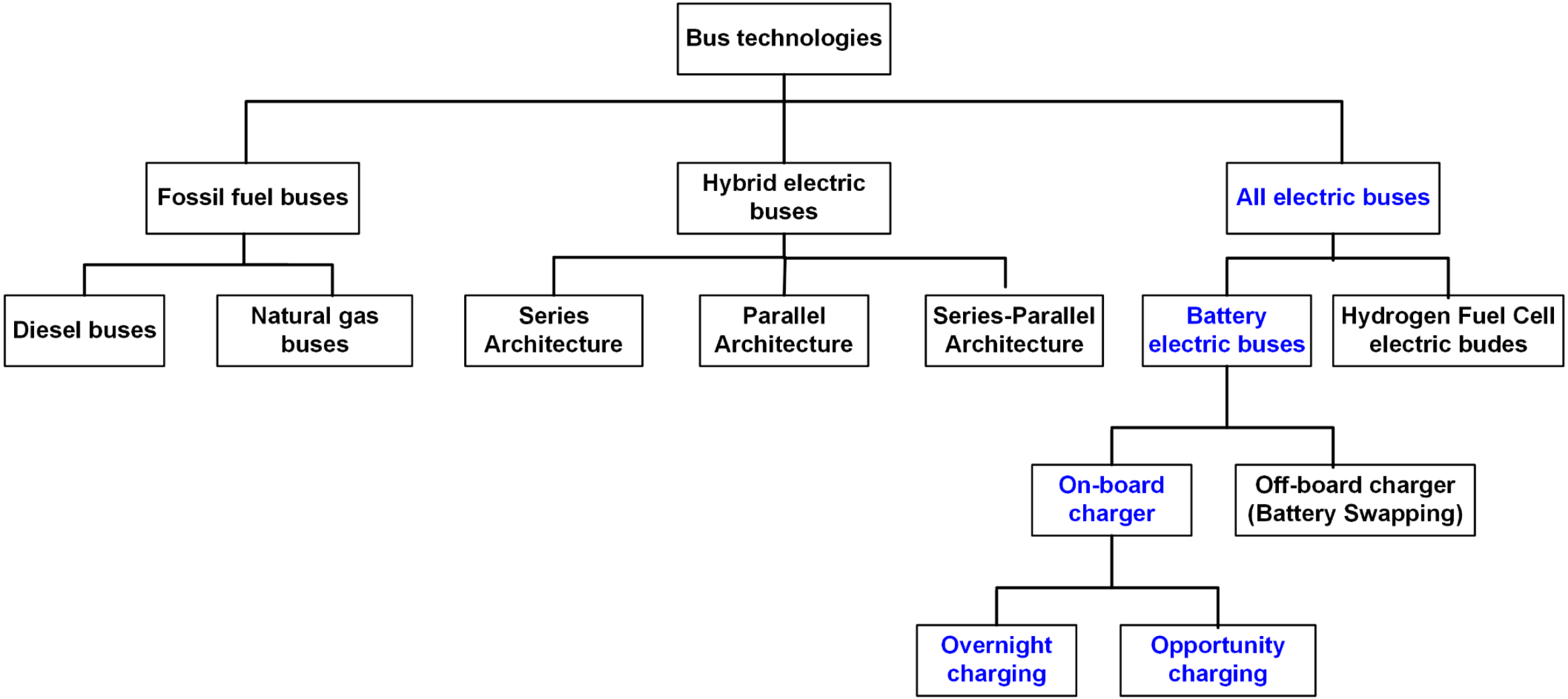
Impacts of Adopting Full Battery-Based Electric Transit Bus Systems on Ontario Electricity Grid

Motivation


Bus technologies
Fossil fuel buses
Hybrid electric buses
All electric buses
Diesel buses
Natural gas buses
Series Architecture
Parallel Architecture
Series-Parallel Architecture
Battery electric buses
Hydrogen Fuel Cell electric budes
On-board charger
Off-board charger (Battery Swapping)
Overnight charging
Opportunity charging

Motivation-1

Electric City Bus

GreenPower Single Decker 40-45 ft: 320 kWh

NewFlyer 40ft: 150-480 kWh

NewFlyer 60ft: 250-600 kWh

Proterra 40 ft: 90-880 kWh

BYD 40 ft: 324 kWh

BYD 60 ft: 591 kWh

Electric Coach Bus

GreenPower Double Decker 45ft: 480 kWh

BYD Double Decker
45ft: 496 kWh

BYD Single Decker
45ft: 420 kWh

Alexander Dennis Inc. Double Decker
45ft: **customized-kWh**

Electric School Bus

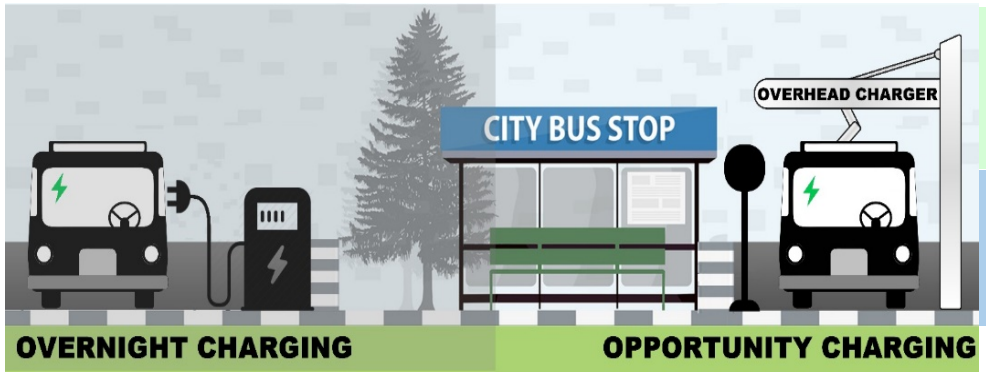
GreenPower 36.5 ft: 100-200 kWh

Lion Bus C: 88-220 kWh

Lion Bus A 26ft (mini school bus):
80-160 kWh

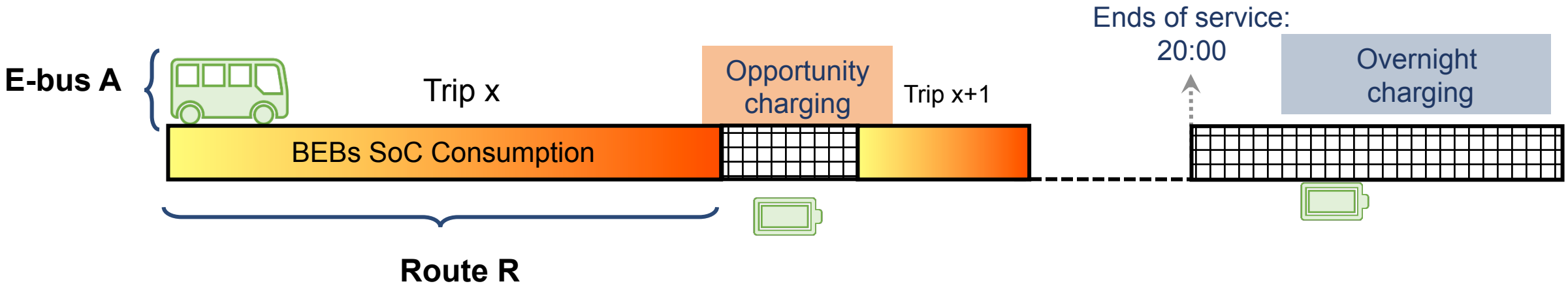
Motivation-2

- ✓ Fixed routes
- ✓ Predefined schedules
- ✓ Shared infrastructure



Battery Capacity
(i.e. mileage range)

Charger Power
(i.e. charging refueling rate)



Motivation-3

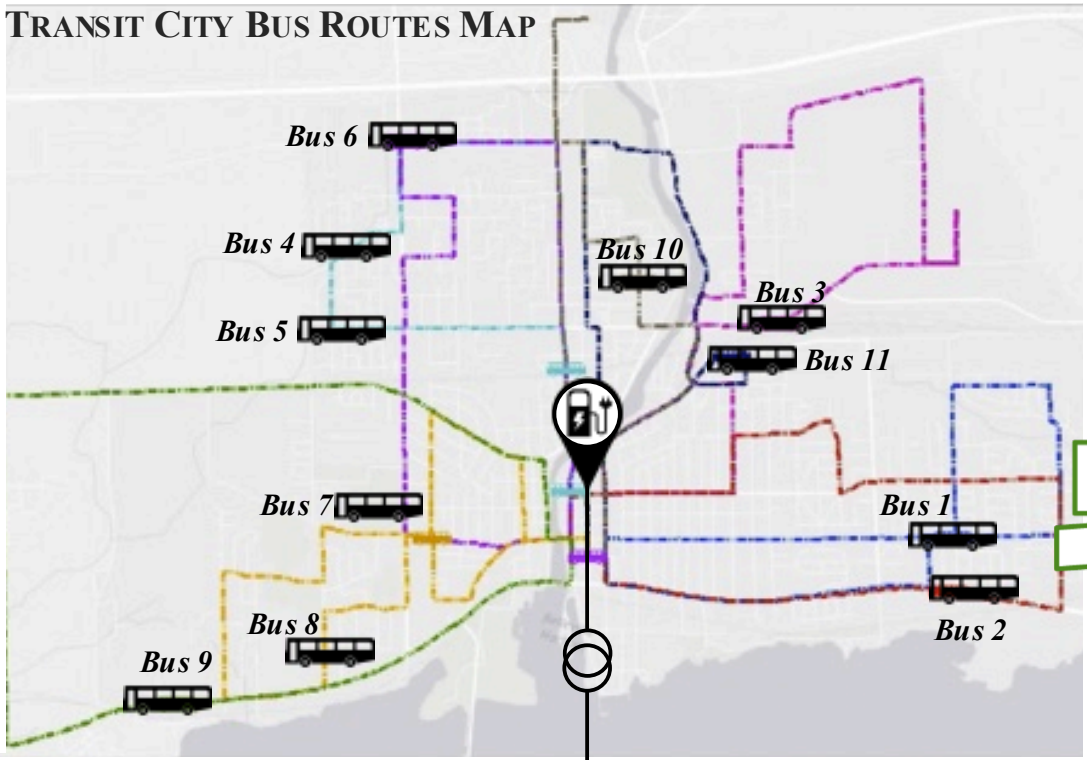
Technical specifications	Overnight charging	Opportunity Charging
Shape of charger		
Key features	• Smart charging • Small infrastructure footprint of the depot charge box • Flexible design for roof and floor mounting • CCS and OCPP compliant • Remote diagnostics and management tools	• Charge in 3 to 6 minutes • One charger can serve multiple vehicle types and brands • Safe and reliable fully automated connection • Based on international IEC 61851-23 standard • Remote diagnostics and management tools
Power	Modular: 50 kW, 100 kW, 150 kW	Modular: 150 kW, 300 kW, 450 kW, 600 kW
Input AC connection	3P + PE	3P + PE
Rated input current and power	3 x 250 A, 173 kVA (per 150 kW module)	3 x 250 A, 173 kVA (per 150 kW module)
Input voltage range	400 VAC +/- 10 % (50 Hz or 60 Hz)	400 VAC +/- 10 % (50 Hz or 60 Hz)
Maximum output current	200 A (per 150 kW module)	250 A (per 150 kW module)
Output voltage range	150 – 920 VDC	150 – 850 VDC 150 – 920 VDC (extended voltage range option)
DC connection standard	IEC 61851-23 / DIN 70121 ISO 15118	IEC 61851-23 / DIN 70121 ISO 15118
Connection method between charger and bus	CCS 1 or CCS 2	4-pole automatic connection system
Environment	Indoor / Outdoor	Indoor / Outdoor
Operating temperature	Standard: -10 °C to +50 °C Optional: -35 °C to +50 °C	-35 °C to +50 °C
Network connection	GSM / 3G modem 10/100 base-T Ethernet	GSM / 3G modem 10/100 base-T Ethernet
Protection	Charge cabinet: IP54 – IK10 Depot charge box: IP65 – IK10	IP54 – IK10

Motivation-4

Size, number, and location of chargers

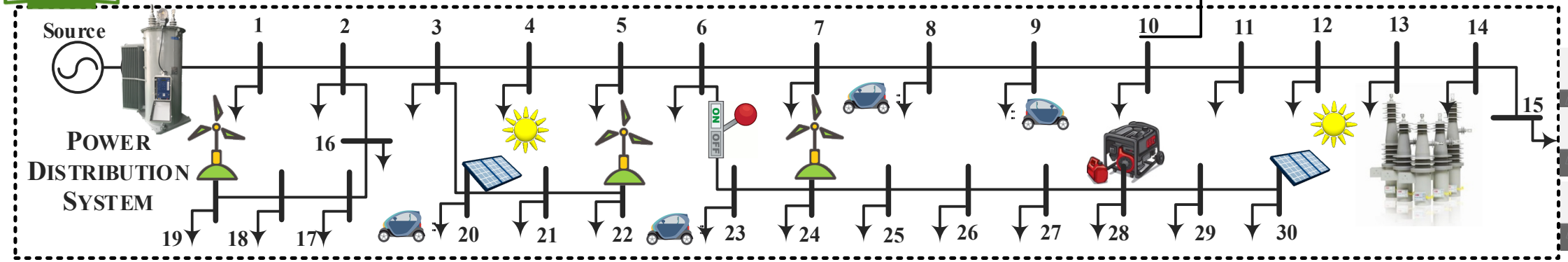
Bus battery size

Transit x Utility Matrix



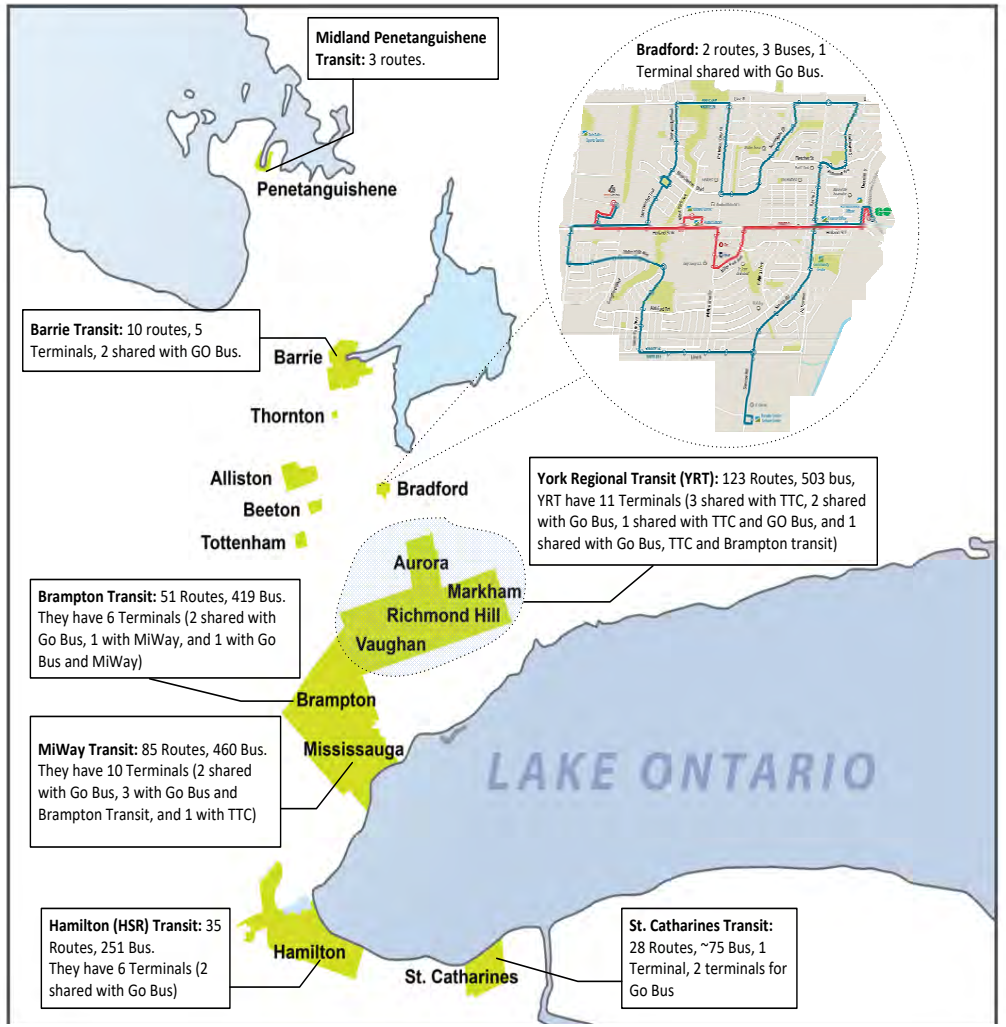
TNO

DNO



Project Objectives

- Develop modeling, simulation, and optimization tools for electrification of public transit bus systems
- Study the impacts of electrifying transit bus systems on local distribution networks and bulk power grids in Ontario



Progress and Vision for Transit Buses Electrification

31/5/2018 — 31/7/2018 — 31/1/2019 — 31/8/2019 — 31/3/2020

Milestone 1

- ✓ **Project startup**
  - Forming team
  - Draft contracts
  - Kick-off meetings
  - Equipment purchase
  - Marketing (web page)
- ✓ **Survey outline**
  - State-of-the-art

Milestone 2

- ✓ **Literature survey**
  - Electrification Technology
    - ❖ Electric City Bus (ECB)
    - ❖ Electric School Bus (ESB)
- ✓ **Data collection - Stage I**
  - ECBs and ESBs technical, economical and charging infrastructure data.
  - Transit bus network data within Alectra Inc. coverage area (i.e., buses, trips, routes, recovery time, etc.)

Milestone 3

- ✓ **Data collection- Stage II**
  - Alectra Utility Inc.: substations, distribution feeders, and demand profiles for the candidate locations of charging stations.
- ✓ **Develop EB energy consumption model**
  - Review and formulation
  - Simulation and validation
- ✓ **Study the annual energy demand and operation feasibility of EB fleets**
  - Complete opportunity-Based ECB Scenario
  - Complete overnight-Based ECB Scenario

Milestone 4

- ✓ **Study the impact of overnight and opportunity EBs on power grids**
  - Analyze EB fleets load characteristics:
    - ❖ Calculating load metrics
    - ❖ Correlation with typical demand profile in each city/zone of Alectra
    - ❖ Correlation with wind and solar
    - ❖ Deriving aggregated load profile
    - ❖ Mapping aggregated load profile to the nearest zone in ON transmission system

- ❑ **Data collection- Stage III**
  - ❖ IESO: transmission and/or sub-transmission zones connected to Alectra Inc. distribution networks
  - ❖ Perform System Impact Assessment (SIA) studies

Milestone 5

- ➢ **Develop a transit-utility toolbox for optimal design and operation of EB fleets**
  - Graphical user interface for data input/ output
  - Formulate mathematical models: for optimal design and operation of EB fleets
  - Software license procurement
  - Coding and validation

Milestone 2-Transit Data Collection

	A	B	C	D	E	F	G	H	I	J	K	L
1	**City**	**Mississauga**	utemaps, https://rideschedules.com/schedule.html?102343, https://cpt									
2	**Number of buses**	**460**										
3	**Number of routes**	**85**	**Block**	**Route number**	**Route name**	**bu**						
4	**Terminal**	**Code**	**1**	1, 1C	1 Dundas (Eastbound)							
5	West of Ridgeway Dr	1	**2**	1, 1C	1 Dundas (Eastbound)							
6	Islington Subway Bus Terminal	2	**3**	1, 1C	1 Dundas (Eastbound)							
7	CITY CENTRE TRANSIT TERMINAL	3	**4**	1, 1C	1 Dundas (Westbound)							
8	GLENGARRY RD at DUNDAS ST	4	**5**	1, 1C	1 Dundas (Westbound)							
9	SHERWAY GARDENS BUS TERMINAL	5	**6**	1, 1C	1 Dundas (Westbound)							
10	LONG BRANCH GO STATION	6	**7**	3	3 Bloor (Eastbound)							
11	LORIMAR DR at CARDIFF BLVD	7	**8**	3	3 Bloor (Eastbound)							
12	DUNDAS ST west of ERINDALE STATION RD	8	**9**	3	3 Bloor (Eastbound)							
13	WESTWOOD SQUARE BUS TERMINAL	9	**10**	3	3 Bloor (Westbound)							
14	PORT CREDIT GO STATION	10	**11**	3	3 Bloor (Westbound)							
15	ERIN CENTRE BLVD at LONGFORD DR	11	**12**	3	3 Bloor (Westbound)							
16	MEADOWVALE TOWN CENTRE	12	**13**	4	4 Sherway Gardens (Eastbound)							
17	REXDALE BLVD at ISLINGTON AVE	13	**14**	4	4 Sherway Gardens (Eastbound)							
18	CLARKSON GO STATION	14	**15**	4	4 Sherway Gardens (Eastbound)							
19	CARDIFF BLVD east of TOMKEN RD	15	**16**	4	4 Sherway Gardens (Westbound)							
20	TRILLIUM HOSPITAL BUS TERMINAL	16	**17**	4	4 Sherway Gardens (Westbound)							
21	HURONTARIO & 407 PARK and RIDE	17	**18**	4	4 Sherway Gardens (Westbound)							
22	ERINDALE GO STATION	18	**19**	5	5 Dixie (Northbound)							
23	COMMERCE BLVD at RENFORTH STATION	19	**20**	5	5 Dixie (Northbound)							
24	HUMBER COLLEGE BLVD at ETOBICOKE HOSPITAL	20	**21**	5	5 Dixie (Northbound)							
25	SHERIDAN CENTRE BUS TERMINAL	21	**22**	5	5 Dixie (Southbound)							
26	MATHESON BLVD east of HURONTARIO ST	22	**23**	5	5 Dixie (Southbound)							
27	SOUTH COMMON CENTRE BUS TERMINAL	23	**24**	5	5 Dixie (Southbound)							
28	ERIN MILLS STATION WEST	24	**25**	6	6 Credit Woodlands (Eastbound)							
29	WOODBINE CENTRE BUS TERMINAL	25	**26**	6	6 Credit Woodlands (Eastbound)							
30	TRELAWNY CIR at MOCKINGBIRD LANES	26	**27**	6	6 Credit Woodlands (Eastbound)							
31	LISGAR GO STATION	27	**28**	6	6 Credit Woodlands (Westbound)							

