20	🔴	🟢	🟡
Power Density (W/kg)	5000 to 7000	300 to 1500	6000 to 7000	🟢	🟡	🟢
Cycle Life[2]	> 1 Mio	50...60k	500…700k	🟢	🔴	🟢
Low Temperature Performance[3] (-30 Deg.Cel)	100% C, 1.4 x ESR	20% of Peak power	90% C, 15 x ESR	🟢	🟡	🟢
Charge/Discharge Efficiency[4]	90 to 98%	85 to 95%	90 to 95%	🟢	🟡	🟡
Self Discharge[5] (@ 25 Deg.Cel & 24h)	~3%	Insignificant	Insignificant	🔴	🟢	🟢
Application Maturity	1995	2010	2011	🟢	🟡	🔴
Suitability for onboard use	Yes	Yes	Yes	🟢	🟢	🟢
Specific energy cost ($/Wh)	16	0.5 to 0.7	-	🔴	🟢	🟡
Specific power cost ($/W)	12	75	-	🟢	🔴	🟡
Life Cycle Costs	-	-	-	🟡	🟡	🟡
Safety	-	-	-	🟡	🟡	🟡
Environmental Impact	-	-	-	🟢	🟡	🟡

ELDC : Electric Double Layer Capacitors or Supercapacitor LIB : Lithium-ion Battery LIC : Lithium-ion Capacitor

[1] Specific energy of LIBs vary a lot because of the multitude of chemistries available in the market and depends whether it is a high energy or high power battery. The quoted values are only for the commercially available cells.

[1] Only HEV batteries with moderately high power have been considered for this comparison: Eg:Altairnano 60Ah LTO, A123 Nanophosphate, LGChem P1 LiB, SAFT VLP Superphosphate, Toshiba SCiB LTO, GS Yuasa LIM30H

[2] Cycle life for LIB is a function of depth of discharge. The value here is based on operation between 80 to 50% DoD with Lithium Titanate Batteries

[3] Low temperature effect and performance of LIB depends on battery chemistry. Value quoted is for Lithium Titanate batteries

[4] Charge discharge efficiency depends on the pulse duration/application

[5] Self discharge rate defined above is for cells with active balancing circuits

[6] Cost of LIB is expected to fall down unlike ELDC which is a mature mass produced technology

Storage Comparison

Vehicle Segments

Segment	Application	Udc	Required Storage [kWh]	Installed Storage [kWh]	Peak Power	Storage	Phase Legs
LRV[1]	Braking Energy Reuse	600/750	1	1.3	300 kW for 10s	ELDC	2
LRV[1]	Catenary Free - Limited	600/750	5	6.7	300 kW for 10s	ELDC	2
LRV[1]	Catenary Free - Extended	600/750	15	45	300 kW for 10s	Battery	2
DMU[2]	Peak Shaving	750	1	1.3	200 kW for 20 s	ELDC	1
DMU[2]	Peak Shaving + Braking Energy Reuse	750	5	6.7	800 kW for 20s	ELDC	4
Trolley Bus	Peak Shaving + Braking Energy Reuse + Range Extension	600	0.2 + 10	0.3 + 12	200 kW for 20s	ELDC + Battery	2
Electric Bus TOSA	Catenary Free	750	15	45.0	200 kW for 20s	Battery	-

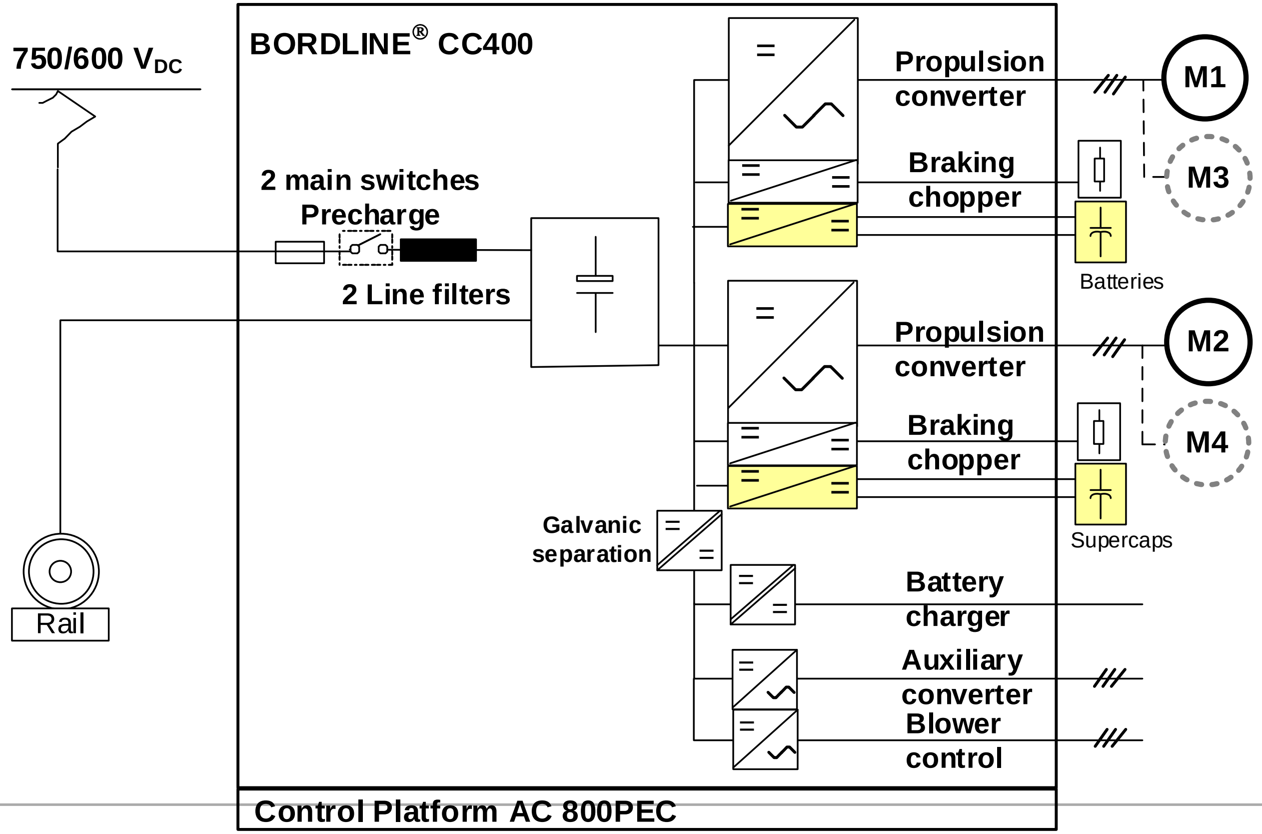
LRV[1] Per motor car of a 40 to 60 tn tram with 3 or 4 cars and two motorcars

DMU[2] Per motor car of a DMU

ABB Solution for Energy Storage Integration

BORDLINE® CC400 for LRV (Example)

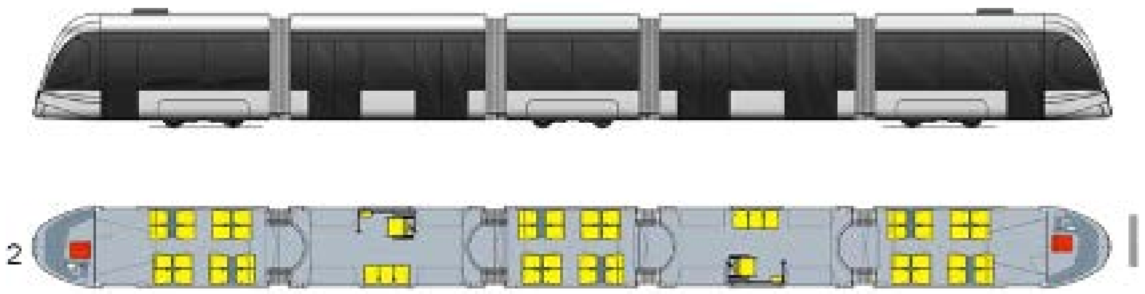
BORDLINE® CC400 with Chopper for Energy Storage System



LRV for Complete Catenary Free Operation

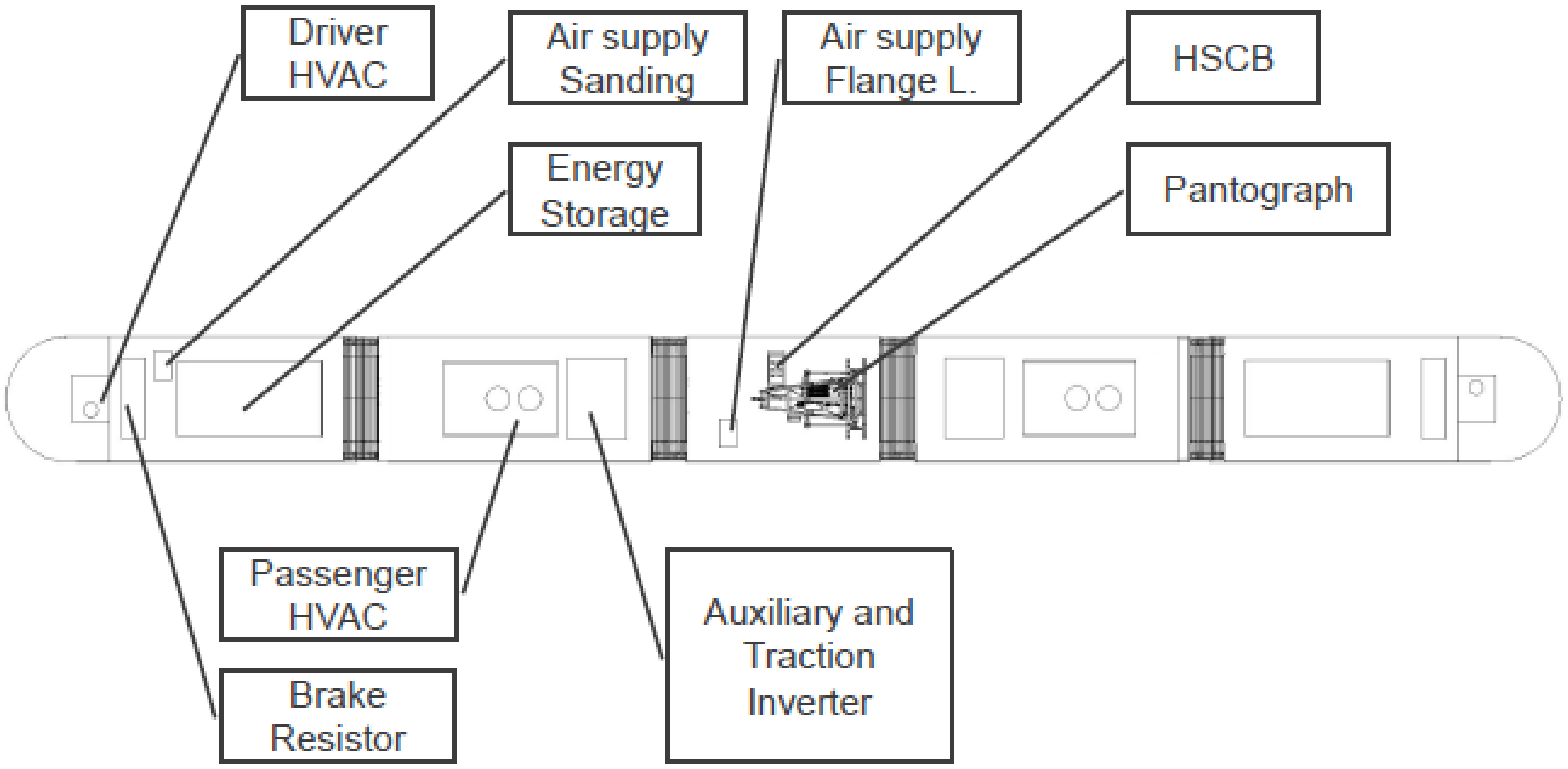
Case Study

- Operation only without overhead line
- Charging at all stops with catenary bar
- 5 carbody modules
- 2 motor and 1 trailer bogie
- 100 % low floor vehicle without ramps
- ~ 33 m length, 2,65 m width, 3,8 m height
- ~ 250 passengers (AW2), 50 – 60 seats
- Maximum axle load 13 t



Roof Layout

Case Study

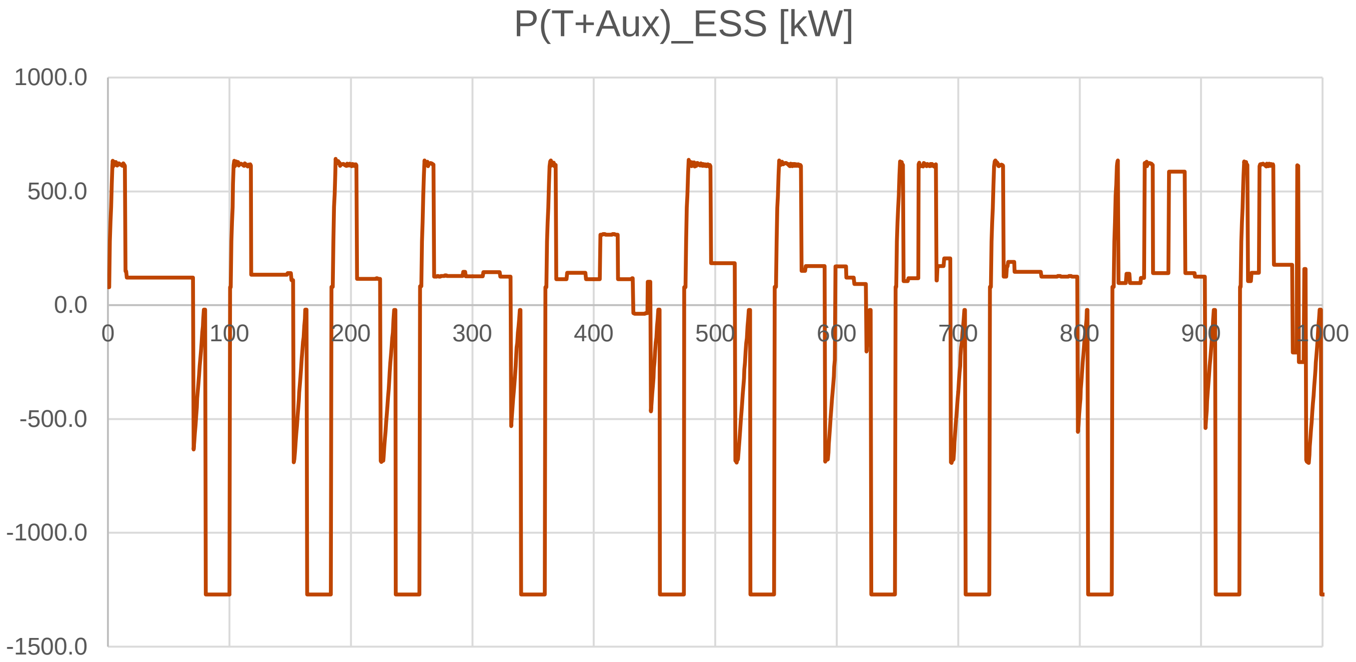


Load Cycle for the Energy Storage System

Case Study

This reqirements lead to following load cycle for the energy storage system

The maximal needed energy between stations is 6 kWh (including one un-sheduled stop)



Energy Storage Comparison

Case Study

Type	LTO 10 Ah HP Cell	Li Capacitor	Supercap Durablue 48V
Nominal Voltage	624 V	620 V	720 V
Maximal Voltage	750 V	740 V	750 V
Minimal Voltage	470 V	440 V	360 V
Energy Installed	31 kWh	6 kWh	6.5 kWh
Peak Power 30s	700 kW	1200 kW	> 4 MW
Continuous Power	400 kW	600 kW	400 kW
Weight including Cooling	1500 kg	1400 kg	2900 kg
Dimensions	1500 X 2500 X 500 mm	1500 X 2000 X 500 mm	1500 X 3000 X 550 mm
Cooling	Active Water Cooling	Forced Air Cooling	Air Cooling
Life Time	10 years	15 years	10 years

Note: This table is per driven bogie, for this case study there are 2 of this energy storage systems needed

Energy Storage in Mass Transit

Selected ABB References

Project Name	Application	Storage Device
Light Rail Vehicle, Switzerland	Braking Energy Recovery & Re-use	Electric Double Layer Capacitor
Light Rail Vehicle, USA	Partial Catenary Free Drive (4 km)	Lithium-Ion Battery
Light Rail Vehicle, Brazil	Partial Catenary Free Drive (0.4 km) & Emergency Operation	Lithium-Ion Battery
Light Rail Vehicle, USA	Partial Catenary Free Drive (1 km)	Lithium-Ion Battery
Light Rail Vehicle, Austria	Emergency Catenary Free Drive (0.4 km)	Lithium-Ion Battery
Light Rail Vehicle, Germany	Partial Catenary Free Drive (1 km)	Lithium-Ion Battery
Light Rail Vehicle, Taiwan* (Danhai)	Partial Catenary Free Drive (0.2 & 1 km)	Lithium-Ion Battery
Light Rail Vehicle, China* (Fangchen)	Partial Catenary Free Drive (1.2 km)	Lithium-Ion Capacitor
Light Rail Vehicle, China* (Tonghao)	Partial Catenary Free Drive (? km)	Electric Double Layer Capacitor
Diesel Multiple Unit, Estonia	Diesel Engine Downsizing	Electric Double Layer Capacitor
Trolley Bus, Switzerland	Line Voltage Stabilisation & Range Extension	Lithium-Ion + Electric Double Layer Capacitor
TOSA, Switzerland	Full Electric Urban Bus	Lithium-Ion Battery

Note :
(a) Dimensioning and scope of energy storage varies with project
(b) * Projects under execution

Traction converter for light rail vehicles

Catenary-free operation

City :
Seattle (USA)

Operator:
SDOT

Category:
LRV

Scope of supply:
Traction converters for 6 LRVs:-
BORDLINE CC 400
TCMS

Deliveries:
2013

Customer Need

- State-of-the-art space optimized propulsion equipment
- Catenary-free operation up to 4 km

ABB Solution

- Customized traction converter with integrated traction battery charger, auxiliary converters, battery charger, heat exchanger and braking resistors

Customer Benefits

- Optimal use of roof space due to highly integrated traction converter
- Customized solution based on well-proven standard building blocks

Traction converter for light rail vehicles

Catenary-free operation

City:
Dallas ,Detroit, OKC, Milwaukee

To come Soon:
Tacoma, Tempe, Portland

Operator:
City opretaors

Category:
Streetcar

Scope of supply:
Propulsion

BORDLINE CC 400
Traction Motor
HEX with Brake Resistor

Deliveries:
2013…….2020

Customer Need

- State-of-the-art propulsion equipment
- Catenary-free operation upto 1 km

ABB Solution

- Liquid cooled traction converter comprising motor inverter, auxiliary converter, traction battery charger & LV battery charger

Customer Benefits

- Customized solution based on well-proven standard building blocks
- Minimized space consumption on the vehicle roof

Full Electric Bus for Urban Transit

Traction Chain

Country:
CH

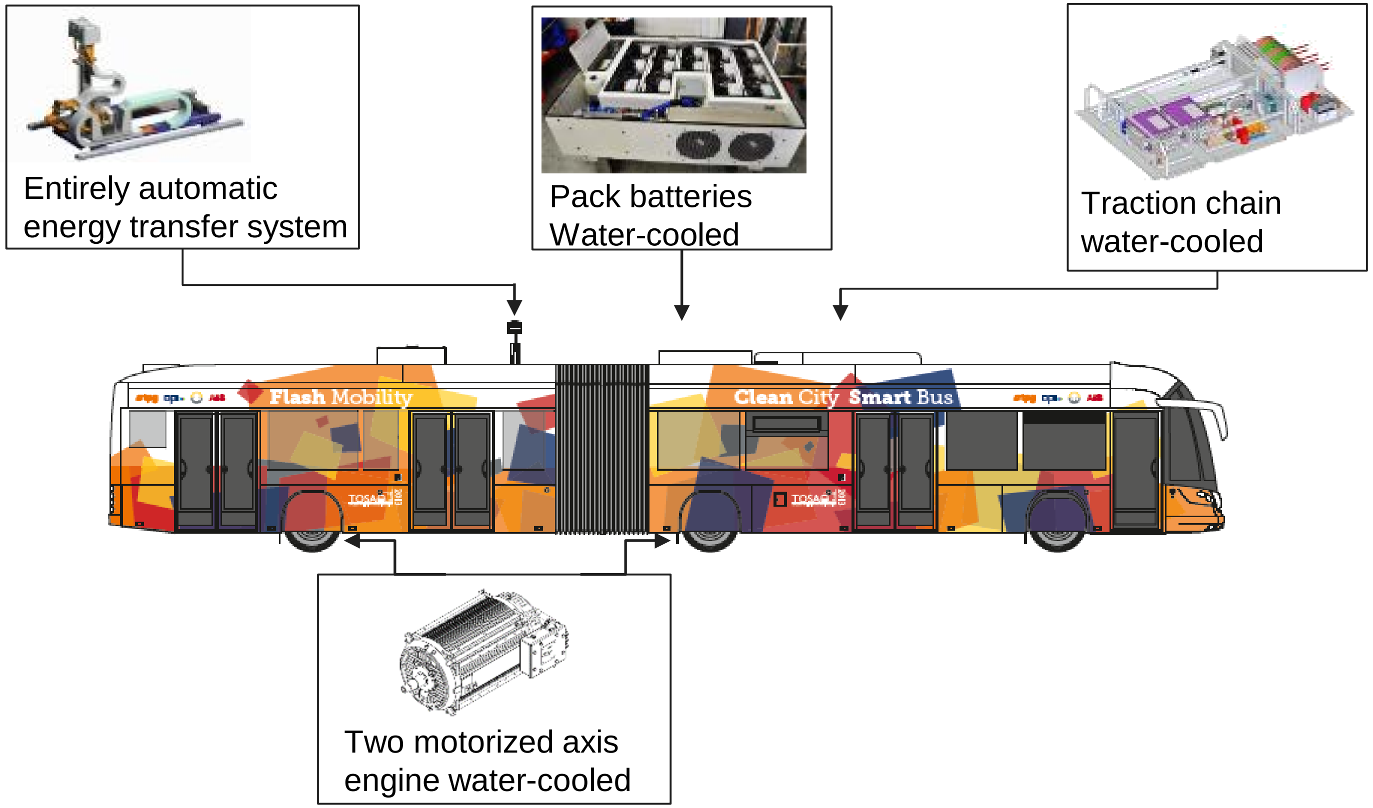
Operator:
TPG

Category:
E-Bus

Scope of supply:
Traction converters for 1 18m articulated E-bus

Key data:
Flash charging in 15s (top-up)
Terminal charging in 3 min (full re-charge)

Deliveries:
2013



APRIL 10, 2018

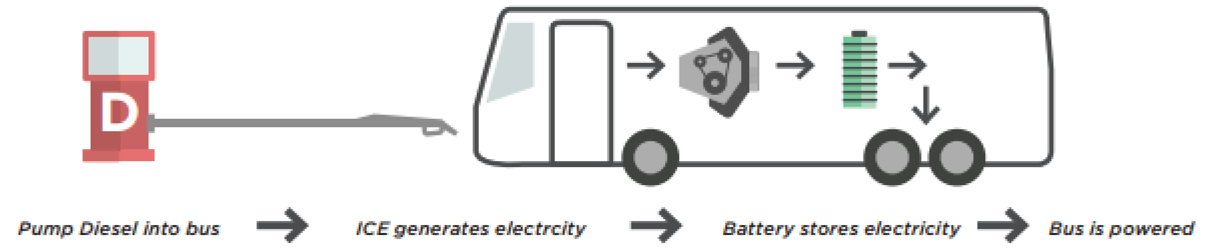
eBus: Mix of fleet and design considerations

Stephanie Medeiros, ABB

Electric Bus Overview

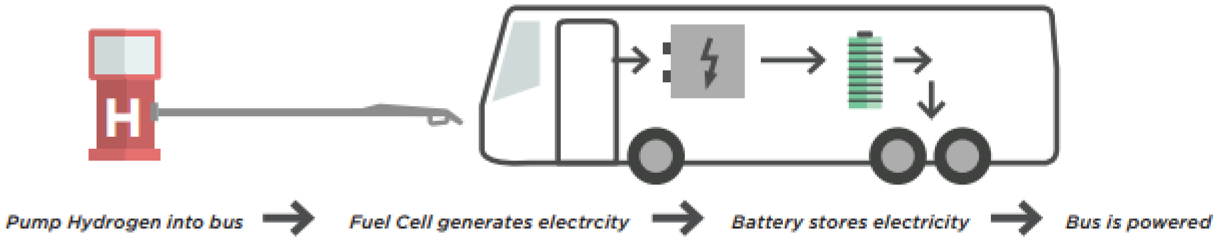
Types of Electric Bus Technologies

Hybrid Electric Bus



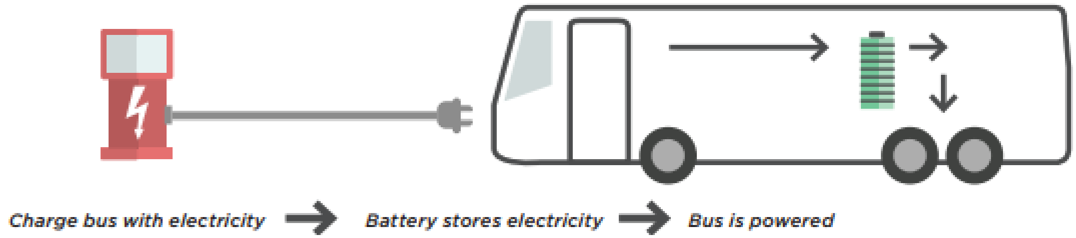
- Low reduction in emissions
+ Lower capital costs (bus and infrastructure)
- Higher O&M costs

Fuel Cell Electric Bus



+ Low emissions
- High infrastructure costs limited availability
- Very high bus costs
- Very high O&M costs

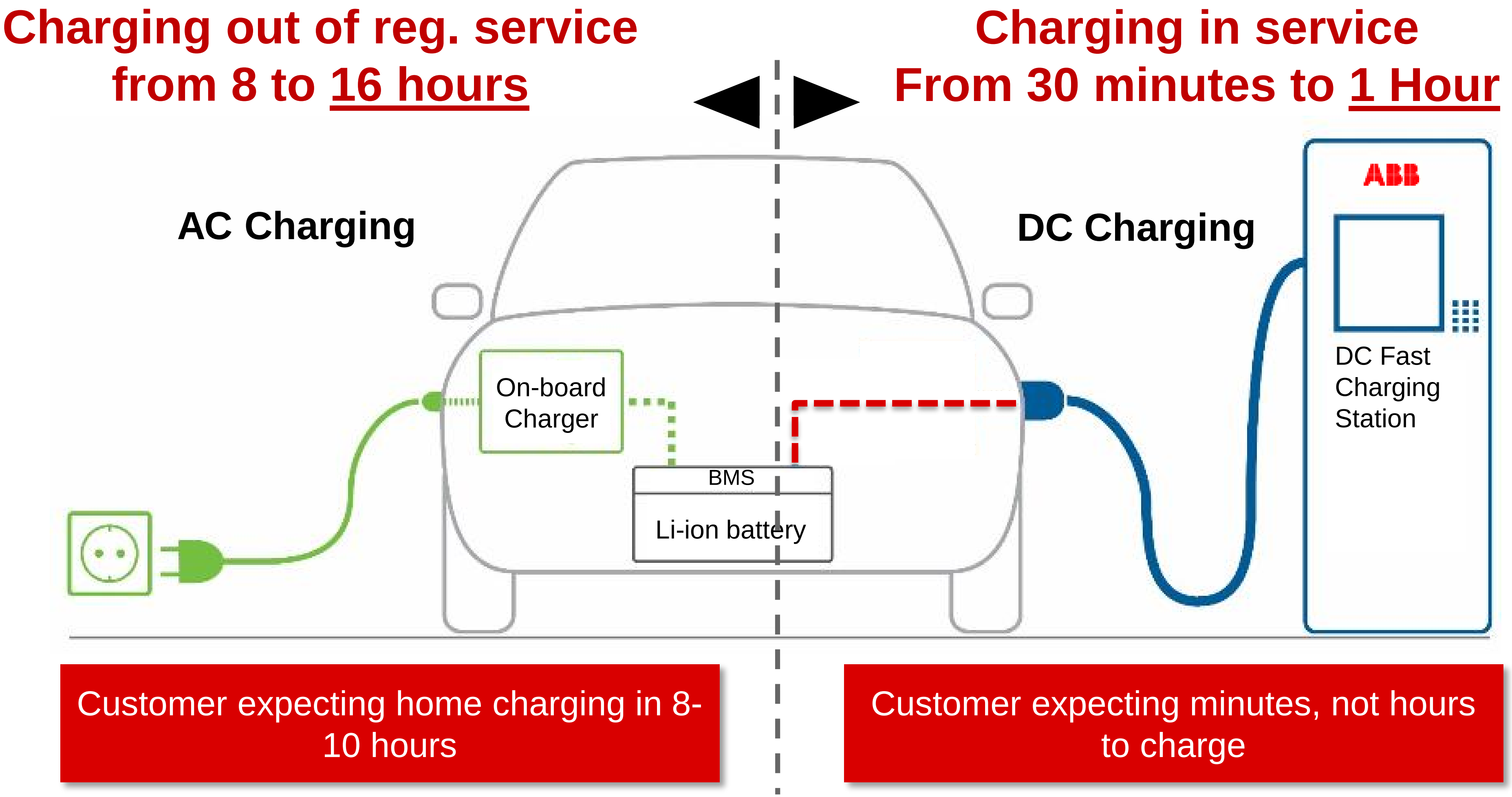
Battery Electric Bus



+ No emissions
+ Reduced O&M costs
- High capital costs (bus and infrastructure)
- Less range (without enroute charging)

