Investigation of Electric Highway Alternatives to MegaWatt Charging

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Context and Objectives

- The present project is part of a broader world-wide thrust aimed at establishing practical and efficient electric transport

- Research currently moving from light to heavy-duty vehicle sector

- Dynamic wireless power transfer (DWPT) technology making electrified highways possible

Research mission:

Can intermittent DWPT provision enhance battery life in electric long-haul transport trucks?

Motivation for Project

*DWPT efficiency ~ **85%***

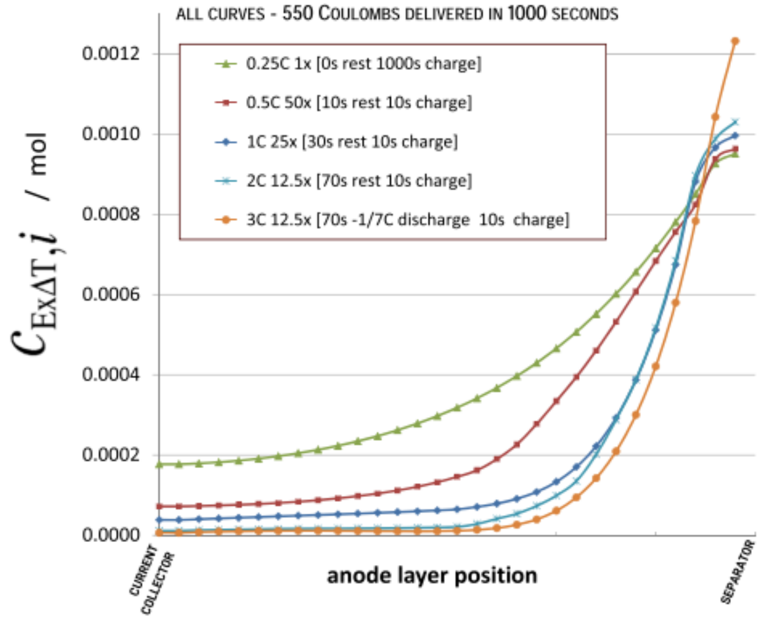


Fig. 14 Values of $c_{Ex\Delta T,i}$ for various equivalent amounts of recharge current applied over a 1000-s period

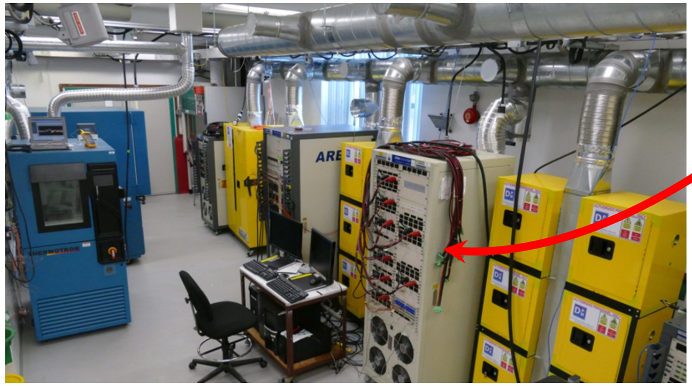
Pulse charging: better battery durability

- Intermittent electrified highway sections envisioned to produce **"pulse discharge" operation**
- Seek to investigate eHwy scenarios to compare to HDEV MegaWatt unit recharging

Benefits include:

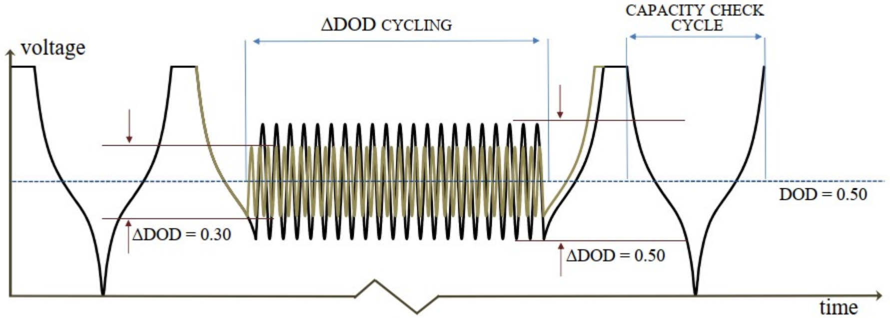
- ✓ Control SOC range
- ✓ smaller battery packs
- ✓ no off-road high current recharging