Terms defintion | Midland and Penetanguishene | Barrie | Bradford | Brampton | Hamilton | St. Catharines | YRT | **Mississauga**

- ❑ Route number and name
- ❑ Number of buses servicing route
- ❑ Start point and end point
- ❑ Operating time schedule days (Mon-Fri, Sat., and Sun.)
- ❑ Trip cycle time
- ❑ Trip frequency (i.e., arrives/leaves every X mins)
- ❑ Recovery time (i.e., time for opportunity charging)
- ❑ Number of complete trips per day
- ❑ Number of partial trips per day
- ❑ Number of stops
- ❑ Route distance (km)
- ❑ Daily travelled distance

Milestone 3–Energy Consumption Analysis

31/5/2018 — 31/7/2018 — 31/1/2019 — 31/8/2019 — 31/3/2020

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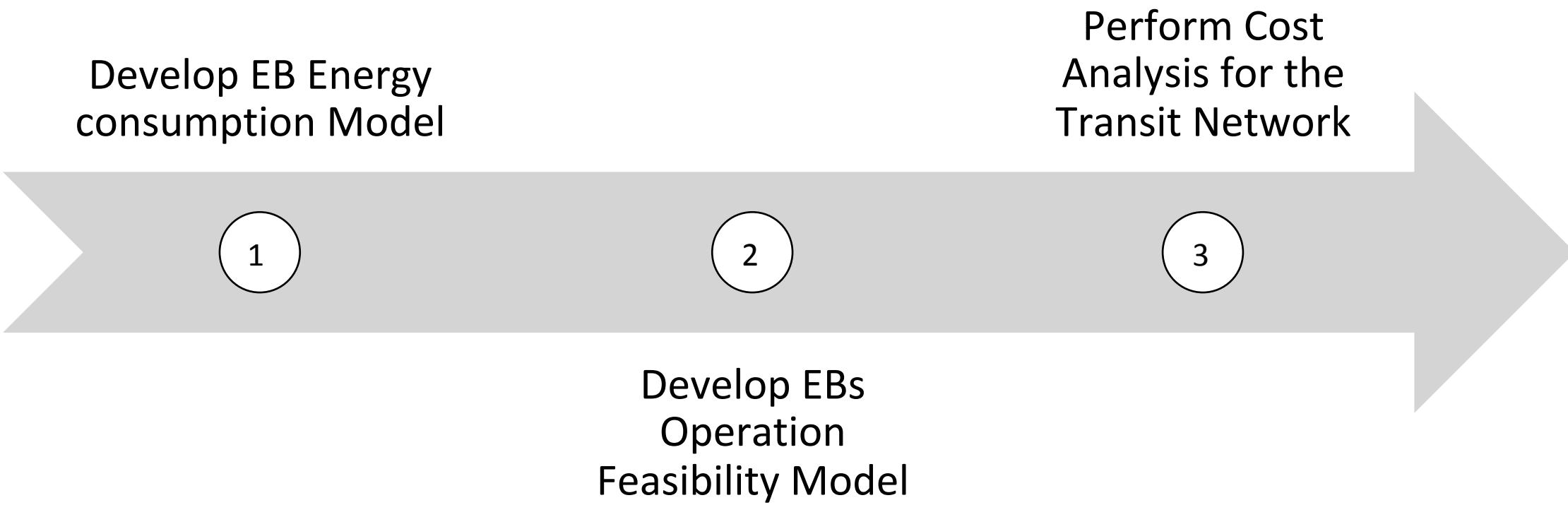
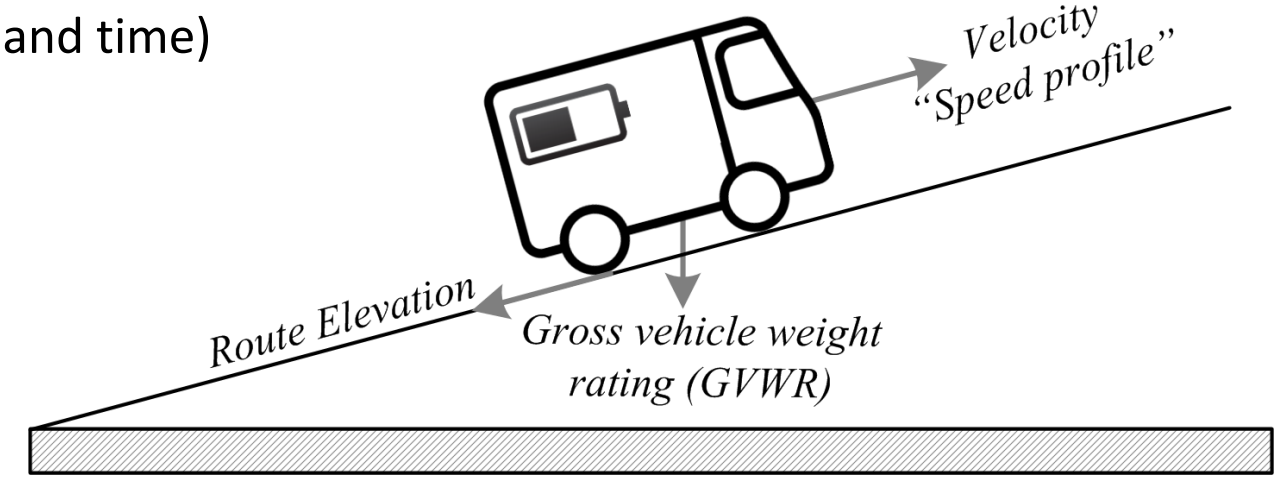
Planning Process of Electrified transit system



Calculating EBs Energy Consumption

❑Factors Impact EB Energy Consumption

- Speed profile (implicitly includes the trip distance and time)
- Level of traffic (service)
- City bus versus intercity bus operation service.
- Route gradient and elevation
- Gross vehicle weight rating (GVWR)
- Auxiliary loads (light, sound, and radio system)
- Heat, ventilation, and air conditioning (HVAC)



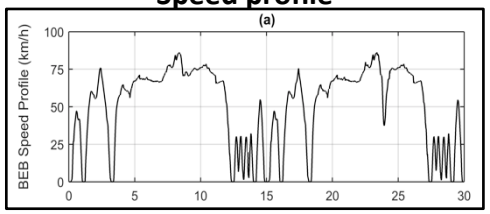
Calculating BEBs Energy Consumption

Inputs

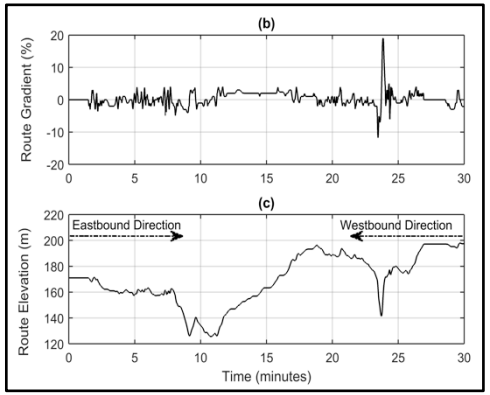
Electric bus specifications

- Bus mass (kg)
- Front area (m^2);
- Auxiliary power (kW)
- Battery capacity (kWh)
- Efficiencies (motor, converter, drive shaft)
- Air density (kg/m^3), and drag coefficient.

Speed profile



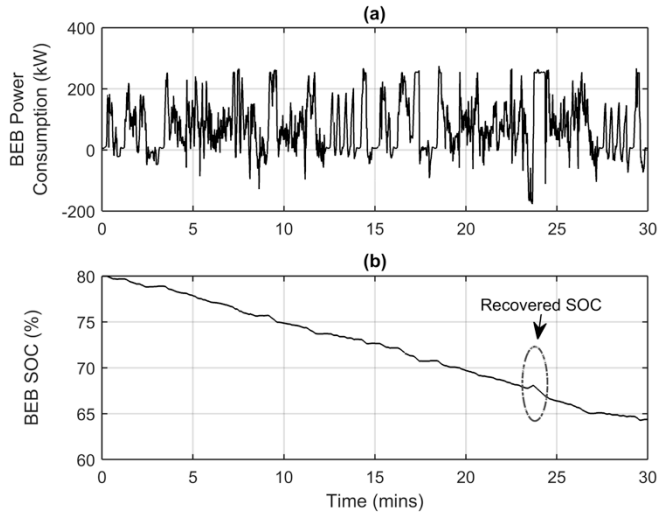
Route topography



Developed Electric bus energy consumption model

Outputs

Average consumption rate (kWh/km)



Off-the-shelf toolbox: ADVISOR

Microsoft® Excel

In-house toolbox using: MATLAB and EXCEL

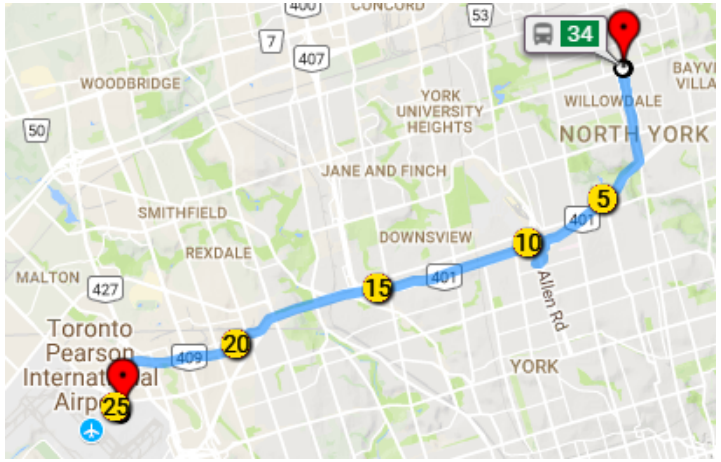
Web-based application: WEBST

Calculating BEBs Energy Consumption

❑Energy Consumption for Go Bus Route 34 (Pearson Airport – North York) using ADVISOR

Route Inputs to ADVISOR Consumption Model

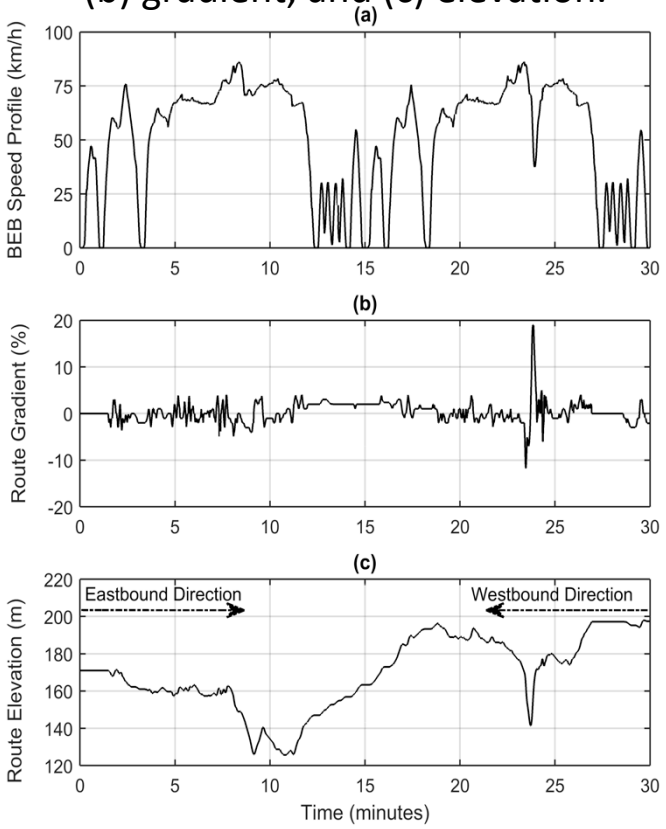
Go Bus Route 34 (Pearson Airport – North York)



GO Bus Route 34 drive cycle characteristics

Trip Distance	25.4 km
Average Time	30 minutes
Average Speed	51.2 km/h

Route 34: (a) Speed profile, (b) gradient, and (c) elevation.



BEB Inputs to the Consumption Model

Alexander Dennis Electric Coach Prototype Data

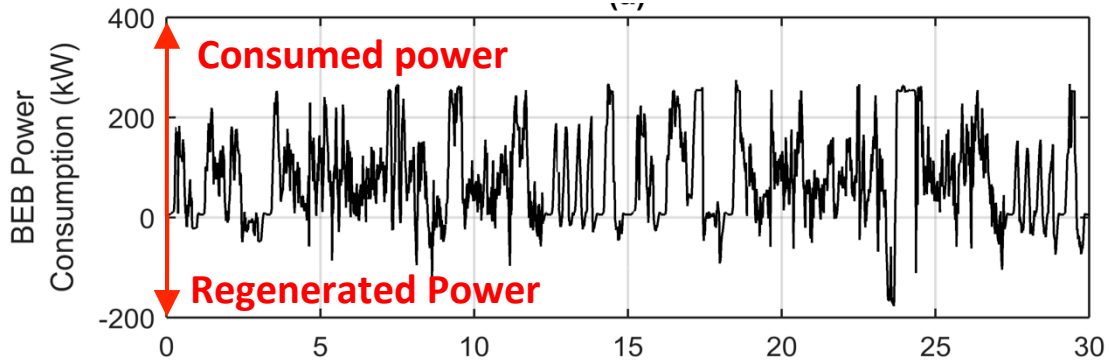
Gross vehicle weight rating (GVWR)	33400 kg
Electric motor rating	283 kW
HVAC load (as a constant load)	30 kW
Auxiliary load	9 kW

Calculating BEBs Energy Consumption

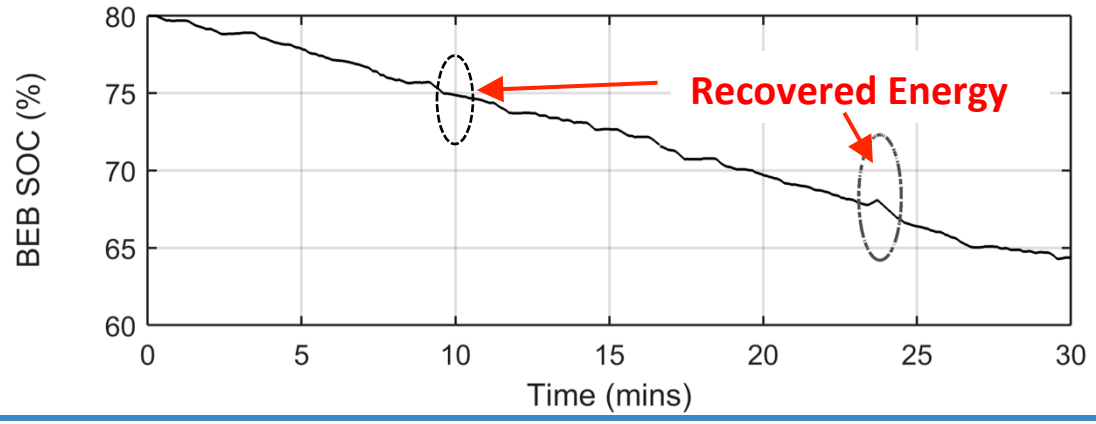
❑Energy Consumption for Go Bus Route 34 (Pearson Airport – North York)

Model Outputs from the Energy Consumption Model

- Route 34 BEB power consumption



- Route 34 BEB state of charge



Route 34 Energy Consumption

Eastbound total consumption	66.05 kWh
Eastbound average consumption	2.6 kWh/km
Westbound total consumption	62.74 kWh
Westbound average consumption	2.47 kWh/km

Eastbound direction has a 5.26% higher consumption rate due to its uphill elevation.

Calculating BEBs Energy Consumption

Off-the-shelf toolbox: ADVISOR

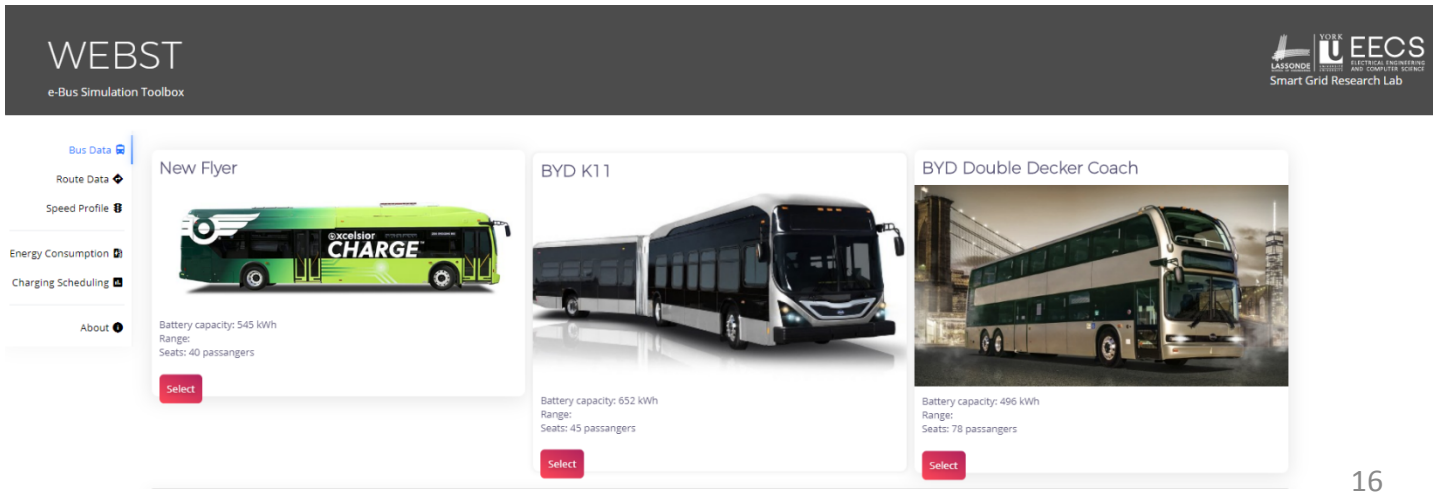
- Not developed for transit electrification.
- Not a user-friendly toolbox i.e., requires MATLAB knowledge and license to upload your own data and installation license.
- Does not include a model for the HVAC consumption.