Electric Bus Overview

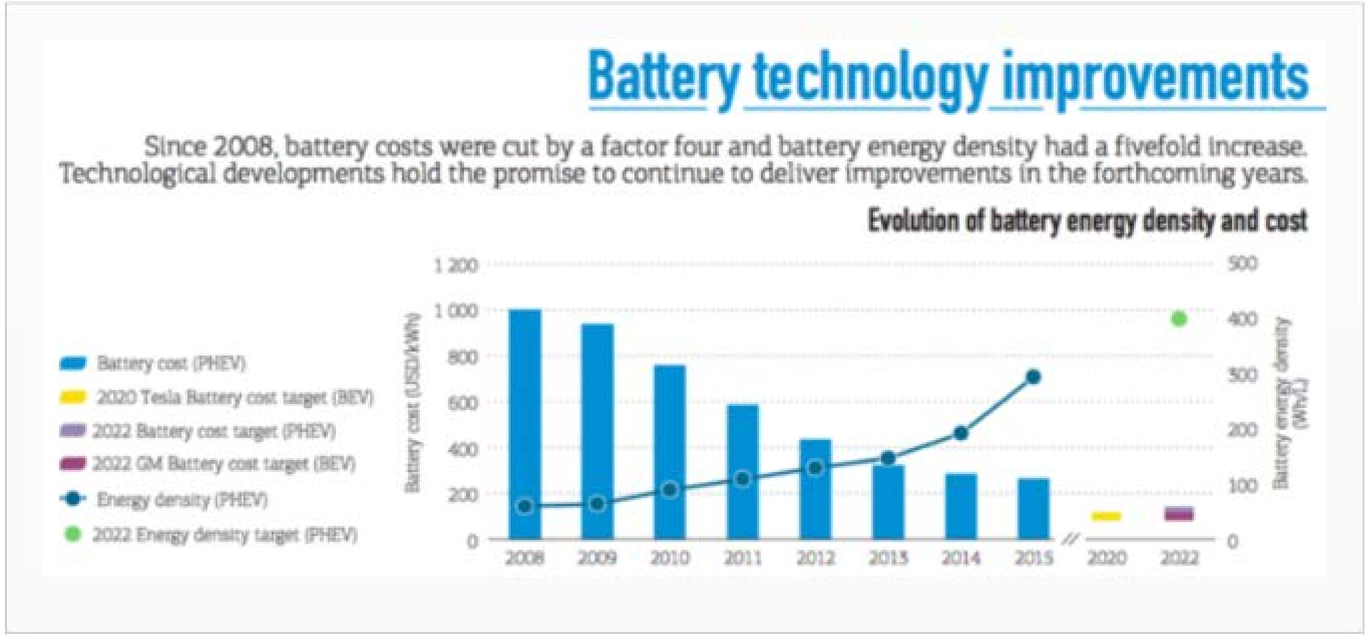
Types of battery charging – car example



Electric Bus Overview

Battery Improvements - Driven by the car industry

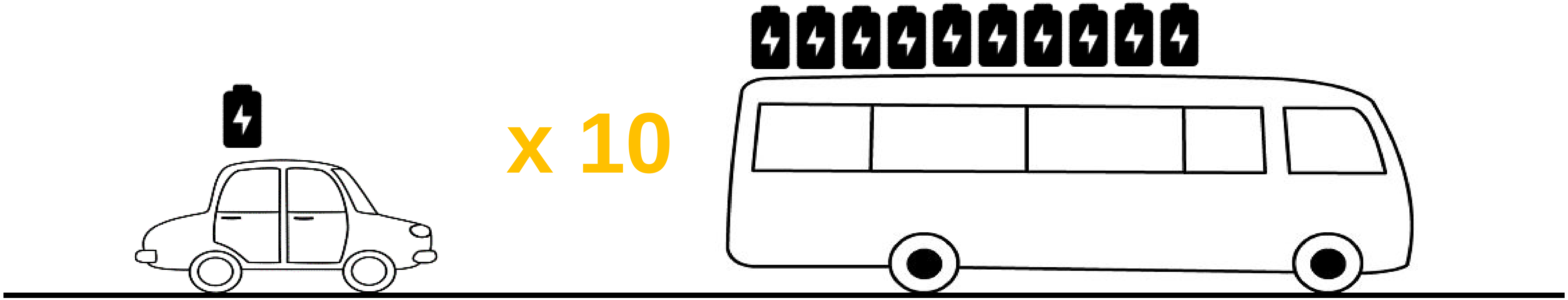
- **Cost reduction** allowing a better market penetration
- Energy density improvement allowing now to answer customer needs for range by **increasing battery capacity** for same vehicle efficiency



*Source: International Energy Agency, Global EV Outlook 2016**

Electric Bus Overview

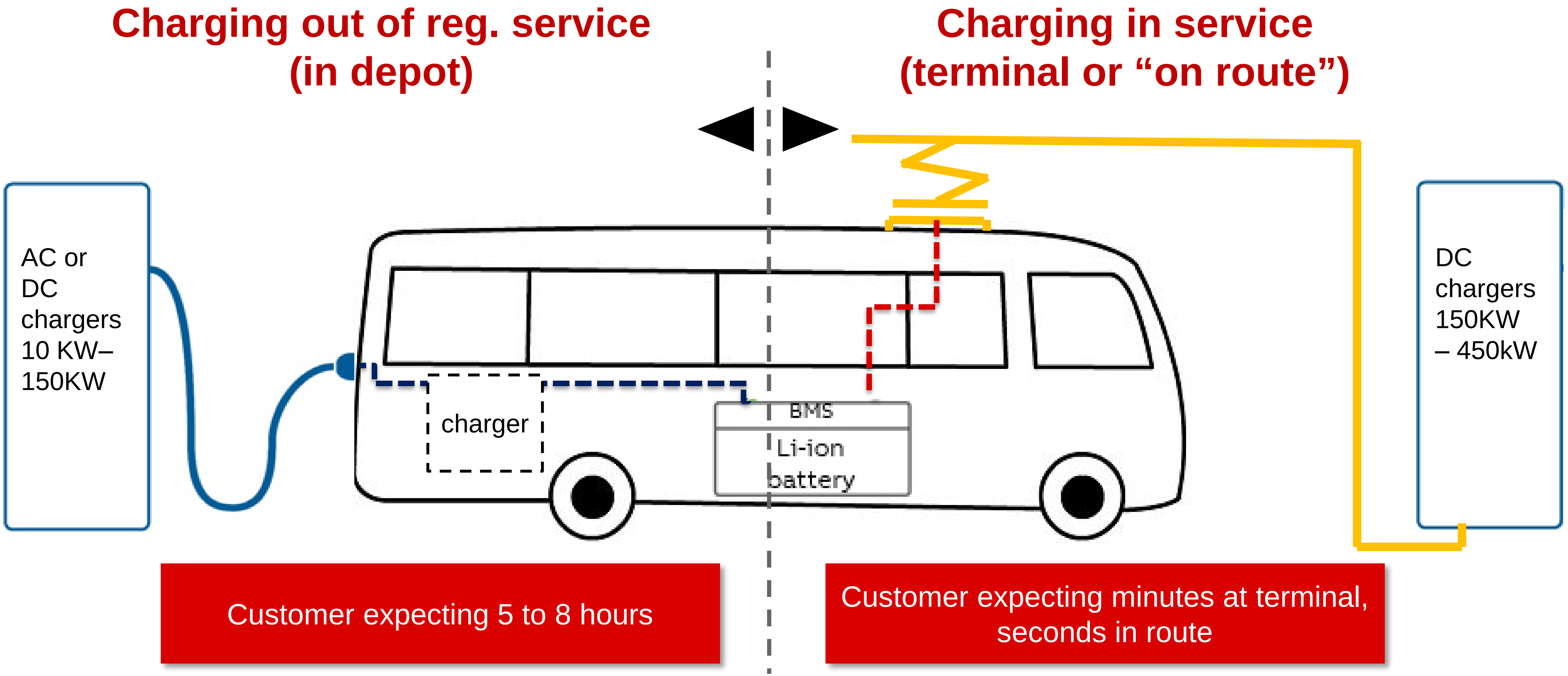
Electrification of buses vs cars



<u>Meaning , **10 times the power**</u>
required to maintain comparable
charging time

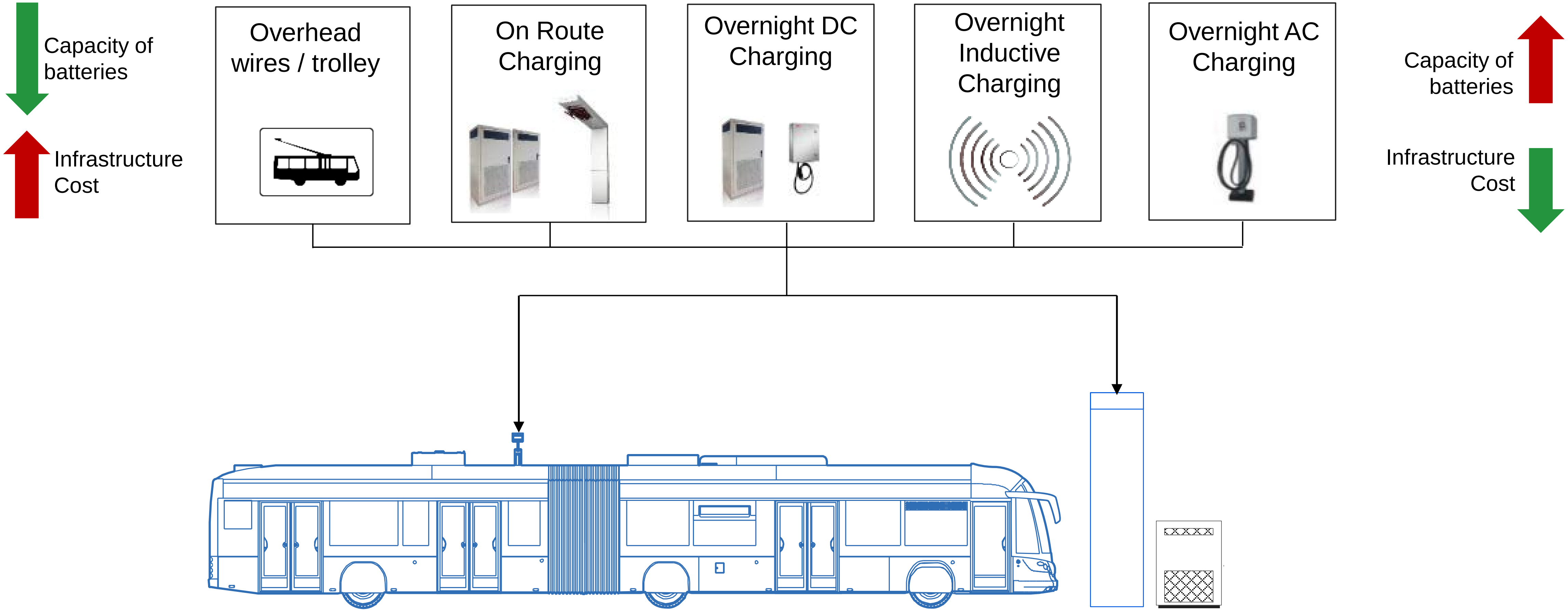
Electric Bus Overview

Time and usage is primordial to a transit agency/operator



Electric Bus Overview

Different Types of Battery Charging

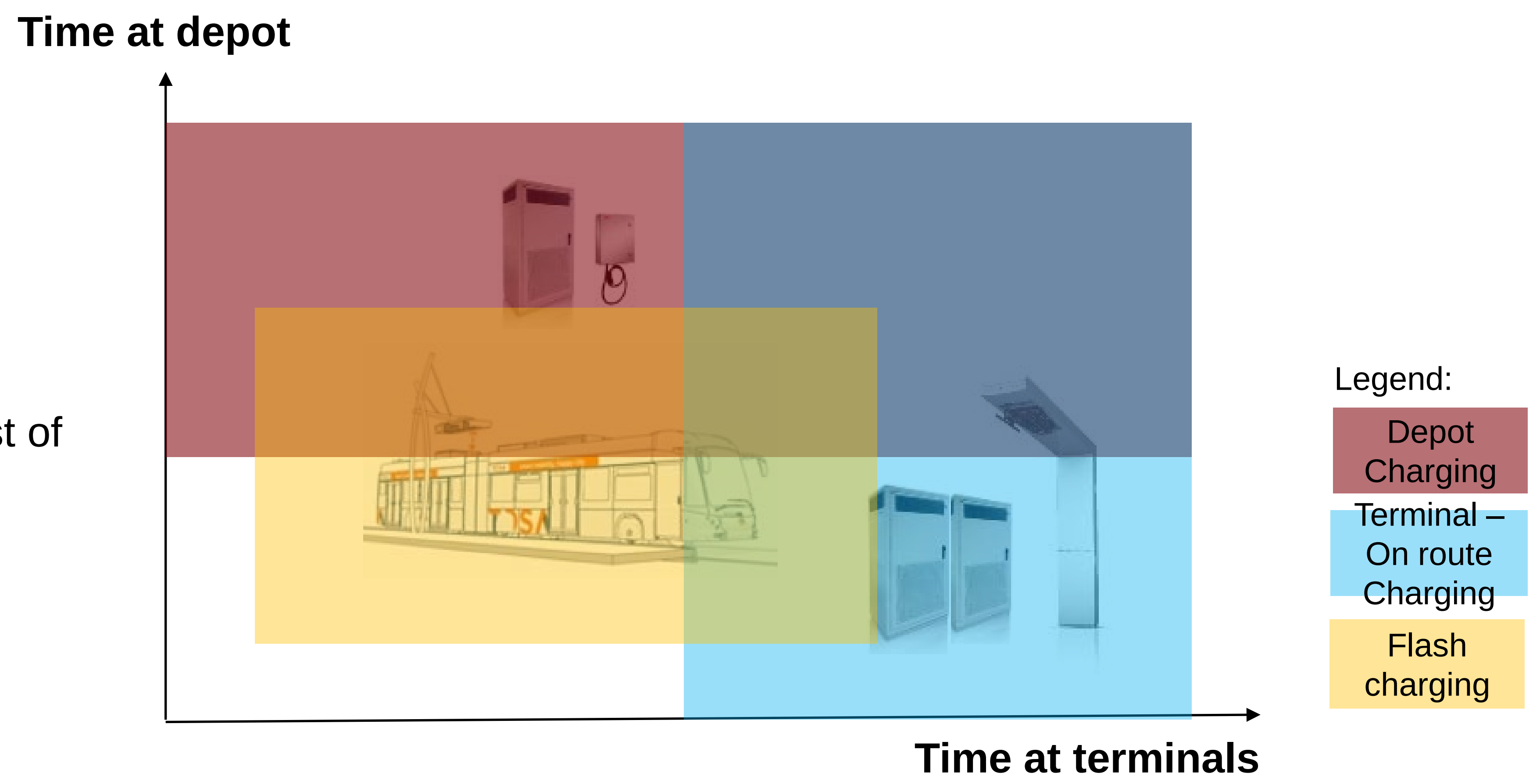


Factors in Selecting Battery Charging

Operation is the key factor for selecting the right technology

Other important elements:

- Fleet size
- Common interface standard product
- Power demand impact
- Capital cost versus total cost of ownership
- Real estate
- etc.



Factors in Selecting Battery Charging

Future Proofing charging equipment

- Civil works and equipment prepared for future higher power
- Easy field upgradeable system
- Equipment Modularity
- Capability to charge more buses as fleet size increas

HVC 100C

Upgrade

HVC 150C

Upgrade can be done in the field by adding an extra module.
No groundworks, digging and disturbance to the site required

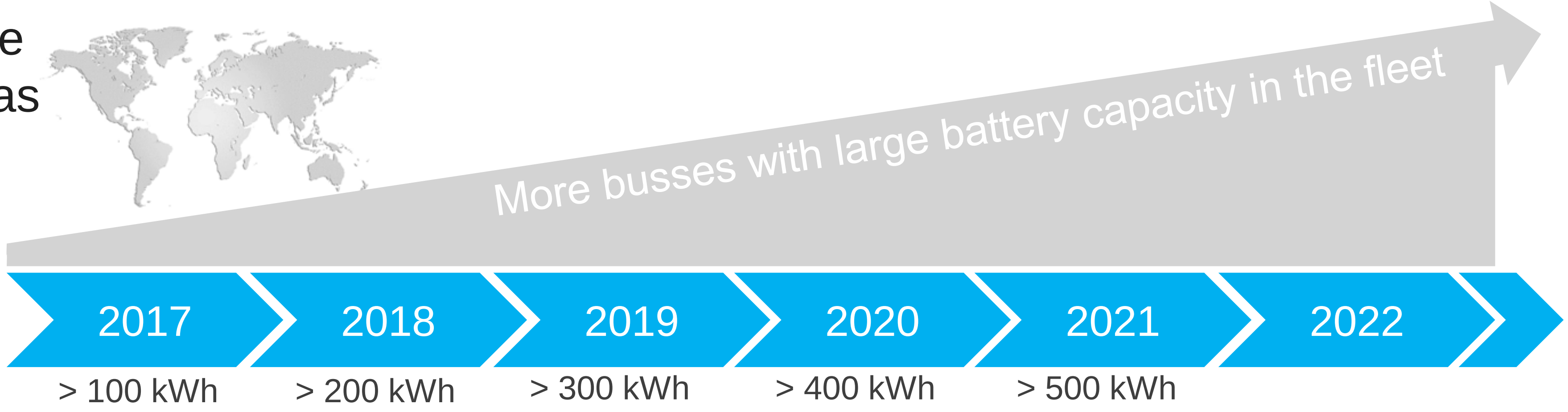


ABB Product portfolio Ebus Charging

Opportunity Charge

HVC 150P

HVC 300P

HVC 450P

Depot or Overnight Charging

HVC 50C

HVC 100C

HVC 150C

P: Pantograph
C: Cable

Factors in Selecting Battery Charging

Operation is the key factor for selecting the right technology

Basic idea, offering flexibility, reliability & redundancy

High speed lanes

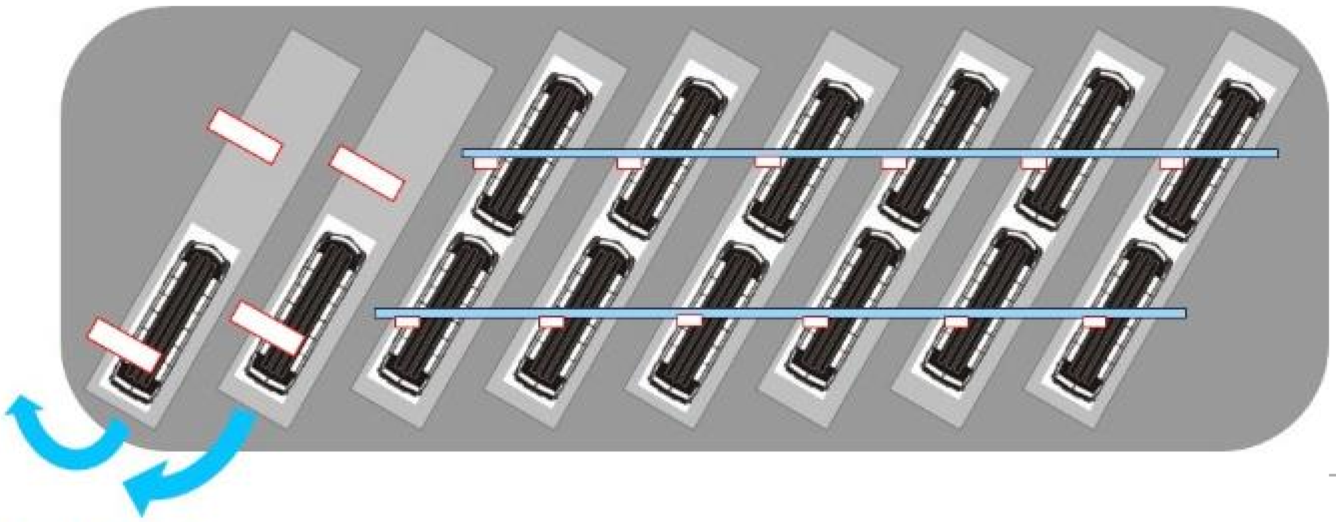
flexibility & incident recovery

Automated Pantograph solution
(300- 600 kW)

Normal lanes

main (overnight) charging operation

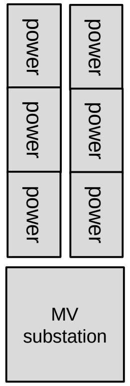
Overhead portals with CCS cable
(50-100-150 kW)



Fast bus flow

Power area

Modular charging systems at convenient location



ABB

Bus Charging – Importance of Standards

CCS standard changes required for power >150 kW

Standard	Specification (today)	Max charging power for EV car
CHAdeMO	50-500V, 125A	~50 kW
CCS	200-500V, 200A	~95 kW

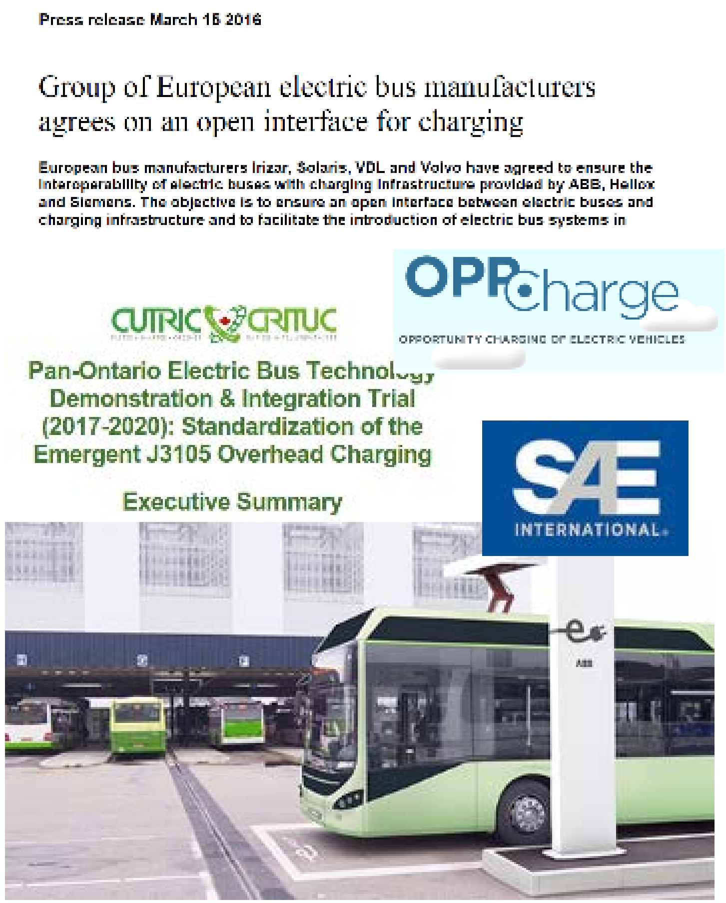
CCS today	New high power CCS proposal
CCS connector	Special CCS connector, backward compatible with today's vehicles
200 – 500 VDC	Up to 920 VDC
200 ADC	350 / 500 ADC
Up to ~80-90 kW charging power	160 kW – 350 kW charging power
	Power electronics cabinet parameters under review: - Current - Voltage - Safety concept - Isolation concept - Electro Magnetic Compatibility (EMC) - Power quality - Accuracy
	Update of IEC standards takes until 2018/2019

CE / UL charger certification based on today's standard

Bus Charging – Importance of Standards

Standardization effort on overhead terminal charging in NAM

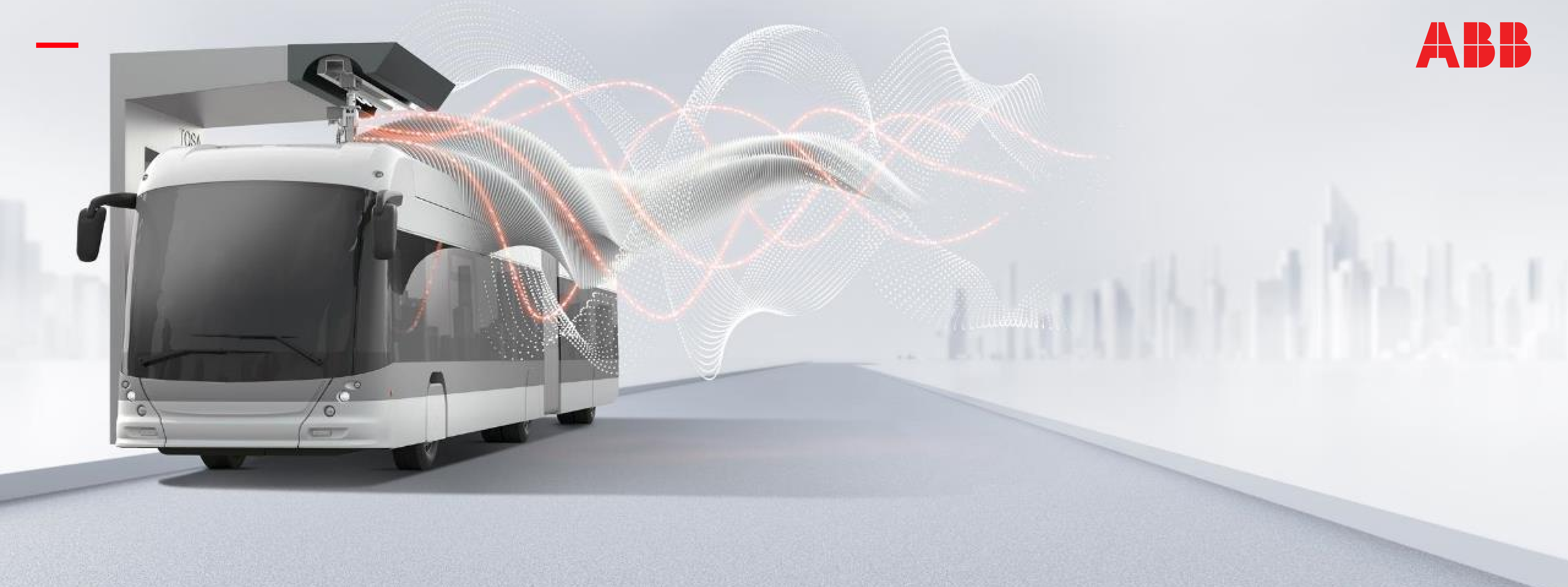
Accelerate the deployment of electric buses in the cities



- manufacturers to create **a common standard** for the overhead opportunity charging
- In USA, ABB is supporting the « EPRI Bus and Truck Charging Working Group » to develop the **SAE J3105**.
- In Canada, ABB is collaborating with **CUTRIC** , (including Novabus, New Flyer, Siemens, city of Brampton, Hydro One, etc.) for demonstration project to **demonstrate interoperability** of the common standard based on Oppcharge ((https://www.oppcharge.org/)

Key Takeaways and Considerations

- Charging design that is **best suitable** for your operation
- Consider **multiple charging** types on an electric bus
- Anticipate and prepare for **high power** infrastructure (both depot & terminals)
- Think **total cost of ownership** vs strictly capital cost
- Support **standardized** solutions & open protocols vs custom designs



CALM strategy for e-bus

Connected Asset Lifecycle Management for electric bus operators

April 2018

ABB Connected Asset Lifecycle Management for e-bus

Solution Scope

Connection to Real Time Systems

Network Manager / SCADA

Connection to real time systems ensures immediate and reliable data integration

Enterprise Asset Management

Ellipse EAM

Manage physical assets, including asset register, work order management, inventory, and procurement functions

Workforce Management

Ellipse SaaS Apps, Ellipse WFM

Maximize productivity of the organization and the individual

Asset Performance Management

Ellipse APM

Optimize asset performance while reducing costs, improving availability, and managing risks