Variable Amplitude Cycling Experiment
- mode change or pulsing shown to mitigate degradation

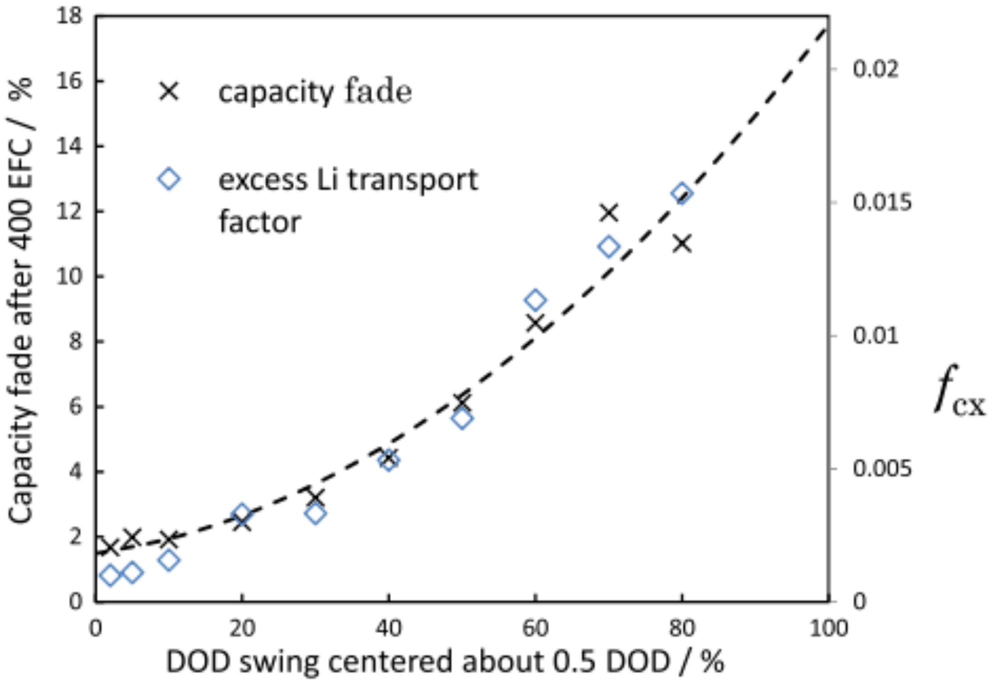


LG Chem LiNMC cell
model ICR18650 S3
2200mAh

- 18650 cells cycled in thermally controlled units



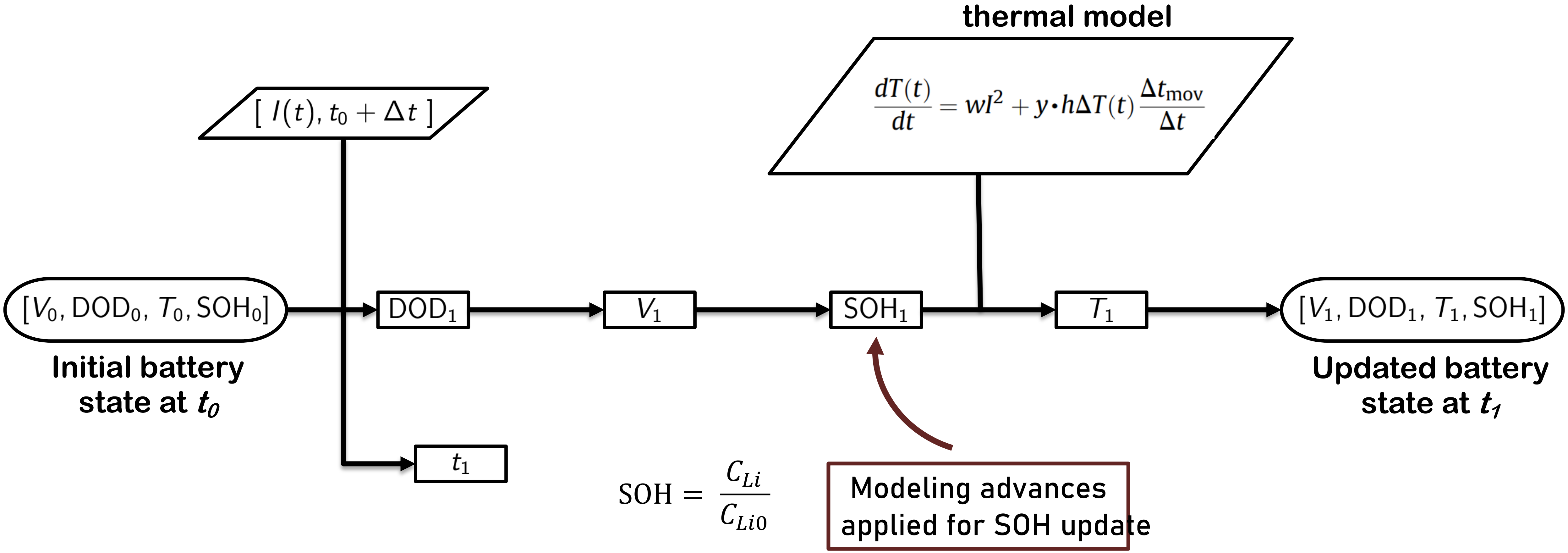
- Schematic of 30% and 50% amplitude cycles