In-house toolbox using: MATLAB and EXCEL

✓ Includes the HVAC model besides the ADVISOR Features

Web-based application: WEBST

✓ User-friendly website

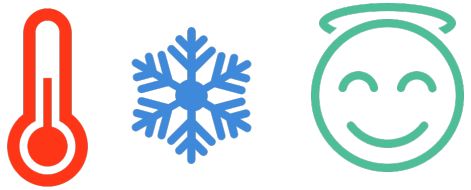


Calculating BEBs Energy Consumption

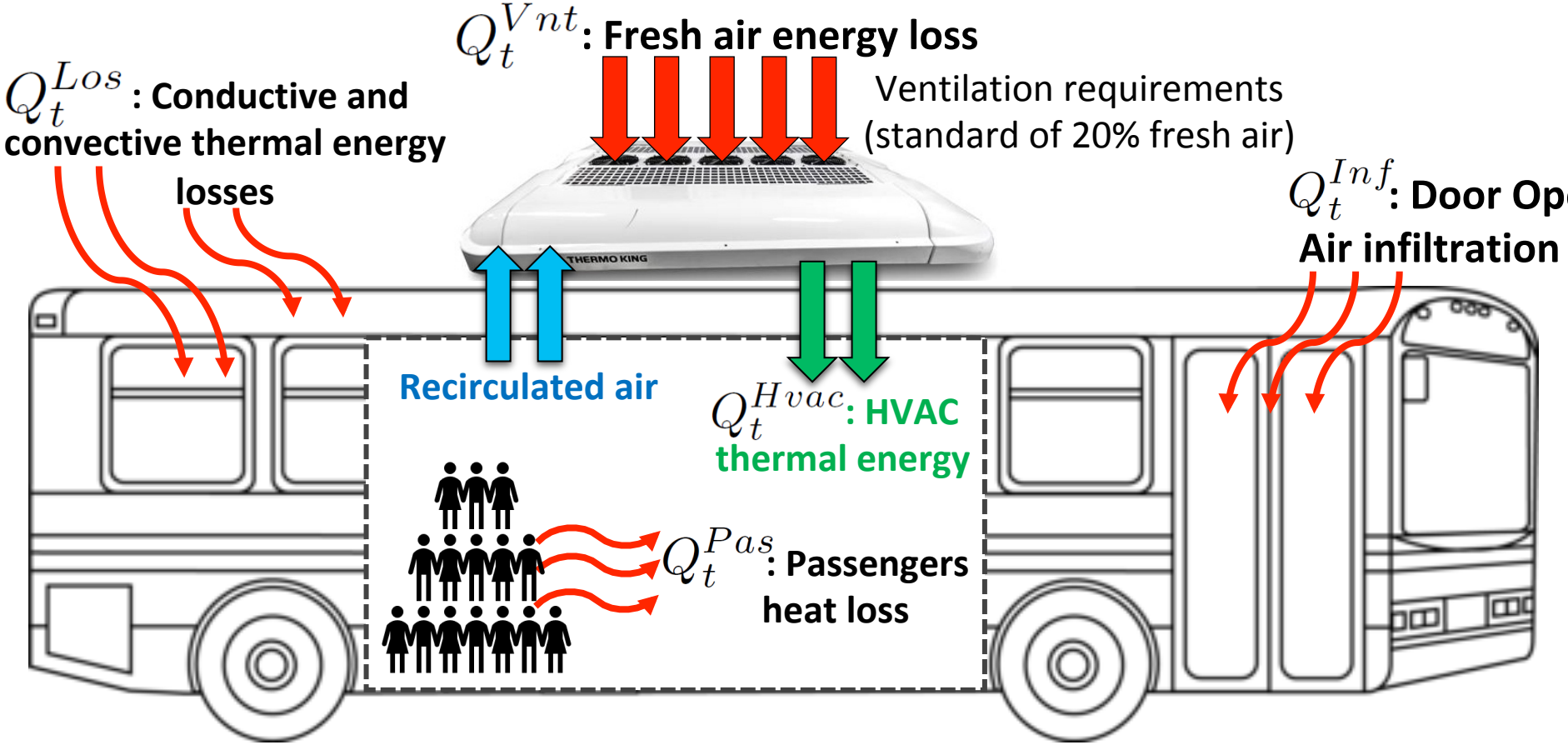
❑Developed HVAC Energy Consumption Model

✓ Thermal and Mass Balance Equation

$$m^{Air}.C_p.\left(k_t^{EB}-k_{t+1}^{EB}\right)=\left(Q_t^{Hvac}-Q_t^{Los}-Q_t^{Inf}-Q_t^{Vnt}+Q_t^{Pas}\right).\Delta t \quad \forall t\in\mathcal{T},$$



Customer Comfort and Satisfaction

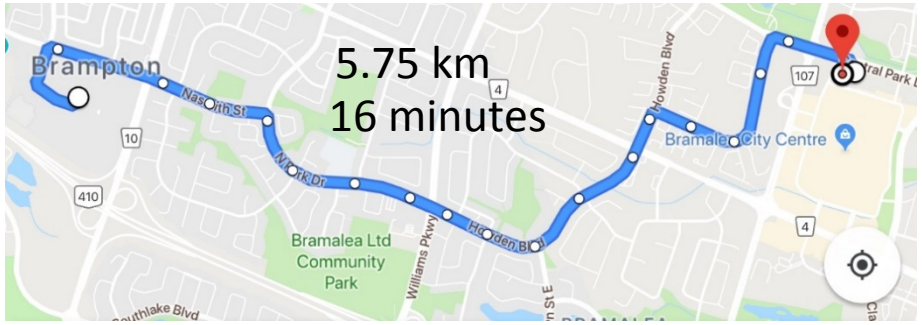


Calculating BEBs Energy Consumption

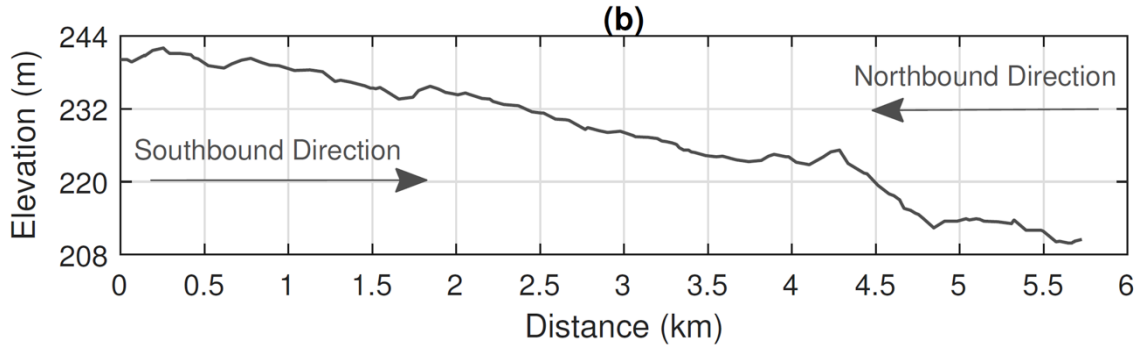
❑**Energy Consumption for Brampton transit Route 17 using the developed in-house model**

Route Inputs to ADVISOR Consumption Model

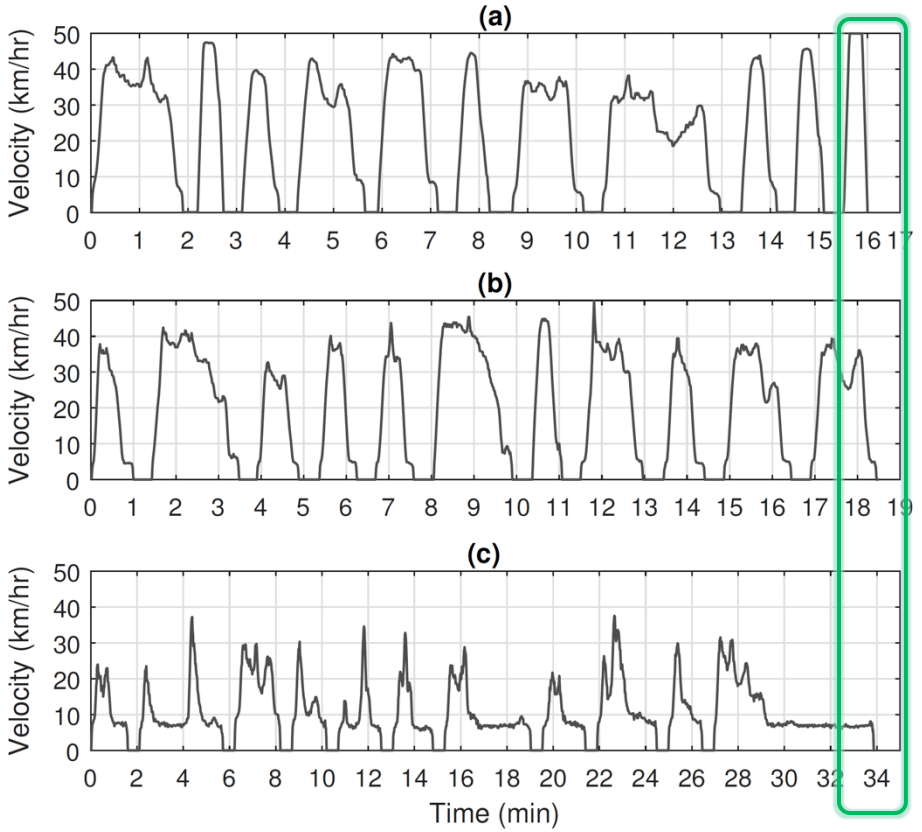
- Brampton Transit Route 17 (Trinity Common Terminal – Bramalea Terminal)



- Brampton Transit Route 17 elevation



- Sample of studied Speed profiles: (a) **Free** traffic, (b) **Light** traffic, and (c) **Congested** traffic



Calculating BEBs Energy Consumption

- **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

BEB Inputs to the Consumption Model

BYD 40ft Battery Electric Bus

Gross vehicle weight rating (GVWR)	19700 kg
Electric motor rating	300 kW
HVAC load (controlled operation)	15 kW
Auxiliary load	9 kW

HVAC Model Outputs

- HVAC operation using the previous Light traffic speed profile.

Temperature Comfort Range

On/off Operation to Control temperature

Infiltration energy loss during door openings

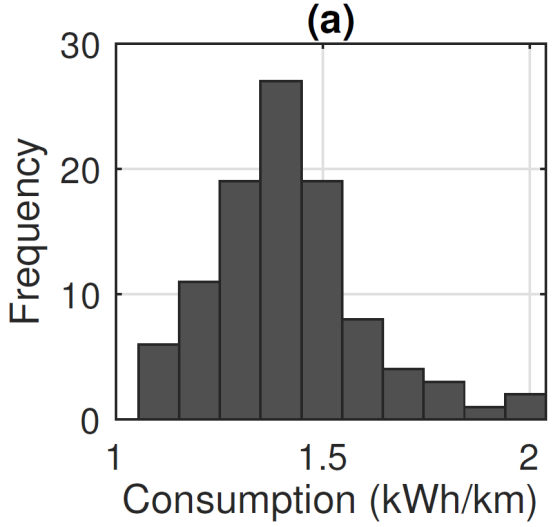
Calculating BEBs Energy Consumption

❑ **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

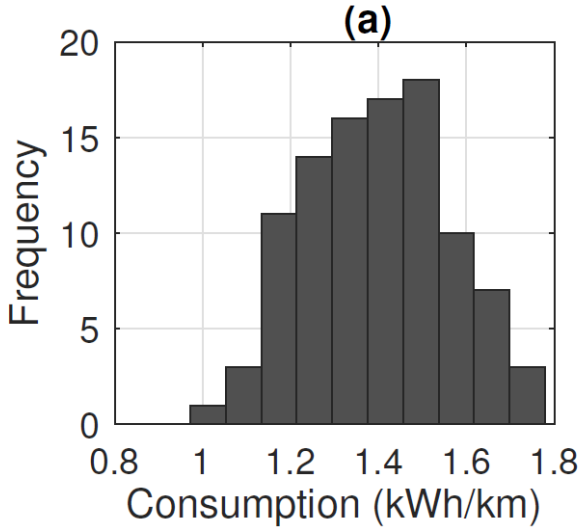
➢ Energy Consumption Analysis for 300 Speed profiles at different traffic conditions

1. Traction Energy Consumption

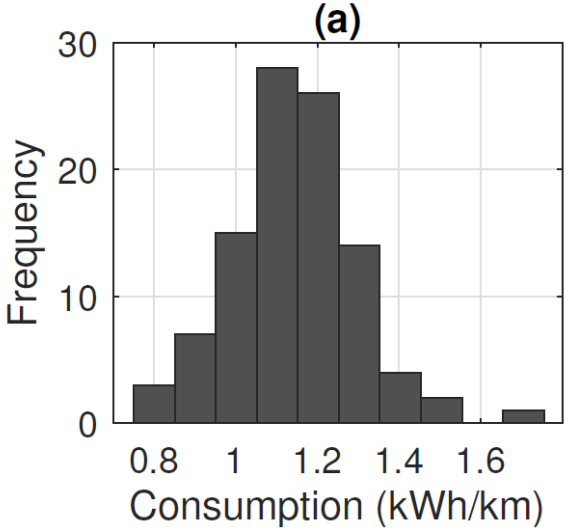
Free Traffic



Light Traffic



Congested Traffic



Higher traffic means lower speed and lower speed requires low motive energy, thus low traction consumption

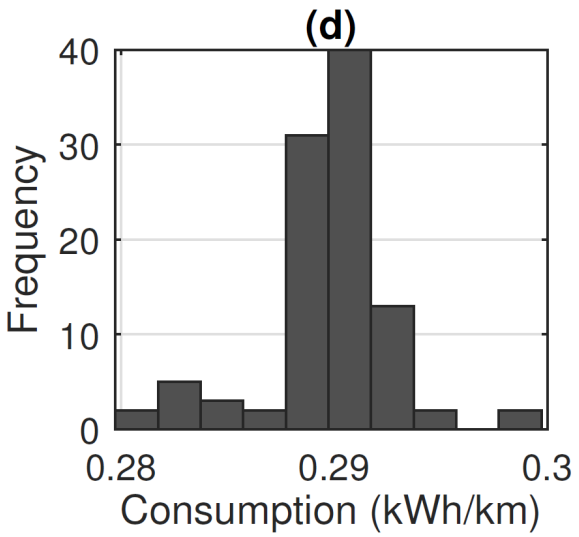
Calculating BEBs Energy Consumption

❑ **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

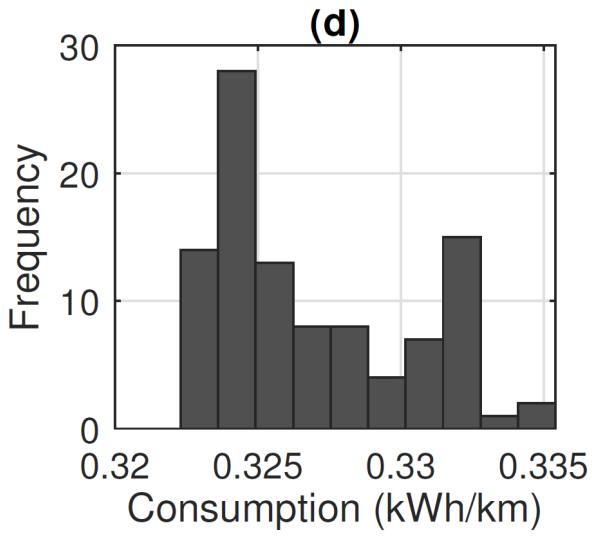
➢ Energy Consumption Analysis for 300 Speed profiles at different traffic conditions

2. <u>HVAC Energy Consumption</u>

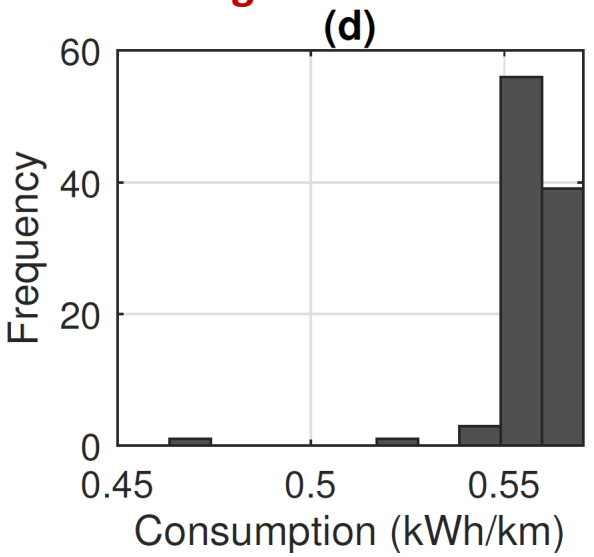
Free Traffic



Light Traffic



Congested Traffic



Congested traffic have longer trip times, hence longer HVAC operation and higher consumption.

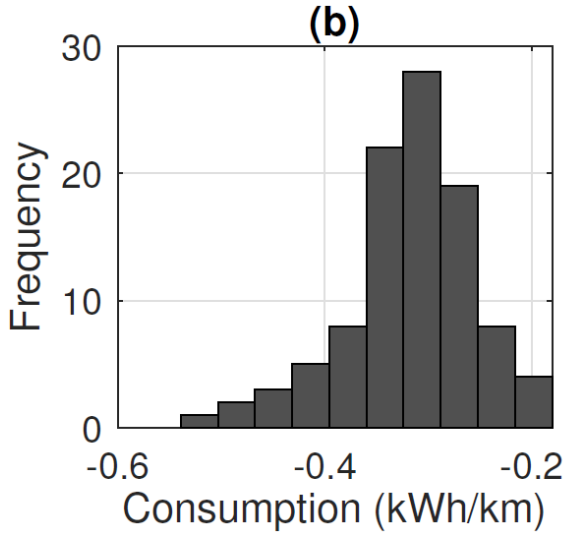
Calculating BEBs Energy Consumption

❑ **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

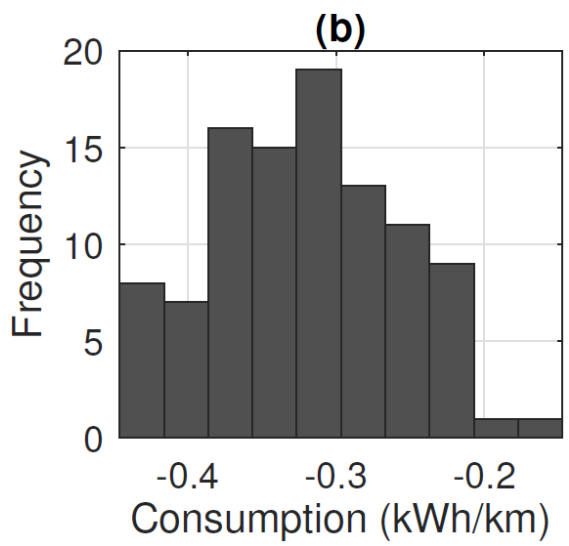
➢ Energy Consumption Analysis for 300 Speed profiles at different traffic conditions

3. Regenerative Energy Consumption

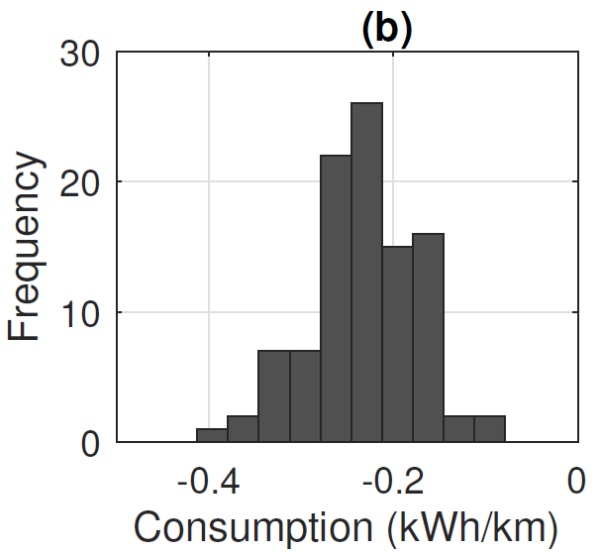
Free Traffic



Light Traffic



Congested Traffic



Regenerative energy consumption is slightly affected by the traffic conditions.