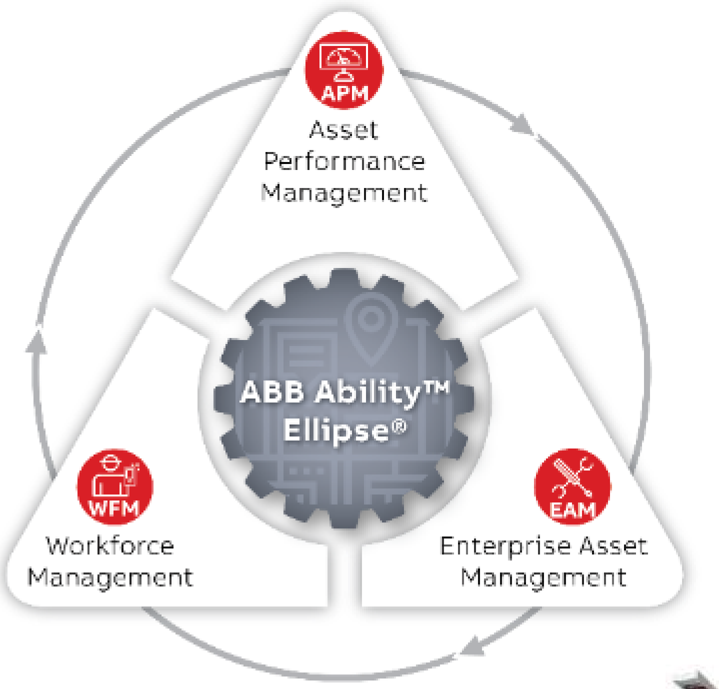
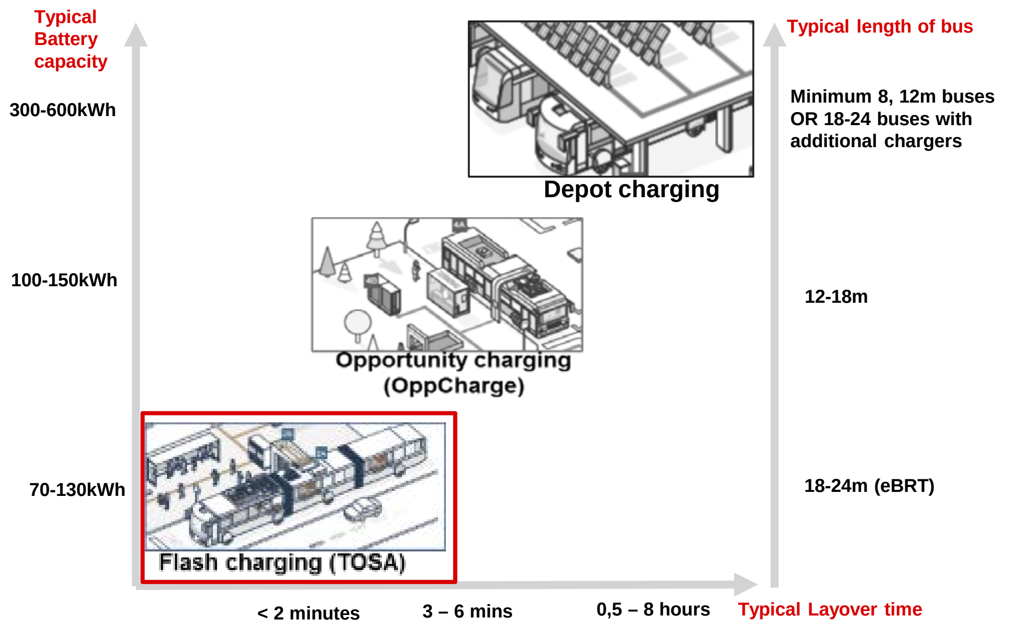
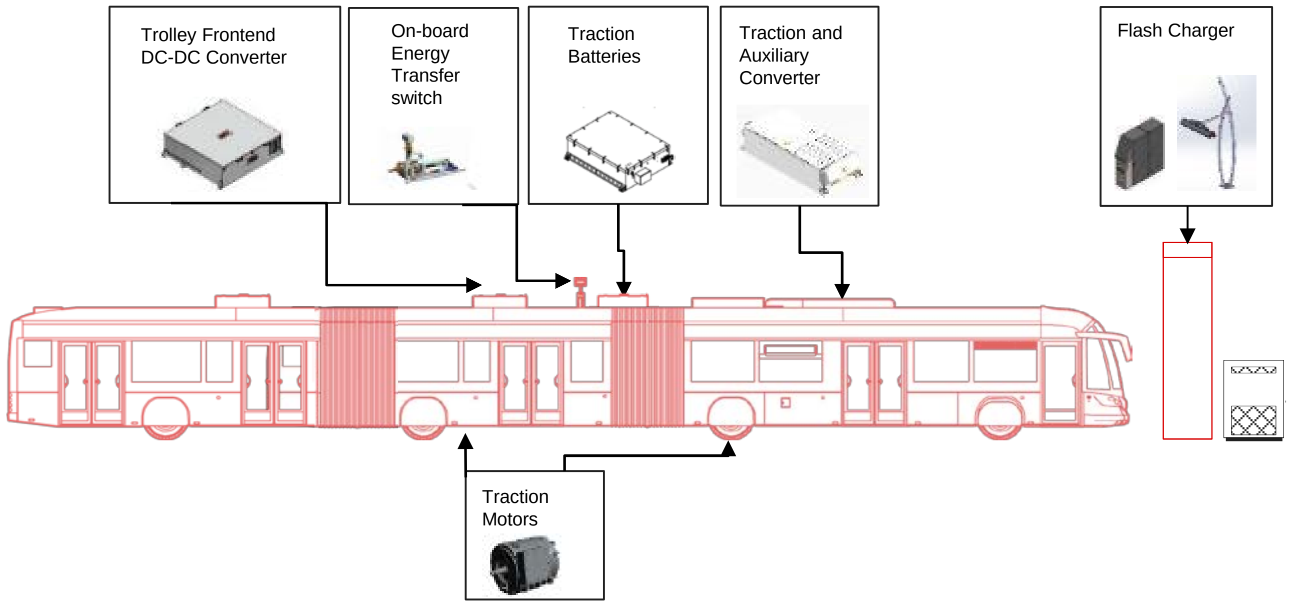


ABB e-bus hardware offering

Different solutions for various requirements



The "TOSA" Flash Charging solution is installed at TPG



Intro to TOSA

Flash charging

Today’s and future ABB e-bus solutions

A unique competitive position on the market

Today’s solutions

Solutions for e-bus on board (drive train and battery pack) and way-side charging infrastructure

Trolley bus/over-night/terminal only (Oppcharge)/Flash charging (TOSA)

On premise software solutions for operation and maintenance of the fleet (SCADA and Enterprise Asset Management)

Future solutions based on ABB Ability platform

- **SCADA system**
- **Fleet and maintenance management**
- **Enterprise asset management & asset performance mgmt**
- **Aggregation of e-bus fleet and charging infrastructure for provision of grid service (eBus2grid and XaaS)**
- **Peer to peer energy trading with blockchains**

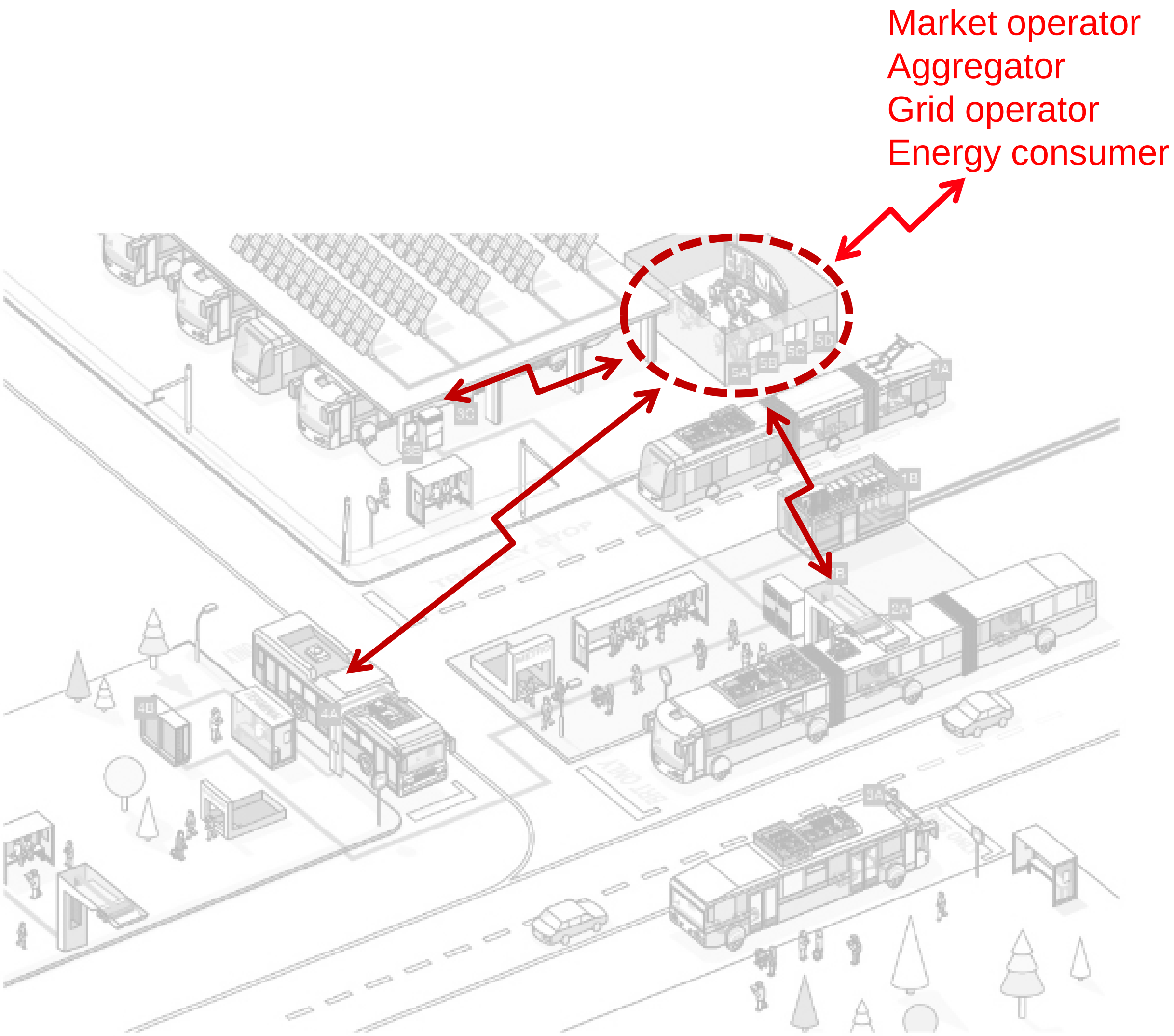


ABB IT/OT – CALM Solution for e-bus

TPG e-bus line 23 in Geneva

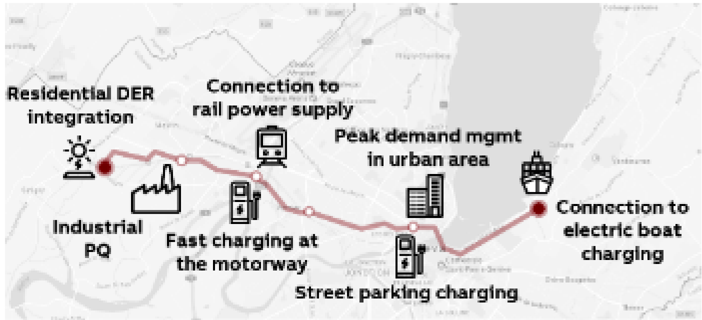


ABB delivers on-board drive train and charging infrastructure for 13 e-buses

ABB Scada and Ellipse EAM monitor and help maintain the line

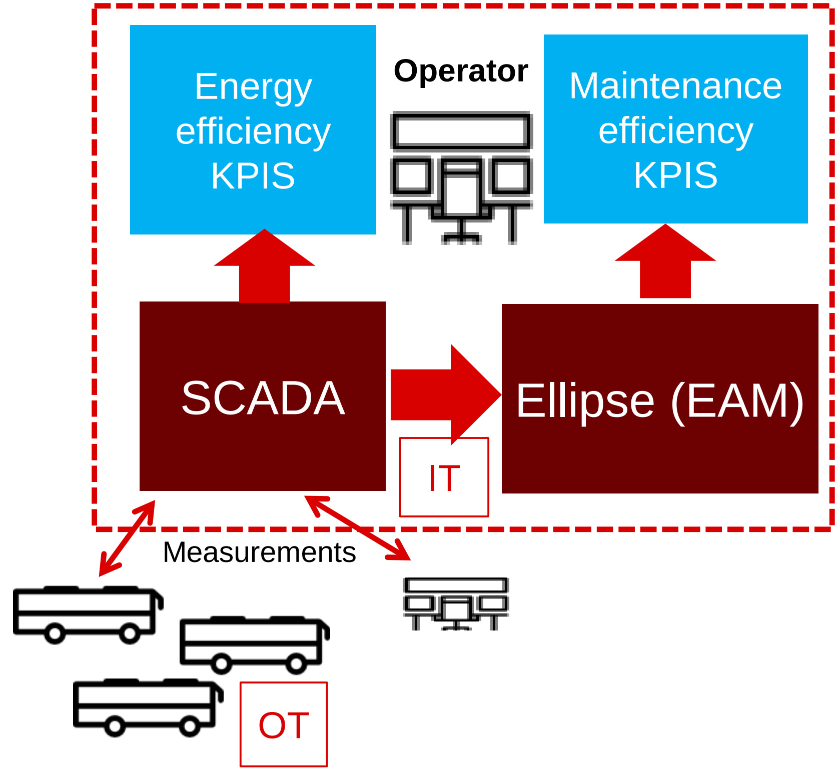
ABB Ability™ for e-bus

The SCADA solution helps:

- For remote monitoring
- Remote control and safe operation of e-bus fleet and charging infrastructure

Ellipse EAM helps for:

- Maintenance optimization
- Cost reduction



Bus2grid and XaaS pilot project

From hardware to software and to ABB Ability platform - on going project in Geneva

TOSA bus line 23 in Geneva

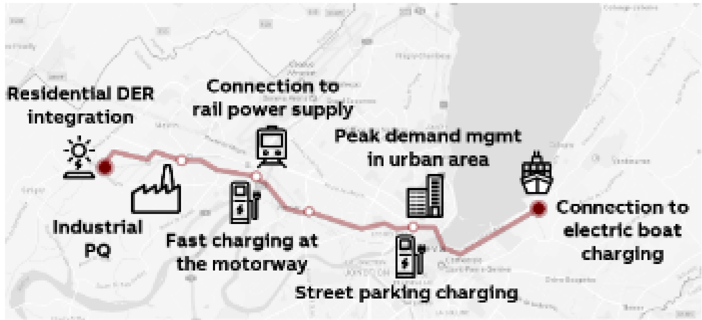


ABB delivers on-board drive train and charging infrastructure for 13 e-buses

Commercial operation Q2/2018

From physical to digital control

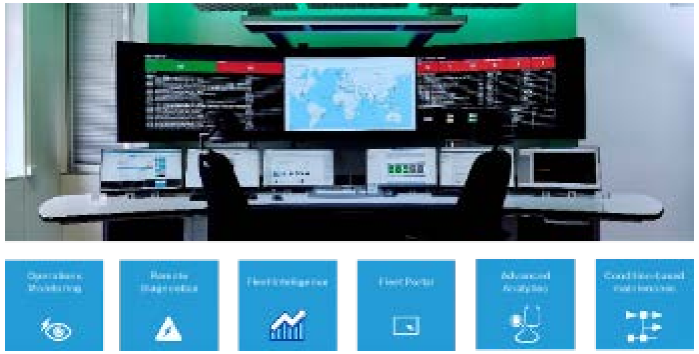
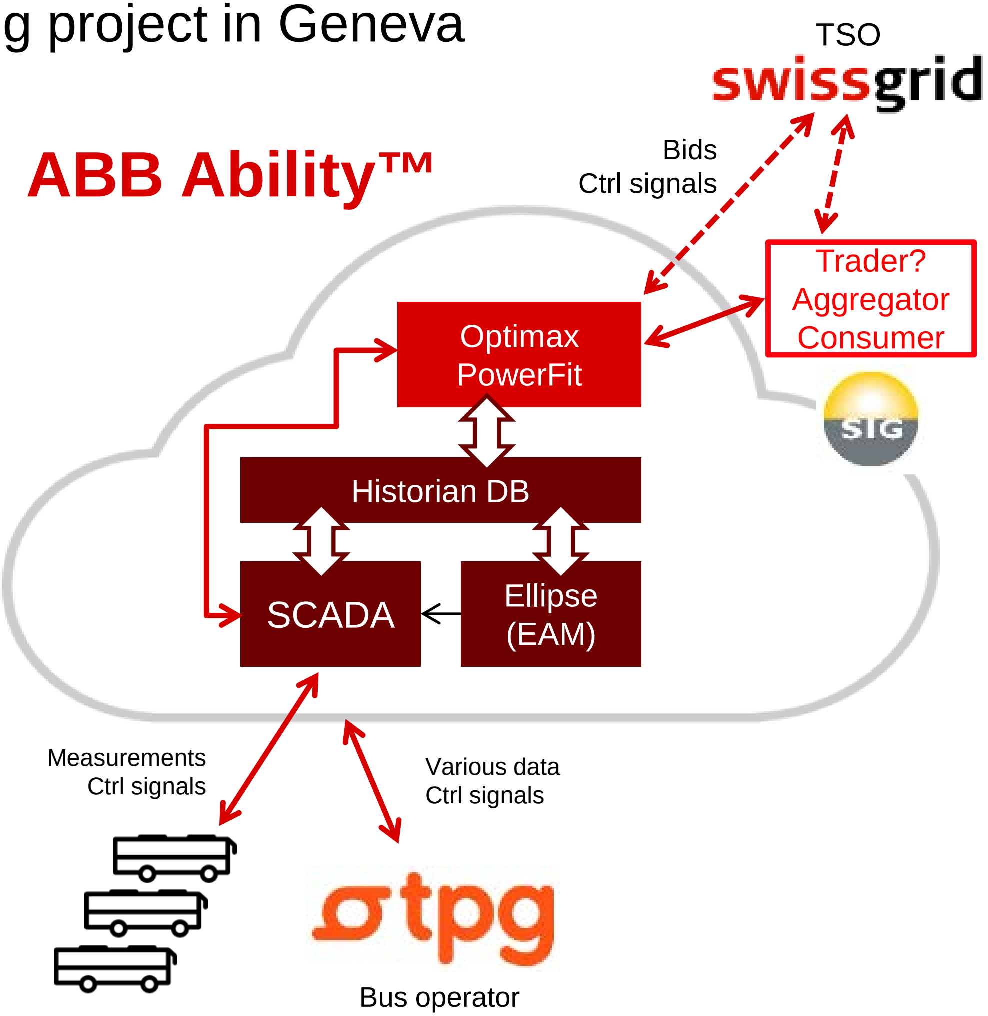


ABB SCADA and Ellipse EAM will be used to operate and maintain the line 23 in Geneva

Commercial operation Q4/2018

ABB Ability™



XaaS – everything as a service, DSO – distribution system operator, TSO – transmission system operator.

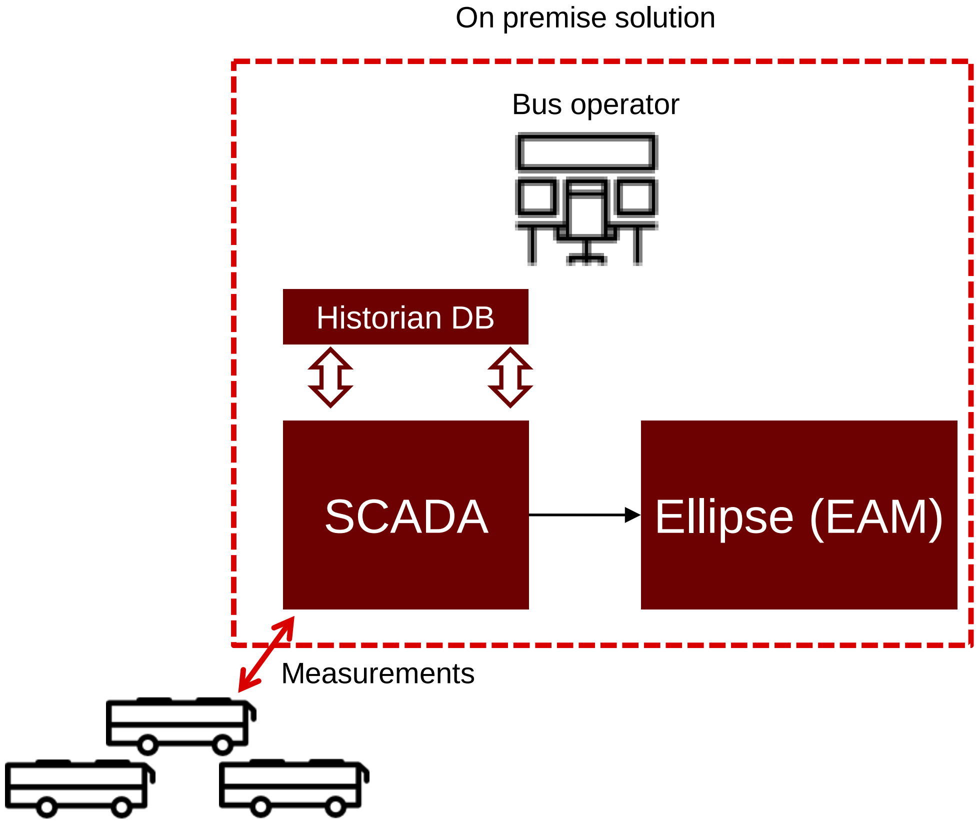
Today's and future ABB e-bus solutions

A unique competitive position on the market

PGGA, Enterprise software

SCADA solutions helps to:
- Remote monitoring (on-board and way-side components)
- Remote control (on-board and way-side)
- Safely operate of e-bus fleet and charging infrastructure

Ellipse Asset Mgmt solutions helps to:
- Condition based maintenance
- Reduce the total cost of ownership



Phase 1

Connect SCADA and Optimax Powerfit

PGGA, Enterprise software

SCADA solutions helps to:

- Remote monitoring (on-board and way-side components)
- Remote control (on-board and way-side)
- Safely operate of e-bus fleet and charging infrastructure

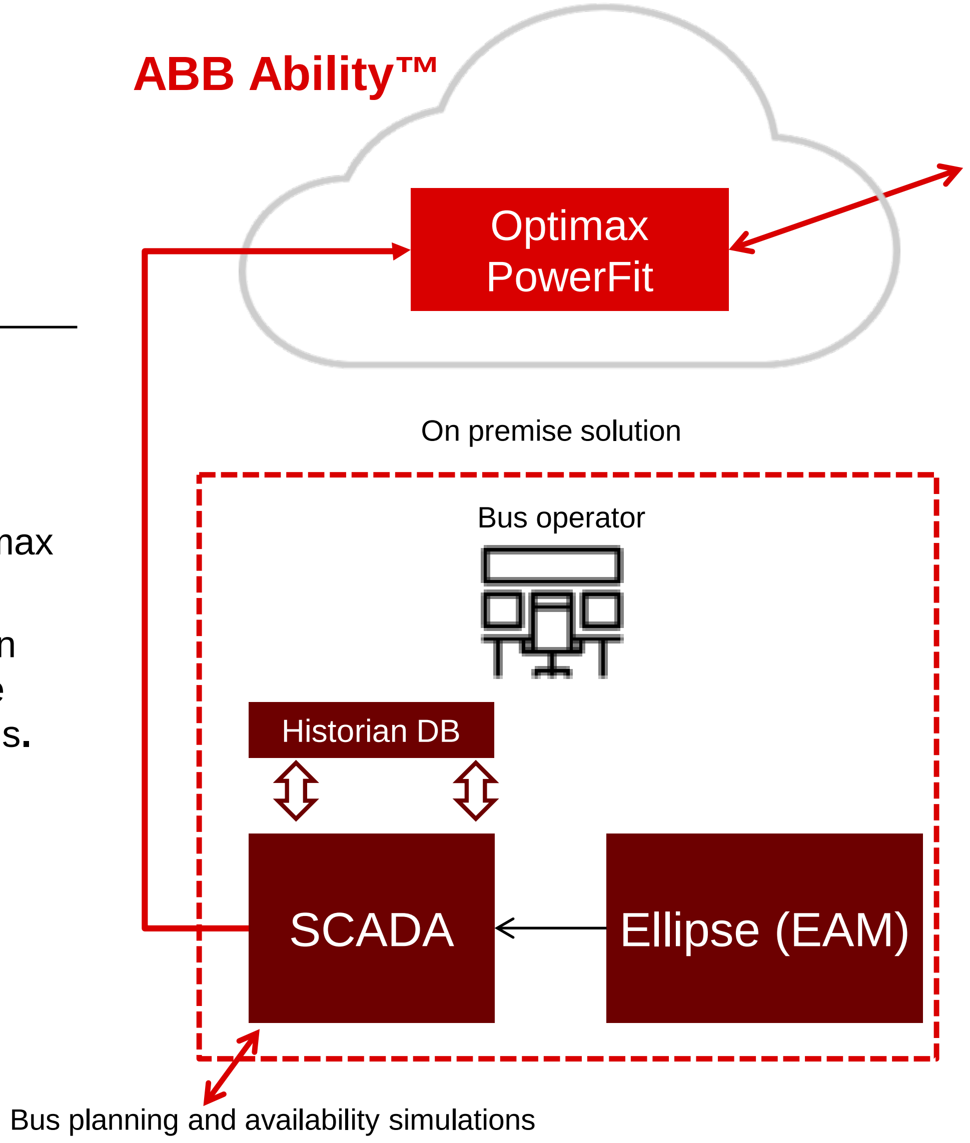
Ellipse Asset Mgmt solutions helps to:

- Condition based maintenance
- Reduce the total cost of ownership

IAPG

Optimax PowerFit solutions helps to:

- Aggregate a large number of assets
- The aggregated volume is optimally dispatched between grid services to max profit
- Distributed resources are scheduled in real time based on application/service needs depending on their actual status.

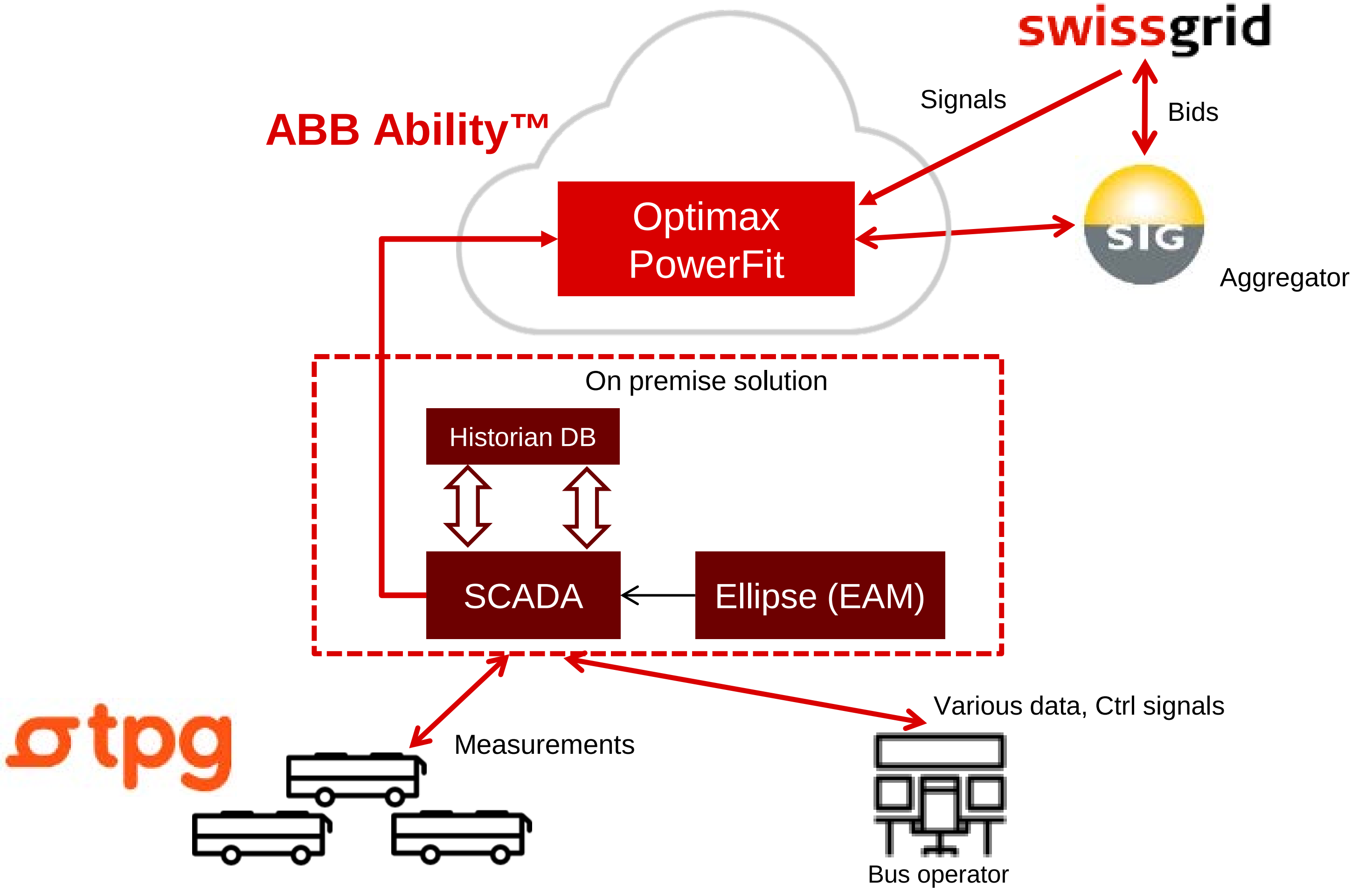


Output of the phase 1 (end of January 2018):

- **Import of price forward curve**
- **Show depot secondary control reserve**

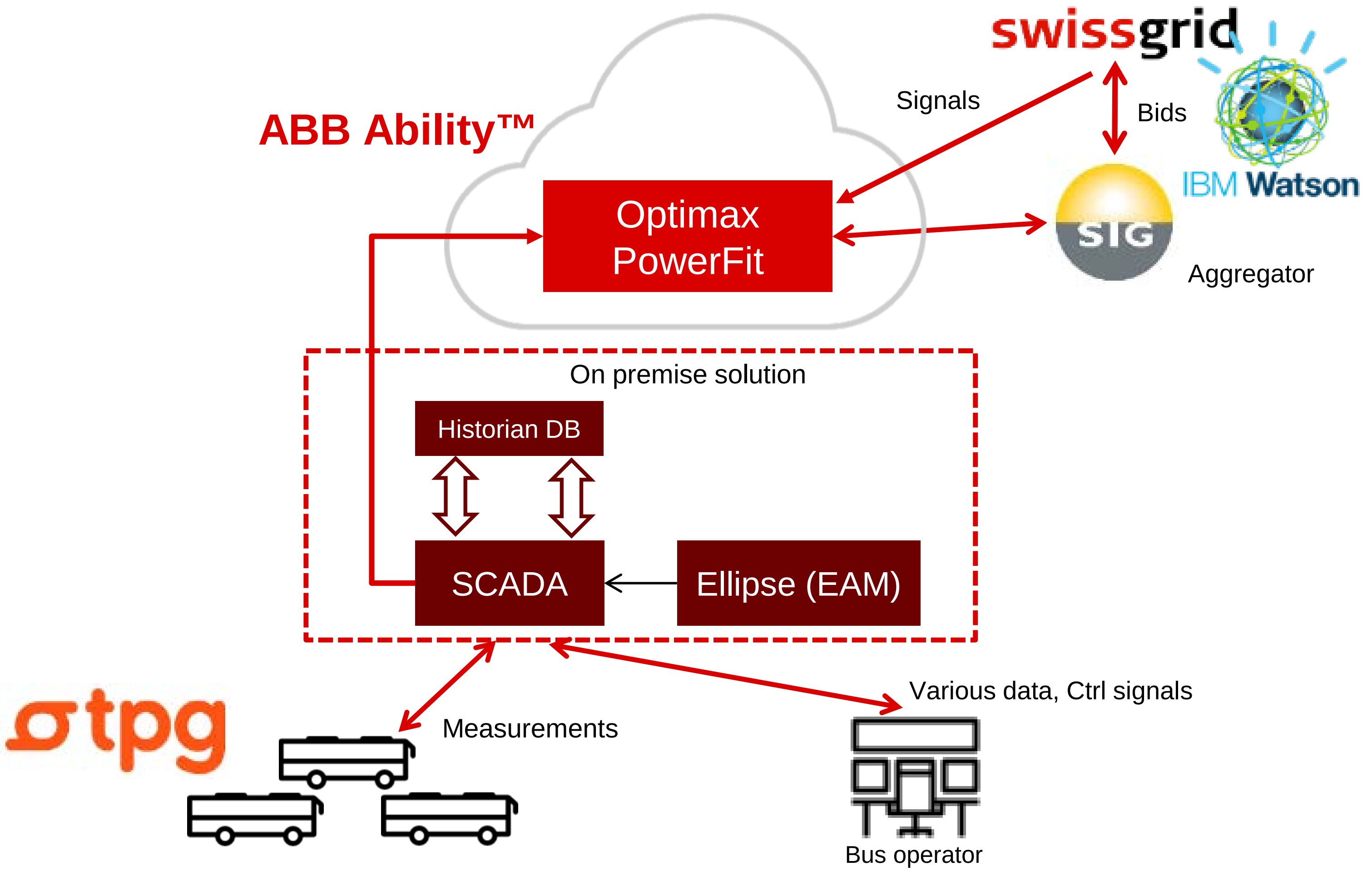
Phase 2

Test run on real buses and interface with a trader aggregator for 1st or 2nd frequency regulation market