Result:

Capacity fade **increases significantly** as function of cycle amplitude. Correlates with excess Li level.

Battery Simulation Flow Sheet



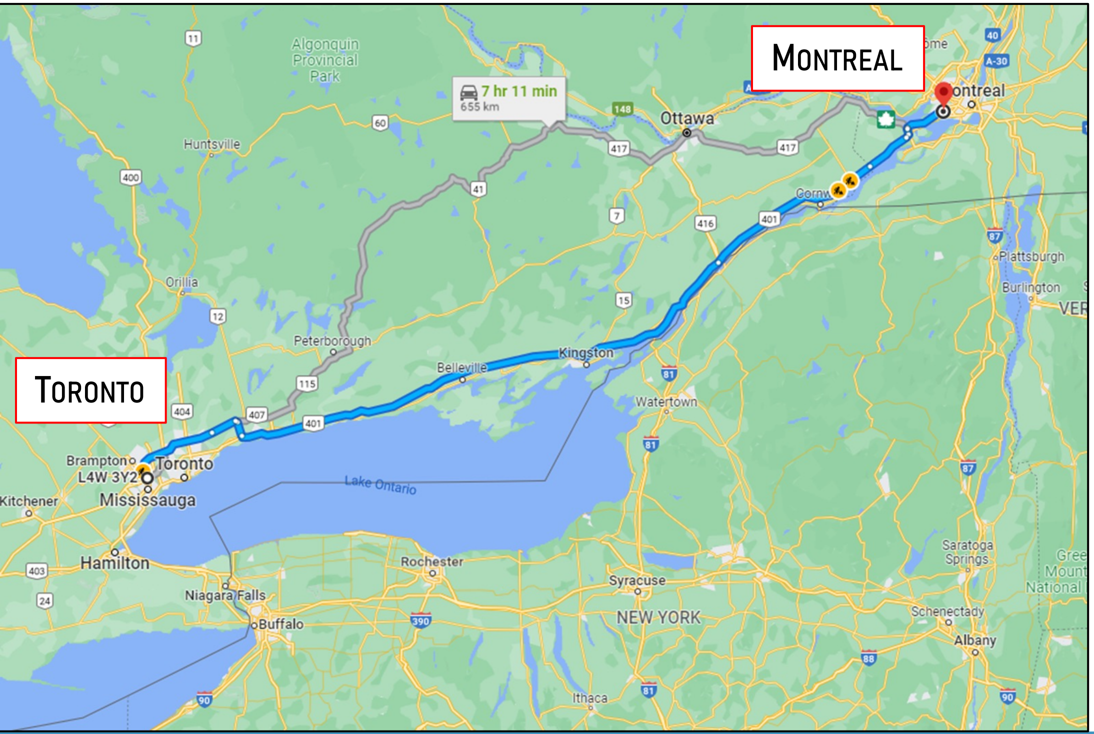
$$\Delta SOH = f(T, I, SOC, t)$$