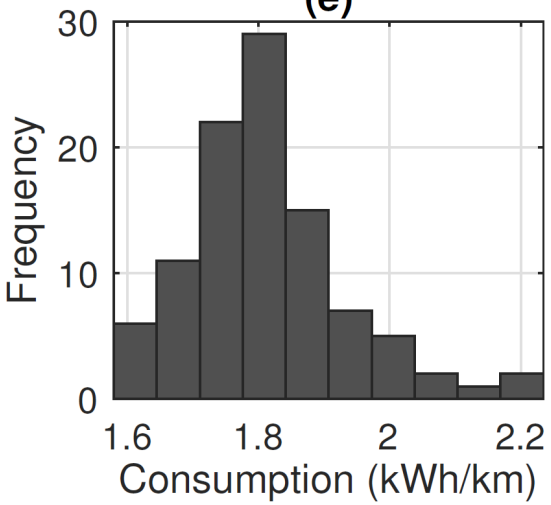
Calculating BEBs Energy Consumption

❑ **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

➢ Energy Consumption Analysis for 300 Speed profiles at different traffic conditions

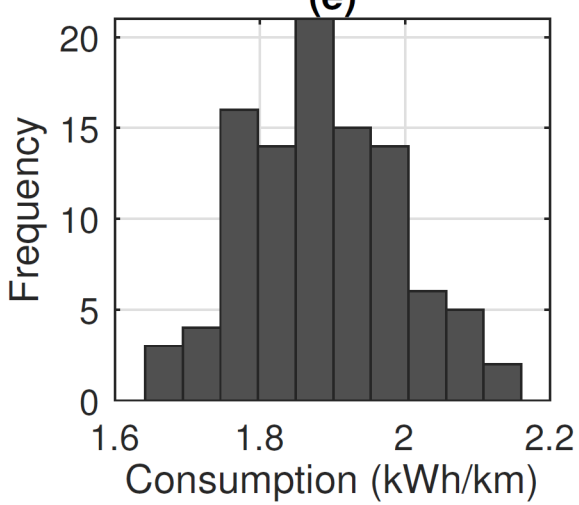
4. Total Energy Consumption (Traction + HVAC + Regenerative)

Free Traffic

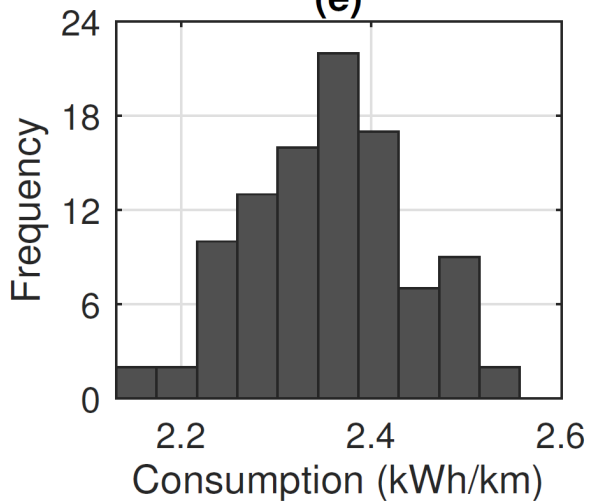


- High traction consumption
- Almost same regenerative energy
- Low HVAC consumption

Light Traffic



Congested Traffic



- Low traction (20% lower)
- Almost same regenerative energy
- High HVAC consumption (doubled)

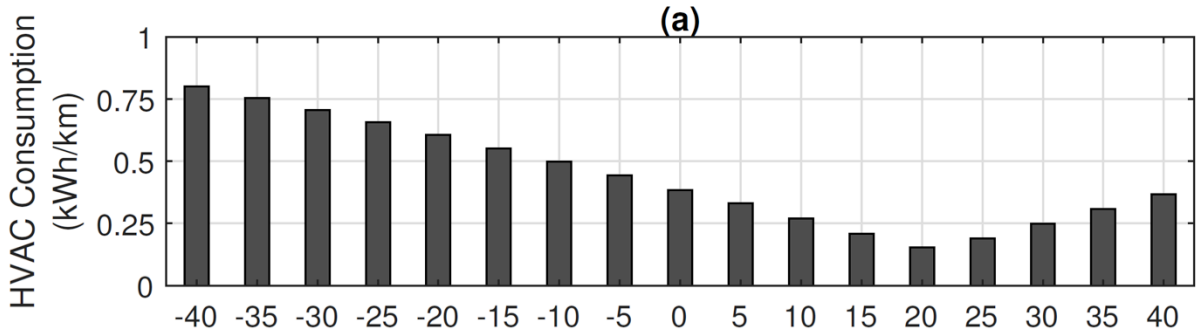
Overall congested traffic have higher consumption rates

Calculating BEBs Energy Consumption

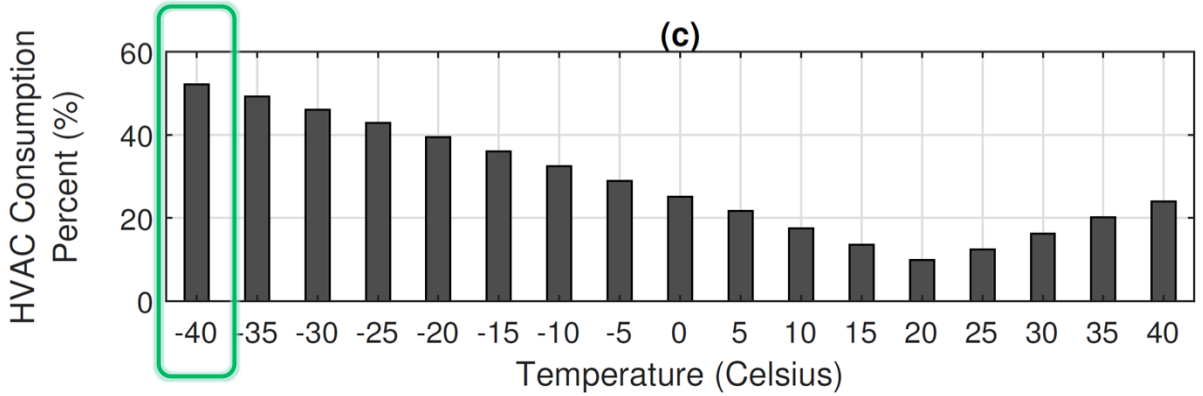
❑ **Energy Consumption for Brampton transit Route 17 using the developed in-house model**

➢ HVAC Energy Consumption Analysis at different temperatures.

- HVAC consumption at different temperatures



- HVAC percentage of consumption with respect to the total consumption at different temperatures



Calculating BEBs Energy Consumption

WEBST

e-Bus Simulation Toolbox

LASSONDE Smart Grid

- Bus Data
- Route Data
- Speed Profile
- Energy Consumption
- Charging Scheduling
- About

New Flyer

Battery capacity: 545 kWh
Range:
Seats: 40 passangers

Select

BYD K11

Battery capacity: 652 kWh
Range:
Seats: 45 passangers

Select

BYD Double Decker Coach

Battery capacity: 496 kWh
Range:
Seats: 78 passangers

Select

Enter bus specifications (Current bus: BydK11)

Electric Bus Mass (Kg)	Rolling Resistance Coefficient	Bus Facing Area m^2	Inverter Efficiency	Electric Motor Efficiency	Driver Shaft Efficiency
30600	0.015	9.095	0.95	0.85	0.95

Auiliary Load for Electric Bus (KW)	Drag Coefficient	Air Density	Gravity (m/s2)
0	0.65	1.2258	9.8

Save

Calculating BEBs Energy Consumption

WEBST

e-Bus Simulation Toolbox

Bus Data

Route Data

Speed Profile

Energy Consumption

Charging Scheduling

About

Select route

Option (1)