Phase 3

Bring artificial intelligence to the bidding process



Phase 4

Peer to peer energy trading with blockchains

Use case based on Power Ledger example of peer-to-peer energy trading

Energy storage is available

- in bus batteries when the buses are at depot
- way-side battery storage when not needed

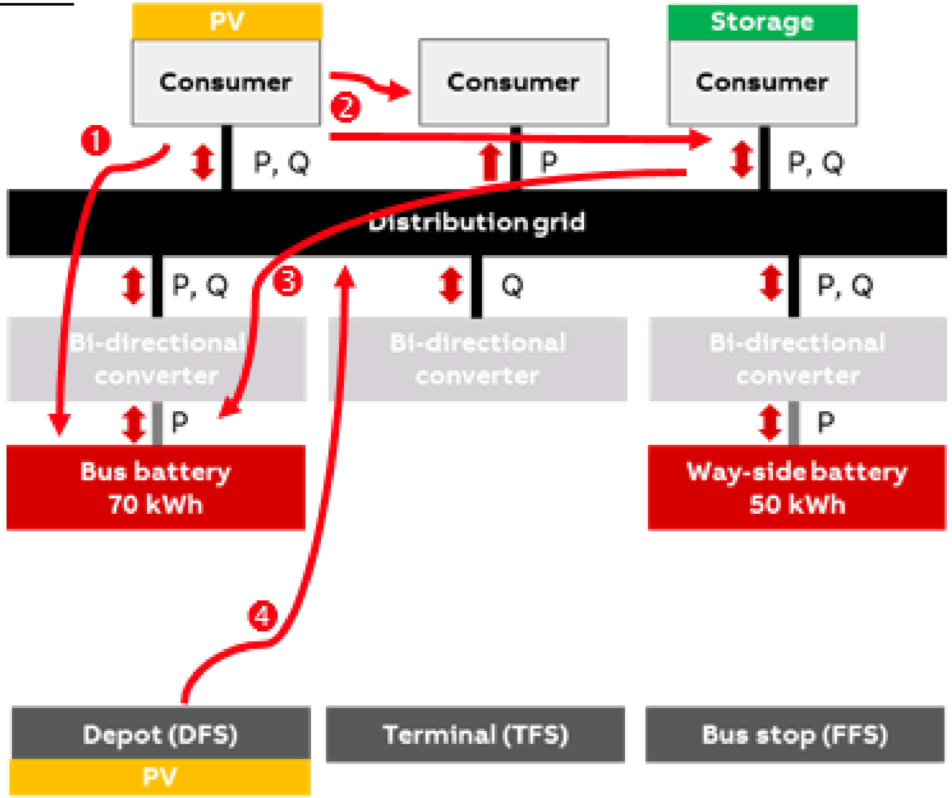
Amount of energy available for grid services depends on the usage pattern and time of day

❶ Depot buys power from consumer with PV between 09:00 and 16:00

❷ Consumer with PV sells excess power to other consumers or stores it in consumer with storage

❸ Consumer with storage sells power to depot for charging in early evening

❹ Depot directly sells excess PV energy to other local consumers



Lunch

12:00-1:30

Impacts of electrified transport on the grid

Transit and utility partnership

Agenda

TIME	TOPIC	SPEAKERS
8:00	Breafast & Check in	
9:00	Welcome & Introductions	Daniel Simounet
9:15	Keynote Speaker: Connecting People: The 2041 Regional Transportation Plan	Peter Paz, Manger of regional partners, Metrolinx
	E-mobility 101: The roadmap to electric transportation. As cities drive to become cleaner, transit authories and transportation providers are expected to go electric. Each city's journey to electrification looks different.	
9:45	Building a roadmap to e-mobility	Naeem Farooqi, Principal Consultant, WSP
10:15	Break	
10:30	Energy storage backed railway traction chain	Elvis Dzindo, ABB
11:00	eBus: Mix of fleet and design considerations	Stephanie Medeiros, EV charging infrastructure, ABB
11:30	Digitalization strategies for electric fleets	Pat Egan, Enterprise Software, ABB
12:00	Networking & Lunch	
	Impact of electrified transport on the grid: The collaboration between transit operators and utilities is imperative. Prepare for the future with design strategies that account for intelligent grid connection, minimized demand charges, and optimized reliability.	
1:30	A utility perspective: Insights on electrified transport's grid impacts, and best practices for utility partnership	Neetika Sathe, VP, Advanced Planning, Alectra
2:30	Electrification of bus fleets: Grid impacts and solutions	Stephanie Medeiros, EV charging infrastructure, ABB
3:00	Break	
3:15	Generating positive cashflow through Rail Energy Storage Systems	Patrick Savoie, Wayside Energy Storage Systems, ABB
3:45	Rail electrification design considerations	Imtiyaz Mashraqi, Grid Integration, ABB
4:15	Q&A & Close	
4:30	Reception	

Utility view: Insights on electrified transport’s grid impacts

Neetika Sathe, Vice President, Advanced Planning, Alectra Inc.

April 10, 2018

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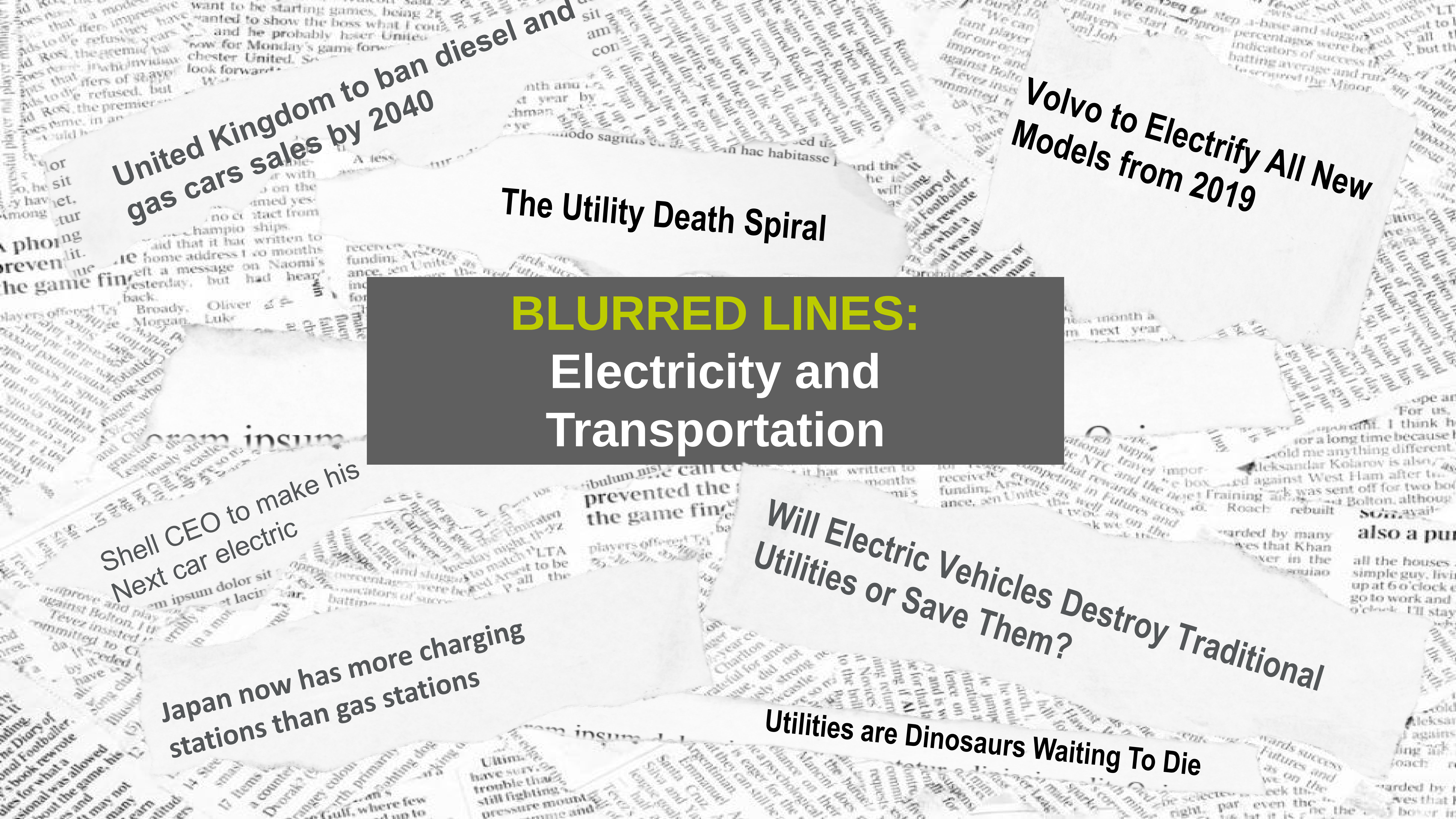
Who is Alectra?

Alectra is an energy company that primarily serves customers in Canada's Province of Ontario

Second largest municipally-owned integrated energy solutions company in North America

over C$4.3 billion in assets and 1,500 employees

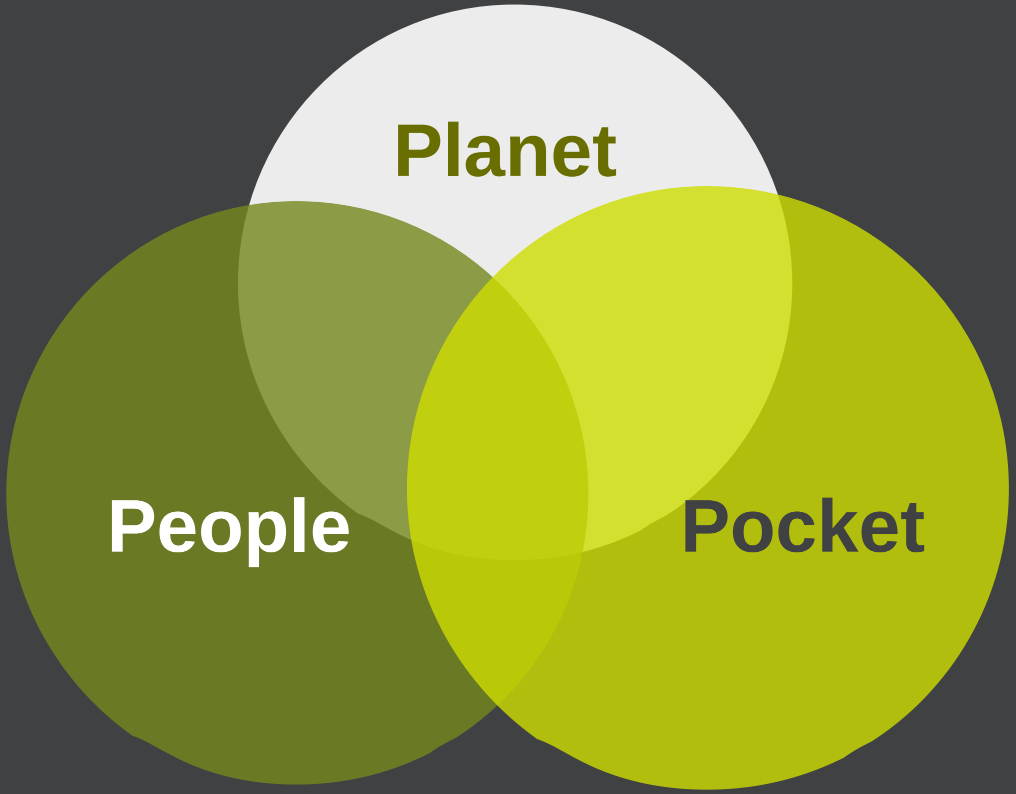
Serving approximately 1million customers across 2,200 sq kms


BLURRED LINES:
Electricity and Transportation
United Kingdom to ban diesel and gas cars sales by 2040
The Utility Death Spiral
Volvo to Electrify All New Models from 2019
Shell CEO to make his Next car electric
Will Electric Vehicles Destroy Traditional Utilities or Save Them?
Japan now has more charging stations than gas stations
Utilities are Dinosaurs Waiting To Die

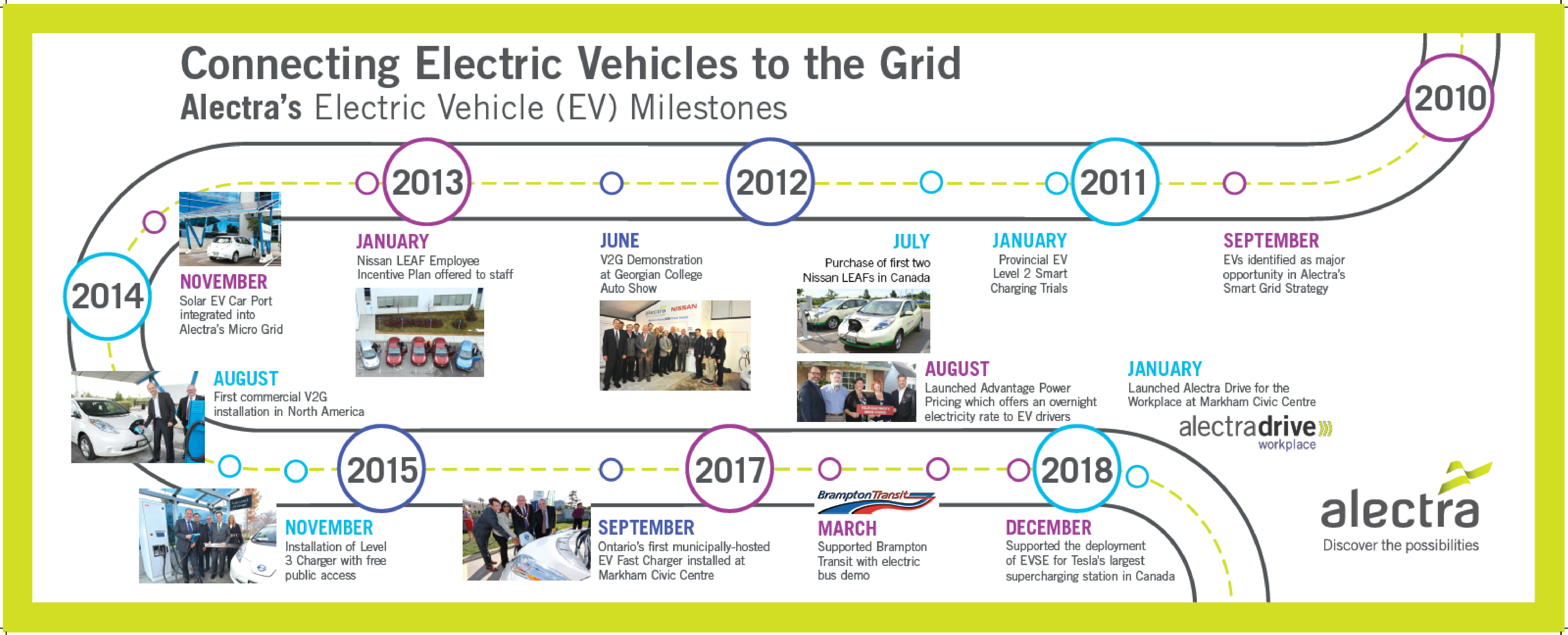

Canada EV Sales 2017
Five Facts
+ 68% YoY in Canada
+ 120% YoY in Ontario
~ 50K EVs in Canada
>2% Quebec EV sales
2X All-electric vs plug in

Why are EVs picking up momentum?

EV Adoption provides a win-win-win solution



Alectra's EV Journey



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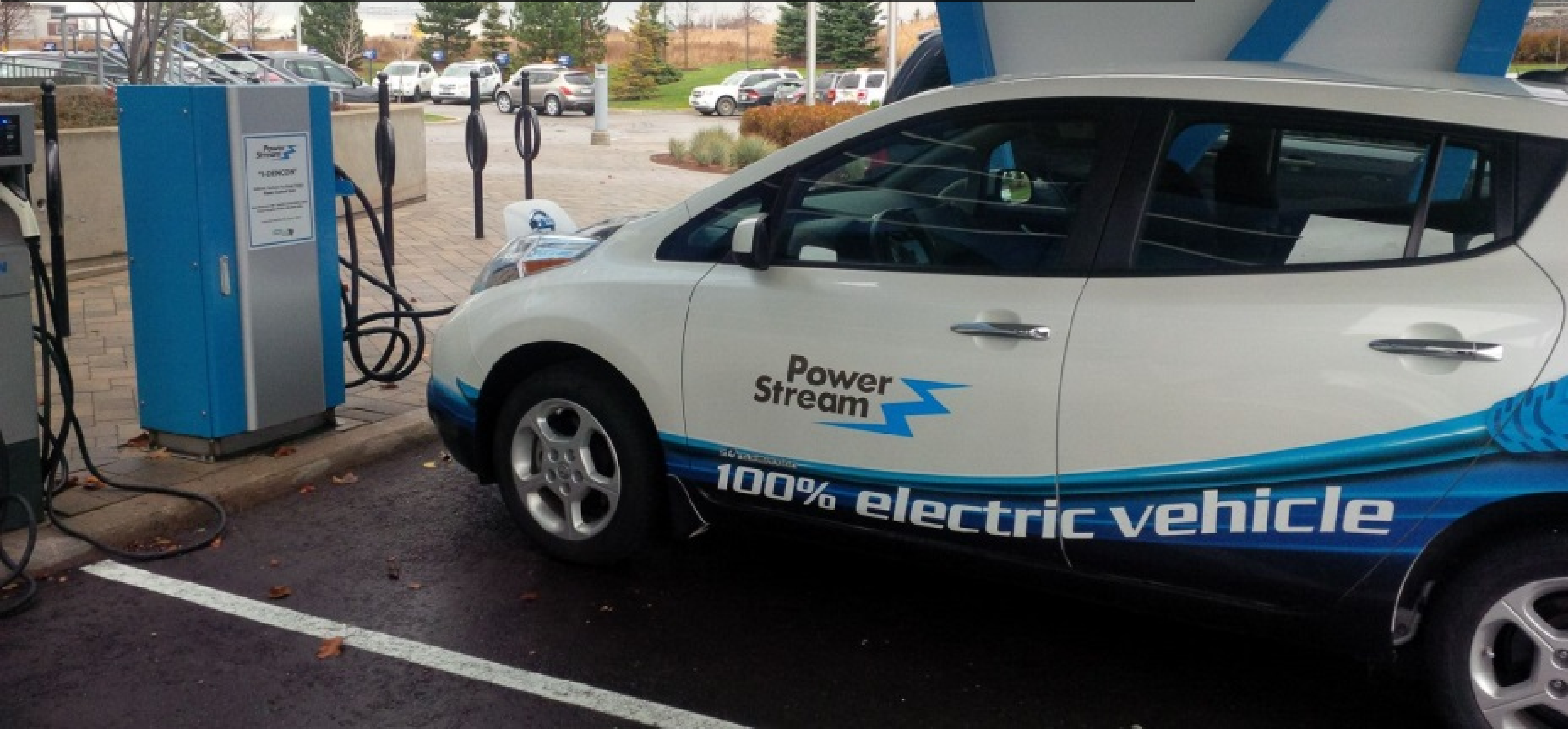
First Canadian customer for two Nissan LEAFs in 2011

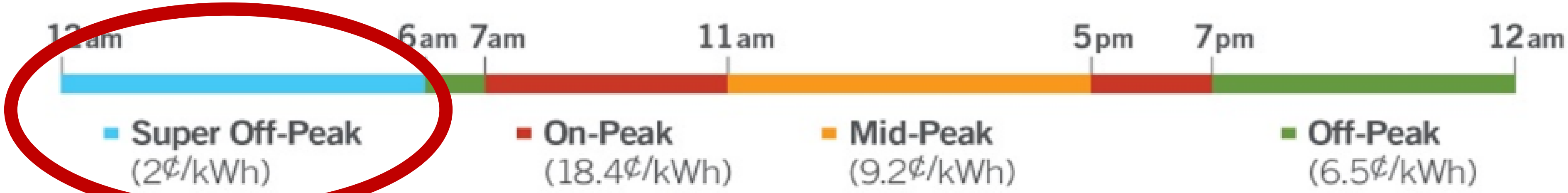
Ontario’s **first Quick Charger (ABB)** for public 24X7

North America's **first V2G Technology** Demonstration, integrated into a microgrid



First time in Canada to offer **low overnight electricity pricing** pilot for EV Drivers

Advantage Power Pricing - Overnight: Weekday price schedule



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First time in Canada to offer end-to-end integrated EV workplace charging pilot

alectradrive
workplace

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Impact of EVs on LDC:
TOP 5 QUESTIONS

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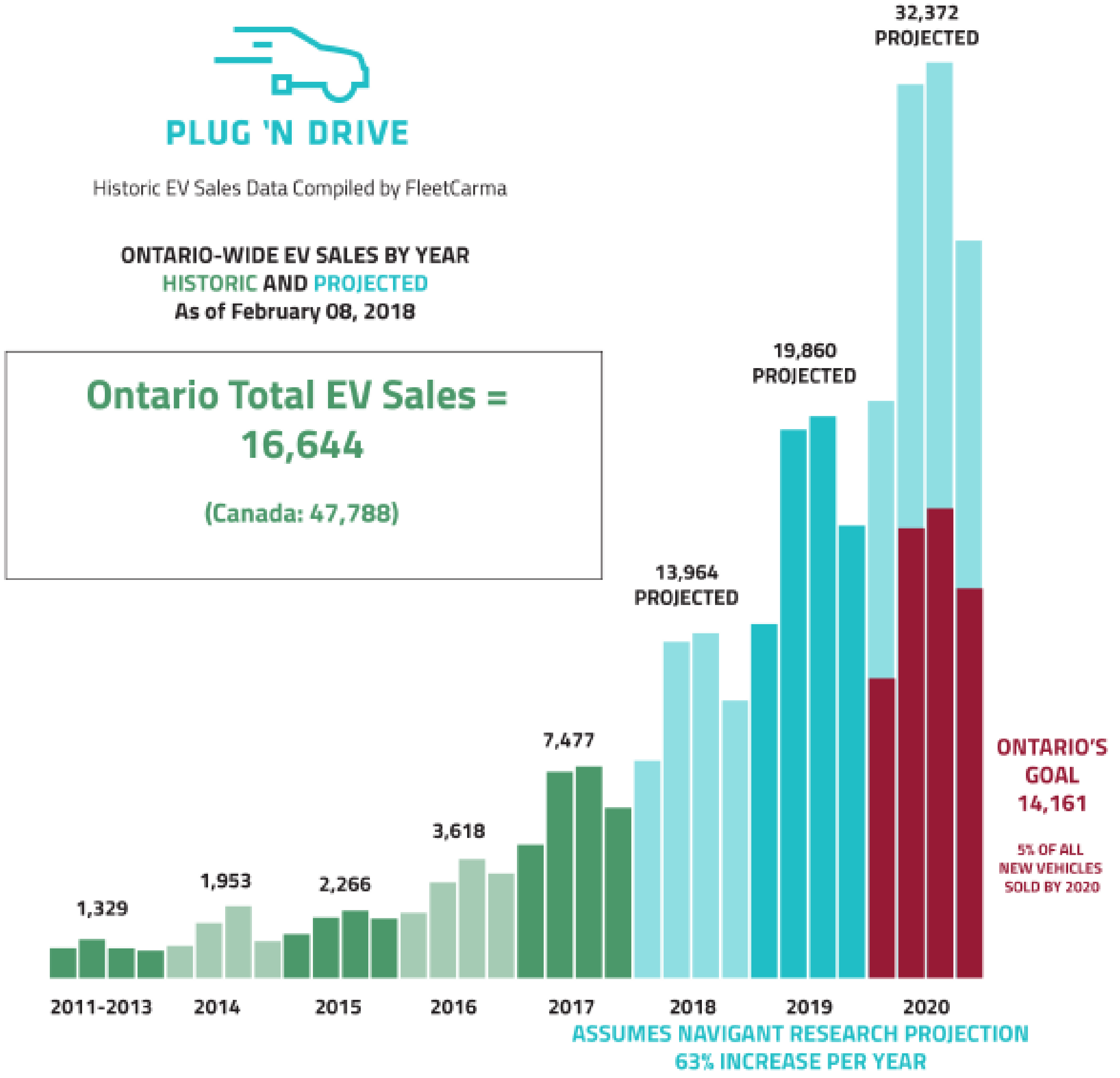
Question 1
Will EVs bring down the power grid?



By 2020, Ontario EV Forecast

~ 100K units

@ 6 KW

= **600 MW**

~ 2.4% of Current Supply

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Question 1
Will EVs bring down the power grid?

Question 2
Will a few EVs bring down the lights in a neighborhood?

Figure 38: Transformer Load Profile on the Warmest Day for Electric Vehicle Charging When the Demand for Power Is High

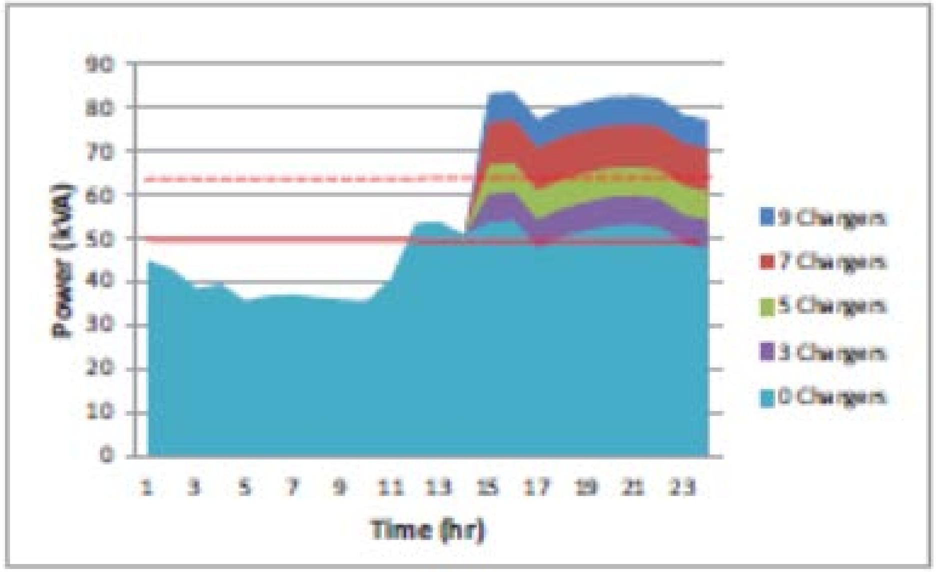
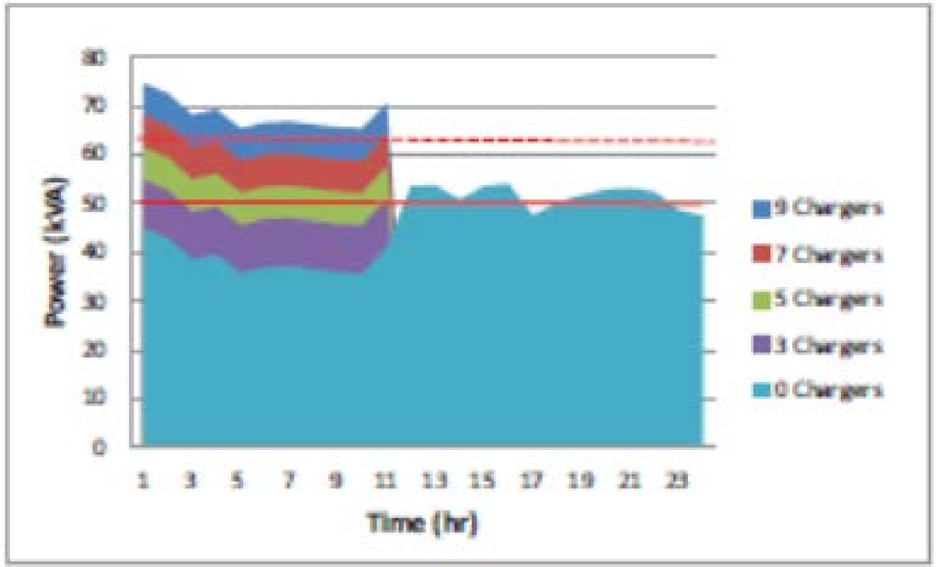


Figure 39: Transformer Load Profile on the Warmest Day for Electric Vehicle Charging When the Demand for Power Is Low



Mitigation Strategies:

Smart grid analytics
to help identify asset overload

Smart chargers to toggle,
queue or throttle charging,
based on customer preference

Encourage off peak charging at
night when electricity is surplus
(and clean)

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Question 2
Will a few EVs bring down the lights in a neighborhood?