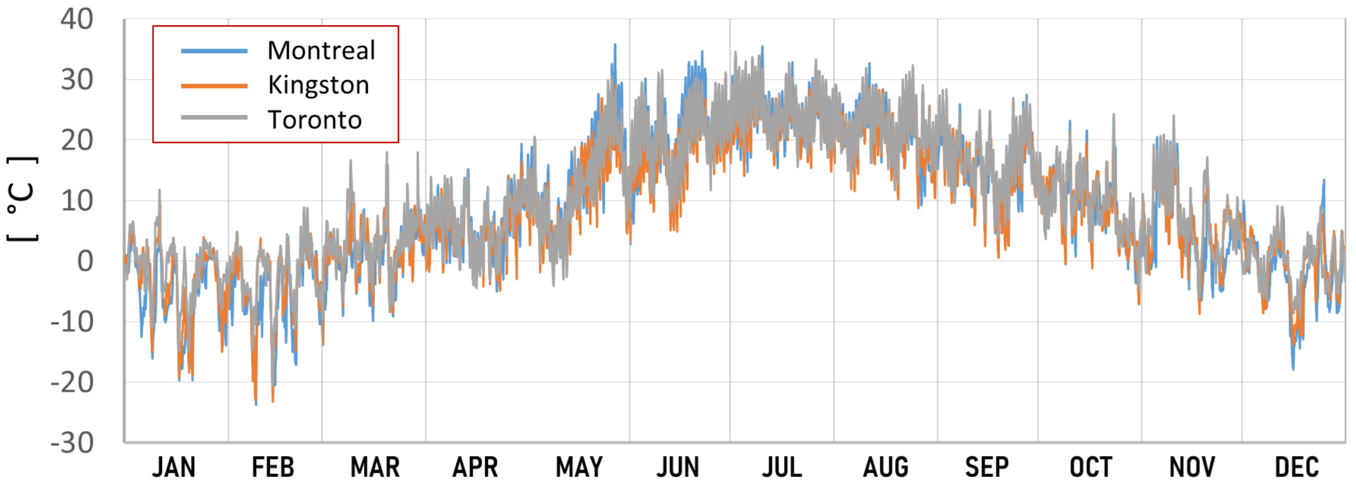
eHwy – the Route and Weather

Toronto – Montreal transit:

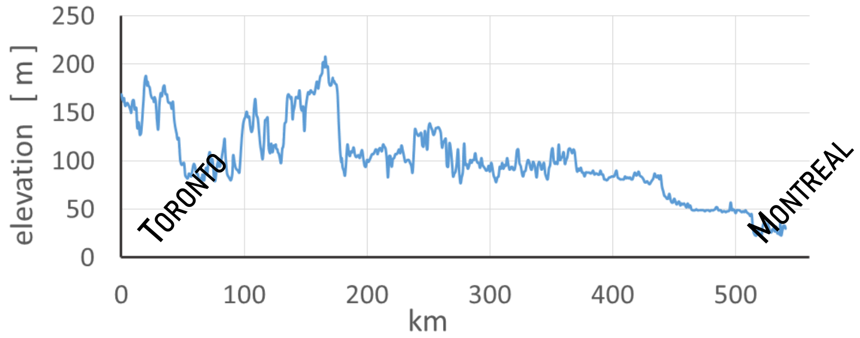
540 km route between shipping depots in Mississauga, ON and Dorval QC