Route: Brampton Transit Route 17

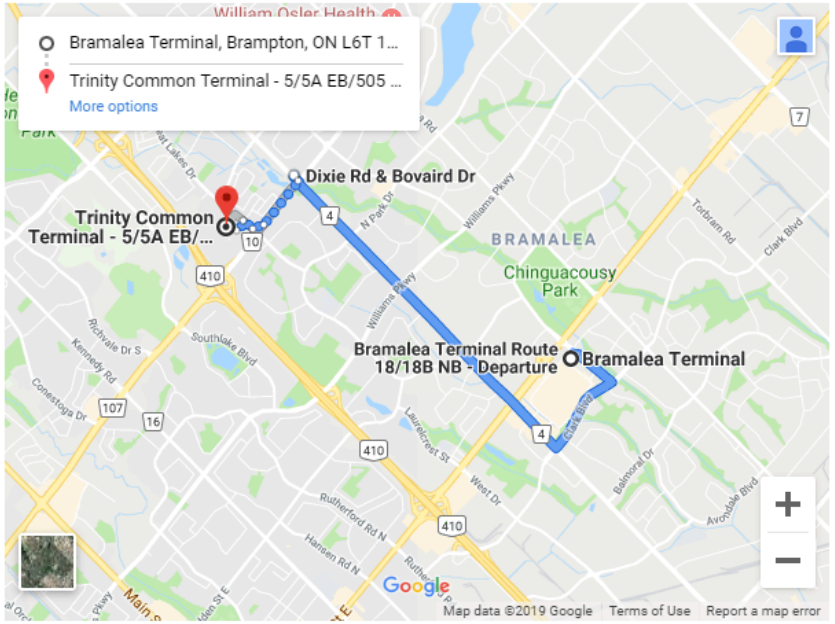
Route start: Bramelea Terminal

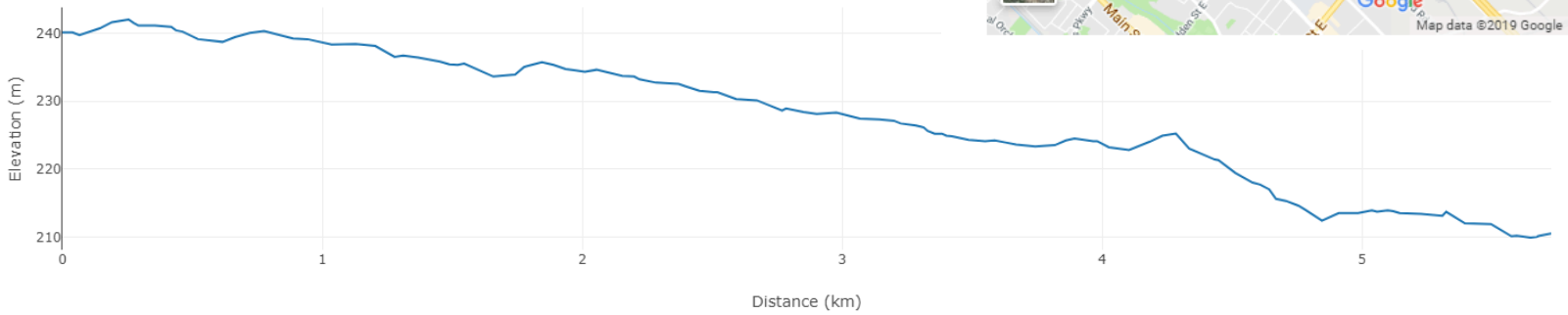
Route end: Trinity Common Terminal

Total distance: 6.100 km

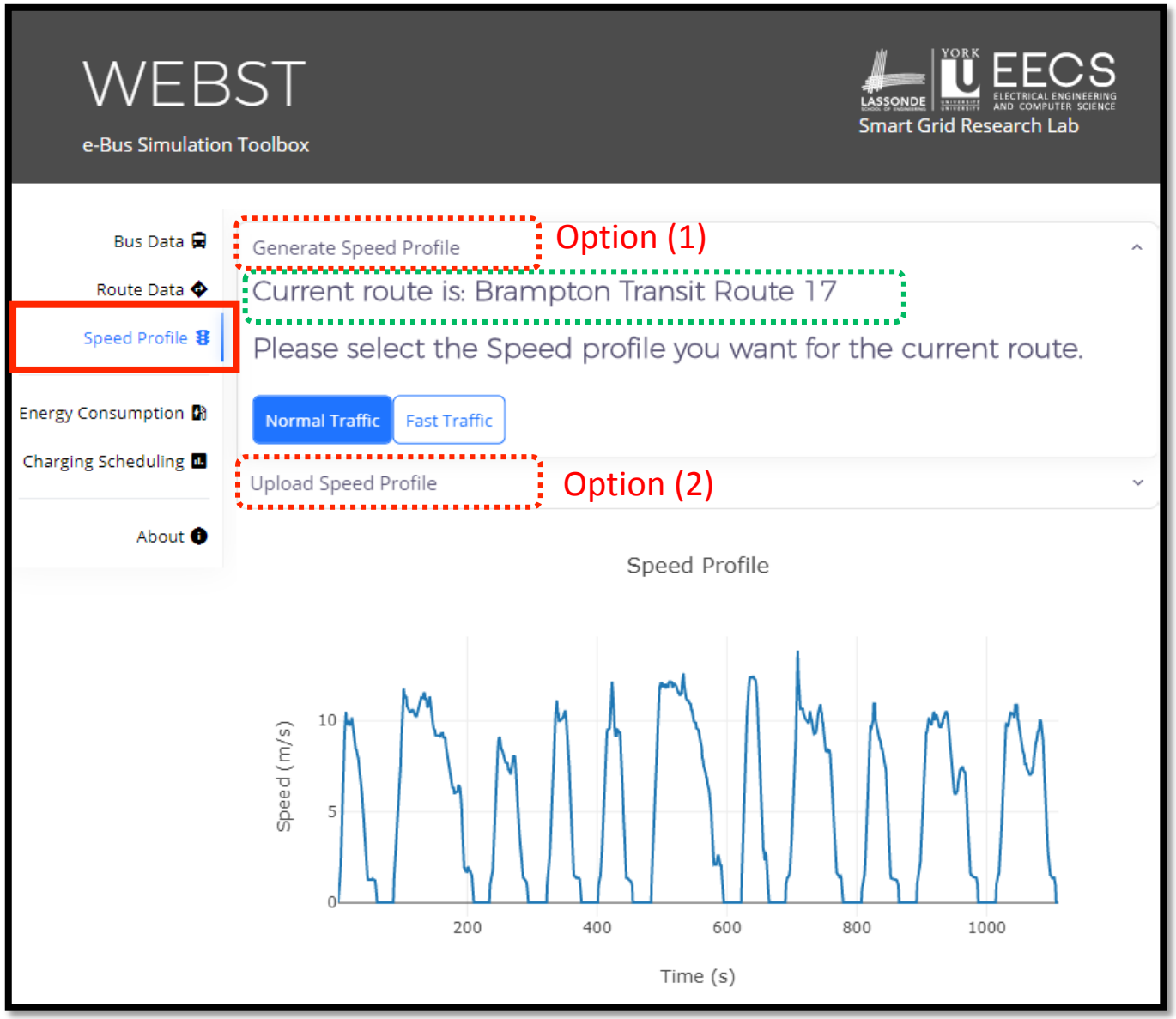
Generate

Option (2) coming soon
upload your own data

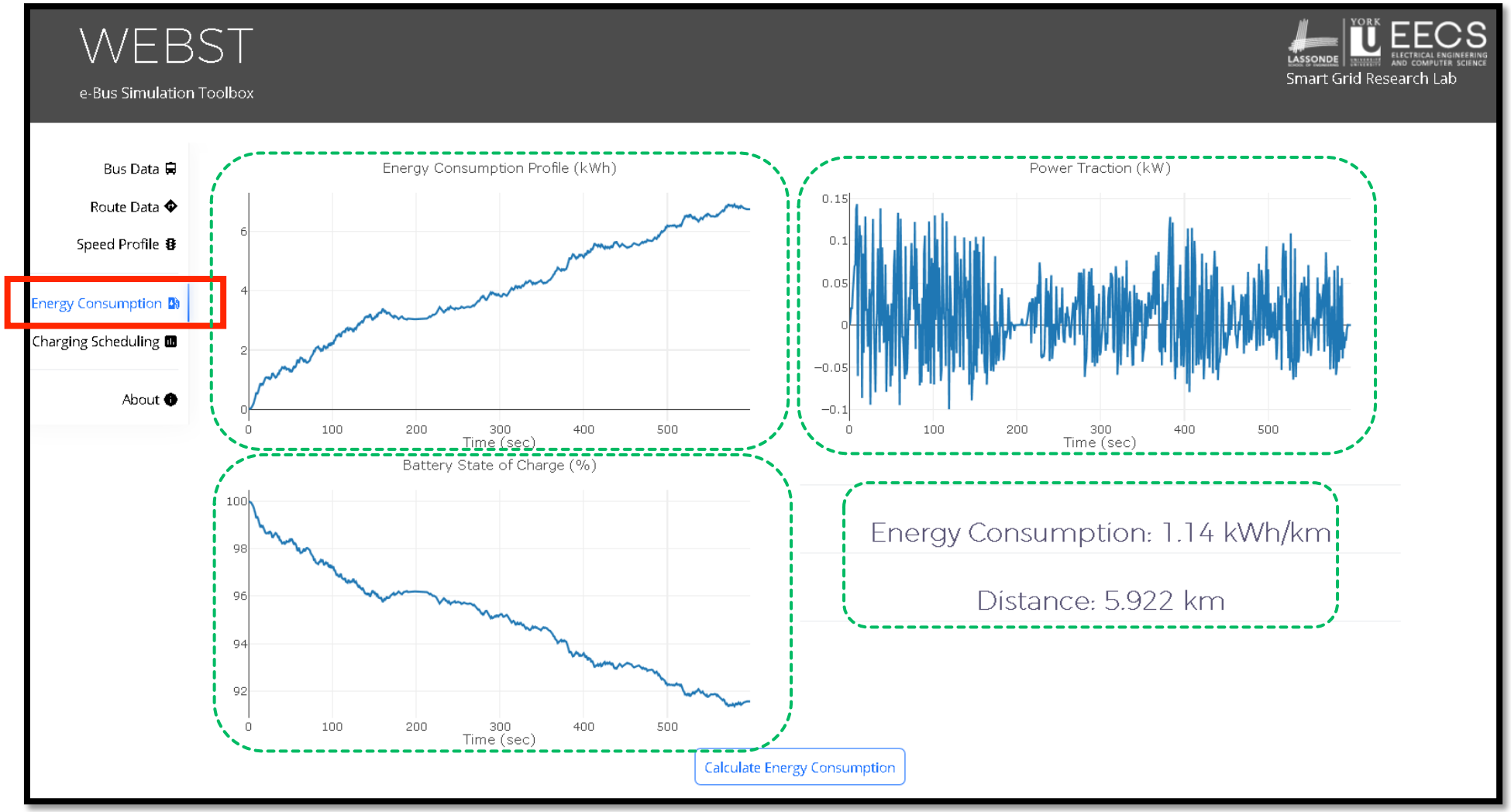




Calculating BEBs Energy Consumption



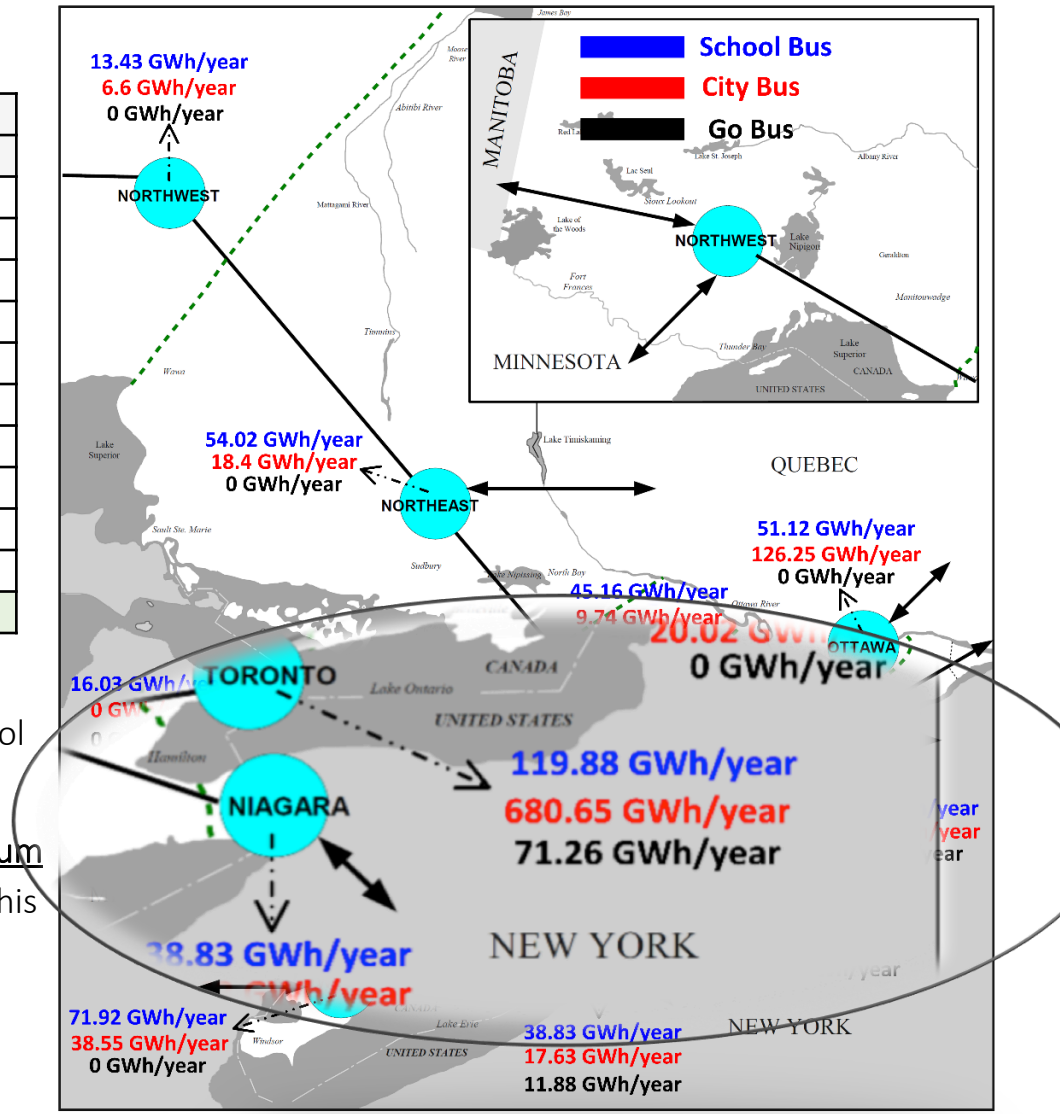
Calculating BEBs Energy Consumption



Estimated Energy Required for E-bus in Ontario

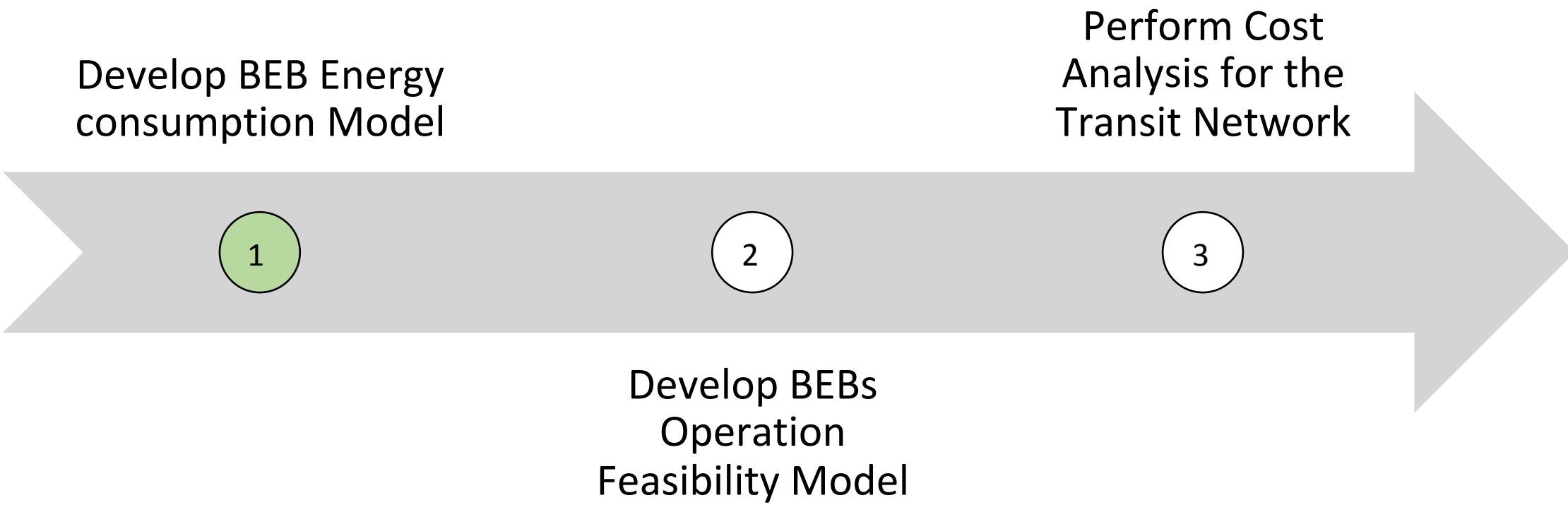
IESO zone	Annual Distance (1000 km)			Total annual Distance (10^6 km)	Energy consumption (GWh/year)		
	School bus	City bus	Go bus		Min[a]	Avg[b]	Max[c]
West	35.962	19.274	0.000	55.236	55.24	110.47	165.71
Southwest	48.176	45.039	11.876	105.091	105.09	210.18	315.27
Bruce	8.017	0.000	0.000	8.017	8.02	16.03	24.05
Niagra	19.416	8.815	5.938	34.168	34.17	68.34	102.51
Toronto	59.940	340.326	35.628	435.894	435.89	871.79	1307.68
Essa	22.579	4.870	0.0	27.449	27.45	54.90	82.35
East	47.110	10.012	0.0	57.121	57.12	114.24	171.36
Ottawa	25.562	63.123	0.0	88.685	88.69	177.37	266.06
Northeast	27.008	9.201	0.0	36.209	36.21	72.42	108.63
Northwest	6.715	3.300	0.0	10.015	10.01	20.03	30.04
Total	**300.484*10³km**	**503.960*10³km**	**53.442*10³ km**	**857.886*10⁶ km**	**857.89**	**1715.77**	**2573.66**

- Electrifying transit buses networks in Ontario (city transit, regional transit (Go Bus), and school bus) will add a significant load/demand burden on the existing electric infrastructure.
- The estimated additional load demand is between a minimum of 900 GWh/year to a maximum of 2500 GWh/year, which depends mainly on the consumption factor of the electric buses. This highlights the importance to investigate the consumption factor of each transit network.
- The additional demand due to electrified city transit, school, and GO buses requires careful/ accurate/optimal design and operation.



Annual aggregated energy consumption for city bus, school bus, and GO bus based on 2 kWh/km consumption rate

Planning Process of Electrified transit system



Developed Electric bus Feasibility/Design Model

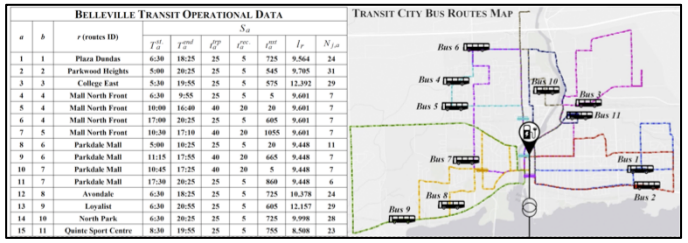
Inputs

Energy Consumption Model

Developed Electric bus energy consumption model

Microsoft Excel MATLAB

Transit Network Schedule



BELLEVILLE TRANSIT OPERATIONAL DATA

a	b	r (routes ID)	S_d						
			T_d^{st}	T_d^{end}	t_d^{pp}	t_d^{rec}	t_d^{int}	l_r	$N_{j,a}$
1	1	Plaza Dundas	6:30	18:25	25	5	725	9.564	24
2	2	Parkwood Heights	5:00	20:25	25	5	545	9.705	31
3	3	College East	5:30	19:55	25	5	875	12.392	29
4	4	Mall North Front	6:30	9:55	25	5	5	9.601	7
5	4	Mall North Front	10:00	16:40	40	20	20	9.601	7
6	4	Mall North Front	17:00	20:25	25	5	605	9.601	7
7	5	Mall North Front	10:30	17:10	40	20	1055	9.601	7
8	6	Parkdale Mall	5:00	10:25	25	5	20	9.448	11
9	6	Parkdale Mall	11:15	17:55	40	20	665	9.448	7
10	7	Parkdale Mall	10:45	17:25	40	20	5	9.448	7
11	7	Parkdale Mall	17:30	20:25	25	5	860	9.448	6
12	8	Avondale	6:30	18:25	25	5	725	10.378	24
13	9	Loyalist	6:30	20:55	25	5	605	12.157	29
14	10	North Park	6:30	20:25	25	5	725	9.998	28
15	11	Quinte Sport Centre	8:30	19:55	25	5	755	8.508	23

TRANSIT CITY BUS ROUTES MAP

Possible BEBs Options (Opportunity Vs. Overnight)

- Charger Power (kW)
- Battery capacity (kWh)

Developed Electric bus Feasibility/Design Model

Microsoft Excel MATLAB

Outputs

Charging Profile

Feasible?

Yes → **Candidate Electrification Option**

No →

Scenario 1

SOC Violation after a trip: Increase BEB Battery

Scenario 2

Insufficient recovery time to charge the BEBs: Increase charger rating and/or BEBs number.

Scenario 3

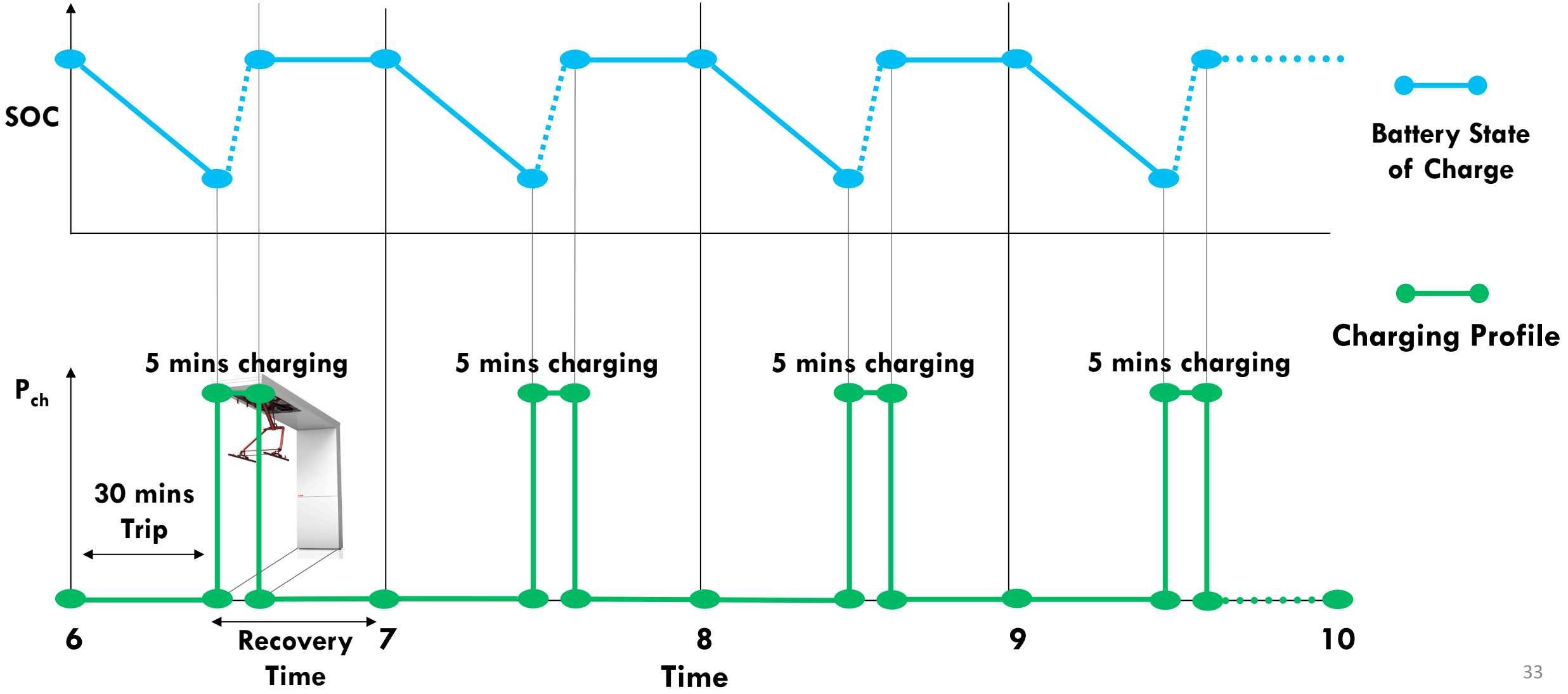
Daily Schedule Violation: Increase charger rating and/ or BEBs number.

Developed Electric bus Feasibility/Design Model

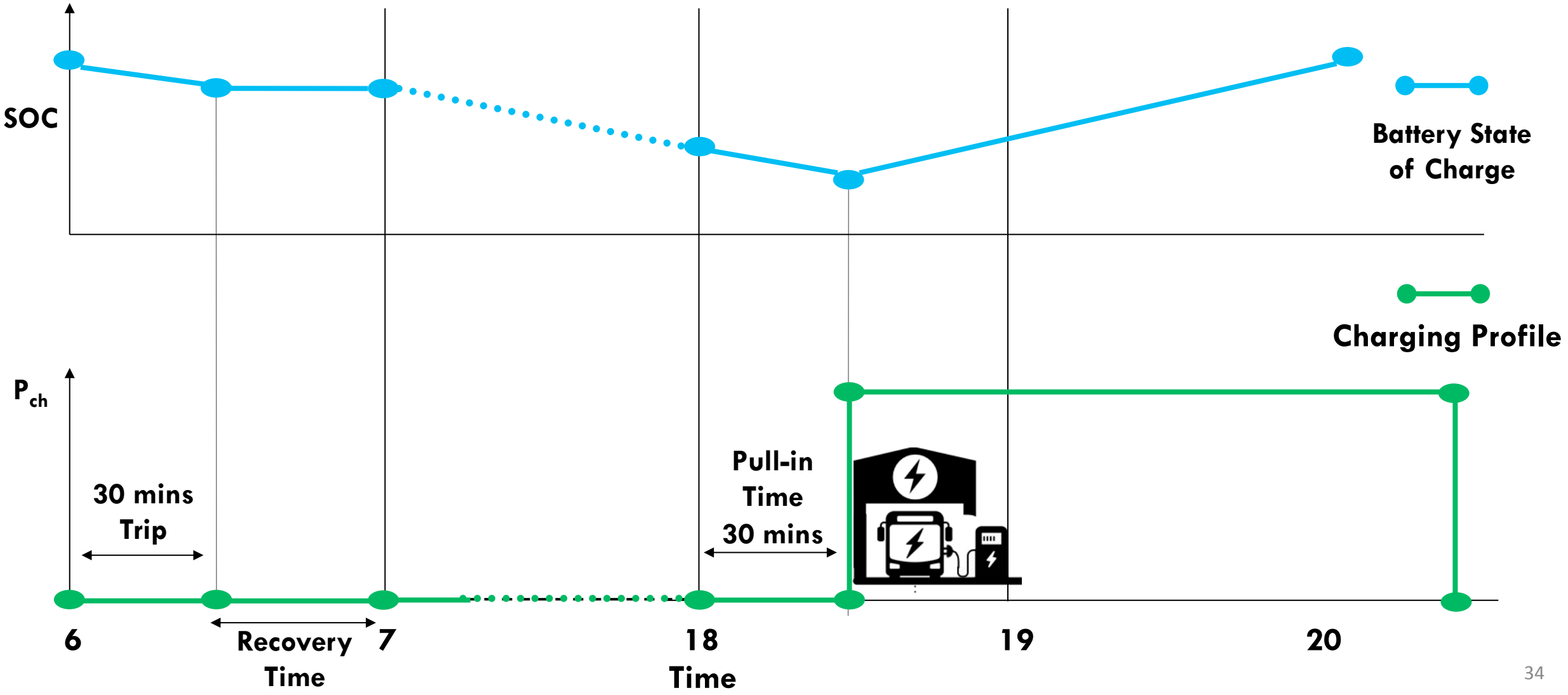
	A	B	C	D	E	F	G	H	I	J	K	L
1	**City**	**Mississauga**	utemaps, https://rideschedules.com/schedule.html?102343, https://cptdb.ca/wiki/index.php/Mississauga_Tran									
2	**Number of buses**	**460**								**Operating time schedule**		
3	**Number of routes**	**85**	**Block**	**Route number**	**Route name**	**buses/route**	**Start point**	**End point**	**Day of week**	**Start time**	**End time**	**Trip cycle time (min)**
4	**Terminal**	**Code**	**1**	1, 1C	1 Dundas (Eastbound)	6	1	2	1	4:23:00 AM	3:18:00 AM	56
5	West of Ridgeway Dr	1	**2**	1, 1C	1 Dundas (Eastbound)	6	1	2	2	4:34:00 AM	2:49:00 AM	54
6	Islington Subway Bus Terminal	2	**3**	1, 1C	1 Dundas (Eastbound)	6	1	2	3	6:35:00 AM	2:05:00 AM	54
7	CITY CENTRE TRANSIT TERMINAL	3	**4**	1, 1C	1 Dundas (Westbound)	6	2	1	1	4:40:00 AM	2:32:00 AM	56
8	GLENGARRY RD at DUNDAS ST	4	**5**	1, 1C	1 Dundas (Westbound)	6	2	1	2	5:09:00 AM	1:58:00 AM	53
9	SHERWAY GARDENS BUS TERMINAL	5	**6**	1, 1C	1 Dundas (Westbound)	6	2	1	3	7:16:00 AM	1:14:00 AM	53
10	LONG BRANCH GO STATION	6	**7**	3	3 Bloor (Eastbound)	6	3	2	1	4:54:00 AM	1:54:00 AM	42
11	LORIMAR DR at CARDIFF BLVD	7	**8**	3	3 Bloor (Eastbound)	6	3	2	2	5:36:00 AM	1:00:00 AM	40
12	DUNDAS ST west of ERINDALE STATION RD	8	**9**	3	3 Bloor (Eastbound)	6	3	2	3	7:36:00 AM	10:48:00 PM	39
13	WESTWOOD SQUARE BUS TERMINAL	9	**10**	3	3 Bloor (Westbound)	6	2	3	1	5:35:00 AM	2:34:00 AM	40
14	PORT CREDIT GO STATION	10	**11**	3	3 Bloor (Westbound)	6	2	3	2	6:17:00 AM	1:39:00 AM	37
15	ERIN CENTRE BLVD at LONGFORD DR	11	**12**	3	3 Bloor (Westbound)	6	2	3	3	7:53:00 AM	11:30:00 PM	36
16	MEADOWVALE TOWN CENTRE	12	**13**	4	4 Sherway Gardens (Eastbound)	3	4	5	1	4:58:00 AM	10:26:00 PM	40
17	REXDALE BLVD at ISLINGTON AVE	13	**14**	4	4 Sherway Gardens (Eastbound)	3	4	5	2	6:14:00 AM	9:42:00 PM	40
18	CLARKSON GO STATION	14	**15**	4	4 Sherway Gardens (Eastbound)	3	4	5	3	7:54:00 AM	7:27:00 PM	41
19	CARDIFF BLVD east of TOMKEN RD	15	**16**	4	4 Sherway Gardens (Westbound)	3	5	4	1	5:38:00 AM	11:12:00 PM	47
20	TRILLIUM HOSPITAL BUS TERMINAL	16	**17**	4	4 Sherway Gardens (Westbound)	3	5	4	2	6:54:00 AM	10:27:00 PM	44
21	HURONTARIO & 407 PARK and RIDE	17	**18**	4	4 Sherway Gardens (Westbound)	3	5	4	3	8:40:00 AM	8:13:00 PM	44
22	ERINDALE GO STATION	18	**19**	5	5 Dixie (Northbound)	5	6	7	1	4:17:00 AM	1:39:00 AM	50
23	COMMERCE BLVD at RENFORTH STATION	19	**20**	5	5 Dixie (Northbound)	5	6	7	2	4:51:00 AM	12:01:00 AM	47
24	HUMBER COLLEGE BLVD at ETOBICOKE HOSPITAL	20	**21**	5	5 Dixie (Northbound)	5	6	7	3	7:40:00 AM	8:28:00 PM	43
25	SHERIDAN CENTRE BUS TERMINAL	21	**22**	5	5 Dixie (Southbound)	5	7	6	1	4:17:00 AM	12:44:00 AM	52
26	MATHESON BLVD east of HURONTARIO ST	22	**23**	5	5 Dixie (Southbound)	5	7	6	2	5:43:00 AM	12:16:00 AM	48
27	SOUTH COMMON CENTRE BUS TERMINAL	23	**24**	5	5 Dixie (Southbound)	5	7	6	3	8:28:00 AM	9:16:00 PM	43
28	ERIN MILLS STATION WEST	24	**25**	6	6 Credit Woodlands (Eastbound)	3	8	3	1	5:10:00 AM	1:40:00 AM	31
29	WOODBINE CENTRE BUS TERMINAL	25	**26**	6	6 Credit Woodlands (Eastbound)	3	8	3	2	5:41:00 AM	11:30:00 PM	30
30	TRELAWNY CIR at MOCKINGBIRD LANES	26	**27**	6	6 Credit Woodlands (Eastbound)	3	8	3	3	8:00:00 AM	8:32:00 PM	30
31	LISGAR GO STATION	27	**28**	6	6 Credit Woodlands (Westbound)	3	3	8	1	5:33:00 AM	1:09:00 AM	30

Terms defintion | Midland and Penetanguishene | Barrie | Bradford | Brampton | Hamilton | St. Catharines | YRT | **Mississauga**

Developed Electric bus Feasibility/Design Model (Opportunity)



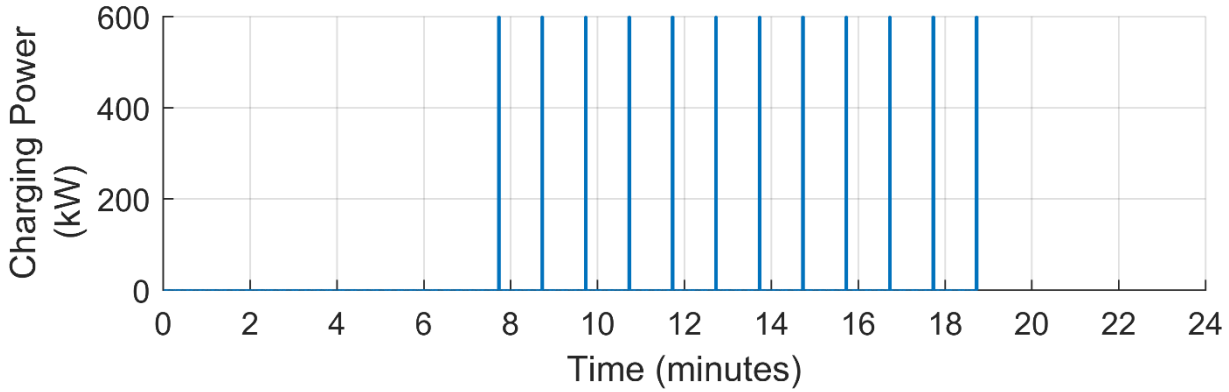
Developed Electric bus Feasibility/Design Model (Overnight)