Question 3
Can EVs help with demand response and GHG response?

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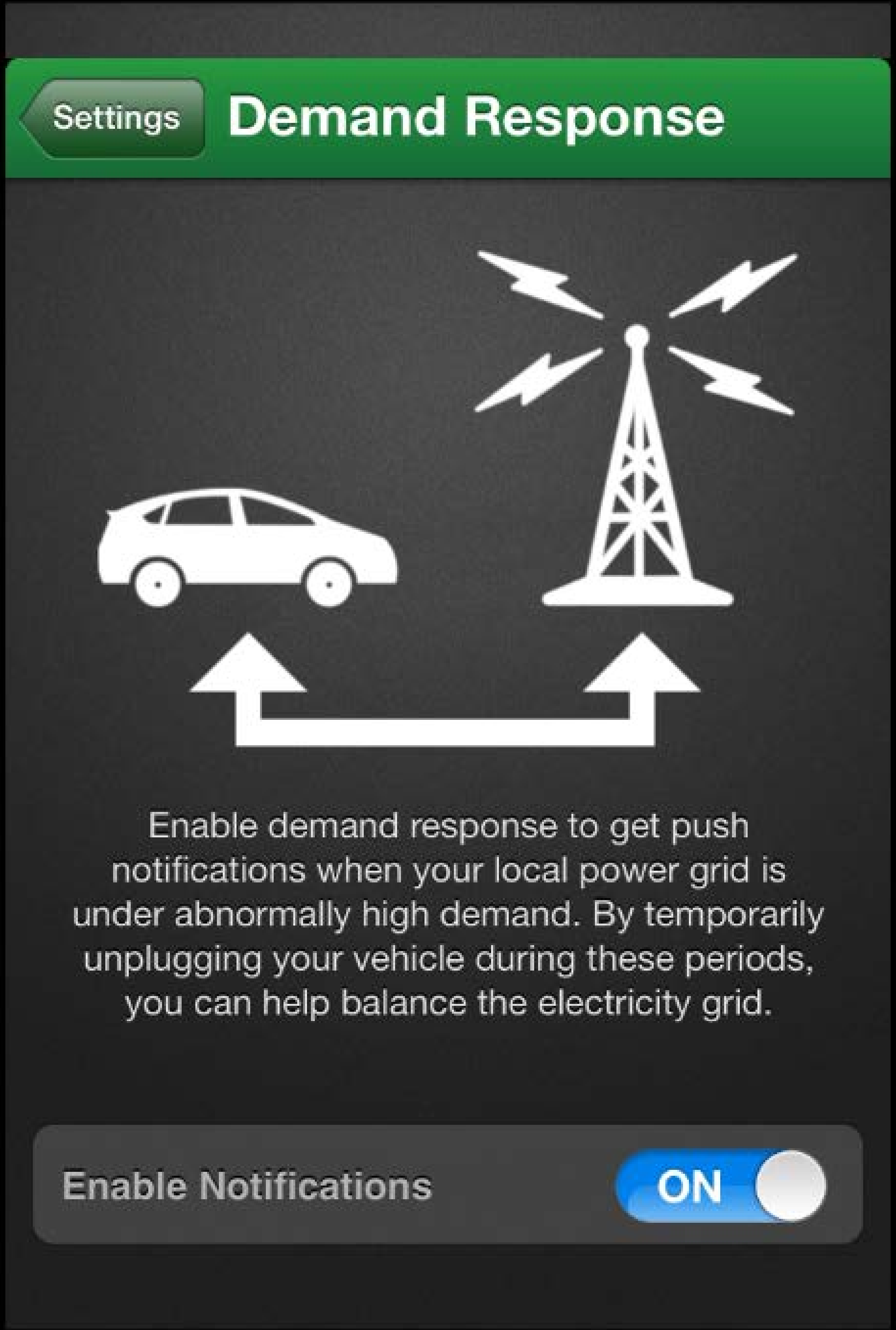

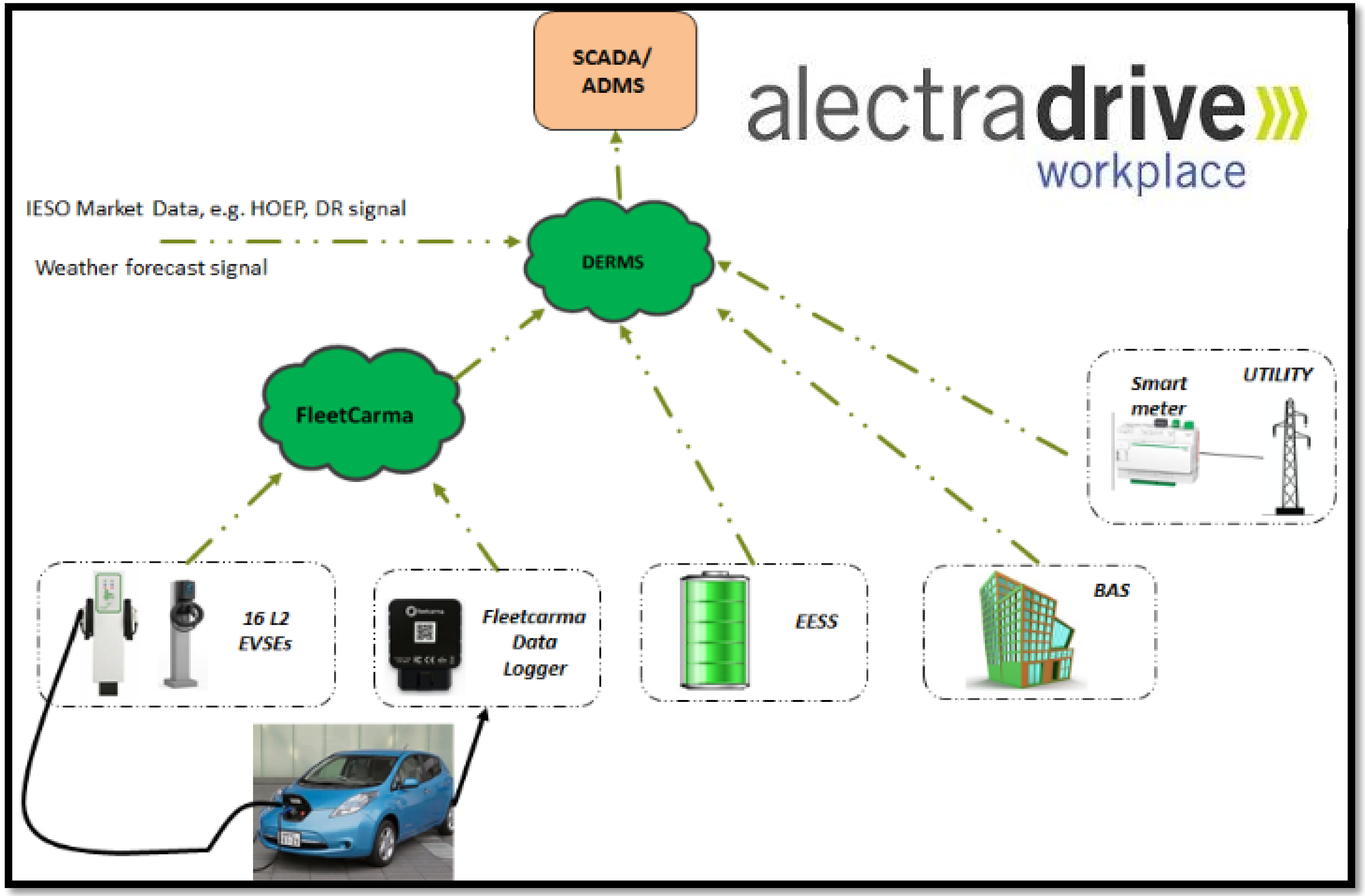

Residential Demand Response Program:

advantage planet

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Question 3
Can EVs help with demand response and GHG response?

Question 4
Can EVs become mobile power stations?

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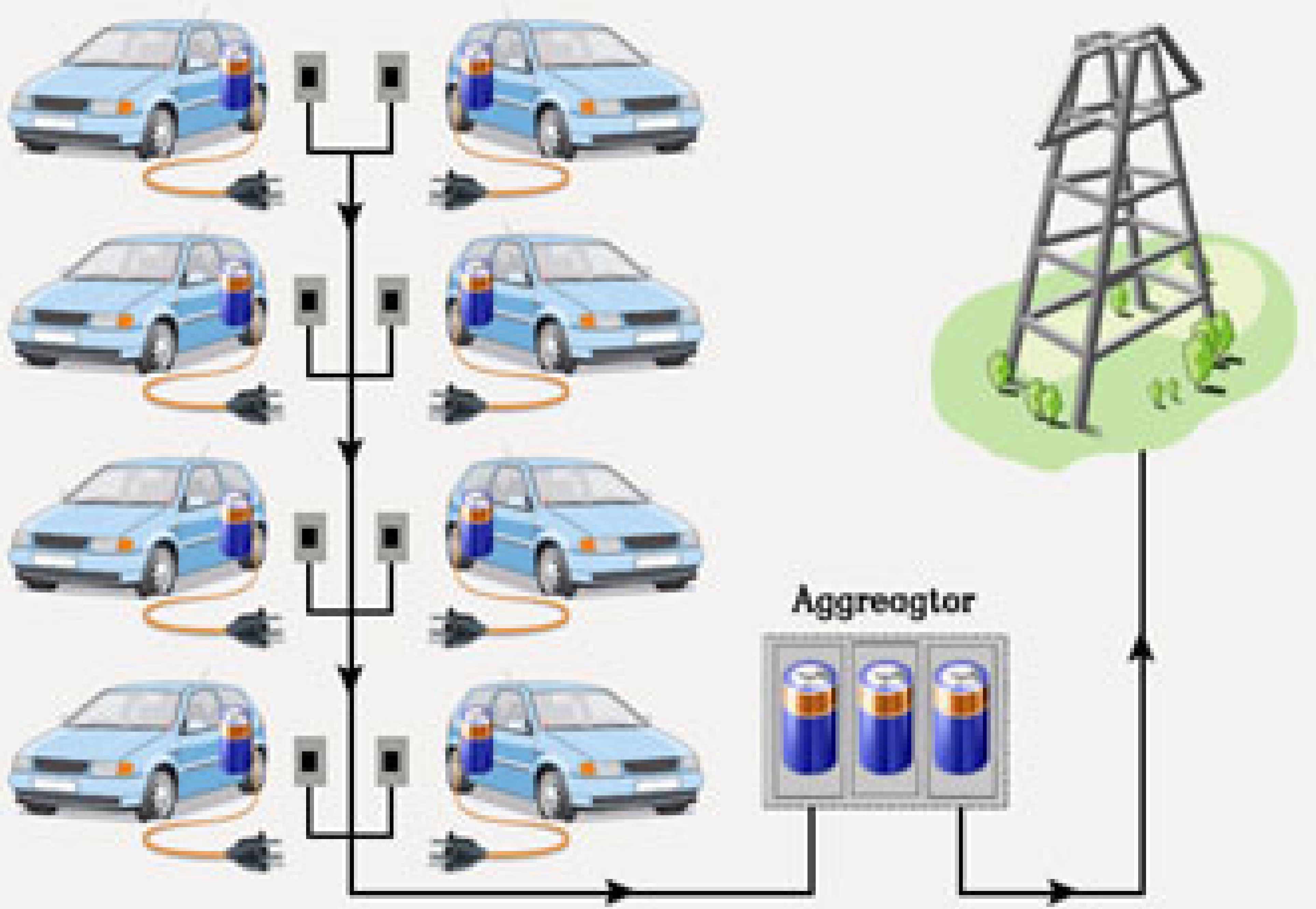

Vehicle-to-home technology:
4s response time

Aggregate EVs to form a **virtual power plant**

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Question 4
Can EVs become mobile power stations?

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Question 5

Can EVs lead to new revenue streams?

Integral part of new energy solutions for **Smart Cities** and **Low Carbon Communities**

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Question 5
Can EVs lead to new revenue streams?

Discover the possibilities

Easter Parades in New York City

Year 1900: One Motor Vehicle

Year 1913: One Horse & Carriage

and no one worried about the horse manure crisis of 1894 anymore….

About the presenter

Neetika Sathe, M.Sc. Physics, MBA
Vice President, Advanced Planning
Alectra Inc.
neetika.sathe@alectra.com

- Neetika Sathe serves on the board of several industry associations such as SmartGrid Canada and Electric Mobility Canada, including serving as Chair on the Board of NSERC Energy Storage Technology (NEST) Network and Vice Chair of National Electricity Roundtable.
- Prior to joining Alectra, Neetika was the Chief Marketing Manager at Nissan Canada responsible for the launch of the all-electric Nissan LEAF in Canada.
- Neetika has a Masters degree in Physics from Panjab University, followed by an MBA from McMaster University.

APRIL 10, 2018

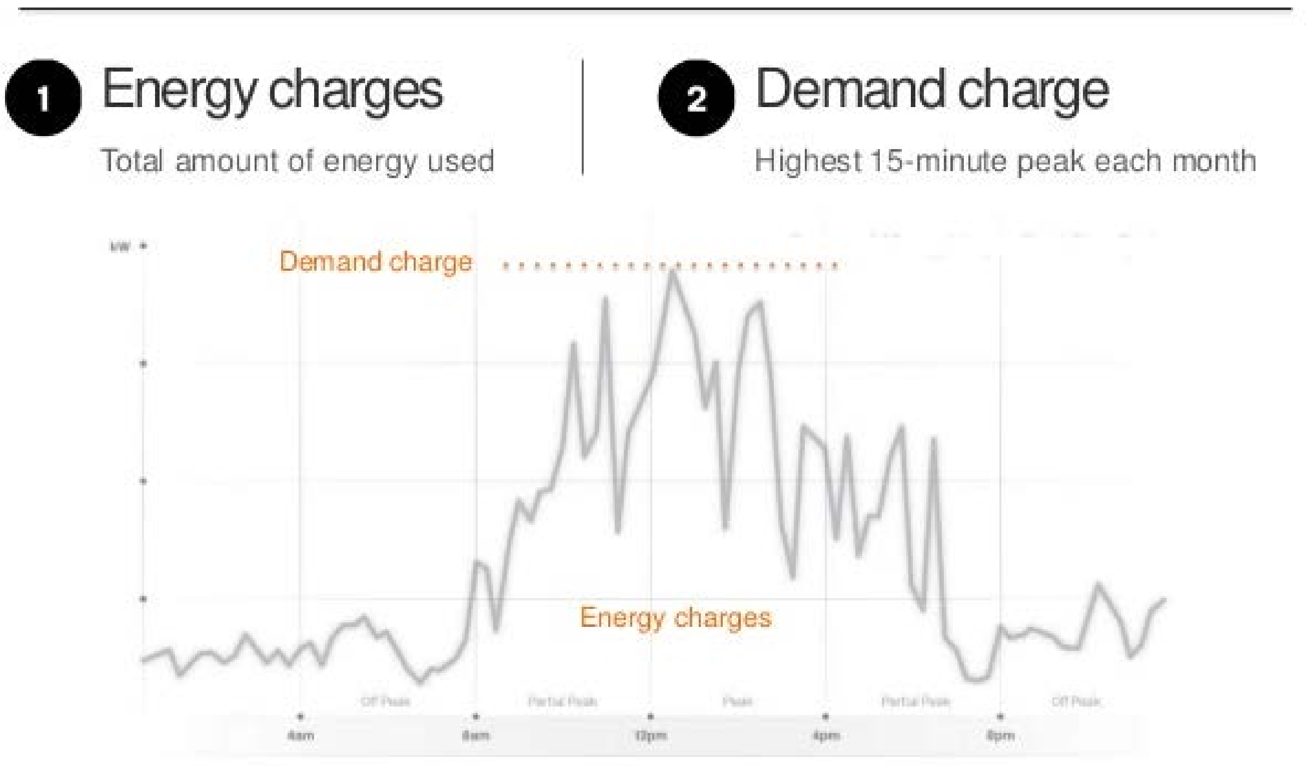
Electrification of bus fleets: Grid Impacts and Solutions

Stephanie Medeiros, ABB

Electrification of bus fleets: Grid Impacts and Solutions

Impact of power demand charge: What is demand charge

- Utility bills consist of energy charges and demand charges
- Energy charges is the energy used kWh
- Demand charge a fee based on the rate of which electricity is consumed (on a 15 minute interval) and is in kW



Electrification of bus fleets: Grid Impacts and Solutions

Impact of power demand charge

Customer A

50kW load for 50 hours:

Usage

Energy = 50kW x 50 hours = 2,500kWh

Demand = 50kW

Bill

Energy = 2,500kWh x $0.15 = $375

Demand = 50kW x $10.00 = $500

Total = $875

Customer B

5kW load for 500 hours:

Usage

Energy = 5kW x 500 hours = 2,500kWh

Demand = 5kW

Bill

Energy = 2,500kWh x $0.15 = $375

Demand = 5kW x $10.00 = $50

Total = $425

Electrification of bus fleets: Grid Impacts and Solutions

Impact of power demand charge

- Energy charges are associated with the costs of **generating** electricity
- Demand charges are associated with the **distribution** of electricity
- The challenge is to manage adequately the power demand which may result in costs to **improved existing infrastructure**
- For the consumer, decreasing the peak demand will decrease demand charges

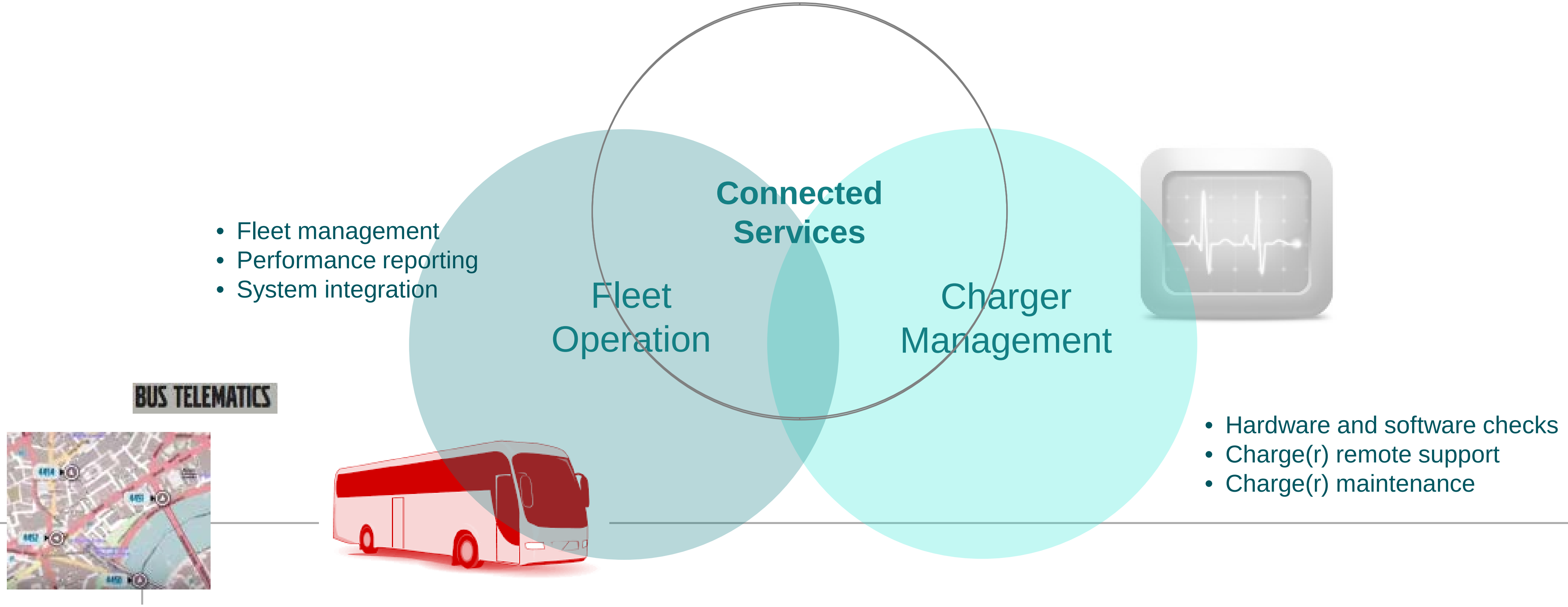
Solutions to grid impacts of demand charges

- Smart Charging
- Opportunity Charging
- Energy Storage

Solutions to grid impacts: Smart charging

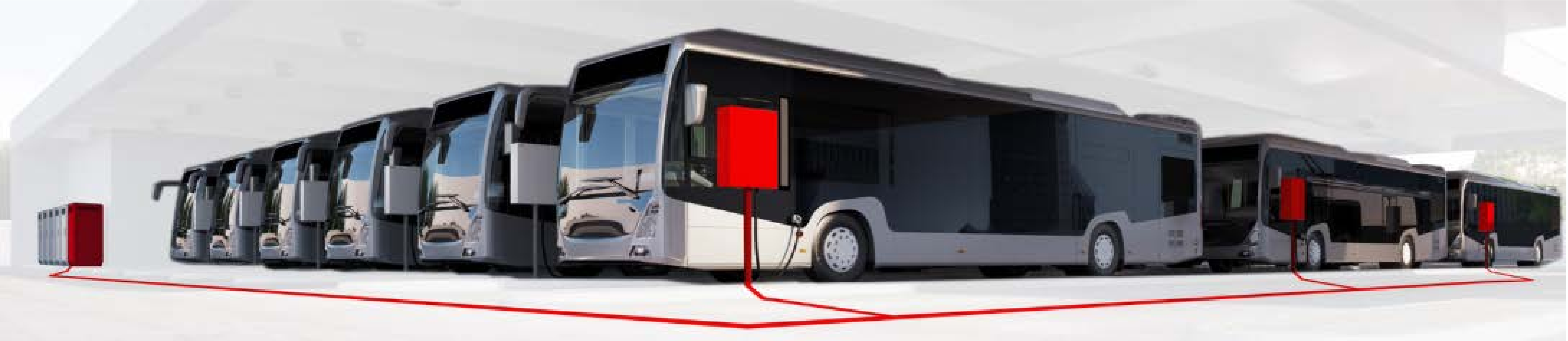
Control charging of buses:

- Rates from utility
- Bus schedule
- Limit maximum power



Solutions to grid impacts: Smart charging

Sequential charging for improved TCO, simple operations management and peak shaving



- A single 150 kW charger charges up to 3 busses.
- Significant reduction on the required grid connection: the total charge load per 3 busses is reduced from 450kW to (simultaneous charge) to 150kW.
- In an overnight session (6 hours) three 300 kWh busses can be fully charged.
- Very cost effective solution with the introduction of three low cost, low maintenance charge boxes.

Solutions to grid impacts: Opportunity Charging

Distribute charging sessions throughout the day

- Charging of buses 3-6 minutes
- Charging throughout the day
- Avoid having buses with empty batteries charging at the same time
- Charging opportunities at the depot (washing bay)

Solutions to grid impacts: Opportunity Charging

Example: 15 buses with power demand charge at 10$/kW

(15Km line, 80KW Depot charger, 300KW Terminal charger, limit of 5 hours charge at depot per bus, bus consumption 1.5kwh/km)

	Depot Charging solution	Terminal & Depot solution
Depot Chargers cost	$ 1,257,142.00	$ 167,619.00
Opportunity Chargers cost		$ 1,160,000.00
Demand charge Depot (/yr)	$ 144,000.00	$ 19,200.00
Demand charge Opportunity Charging (/yr)		$ 54,000.00

Capital cost difference Depot only versus Depot & terminal	**$70,476.00**
Annual power demand charge difference	**$(70,800.00)**
Payback (in years)	**1**

Note: do not consider additional benefits such as lower weight, better efficiency, bus price, higher passenger capacity per bus, etc.

*Notes: * costing estimates including installation and are based on estimates published in report: “King County Metro Transit Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet March 2017”*

Solutions to grid impacts: Battery Energy Storage

Peak Shaving with Battery Energy Storage

Description

– Peak shaving stores power during periods of light loading on the system and delivers it during periods of high demand for the purpose of reducing peak demand for the electricity consumer

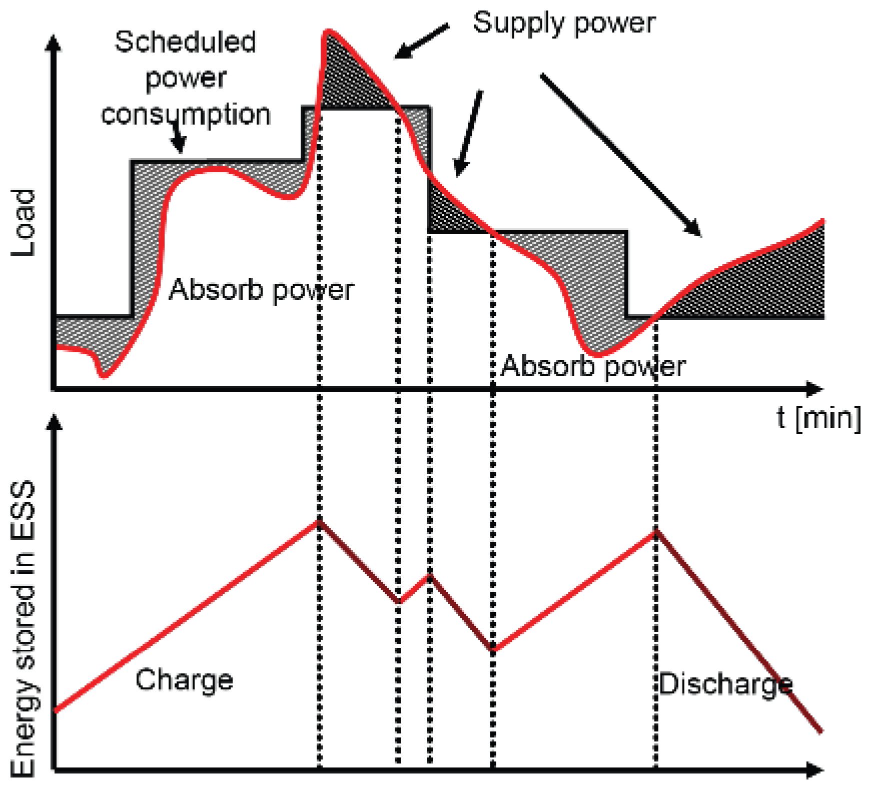
Response time

– Short duration application that requires ability for fast discharging (generally measured in minutes)

Benefit

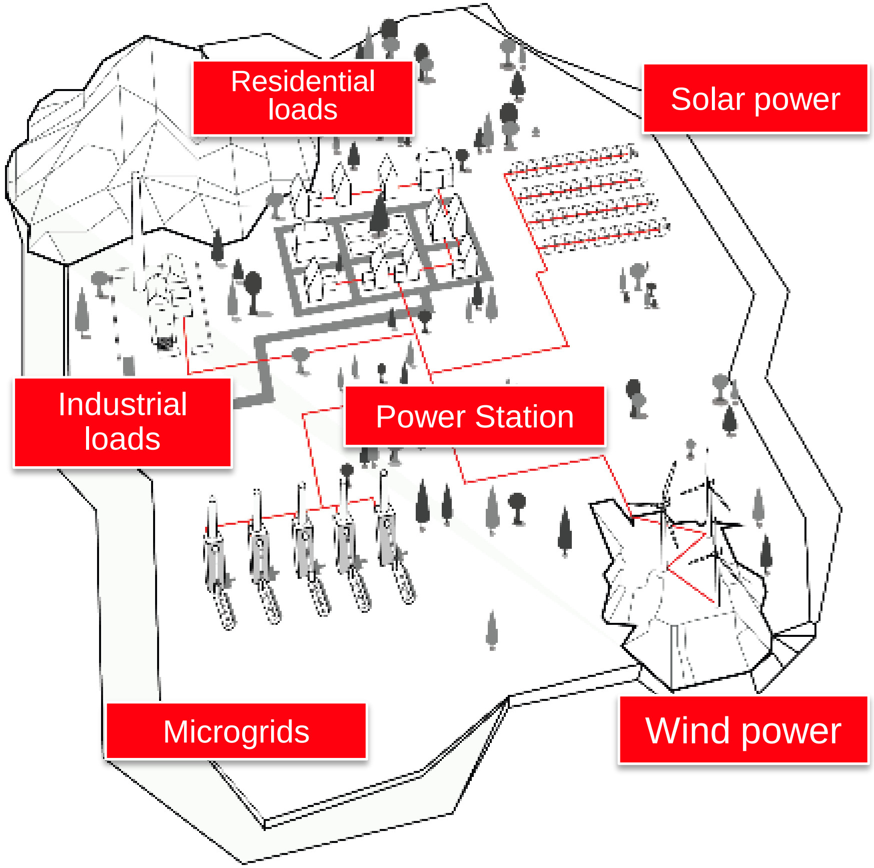
– Customers can save on their utility bills by reducing peak demand charges

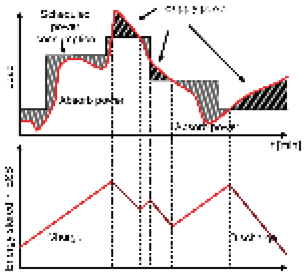
– Utilities can reduce the operational costs meeting peak demand



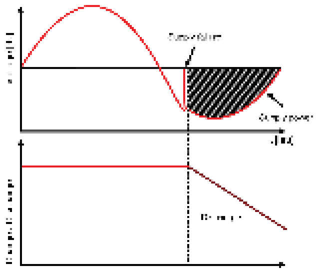
Solutions to grid impacts: Battery Energy Storage

Other Battery Energy Storage Applications

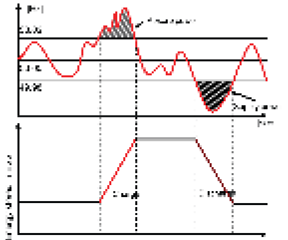




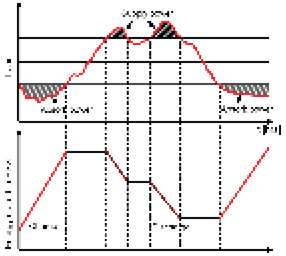
Peak Shaving



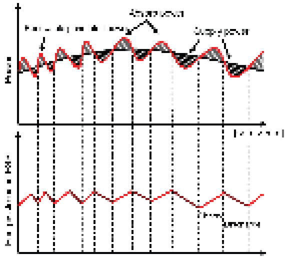
UPS / Islanding



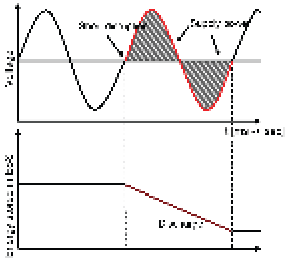
Frequency Regulation



Load Levelling



Capacity firming



Voltage support

Solutions to grid impacts: Battery Energy Storage

Components of a Battery Energy Storage System

500 kW / 224 kWh Platform BESS

Conclusion

- **Smart charging** for charger management and avoid demand peaks
- **Distribute** as much as possible your charging infrastructure that can be done with Opportunity Charging
- **Energy storage** for peak shaving
- Do not underestimate **power demand charges** and explore the right mix of solutions for **your reality**

APRIL 10, 2018

Generating positive cash flow through Rail ESS

Patrick Savoie, ABB

Wayside Energy Storage

Ontario on the Right Path to Creating a More Efficient, Effective Energy Grid

Benefits of Distributed Energy Resources (DER)

A robust, efficient and resilient grid is required

Minister Thibeault and his Government's Long-Term Energy Plan's commitments illustrate that Ontario recognizes the urgency and necessity of finding more sustainable, reliable, efficient, and cost-effective solutions."