07h00 leave Toronto, ~19h30 return





2020 hourly temperature data from Environment Canada



Road elevation between Toronto and Montreal

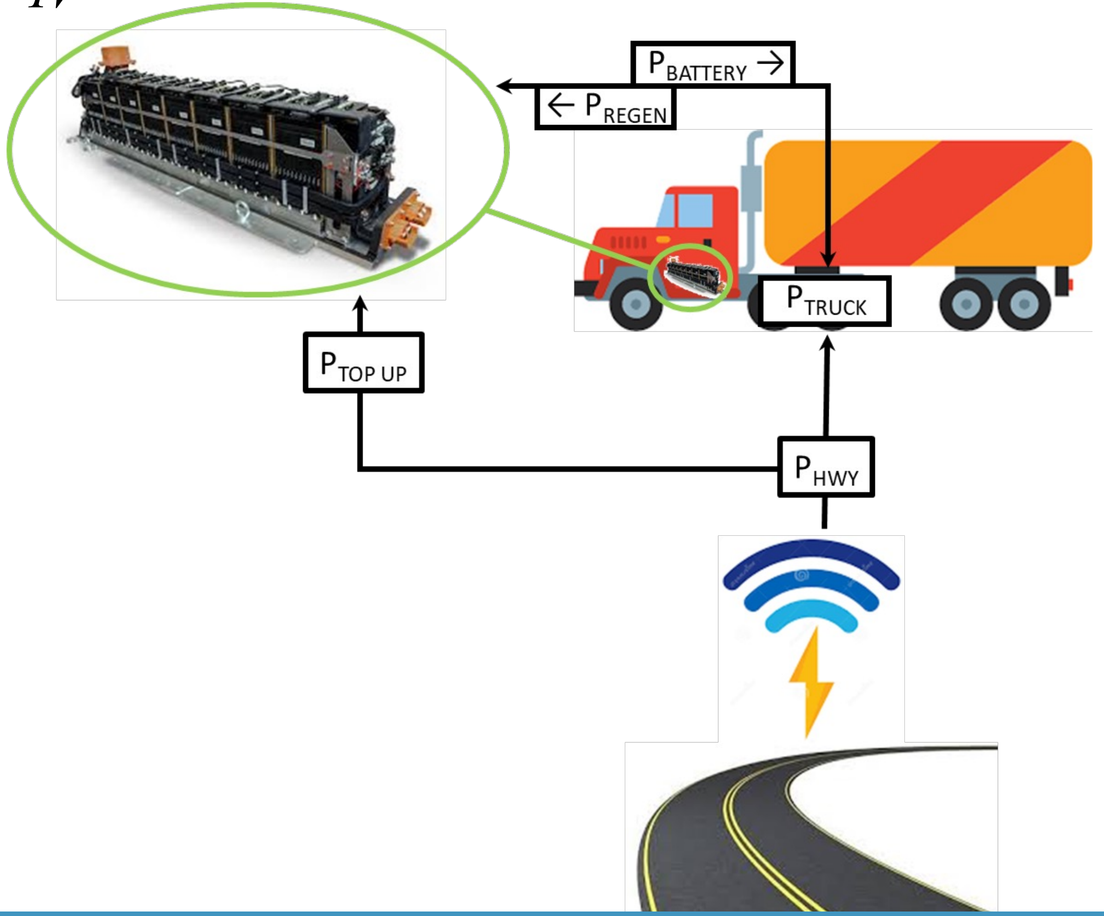
eHwy – eTruck Power Demand and Power Flow

$$*\quad P_{truck} = \underbrace{\frac{(\mu_r + \sin\alpha)Mg}{\eta_{eq}}}_{\text{rolling resistance, elevation}} v(t) + \underbrace{\frac{C_d A v(t)^3 \rho}{2\eta_{eq}}}_{\text{form drag}} + \underbrace{\frac{\delta M a(t) v(t)}{\eta_{eq}}}_{\text{acceleration}} = \eta_{\text{eff}} \cdot IV$$

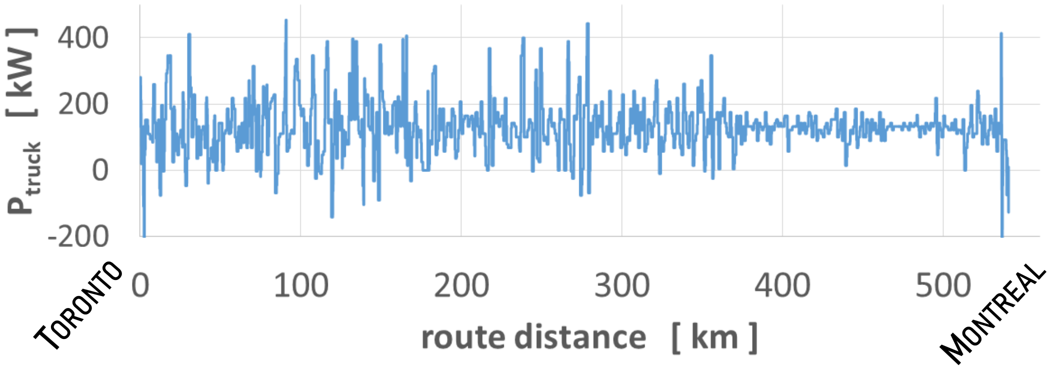
rolling resistance, elevation

form drag

acceleration



36,000 kg truck (maximum legal weight)