Developed Electric bus Feasibility/Design Model

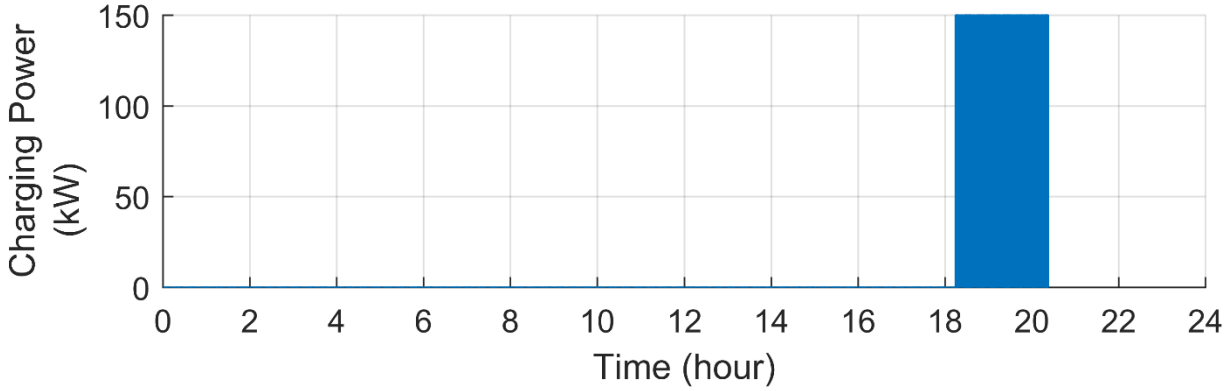
❑Typical charging profile BEB:

1. Opportunity Electrification Concept:



- Scattered charging across the day
- High charging power magnitude
- Charge in few minutes

2. Overnight Electrification Concept:

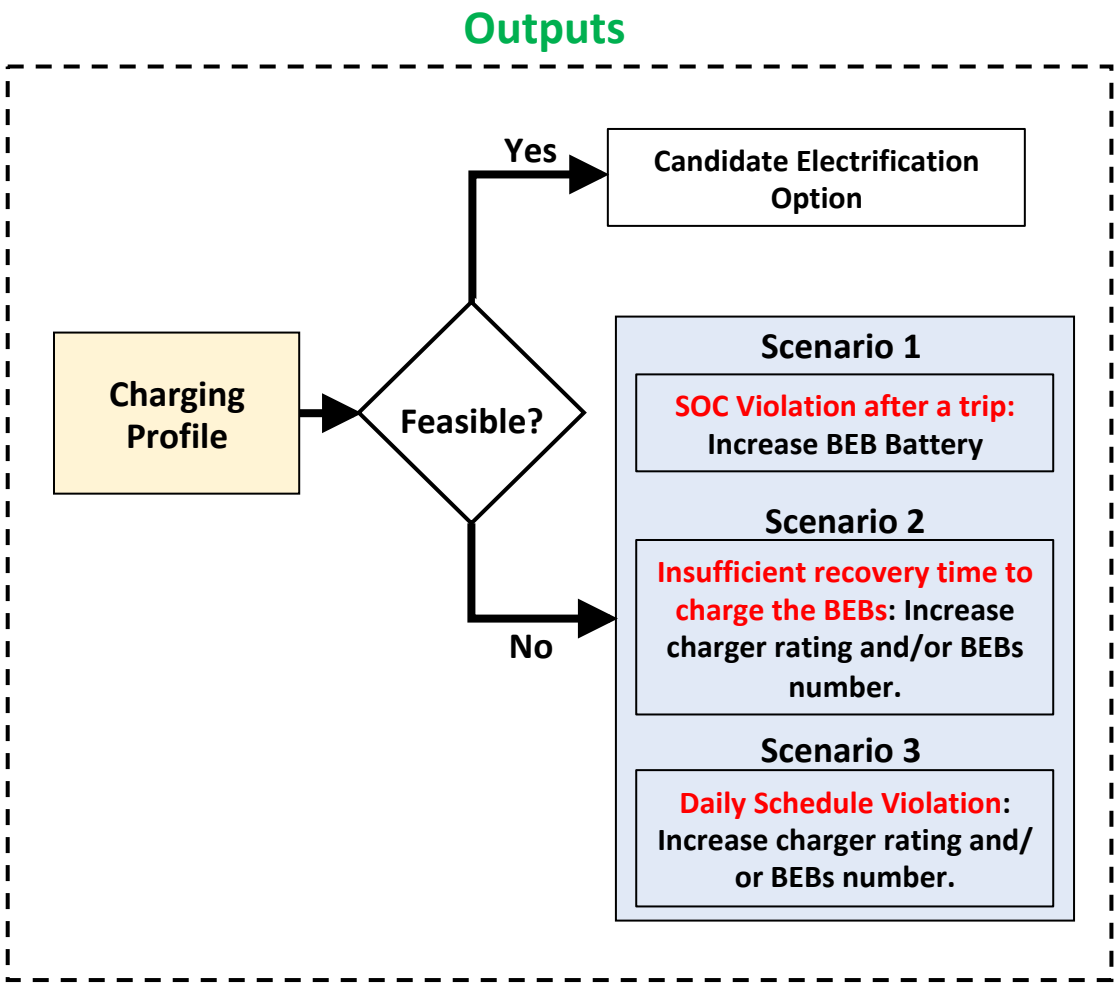


- Bulk charging at the end of the day
- Low charging power magnitude
- Charge in few hours

Developed Electric bus Feasibility/Design Model

❑Feasibility Constraints Check:

1. Battery is sufficient for the trip distance, else increase the battery size.
2. In opportunity charging, the chargers should provide sufficient energy during the recovery time, else increase the charger size and/or number of BEBs.
3. In overnight charging, BEBs charging sessions should ends before the next day scheduled trip, else increase the charger size and/or number of BEBs.

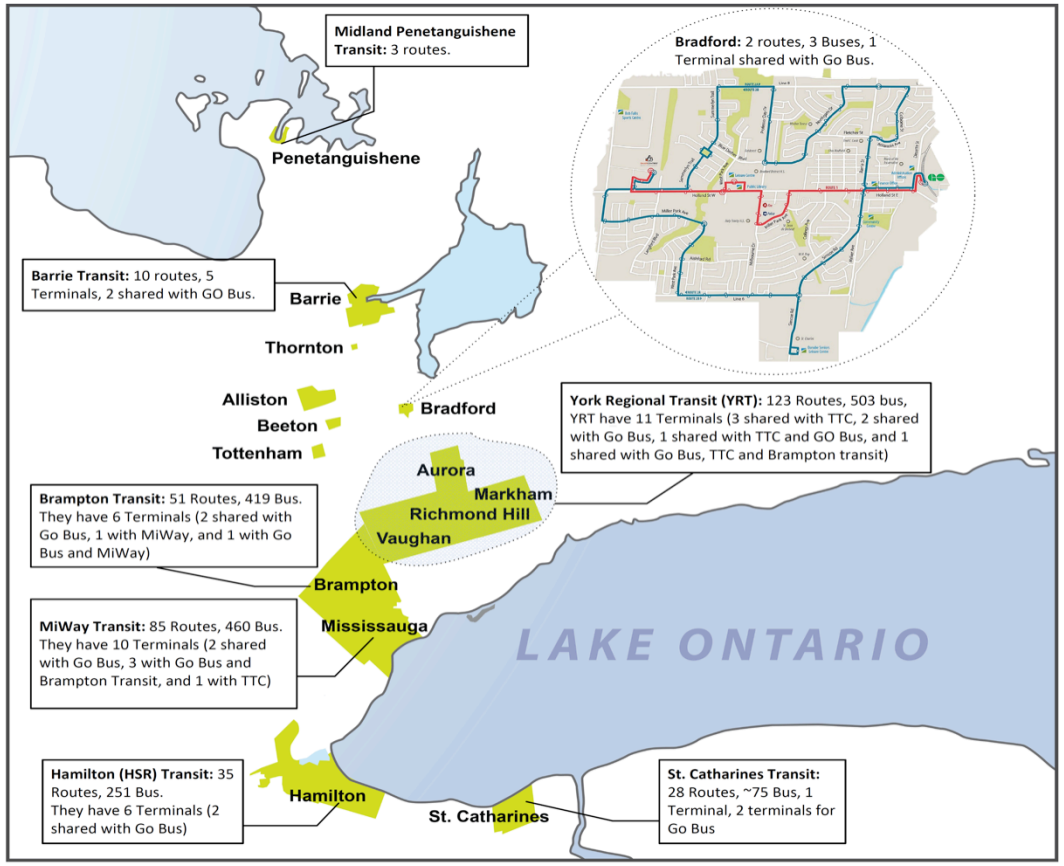


Developed Electric bus Feasibility/Design Model

❑ Example for the feasibility check:

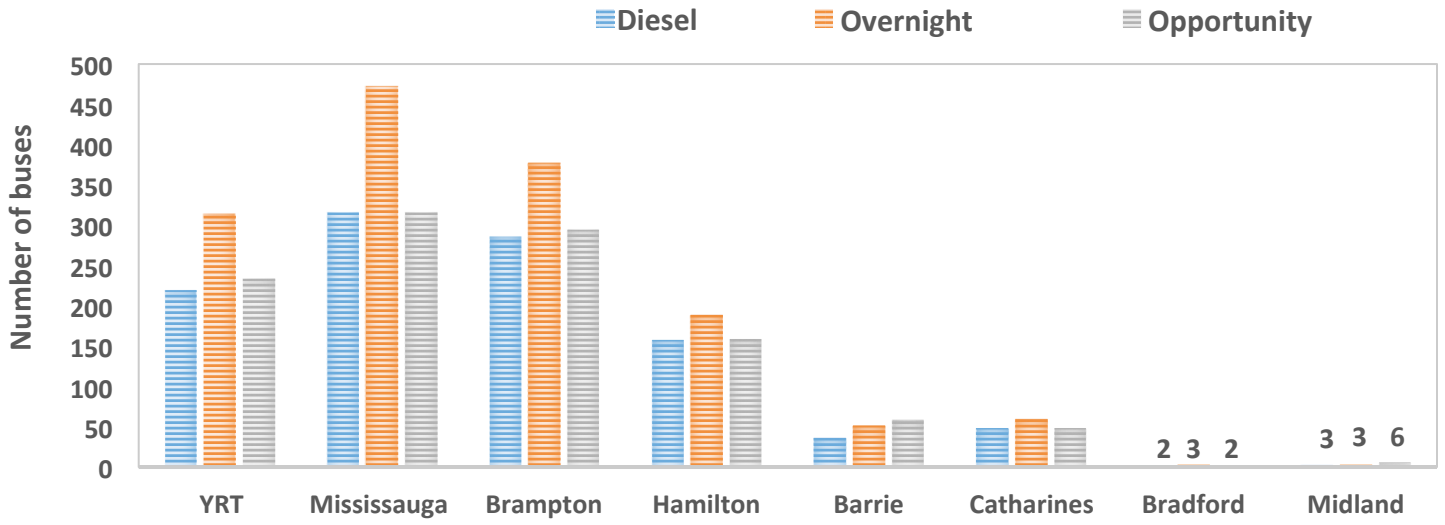
- Evaluate the technical operation feasibility for BEBs (i.e., overnight and opportunity) to take over diesel buses for each bus fleet within Alectra's coverage area based on the specified options below:

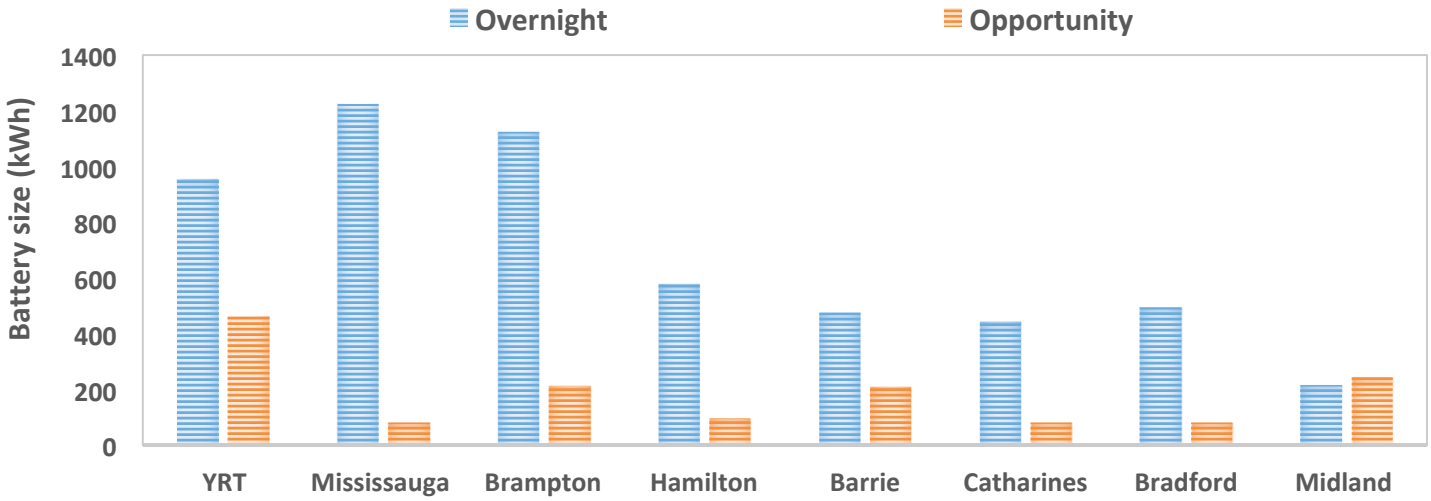
Bus specifications for different BEB configurations		
Variables	**Opportunity Electric Bus**	**Overnight Electric Bus**
Manufacture	Proterra	BYD
Model	Catalyst	40-Electric
Length (ft.)	40	40
Seating (#)	41	36
Battery Capacity (kWh)	80	324
Charging Power (KW)	500	200
Charging Rate (kW/min)	8.33	3.33



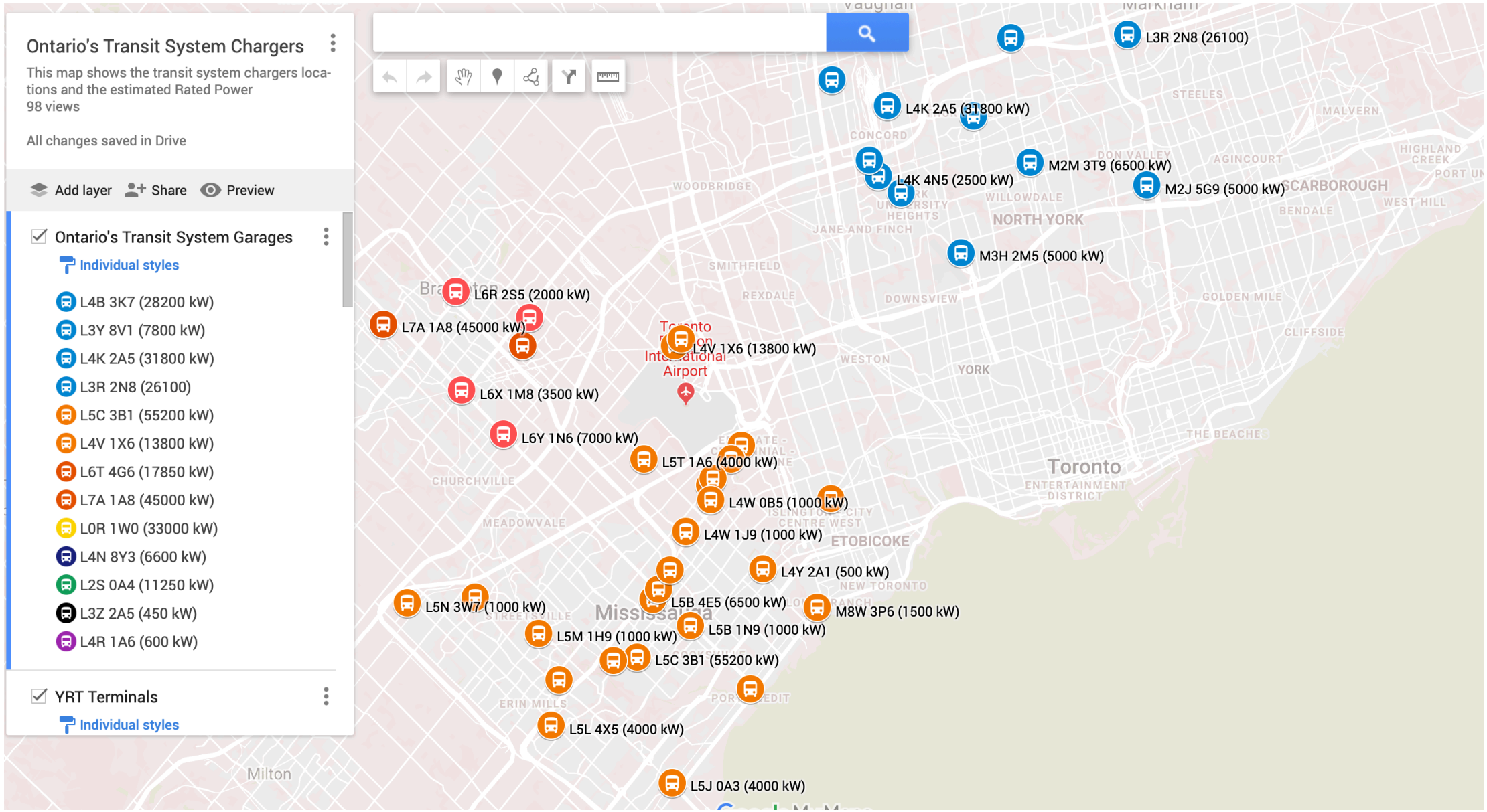
Bus fleets operation feasibility

- Overnight and opportunity BEBs are capable of satisfying the bus fleet operation requirements. However, the number of required BEBs may be higher than number of DBs in some routes.
- Route characteristics (i.e., trip distance, number of daily trips, and recovery time) significantly affects the number of required BEBs
  - ❖ Recovery time and trip distance (kWh per trip) are the major factors which affect number of Opportunity BEBs.
  - ❖ Daily distance (trip distance × number of daily trips) is the main factor which affects number of Overnight EBs.