ENERGY STORAGE CANADA

JOIN THE VOICE OF LEADERSHIP IN ENERGY STORAGE

Breaking News: Ontario Government Announces Commitment to Remove Uplift and Global Adjustment Charges on Energy Storage

Ontario Energy Minister Glenn Thibeault has announced that the Ontario government will remove uplift and global adjustment charges on energy storage. This has been a key ask for Energy Storage Canada and our member companies have worked diligently to make strides in this area.

DC Traction Power Supply

Electrification of Transportation: What's the Challenge?

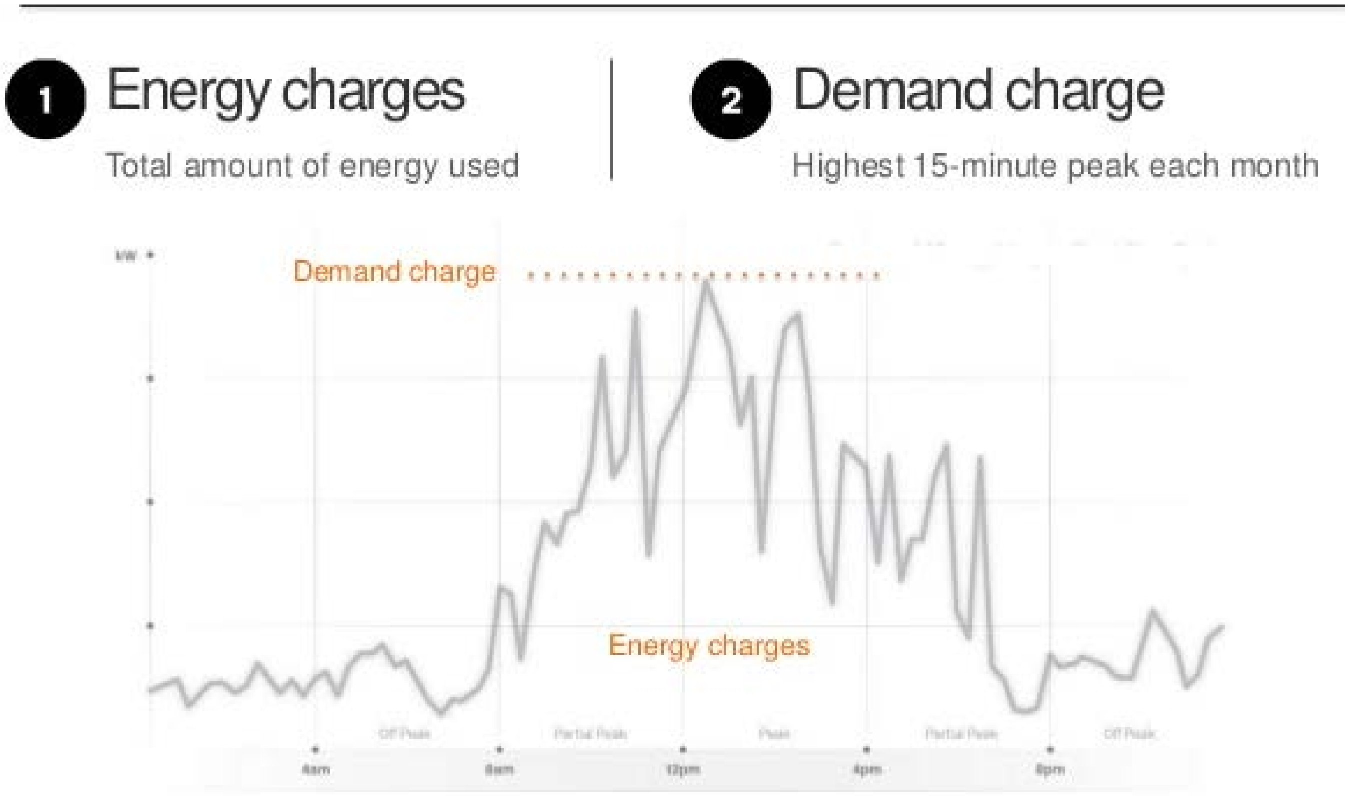
Traffic jams are acceptable, blackouts are not

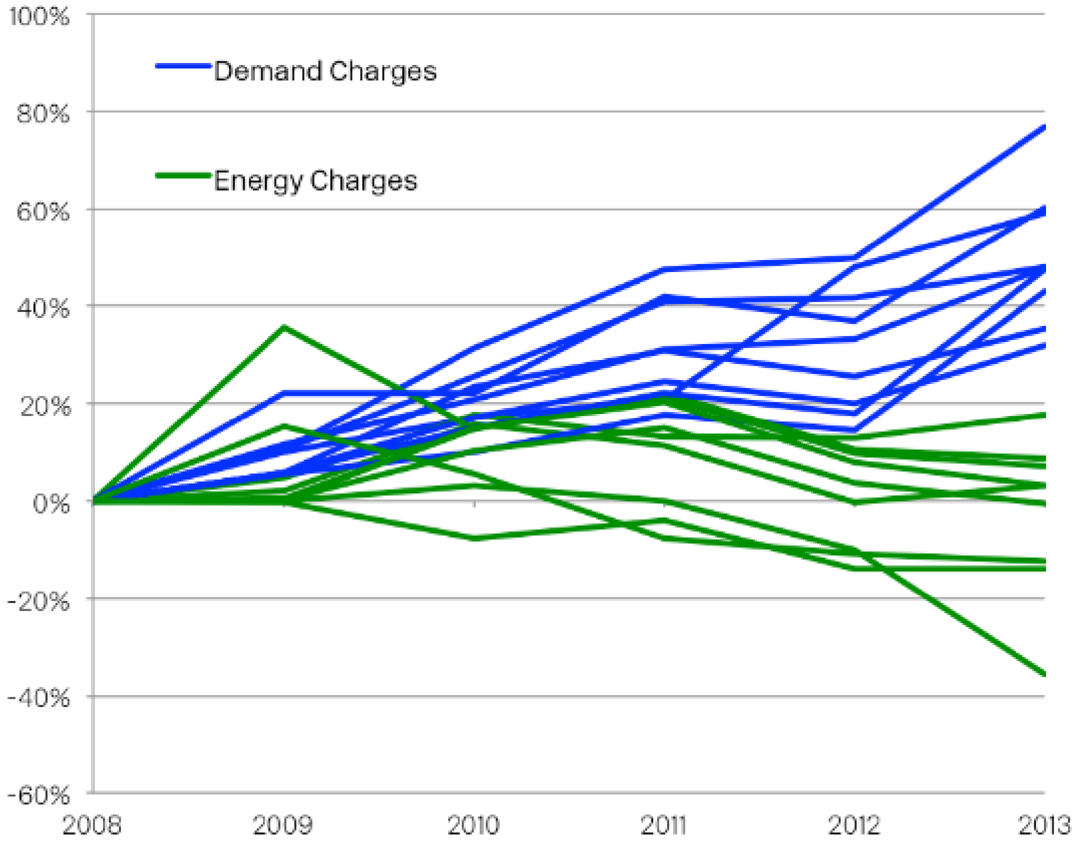
Utilities have to size all of their infrastructure to accommodate momentary peak demand

The analogy is building highways to meet rush hour traffic; this is not an efficient solution

The result is that the utility tariff structure to meet this increase in power demand is passed on to consumers

Energy and Demand Charges
Trending upwards





DC Traction Power Supply

Electrification of Transportation: At what cost?

A robust, efficient and resilient grid is required

Transportation is power and energy intensive. Electric rail transit operators are amongst the largest consumers of electricity in their urban territory.

ABB offers a complete range of energy efficiency solutions

RÉSEAU DU MÉTRO

(en milliers de dollars)	Budget 2017	Budget 2016	Prévision 2016	Réel 2015	Budget 2017 vs 2016 Écart	Écart %
Dépenses liées à l'exploitation						
Rémunération						
Rémunération de base	153 817	151 397	148 074	136 892	2 420	1,6
Heures supplémentaires	10 347	10 256	9 862	13 587	90	0,9
Primes diverses et autres paiements	14 315	13 922	13 315	13 832	393	2,8
Avantages sociaux	31 228	27 865	26 377	27 405	3 363	12,1
Cotisations aux régimes publics	18 748	18 498	17 516	18 531	250	1,4
Coût de la CNESST	1 783	1 798	1 798	1 565	(15)	(0,8)
	230 238	223 737	216 941	211 812	6 501	2,9
Biens et services						
Dépenses majeures	1 699	3 247	2 531	3 122	(1 548)	(47,7)
Énergie	27 712	26 575	25 572	25 478	1 137	4,3
Services professionnels	1 142	1 129	1 167	1 025	13	1,2
Services techniques et autres services	19 933	19 751	19 586	19 057	182	0,9
Matériel et fournitures	19 540	20 267	18 790	19 523	(728)	(3,6)
Location	1 278	1 357	1 227	1 176	(78)	(5,8)
Dépenses diverses	(174)	(860)	382	404	686	(79,8)
	71 130	71 467	69 255	69 785	(336)	(0,5)
Total	301 368	295 204	286 196	281 597	6 165	2,1

DC Infra Traction Power

The opportunity for Energy Storage

Path to energy recovery

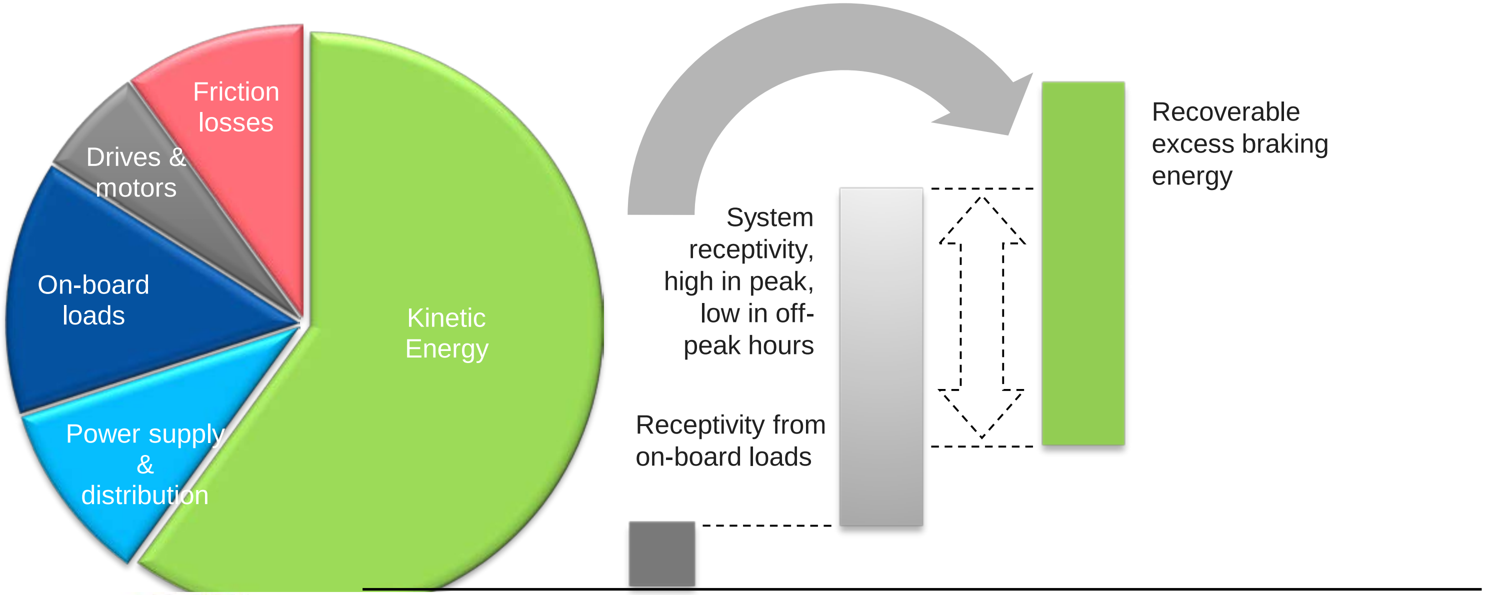
Most modern trains are equipped with regenerative braking capability

If the network isn't receptive, that energy is wasted in onboard or wayside resistors

ABB offers a complete range of energy efficiency solutions

- Energy storage systems
- Energy recuperation systems

Towards a better use of existing infrastructure



ENVILINE Energy Storage System (ESS)

Infrastructure Asset for Transit Authorities

ESS Applications

Value stacking proposition for the ESS asset

1. Recovers surplus regen braking energy
2. Reduces peak power demand
3. Provides Voltage stabilization
4. Smart Grid services (Behind the meter)
5. Emergency ride home (back up power)

ENVILINE ESS helps to lower OPEX AND CAPEX

DC Traction Power Supply

Regenerative Braking

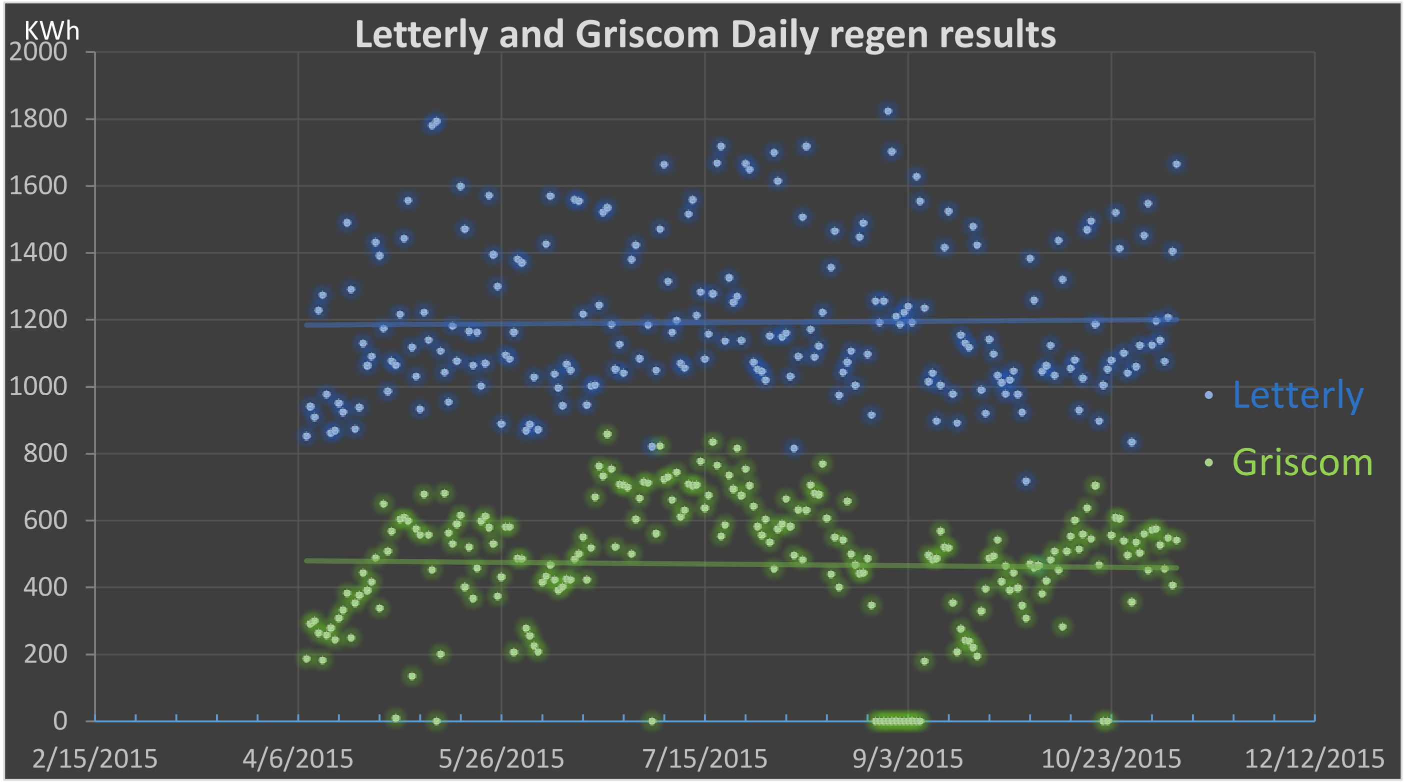
Regenerative braking opportunity

ESS project results:

- Letterly: 1200kWh/day (real)
- Griscom: 500kWh/day (real)
- Warsaw: 3000kWh/day (real)
- Minneapolis: 800kWh/day (estimated)
- LA metro: 1500kWh/day (real)

– 3MWh equivalent to 100x USA homes avg daily consumption

– This is equivalent to a 2kW solar array annual production

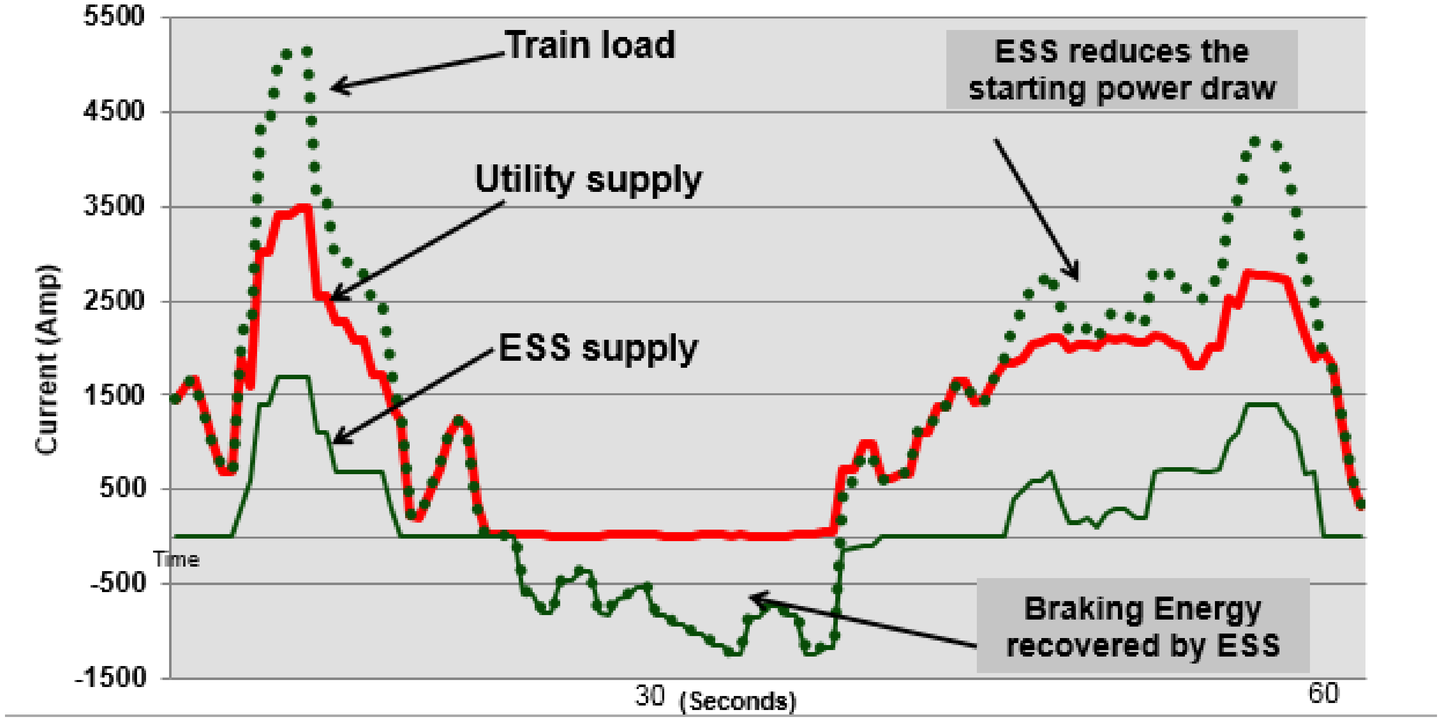


DC Traction Power Supply

Peak Shaving

Peak Power savings

- Between 100-350kW per billing period
- ≈ $1000-$7000/billing period/meter



** Based on a $10-20/kW demand charge*

ENVILINE ESS

Voltage Stabilization

Voltage Stabilization benefits:

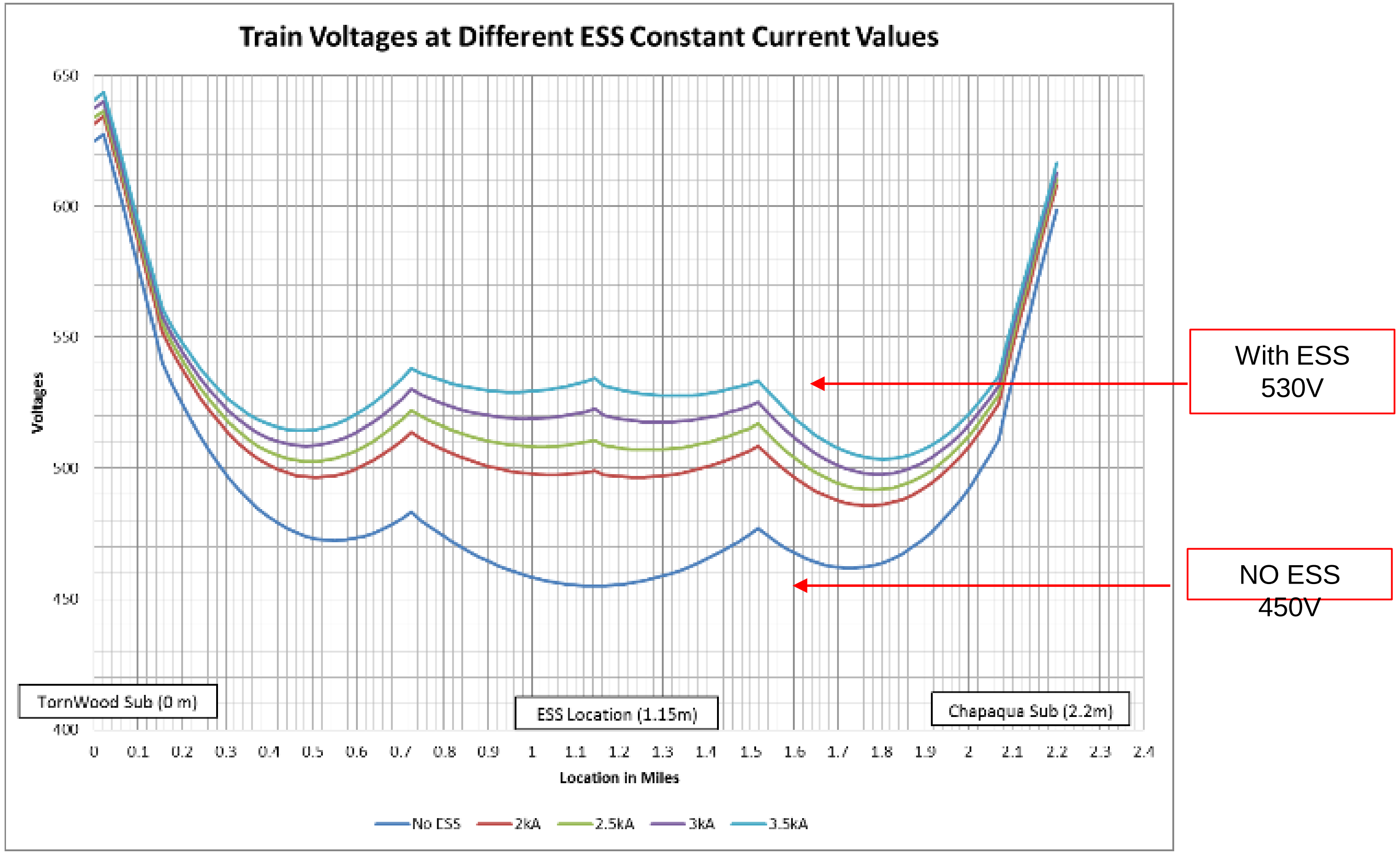
Defers capital expenditure for new substations between 40-70% of traditional TPSS cost

Raises voltage sags to appropriate levels

Helps to maintain schedule

Supports longer distances between TPSS

Decreases the number of required TPSS



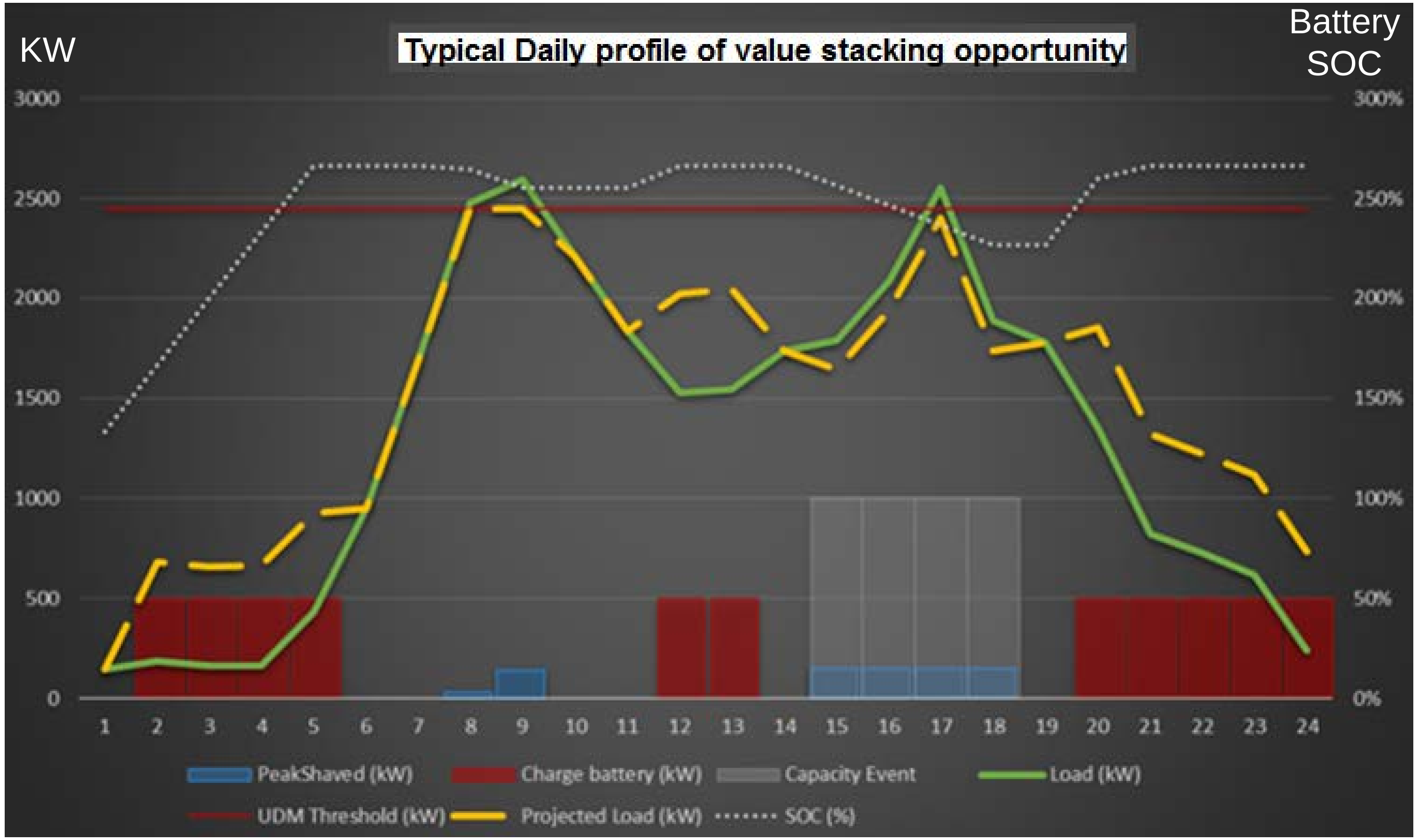
ENVILINE ESS

Smart grid value + stacked services

Smart Grid Services:

- Participation in various curtailment services when applicable = $$$
- PJM/IESO/ERCOT/ NYISO
- 1MW/1MWh in PJM ≈$250 000/year
- 1MW/3MWh in IESO ≈ $500 000/year
- 1MW/4MWh in NYISO ≈ $450 000/year