* *Foote A, Onar OC, Debnath S, Chinthavali M, Ozpineci B, Smith DE. Optimal sizing of a dynamic wireless power transfer system for highway applications. In2018 IEEE Transportation Electrification Conference and Expo (ITEC) 2018 Jun 13 (pp. 1-6). IEEE.*

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eHwy – Truck Battery Packs and Highway Electrification

Reference for transport truck:

Tesla Semi 947 kWh battery pack (800 km range)

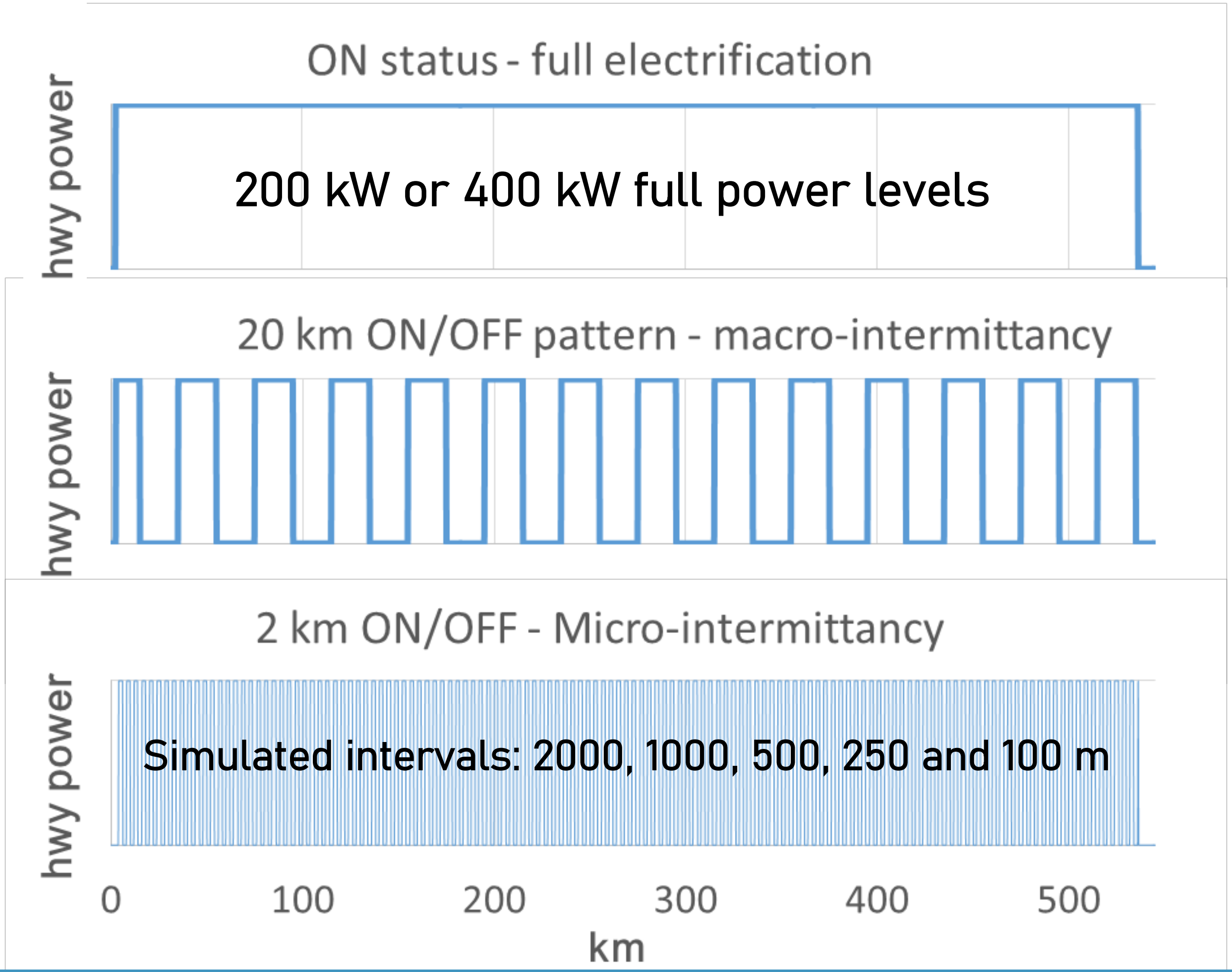
Simulated packs:

banks	cells Par	Ah	kWh
4	296	76332	267
6	444	114500	401
8	592	152665	534
14	1036	267163	935
16	1184	305330	1068