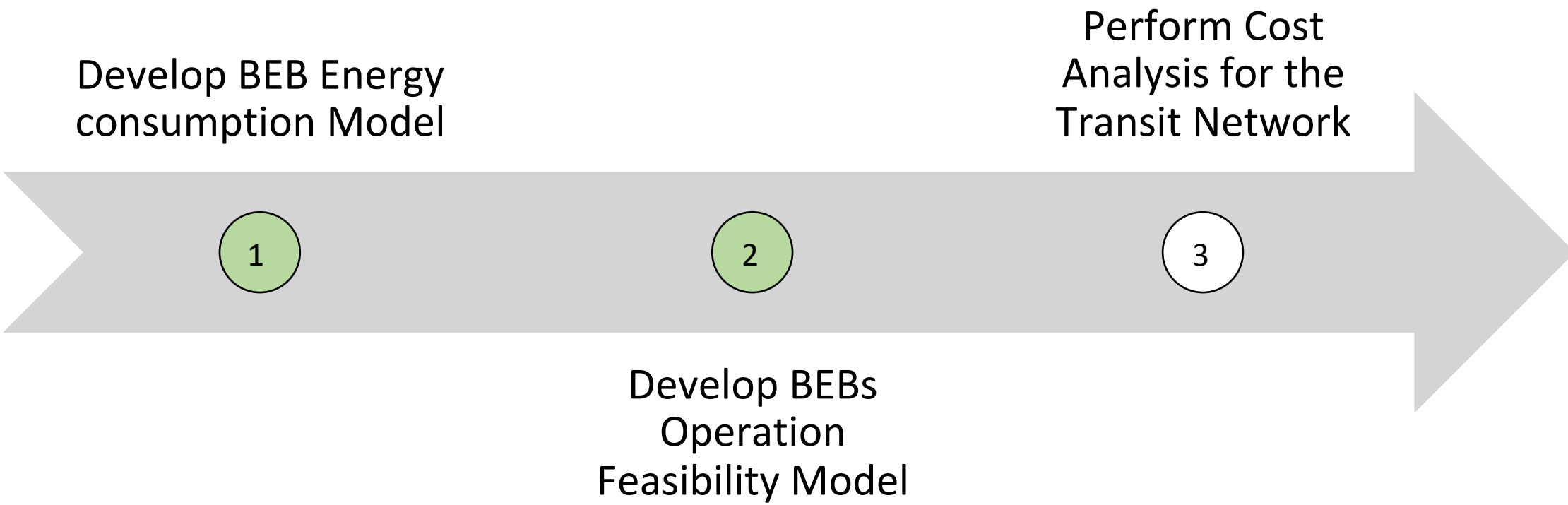




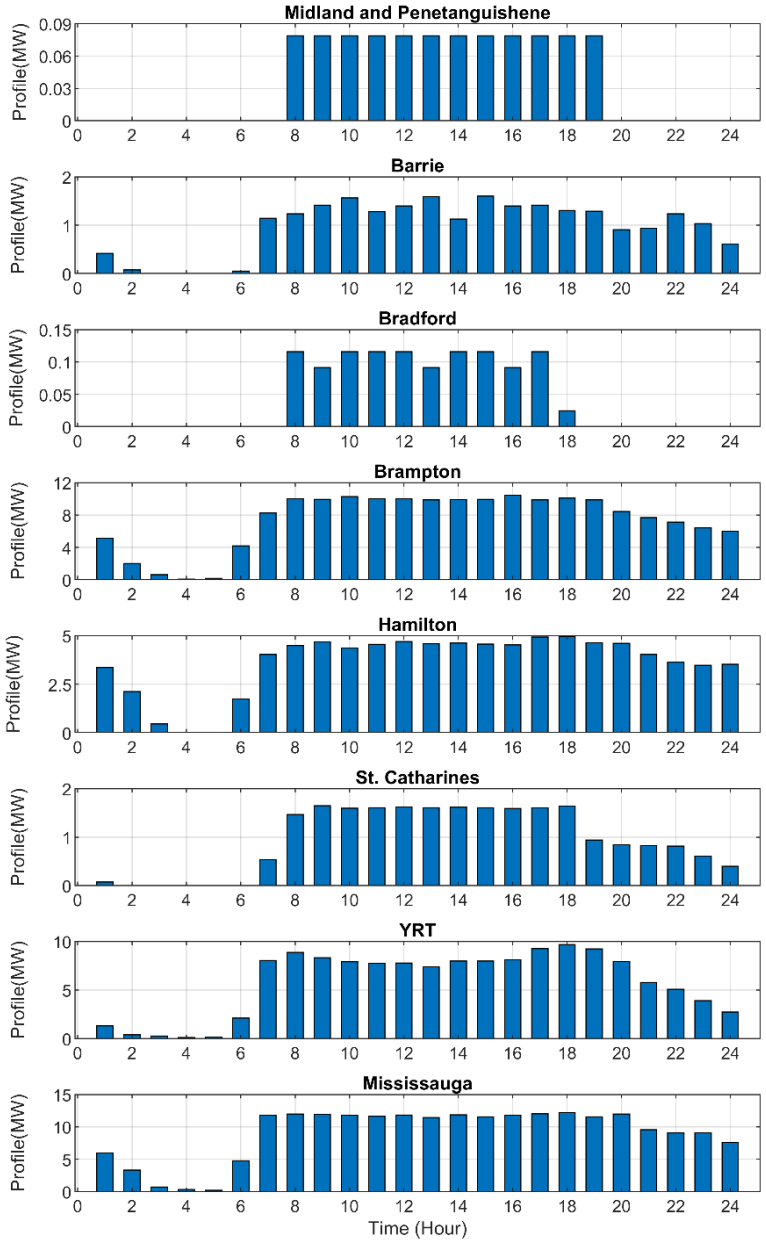
Customized Design for the chargers



Planning Process of Electrified transit system

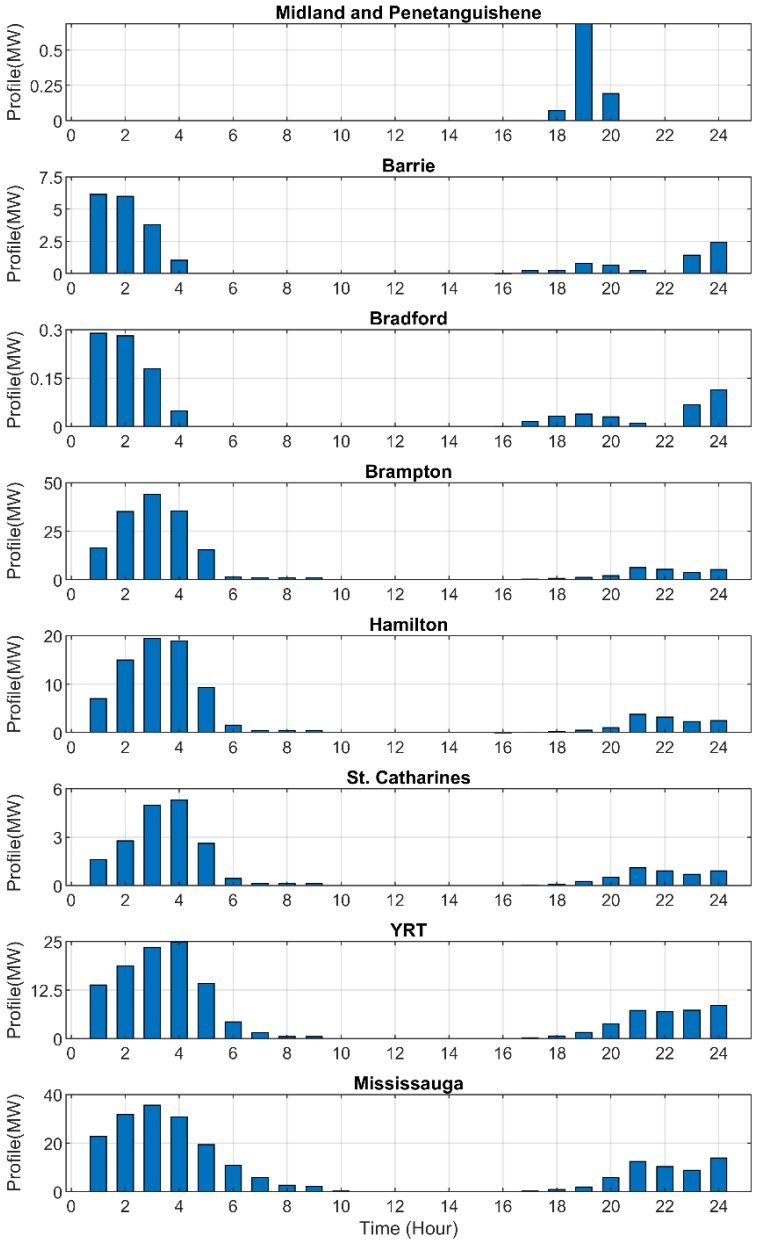


BEBs Charging Cost Analysis



Aggregated opportunity charging profile

Aggregated overnight charging profile

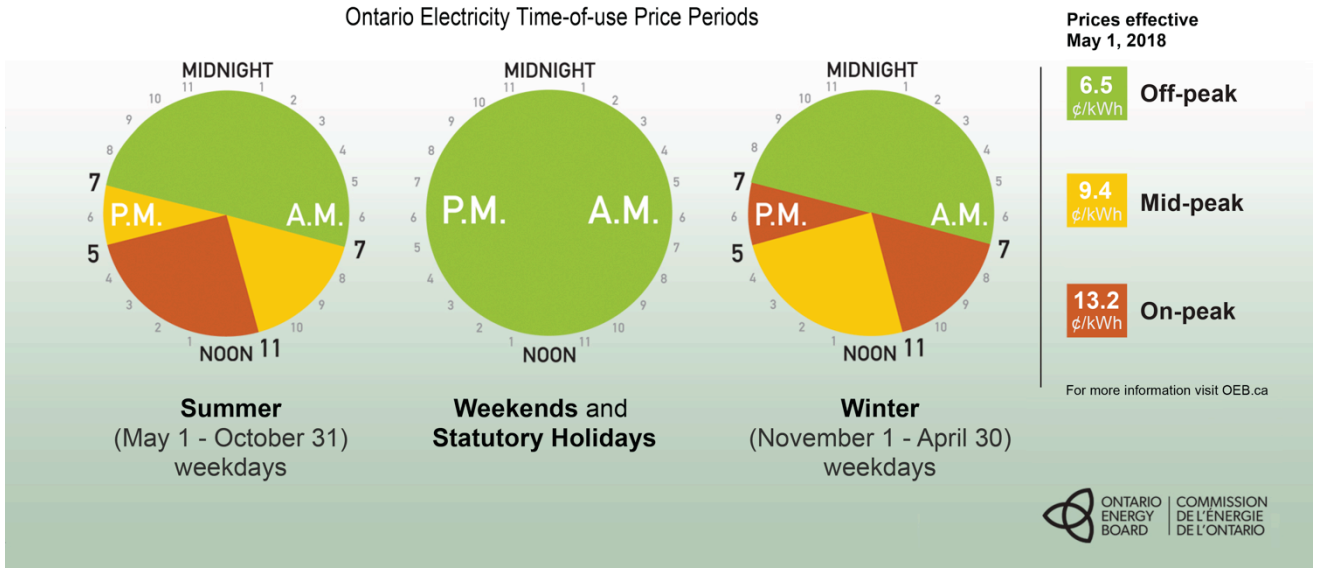


BEBs Charging Cost Analysis

Load Metering:

- For billing purpose utilities classify the consumers into different rate classes:

1. **Residential Class**: Using a smart meter residential customers are metered and billed based on the kWh consumption. Where, the electricity rate is determined based **Time of Use (TOU) rates**, besides the electricity delivery and regulatory charges.



Time of Use electricity rates applied by the Ontario Energy Board

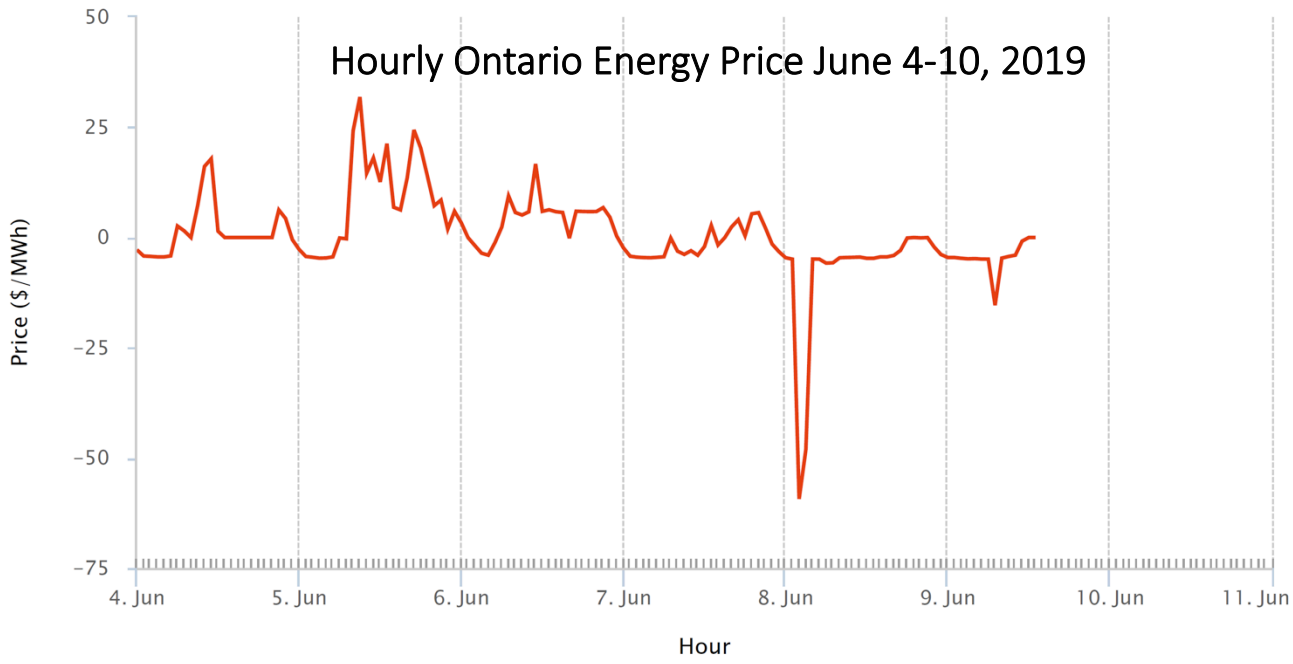
https://www.oeb.ca/rates-and-your-bill/electricity-rates/managing-costs-time-use-rates
https://www.powerstream.ca/customers/rates-support-programs/residential-rates.html
https://www.hydroone.com/rates-and-billing

BEBs Charging Cost Analysis

Load Metering:

❑For billing purpose utilities classify the consumers into different rate classes:

2. General Service (GS): also known as **business** account and is billed using the **Hourly Ontario Energy Price (HOEP)** and includes the following classifications:
   a) GS < 50 kW - (Low volume consumer)
   b) GS > 50 kW
   c) GS > 5000 kW (Large Use)



http://www.ieso.ca/en/Power-Data
https://www.powerstream.ca/customers/rates-support-programs/residential-rates.html
https://www.hydroone.com/rates-and-billing

4-10 Jun

BEBs Charging Cost Analysis

Load Metering:

❑For billing purpose utilities classify the consumers into different rate classes:

2. General Service (GS): also includes **Delivery and Regulatory Charges** as shown in the table.

➢ Delivery and Regulatory Charges for different consumer rate class issued by Alectra Utility in Ontario effective by January 2019

Rate Classification	non-residential consumers (GS> 50 kW)	non-residential consumers (GS> 5000 kW)
Fixed Charge ($/month)	146.46	6282.42
Distribution Charge ($/kW)	2.9028	-0.2810
Transmission Network charge ($/kW)	2.7391	3.1569
Transmission Connection charge ($/kW)	1.4431	1.3931
Loss adjustment factor ($/kWh)	3.69%	1.45%
Wholesale Market Services ($/kWh)	0.003	
Standard Supply Service Charge ($/kWh)	0.003	
Capacity Based Recovery ($/kWh)	0.0004	
Rural and Remote Rate Protection	0.0005	

https://www.powerstream.ca/customers/rates-support-programs/residential-rates.html

BEBs Charging Cost Analysis

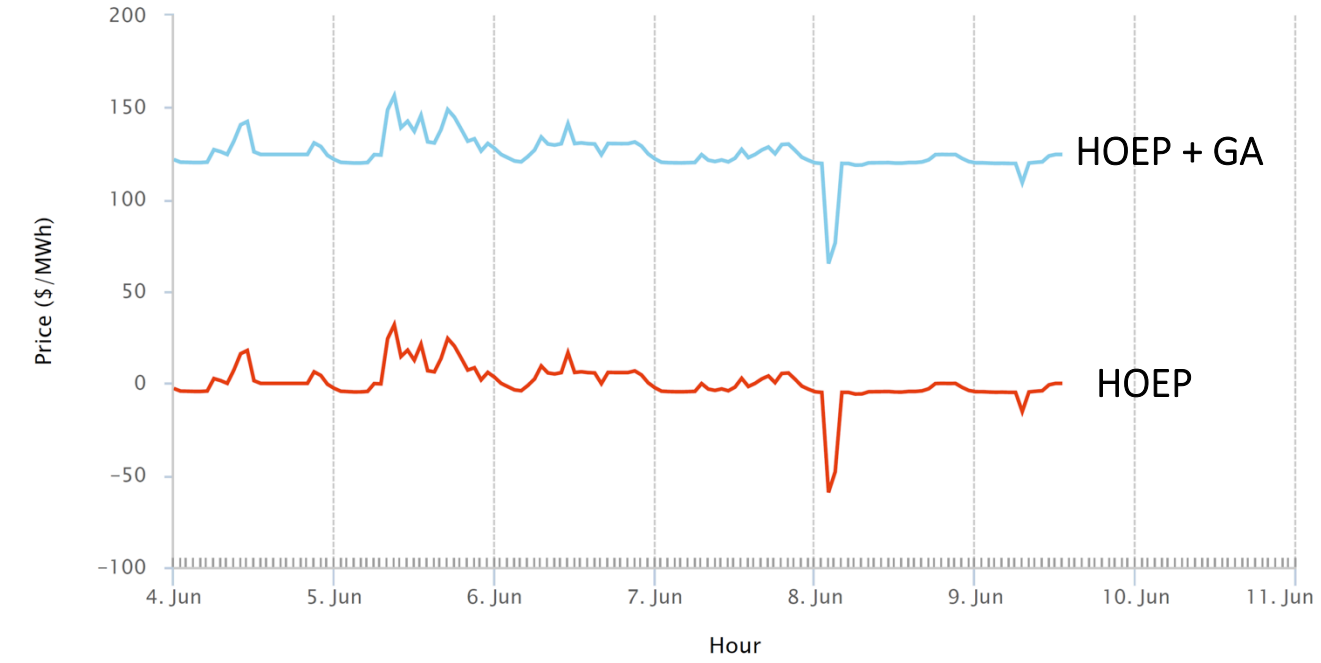
Load Metering:

❑For billing purpose utilities classify the consumers into different rate classes:

2. General Service (GS): in addition includes the **Global Adjustment** cost and is classified as:

a) Class A: customers pay GA according to their contribution to the top five peaks in Ontario over the year.

b) Class B: customers pay GA according to a monthly fixed rates announced by the IESO.



http://www.ieso.ca/en/Power-Data

BEBs Charging Cost Analysis

Load Metering:

❑For billing purpose utilities classify the consumers into different rate classes:

2. General Service (GS): in addition includes the **Global Adjustment** cost and is classified as:

2018 Historical GA prices for Class B in $/MWh and the GA system-wide cost in M$ for the calculation of Class A payment.												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly GA class B ($/MWh)	67.36	81.67	94.81	99.59	107.93	118.96	77.37	74.90	85.84	120.59	98.55	74.04
Monthly GA system wide (M$)	786.8	796.3	962.8	937.8	1001.1	1151.0	911.8	876.4	847.3	1135.3	936.4	853.2

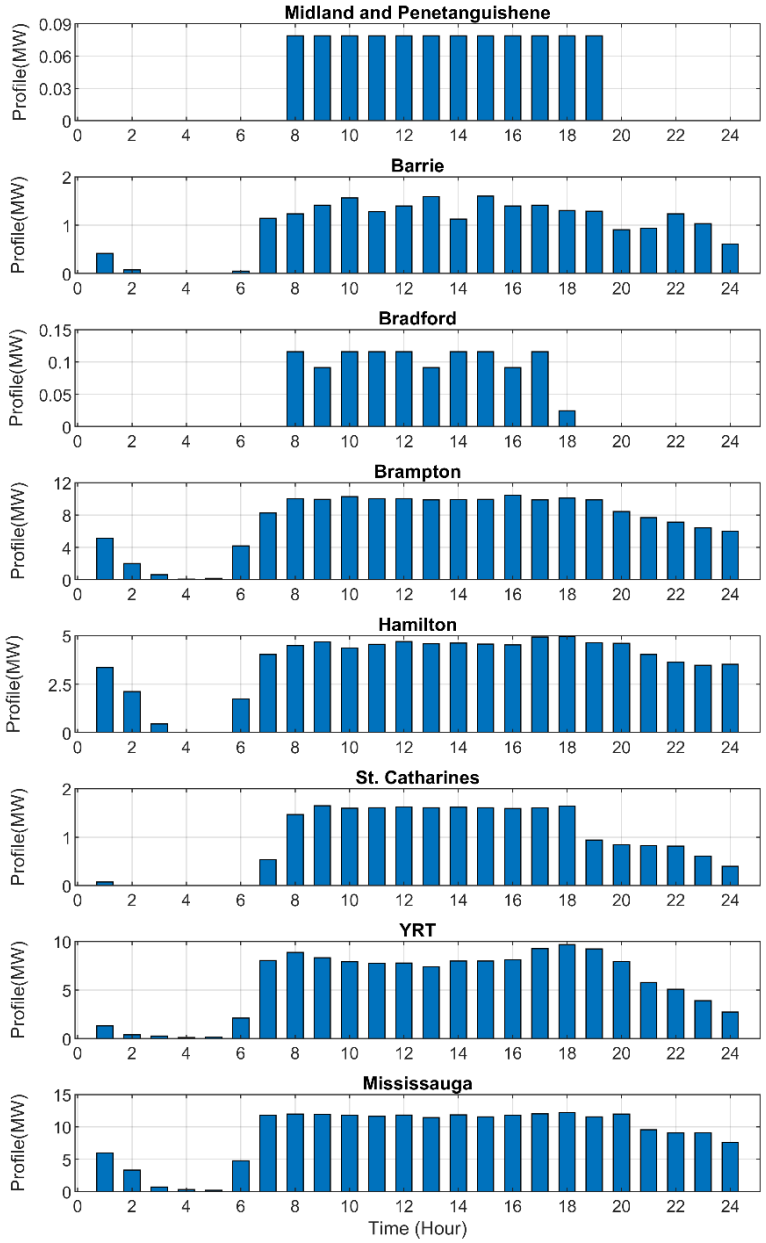
Class B GA ($) = Monthly GA class B × Monthly Consumption