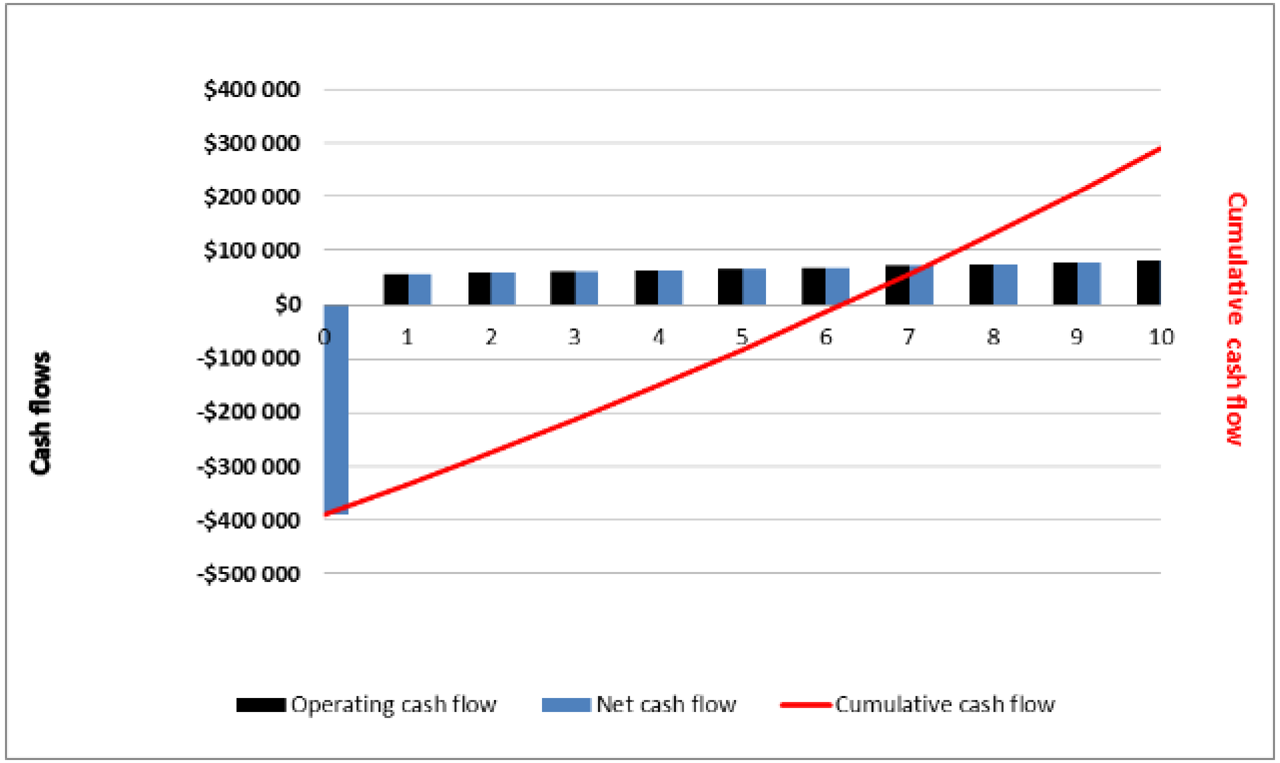
The more services an energy storage asset can provide the more likely it will be economically viable



ENVILINE ESS

Cashflow simulation for regen/Peak shaving (Supercapacitor)

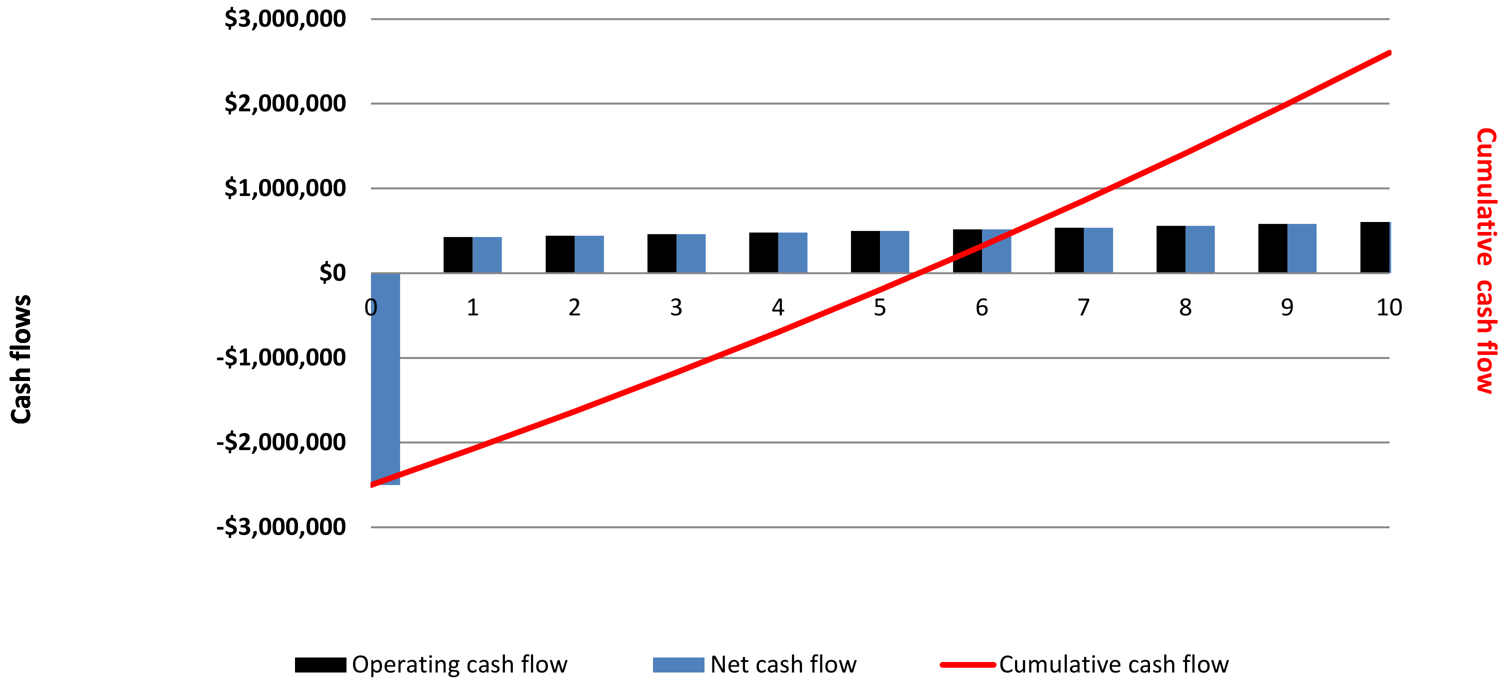
	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
Net cash flow	$ (389 844)	$ 56 611	$ 58 876	$ 61 231	$ 63 680	$ 66 227	$ 68 876	$ 71 631	$ 74 496	$ 77 476	$ 80 575
Cumulative cash flow	$ (389 844)	$ (333 232)	$ (274 357)	$ (213 126)	$ (149 446)	$ (83 219)	$ (14 343)	$ 57 288	$ 131 784	$ 209 261	$ 289 836
10-year NPV of cash flow	$ 120 744				**IRR =**	**11%**					



ENVILINE ESS

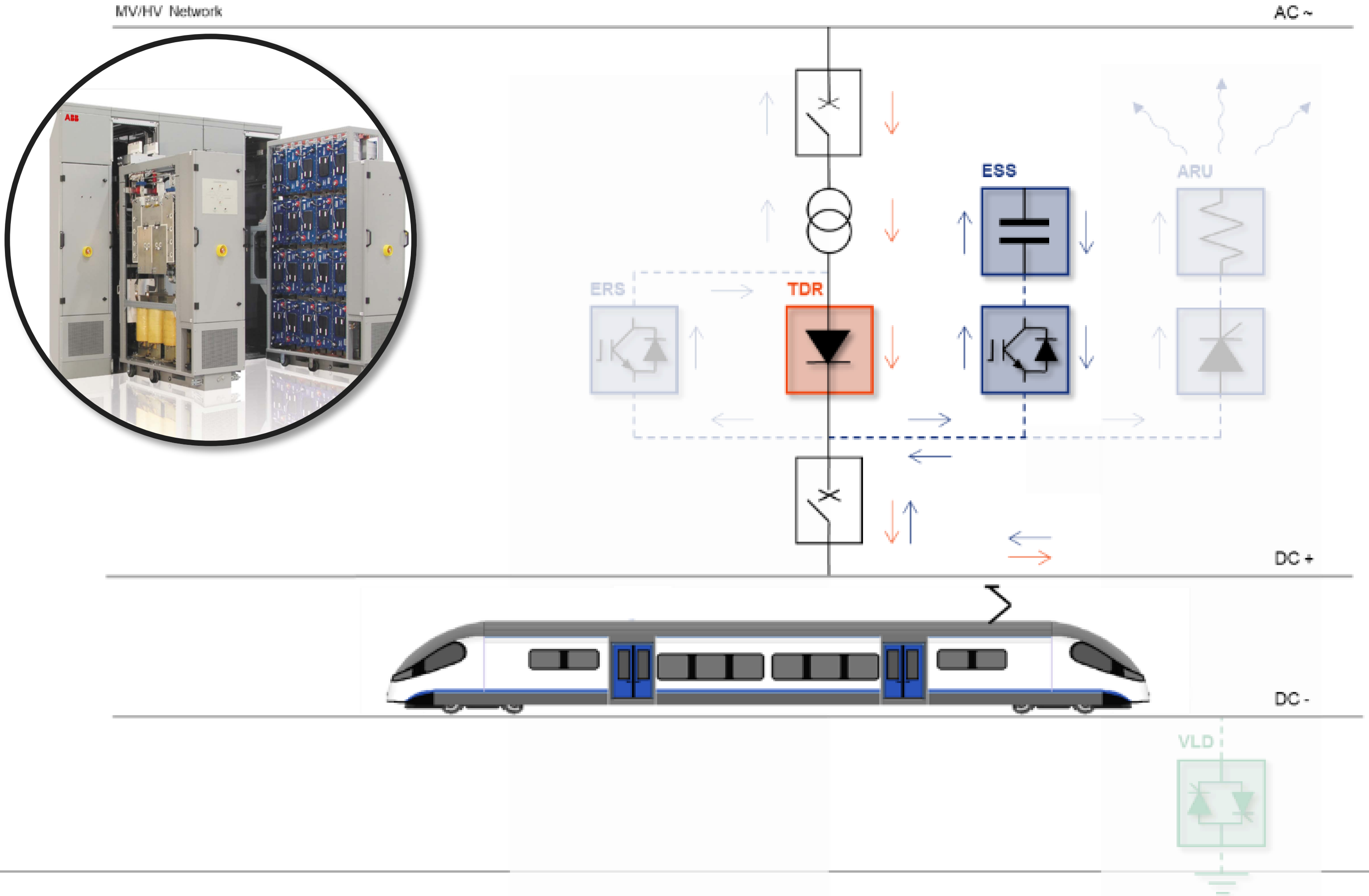
Cashflow simulation

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Net cash flow	$ (2 500 000)	$ 425 000	$ 442 000	$ 459 680	$ 478 067	$ 497 190	$ 517 077	$ 537 761	$ 559 271	$ 581 642	$ 604 908
Cumulative cash flow	$ (2 500 000)	$ (2 075 000)	$ (1 633 000)	$ (1 173 320)	$ (695 253)	$ (198 063)	$ 319 015	$ 856 775	$ 1 416 046	$ 1 997 688	$ 2 602 596
15-year NPV of cash flow	$ 3 031 337				**IRR =**	**19%**					



ENVILINE™ ESS

DC infrastructure connection



ENVILINE ESS

A modular architecture to meet power and energy needs

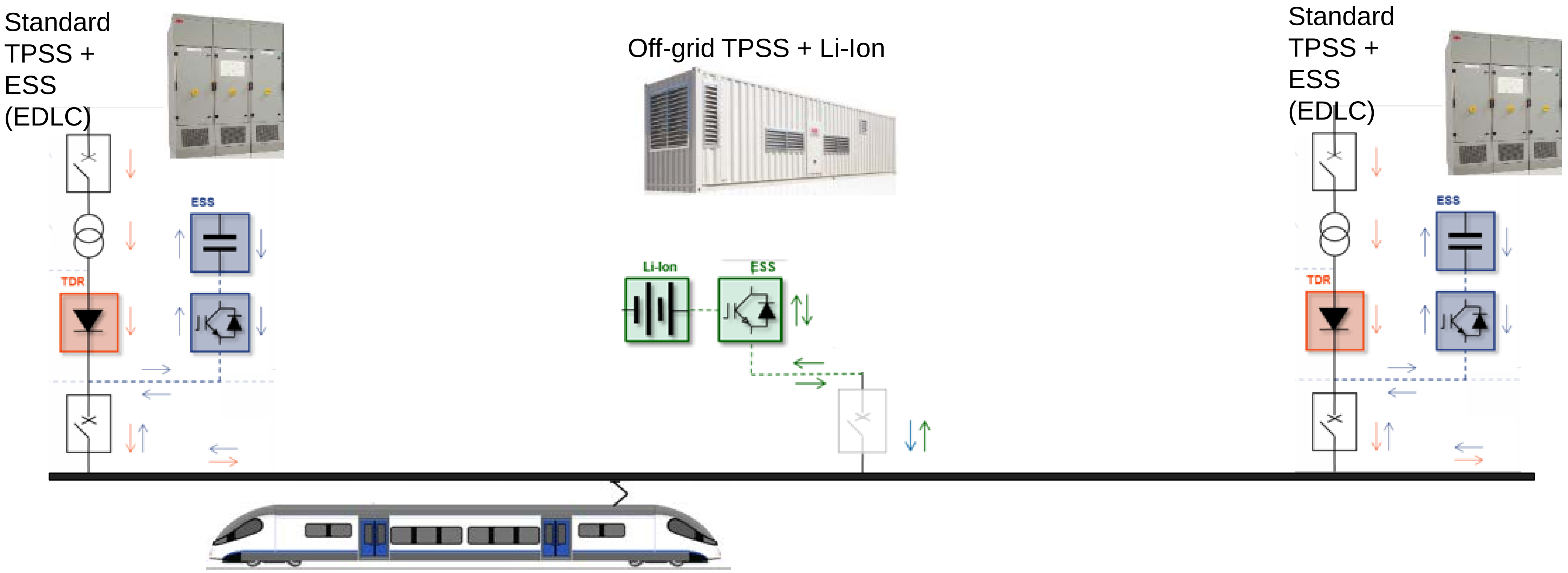
supercapacitors (EDLC)

Lithium battery

Or hybrid (EDLC + Li-Ion)

DC Traction Power Supply

Rail network of the future



Energy Storage and smart grid optimization

SEPTA investment in smart grid technologies – Philadelphia, Pennsylvania USA

- In 2012, SEPTA initiated the first of its kind storage system through the Pennsylvania green fund.
- The revenues generated by participation in the PJM frequency regulation program was so lucrative that it brought a subsequent public tender that was awarded to ABB and further third party investor Constellation for a network rollout of 7 additional ESS.
- The total capacity is 10MW of FR capability with 4.3Mwh storage.

Customer's needs:

- Customer looking to invest in ESS system to generate smart grid revenues and recover braking energy

ABB solution

- Supply and Commission of 7 ESS systems
- 10 year performance, service and warranty
- Total of 19 converters, DC switchgear, and batteries

Customer benefits

- As an expert with energy management systems and a dedicated R&D team to support communication with grid operators, curtailment suppliers and transit Eng, ABB was able to deliver a unique solution
- Stable revenues from PJM, regenerative braking recovery reduces OPEX for the Transit Authority

APRIL 10, 2018

Rail electrification design considerations

Imtiyaz Hussain Mashraqi, ABB

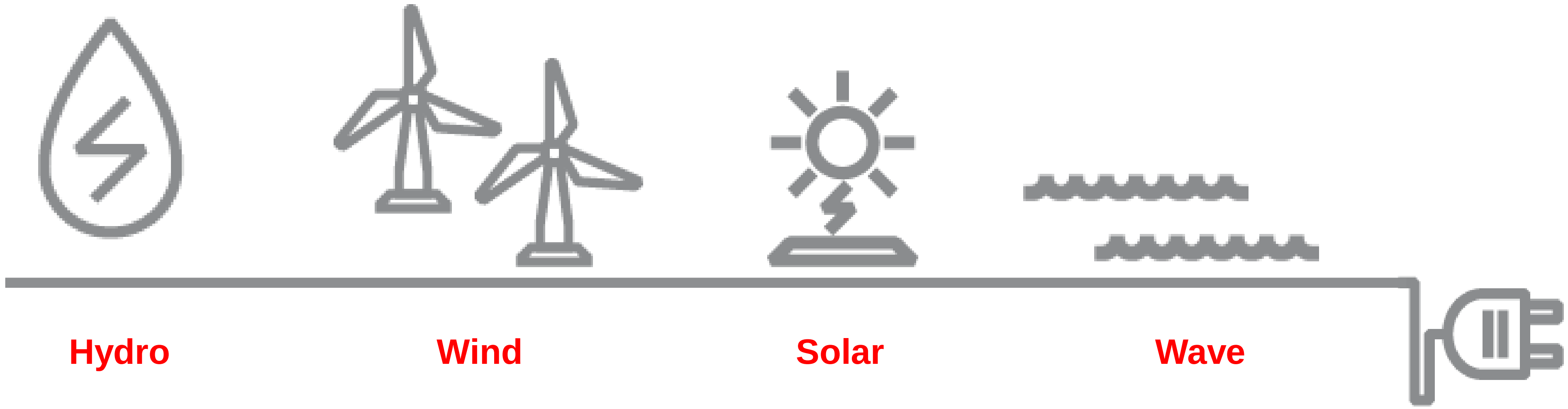
Substations for reliable power supply

Introduction

Trends in Electrical Power grid

Energy Mix

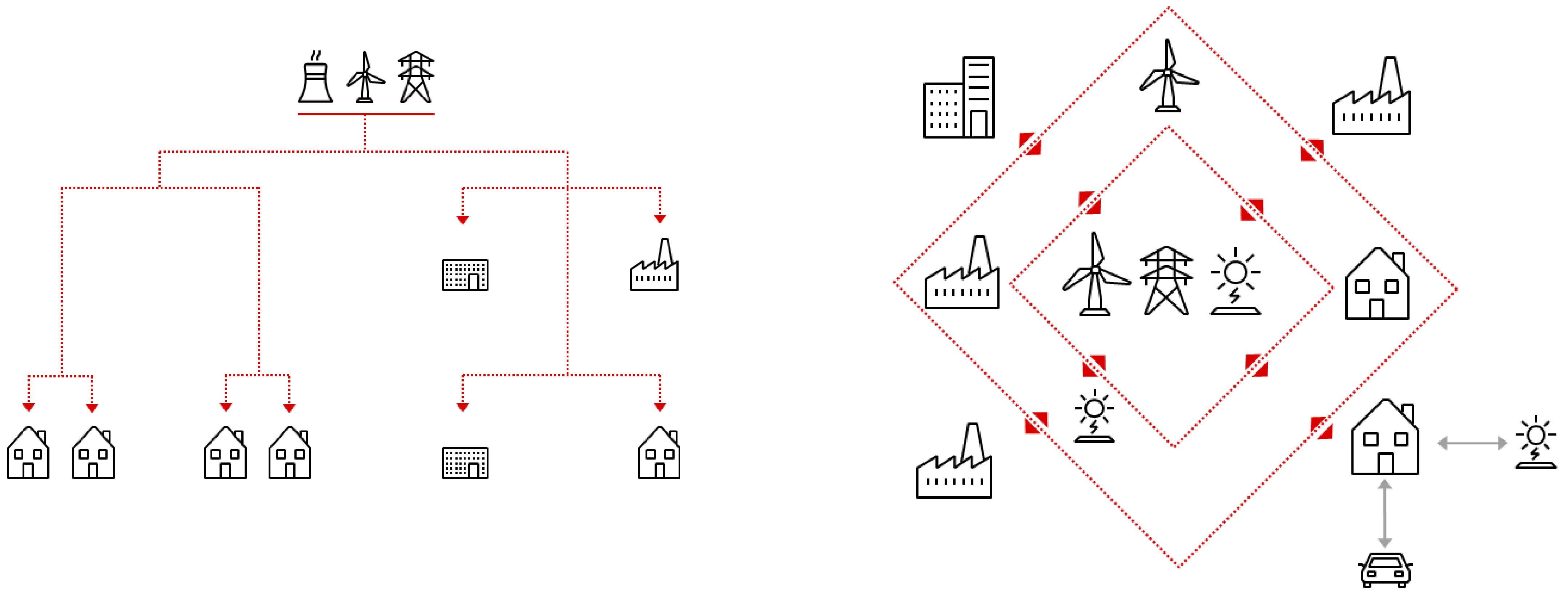
Is changing the utility grid dynamics



ABB

Trends in utility grids

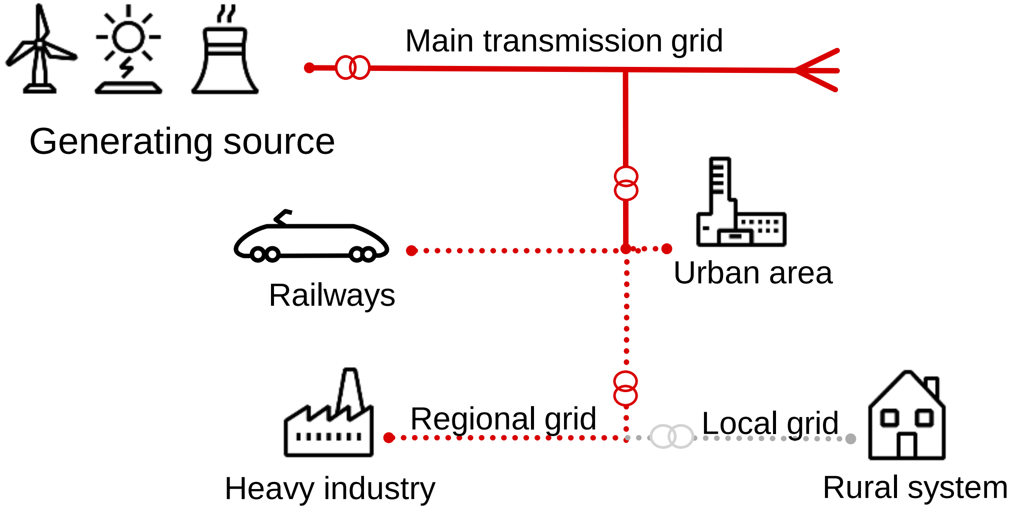
Shift in the electrical value chain



Trends in electrical power grid

Grid Codes

Grid



Influences on the Grid

- Change from centralized to decentralized generation supply
- Heavy industry generates disturbances
- Railways generates disturbances
- Complaints from local grid consumers
- Disturbances should be reduced locally

Grid codes to ensure system stability and reliability

Definition of conditions for example:

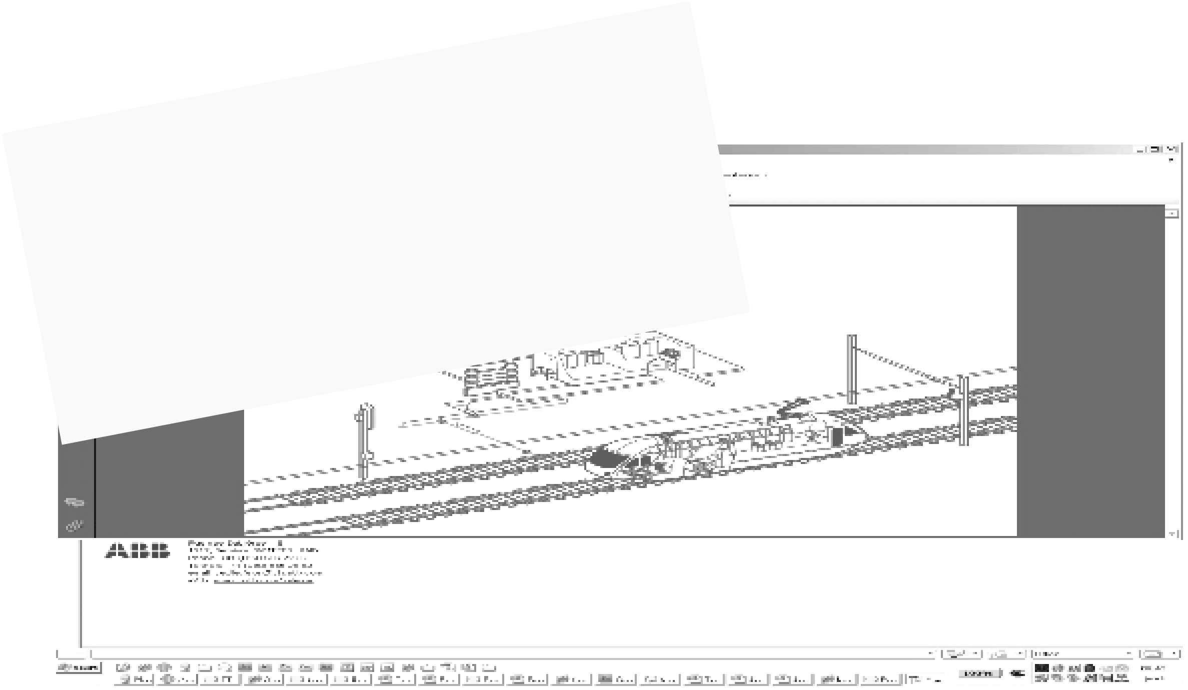
- Voltage unbalance
- Voltage fluctuations
- Harmonics
- Power Factor

Power Quality is becoming subject to rules and regulations (Grid Codes).
Grid codes ensure reliability and define conditions for consumers and generators.