Class A GA ($) = Monthly GA System Wide × Contribution % to top five peaks

Historical top five peaks in Ontario in 2018		
Top five Ontario's Peak in 2018 (MW)	Hour Time	Date
21998.881	17	June-12-17
20984.125	18	July-19-17
21811.609	17	September 25, 2017
21665.003	17	September-26-17
20885.139	18	January-05-18

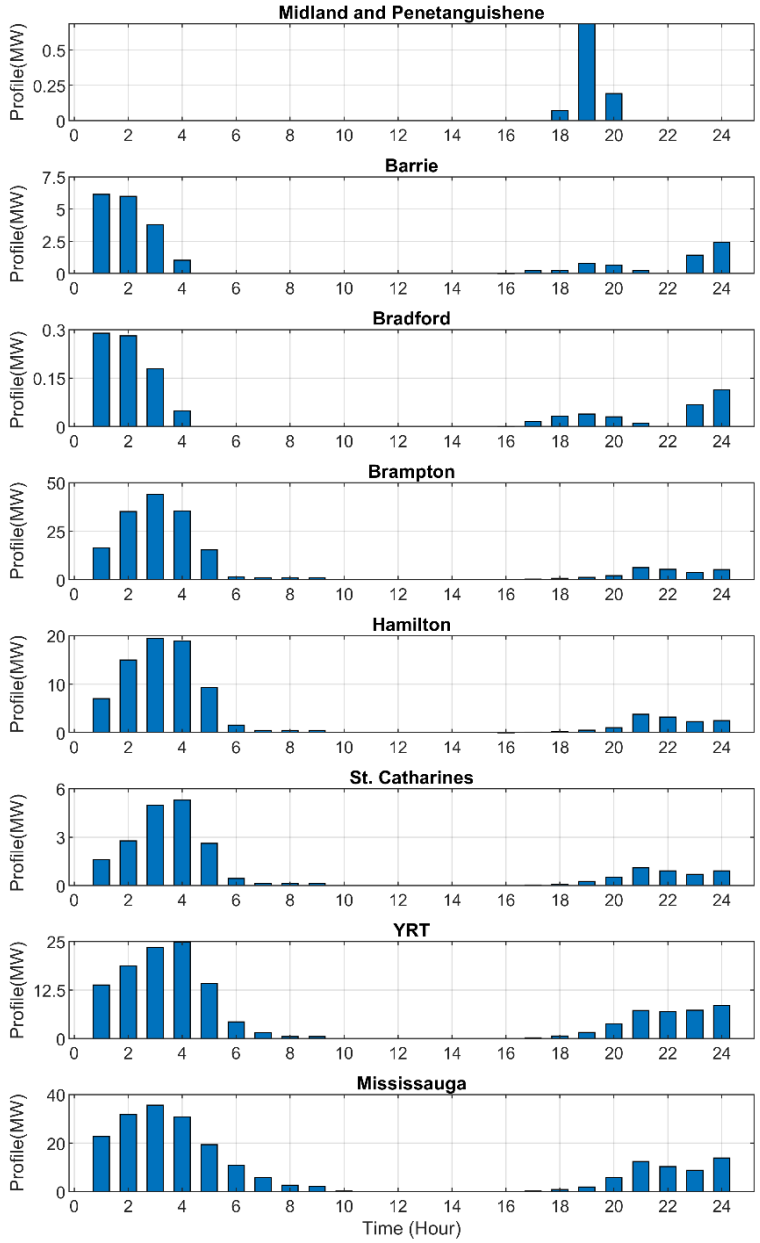
http://www.ieso.ca/en/Power-Data

BEBs Charging Cost Analysis



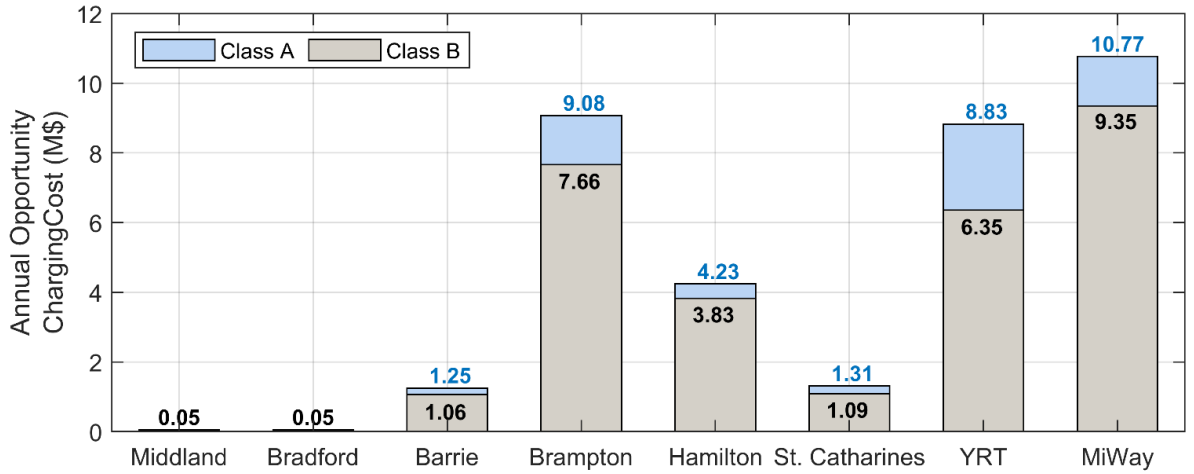
Aggregated opportunity charging profile

Aggregated overnight charging profile

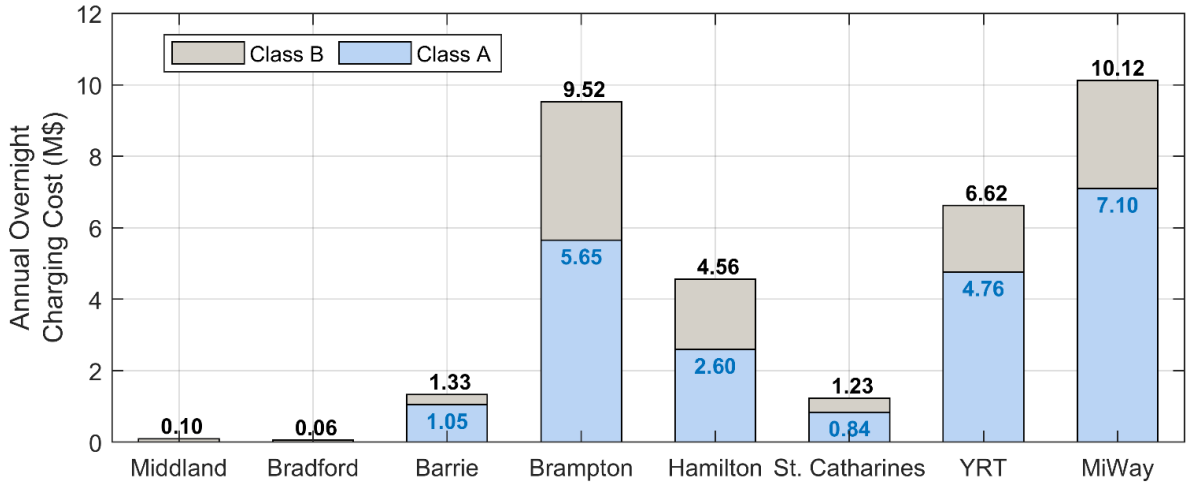


BEBs Charging Cost Analysis

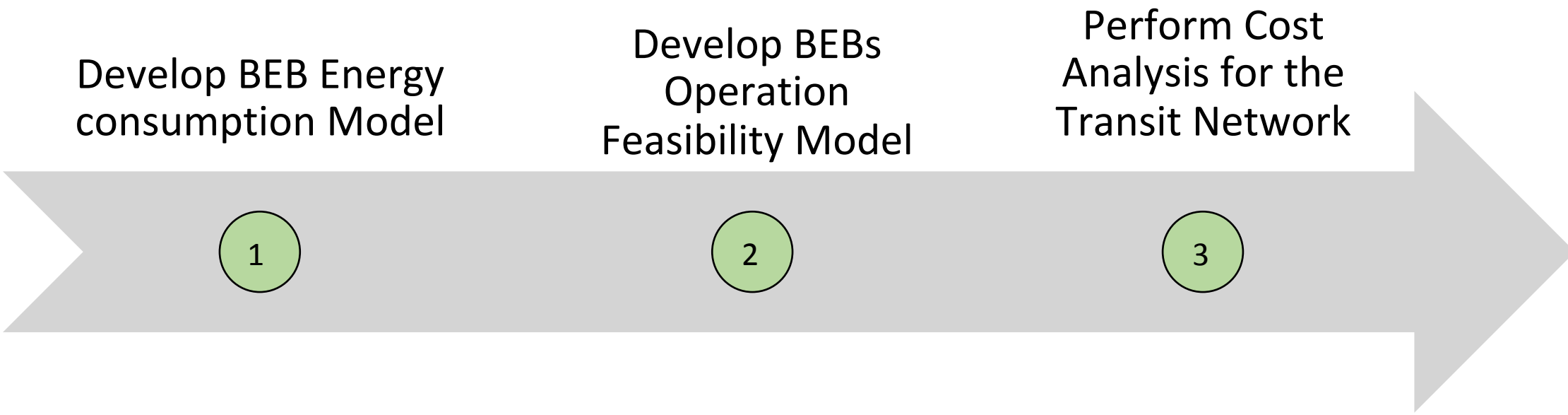
- Opportunity charging operation cost for electrified transit networks for Class A and Class B electricity market participant.
  - ✓ Class B is more economical for Opportunity charging operation



- Overnight charging operation cost for electrified transit networks for Class A and Class B electricity market participant.
  - ✓ Class A is more economical for Overnight charging operation.



Summary



- ✓ Determine the BEB consumption ADVISOR
- ✓ Develop an HVAC model to overcome ADVISOR drawbacks
- ✓ WEBST "Web-based application" is under development

- ✓ Logic based model is developed to create:
  1. Charging profile
  2. Validate the feasibility
  3. Design the BEBs battery and charger.

- ✓ Cost analysis for the studies transit network within Alectra's Coverage area is carried out.

THANK YOU

Table I: Total Daily consumption and covered distance by each electrified transit network.

	Midland and Penetanguishene	Barrie	Bradford	Brampton	Hamilton	St. Catharines	YRT	Mississauga
Daily Consumption (MWh)	283	7521	290	54423	27362	7298	41996	65855
Covered Distance (1000 km)	142	3760	145	27211	13681	3649	20998	32928

Table 1: Transit Networks Operation cost and normalized indices for the opportunity charging scenario**

	Midland and Penetanguishene	Bradford	Barrie	Brampton	Hamilton	St. Catharines	YRT	Mississauga
Class A Opportunity								
Total GA Cost ($)			$ 879,027	$ 6,409,943	$ 2,919,442	$ 889,233	$ 6,331,893	$ 7,471,469
Total Annual ($)			**$ 1,248,405**	**$ 9,075,501**	**$ 4,234,925**	**$ 1,309,790**	**$ 8,829,070**	**$ 10,770,813**
$/km Index			0.33	0.33	0.31	0.36	0.42	0.33
$/kWh Index			0.17	0.17	0.15	0.18	0.21	0.16
Class B Opportunity								
Total GA Cost ($)	$ 26,041	$ 26,645	$ 690,693	$ 4,997,699	$ 2,512,614	$ 670,054	$ 3,856,840	$ 6,048,053
Total Annual ($)	**$ 45,825**	**$ 48,537**	**$ 1,060,072**	**$ 7,663,257**	**$ 3,828,096**	**$ 1,090,610**	**$ 6,354,018**	**$ 9,347,397**
$/km Index	0.32	0.33	0.28	0.28	0.28	0.30	0.30	0.28
$/kWh Index	**0.16**	**0.17**	**0.14**	**0.14**	0.14	0.15	0.15	0.14

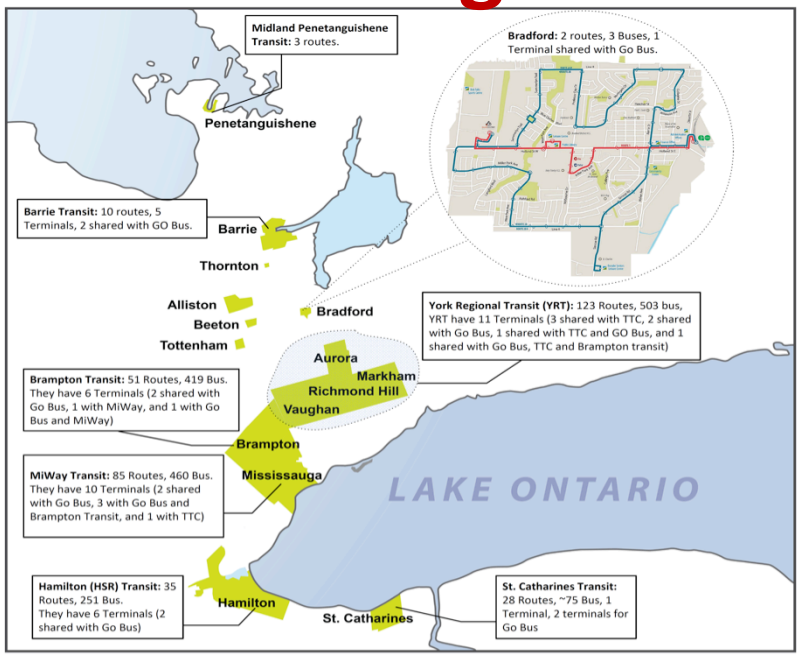
Table 2: Transit Networks Operation cost and normalized indices for the overnight charging scenario**

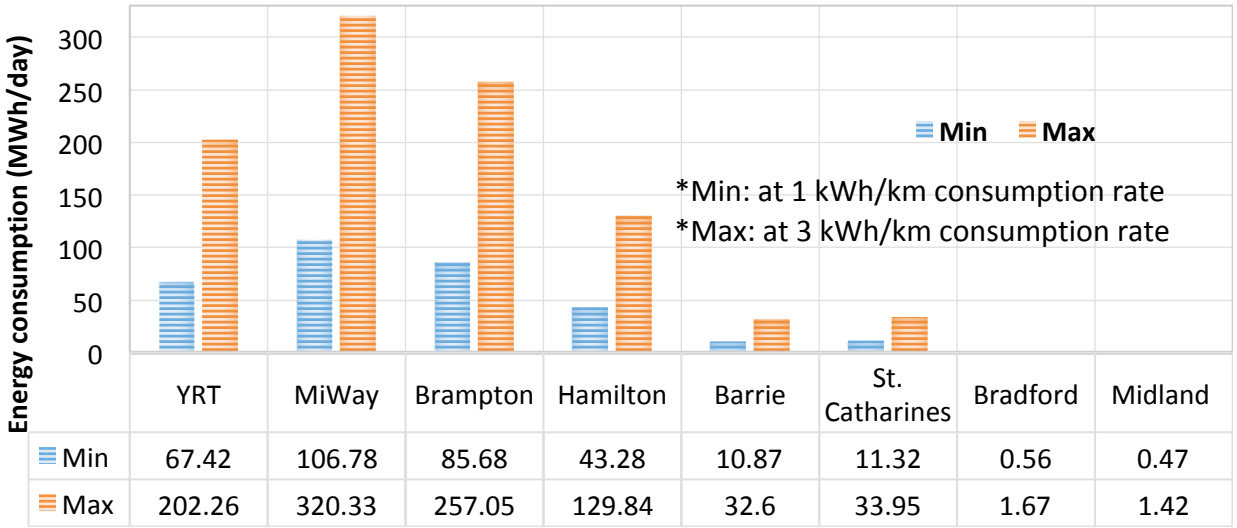
	Midland and Penetanguishene	Barrie	Bradford	Brampton	Hamilton	St. Catharines	YRT	Mississauga
Class A Overnight								
Total GA Cost ($)			$ 409,977	$ 1,127,416	$ 552,290	$ 276,091	$ 1,996,985	$ 3,026,768
Total Annual ($)			**$ 1,051,921**	**$ 5,652,542**	**$ 2,600,223**	**$ 837,638**	**$ 4,761,618**	**$ 7,103,462**
$/km Index			0.28	0.21	0.19	0.23	0.23	0.22
$/kWh Index			**0.14**	0.10	**0.10**	**0.11**	**0.11**	**0.11**
Class B Overnight								
Total GA Cost ($)	$ 26,041	$ 26,645	$ 690,693	$ 4,997,699	$ 2,512,614	$ 670,054	$ 3,856,840	$ 6,048,053
Total Annual ($)	**$ 95,726**	**$ 57,615**	**$ 1,332,637**	**$ 9,522,824**	**$ 4,560,546**	**$ 1,231,601**	**$ 6,621,474**	**$ 10,124,747**
$/km Index	0.68	0.40	0.35	0.35	0.33	0.34	0.32	0.31
$/kWh Index	0.34	0.20	0.18	0.17	0.17	0.17	0.16	0.15

**Green cells with bold green font represents the cheapest option for a given transit network.

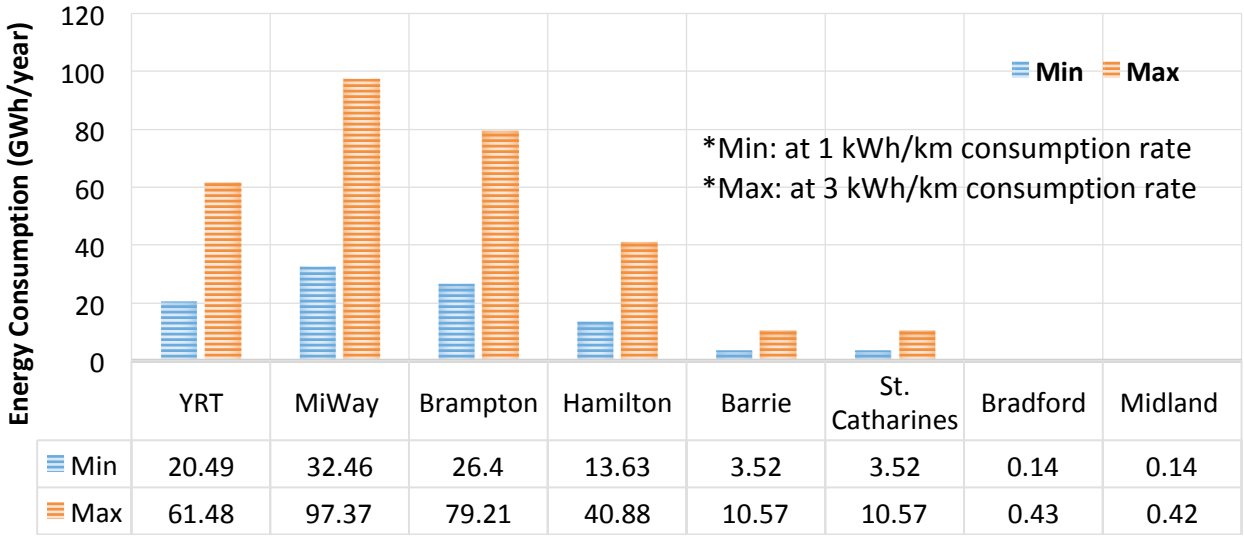
Estimated Energy Consumption for Alectra Coverage Area

Transit network	# buses	# routes	Daily Distance (km)			Annual Distance (km)
			M-F	Sat.	Sun.	
York Region Transit (YRT)	626[a]	137	67.420	34.077	22.944	20.494
Mississauga	460	85	106.776	53.657	36.617	32.456
Brampton	419	51	85.684	43.859	35.506	26.405
Hamilton	251	35	43.280	26.472	19.171	13.626
Barrie	44	10	10.867	9.099	4.323	3.523
St. Catharines	75	29	11.317	6.697	4.463	3.523
Bradford	3	2	0.556	0.0	0.0	0.144
Midland and Penetanguishene	4	3	0.473	0.351	0.0	0.141
Total			**326.4*10³ km**	**174.22*10³ km**	**123.023*10³ km**	**100.32*10⁶ km**





	YRT	MiWay	Brampton	Hamilton	Barrie	St. Catharines	Bradford	Midland
Min	67.42	106.78	85.68	43.28	10.87	11.32	0.56	0.47
Max	202.26	320.33	257.05	129.84	32.6	33.95	1.67	1.42



	YRT	MiWay	Brampton	Hamilton	Barrie	St. Catharines	Bradford	Midland
Min	20.49	32.46	26.4	13.63	3.52	3.52	0.14	0.14
Max	61.48	97.37	79.21	40.88	10.57	10.57	0.43	0.42