Electrical 50/60Hz 25kV AC railways

Are effecting the supply grid

- Traction loads are not symmetrical three-phase loads
- Traction loads exhibit frequent and large changes in active and reactive power
- Traction loads may consist of diode converters feeding DC currents, that generate harmonics



Growth in Railway Electrification

Increased power demand

- Power demand increases due to:
  - Increased traffic relative to…
  - More passengers are travelling
  - More freight
  - New lines
  - Electrification of existing lines
  - Request for High Speed lines

Rail and urban transport electrification

Complicated issues with rail power supply system :

- Grid compliance
- EMC
- RAMS
- Stray currents
- Braking energy recovery
- Earthing
- Protection
- End-user approval

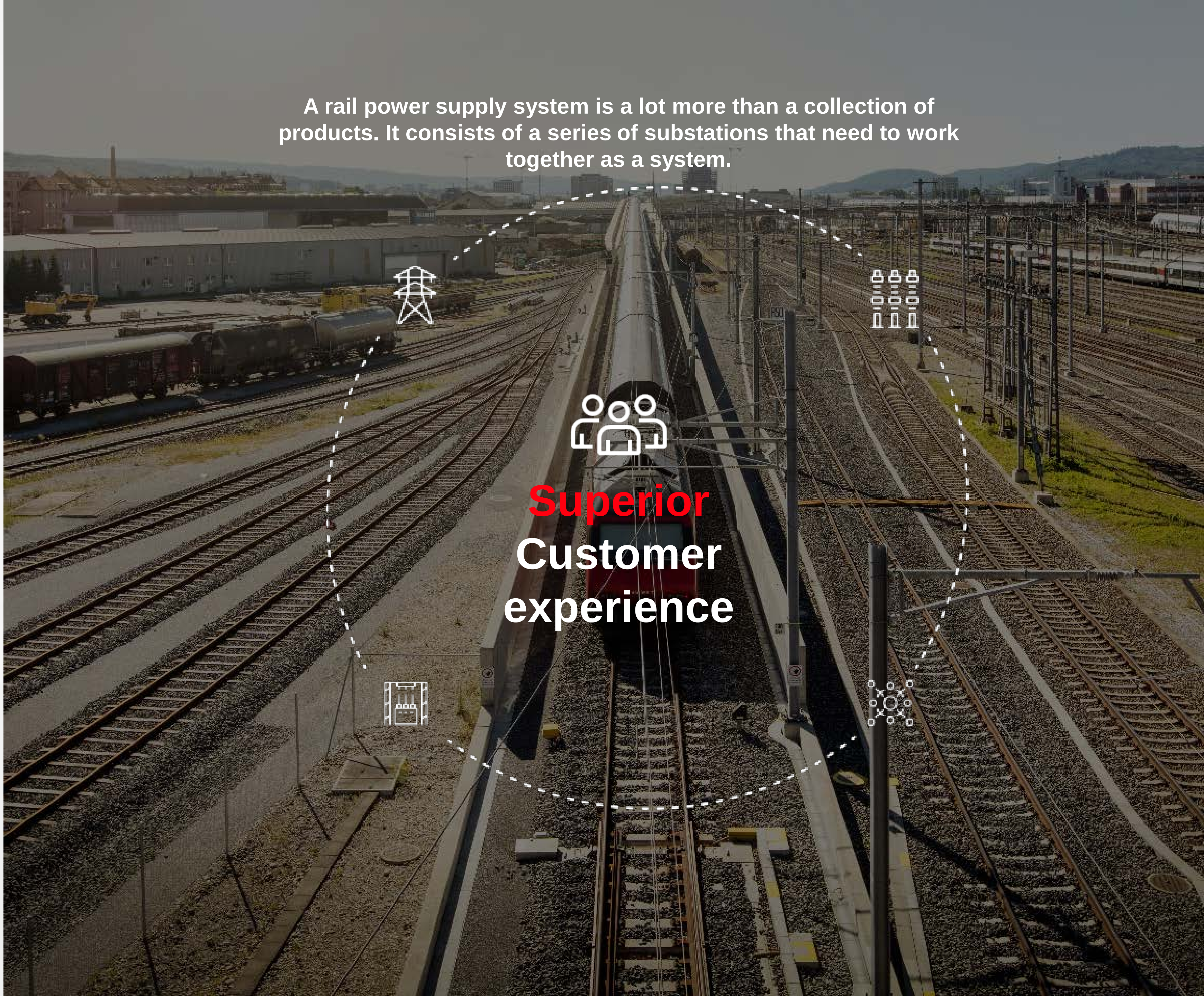
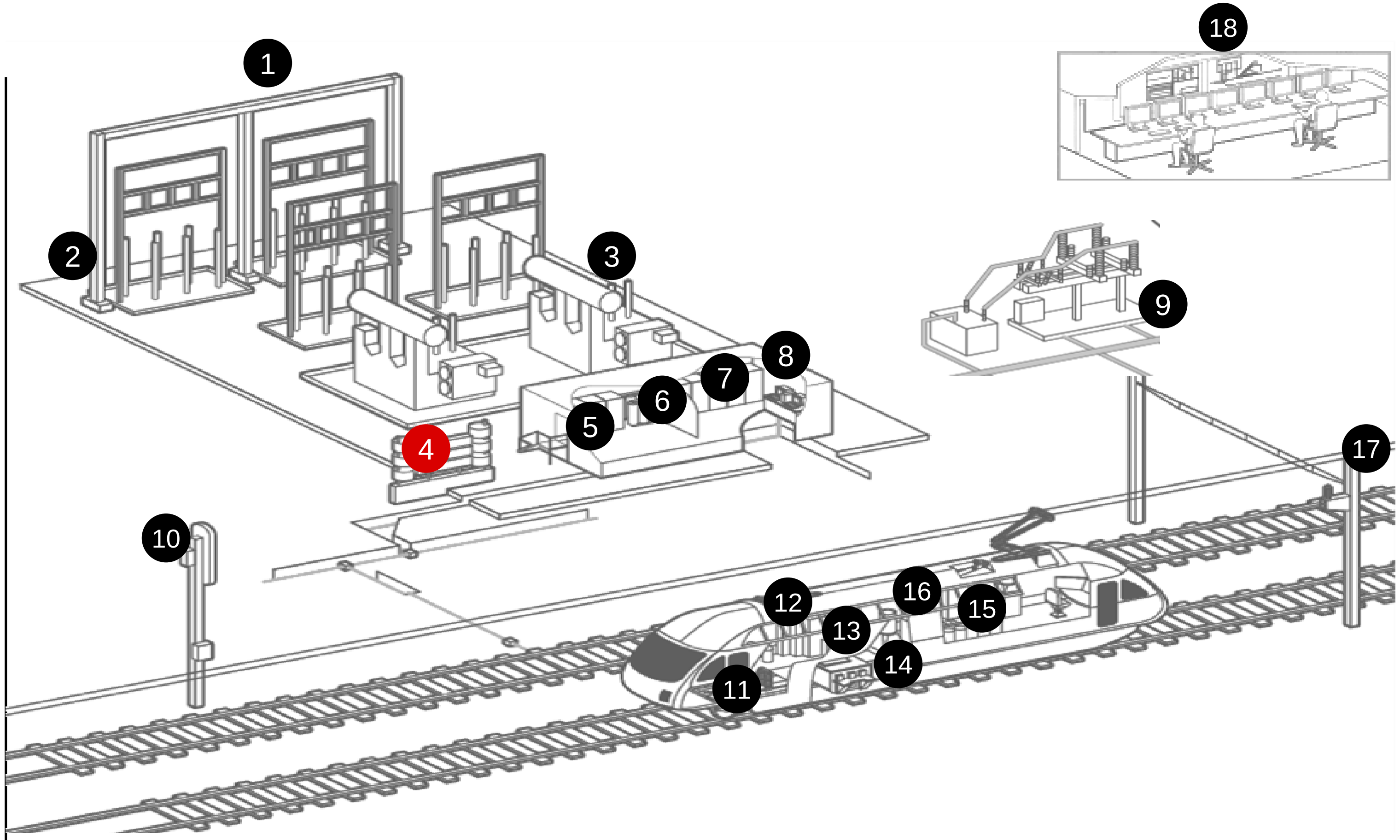


ABB in the rail industry

Global portfolio for railway applications

1. Traction Substation and SFC
2. High Voltage Products
3. Power Transformers and Surge Arresters
4. Power Quality
5. Indoor Medium Voltage Switchgears
6. Distribution & Special Transformers & Rectifiers
7. Low Voltage Switchgear
8. Braking Energy Management Systems
9. Outdoor Medium Voltage Modules
10. Communication
11. Motors - Generators – Turbochargers
12. Traction Fuses
13. Converters – Semiconductors
14. Traction Transformers
15. Low Voltage Components
16. DC circuit breaker
17. Outdoor Medium Voltage Products
18. Enterprise Asset Management & SCADA



Rail and urban transport electrification

Portfolio and positioning

Value creation

Products
Circuit breakers and switches
Air or gas insulated switchgear
Protection and control relays

Modules
Pre-fabricated and factory tested 1AC and 2AC indoor and outdoor module including protection and control

Traction substations
AC traction substations for 1AC and 2AC applications
DC traction substations
Frequency converter stations

Multidisciplinary projects
Complete electrification projects covering a variety of different domains:
Bulk power substations, AC or DC traction substations, passenger station power distribution, wayside equipment, energy storage systems, SVC, SCADA, civil construction, etc.

Engineered packages and turnkey systems
System integration scope

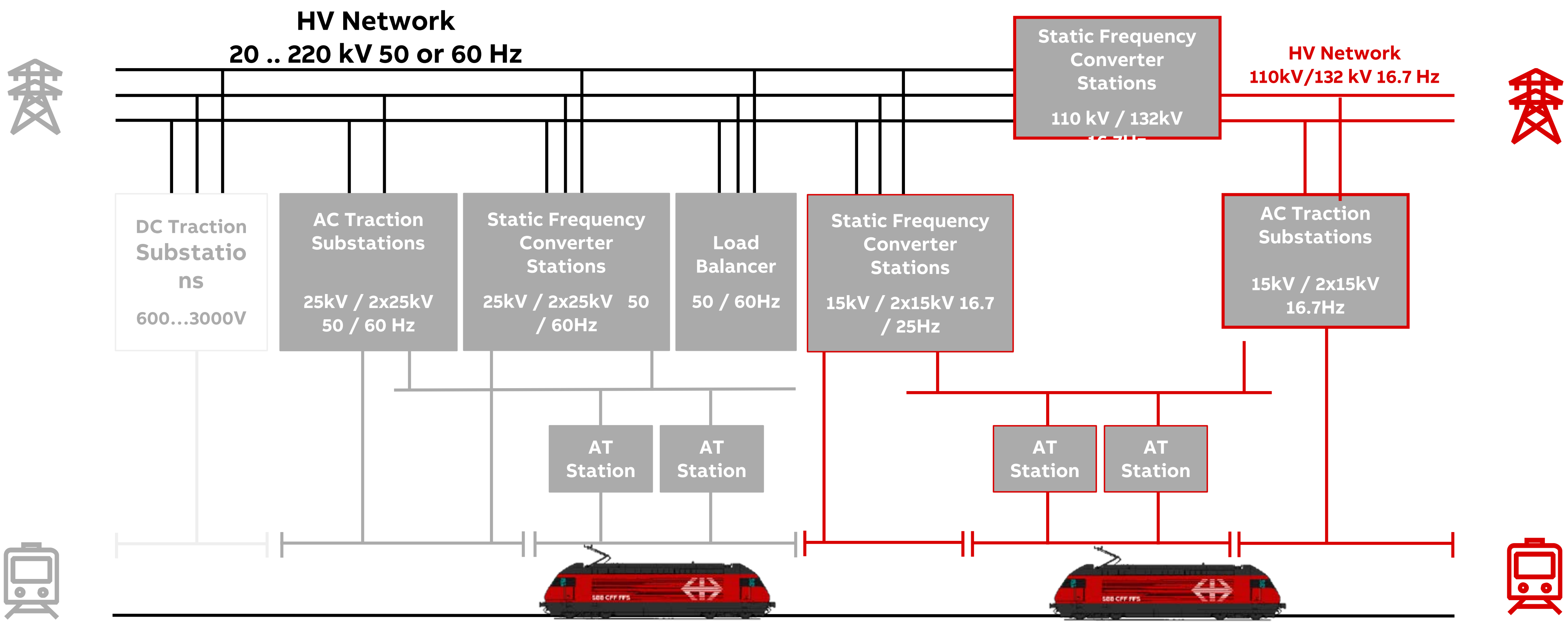
Complexity

Introduction to Railway Power Supply System

AC Traction System

Introduction to railway power supply systems

Supply Overview



Introduction to railway power supply systems

25 kV AC Supply, Autotransformer System a common case

Autotransformer System

– Less power losses

– More constant power

– Greater distance between substations

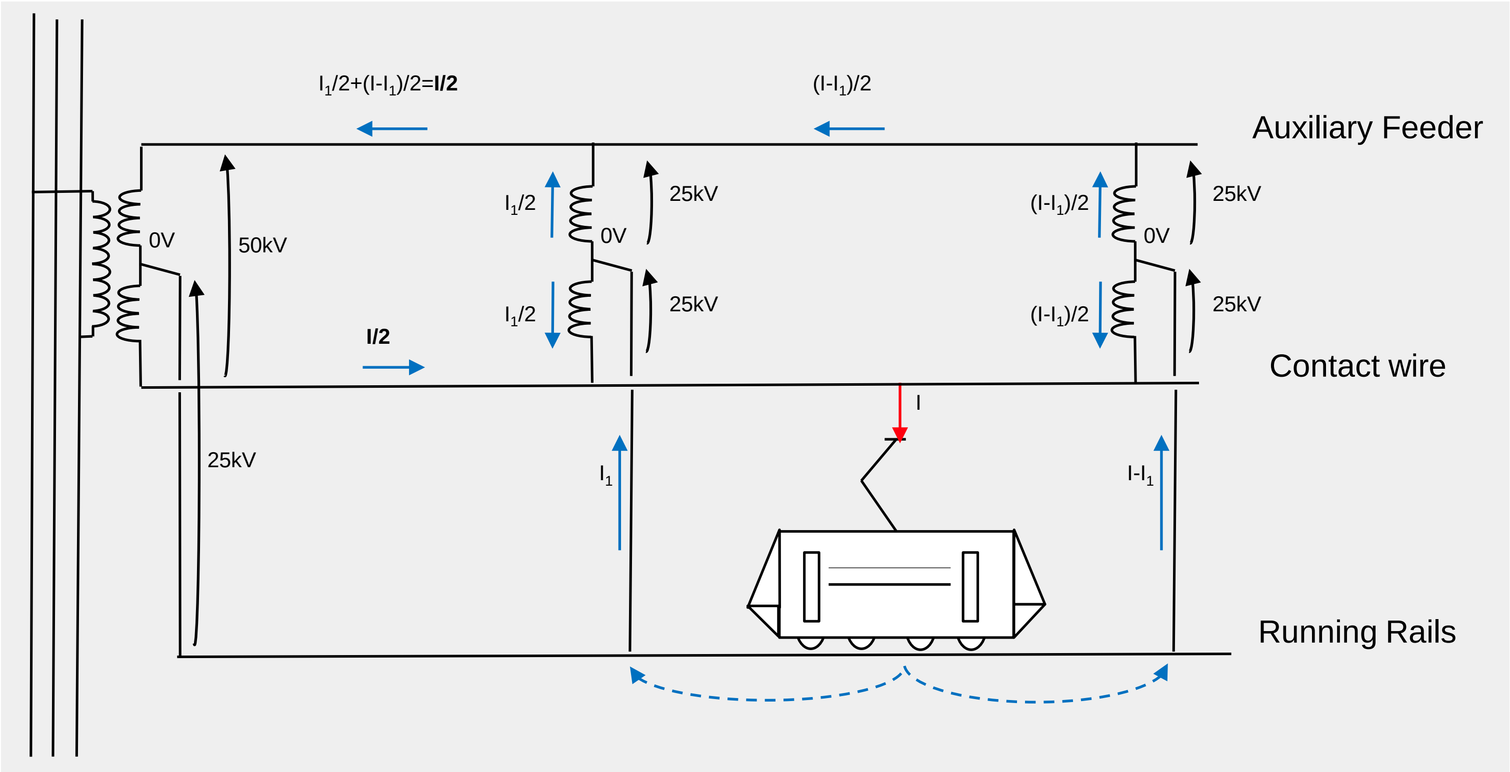
- Spacing between feeder stations

  1 x 25 kV system: 60 to 80 km

  2 x 25 kV system: 120 to 140 km

- Spacing between autotransformer stations

  10 to 20 km



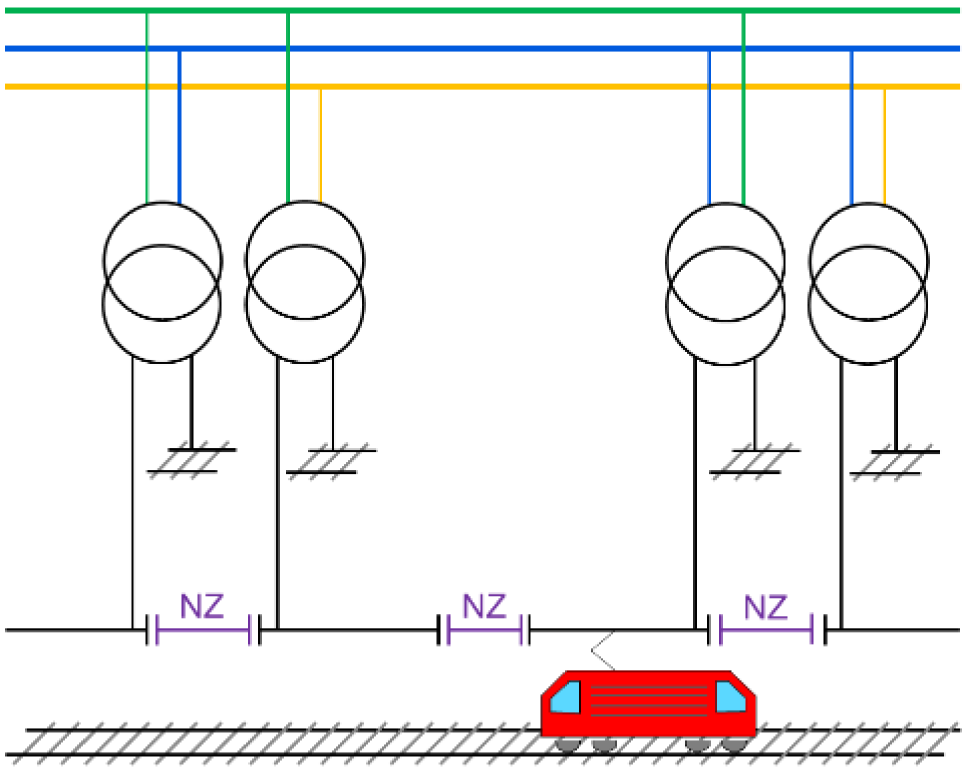
60Hz Railway Power Supply

Conventional Power Supply

Transformer Power Supply

Simple solution with drawbacks

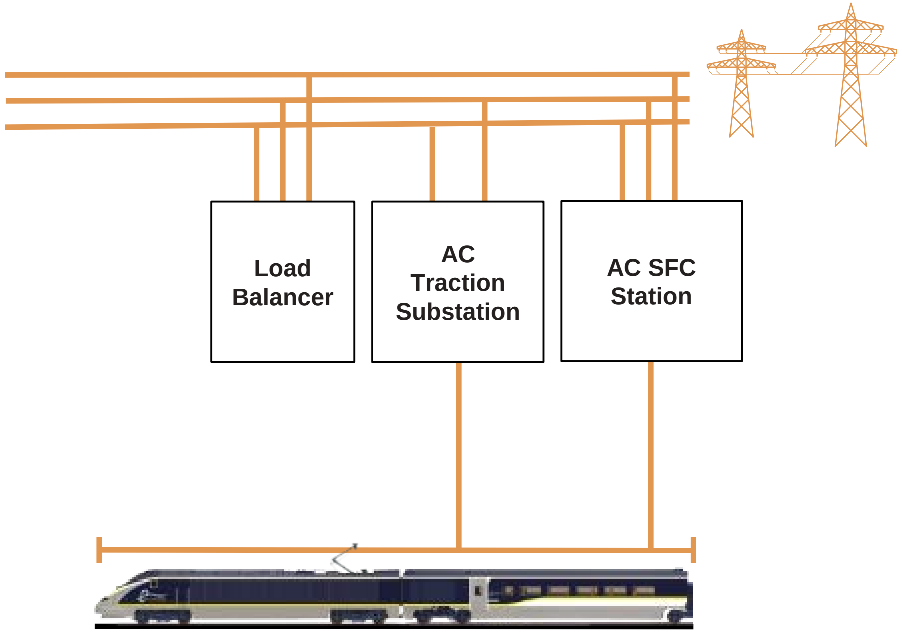
- **Unbalance effect on feeding grid** (only two phases connected)
- **Uncontrolled power factor**
- **High harmonics injection into feeding grid from traction vehicles**
- **High voltage fluctuations in feeding grids caused by fluctuations of railway loads**
- Non optimal catenary voltage
- High catenary short circuit current



From Utility Grid to Catenary system

Power Electronics Systems are the solution

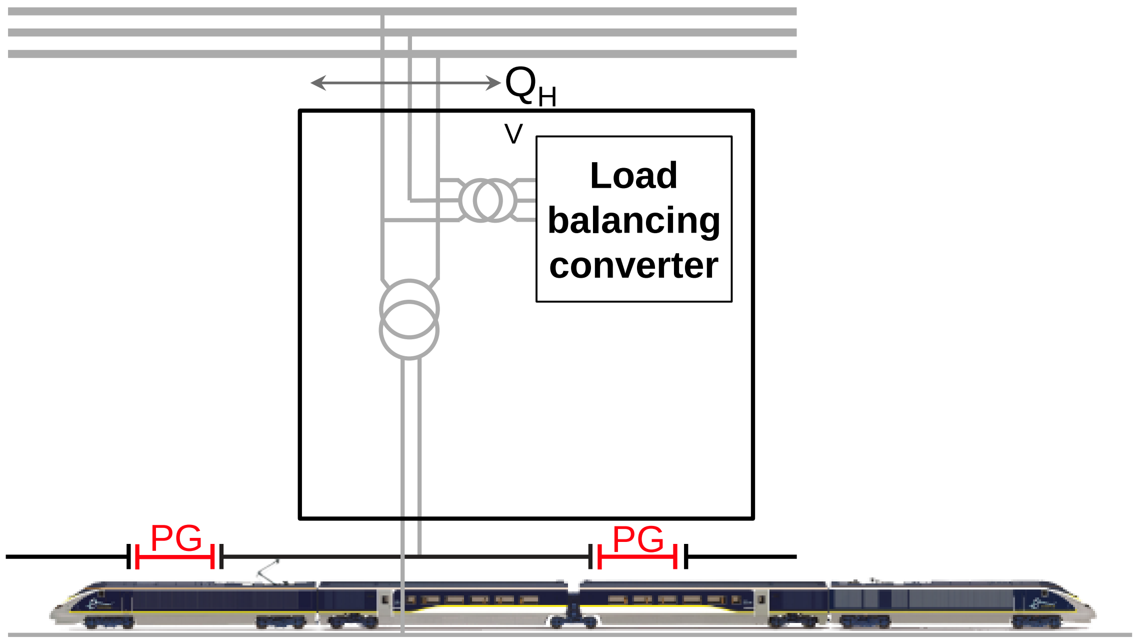
- Megawatts of electrical power can be controlled
- Negative effects such as harmonics, unbalance or fluctuations can be mitigated
- Converters are controllable devices that can be integrated within higher level control and thus become a part of the smart grid



Solution

Rail Load Balancers 60 Hz AC Railways

- Active load balancing between 2 phase consumption in 3 phase grid
- Benefits
  - Balanced phases on HV grid
  - Mitigates voltage fluctuations
  - Harmonics mitigation
  - Fulfillment of grid code requirement at PCC
- Power electronics solutions
  - FACTS (Flexible AC Transmission Systems)
    - SVC (Static Var Compensator)
    - STATCOM (Static Synchronous Compensator)



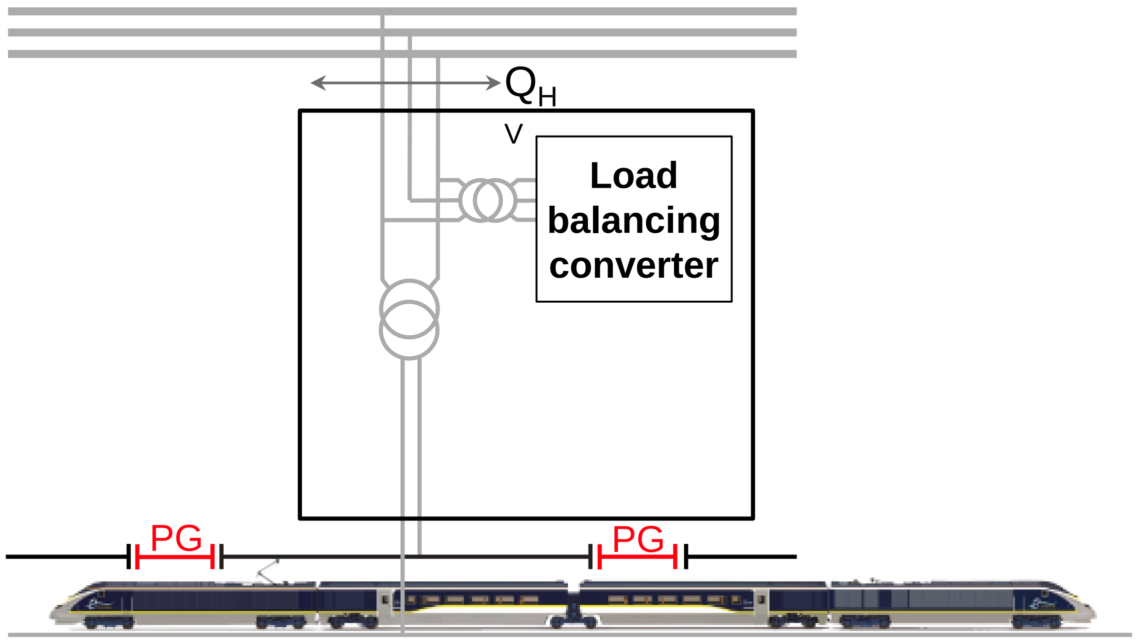
Rail Load Balancers

Load balancers for 60Hz AC railways

Benefits using Load Balancer in railways

- Increasing the traffic intensity without disturbing the power system
- Improving the power quality, reducing harmonics, reducing voltage fluctuations and balancing the three phase system
- Minimizing the investment
- Allowing the grid connection to be done at lower grid voltage levels

The need and the size of a load balancer will be defined by the connection agreement between the railway operator and the utility. The power quality limits are typically defined by the local grid code



60Hz Railway Power Supply

Static Frequency Converter Power Supply

Technical benefits of SFC based supply

3 phase supply from HV or MV grid

Independent active and reactive power control

- Optimized use of regenerative energy
- Dynamic catenary voltage control
- Reactive power control

Coupled through catenary system

Reduced number of separation sections

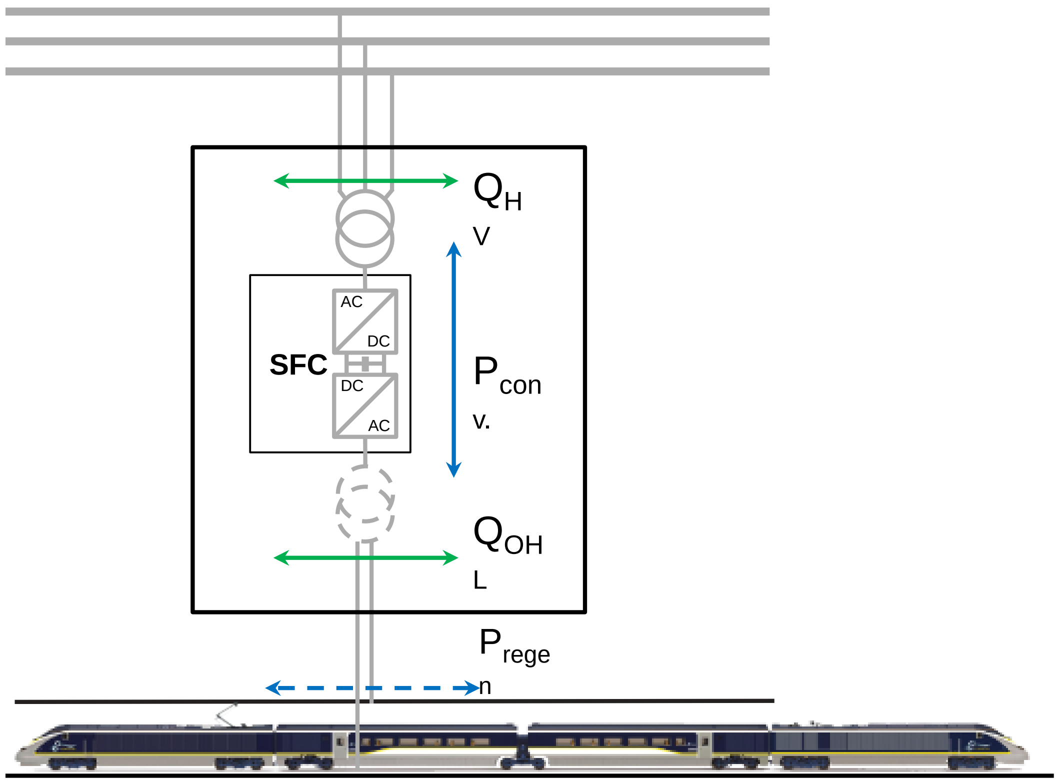
Lower rated peak for substations

Partial redundant supply

Low harmonics content

Limited catenary short circuit current

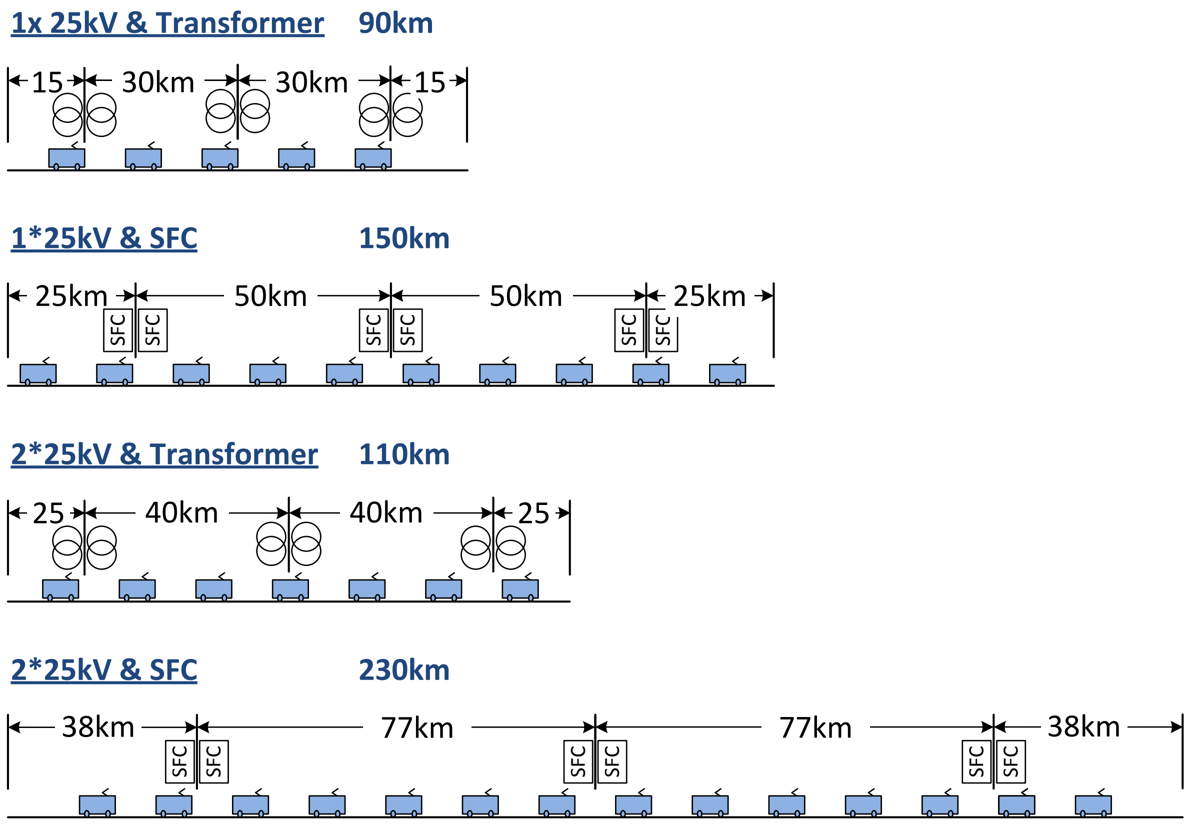
Reference: 16.7 Hz railway supply in Europe



Railway power system simulation 25 kV/50 Hz

Simulations results

– Increased distance between feeding points with SFC
  - Voltage control capability
  - Catenary supply at higher voltage
  - Independent from supply grid voltage
  - No unbalance effect



Rail/urban transport electrification
Conclusion

On track for reliable power worldwide

Whatever your substation needs - from high speed rail transport to urban e-buses – ABB will deliver the ideal solution. And our global footprint means that location is never an issue.

We cover both AC and DC substations and we have the expertise to handle even the toughest technical challenges such as power quality, grid code compliance and regenerative braking.

Our comprehensive services will take your assets from design and development to installation and commissioning and support them through life.

“ABB’s proven, energy-efficient technology ensures reliable power for rail projects across the globe. We are dedicated to delivering innovative, high quality rail substations that shape and accelerate the transformation of mobility.”

Ulrich Spiesshofer
CEO, ABB

Q&A

Electrification of public transportation

ABB