Banks modeled after Tesla car : 3.07Ah cells: 74p-84s

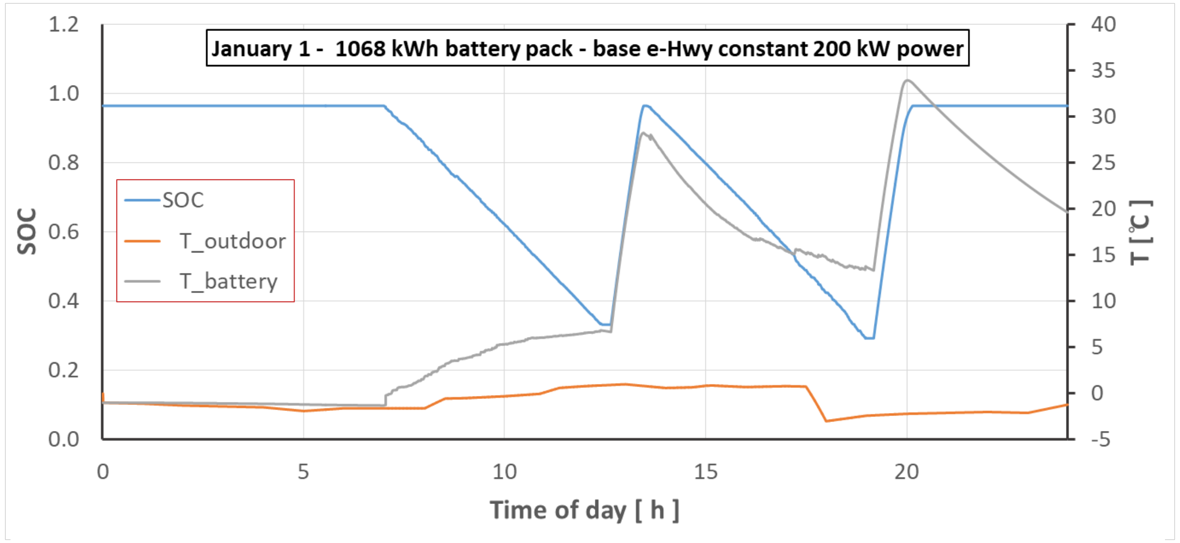
84s required for floor level 240 V operation

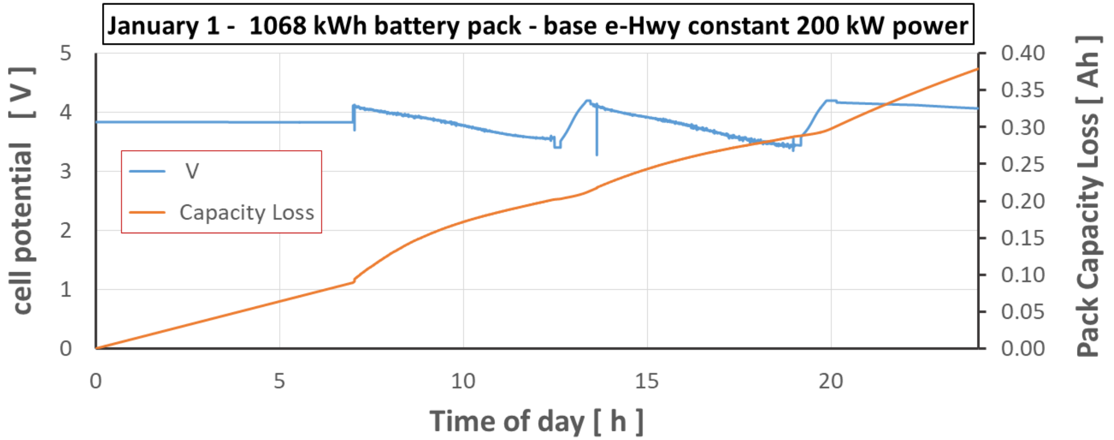
Simulated highway electrification configurations:



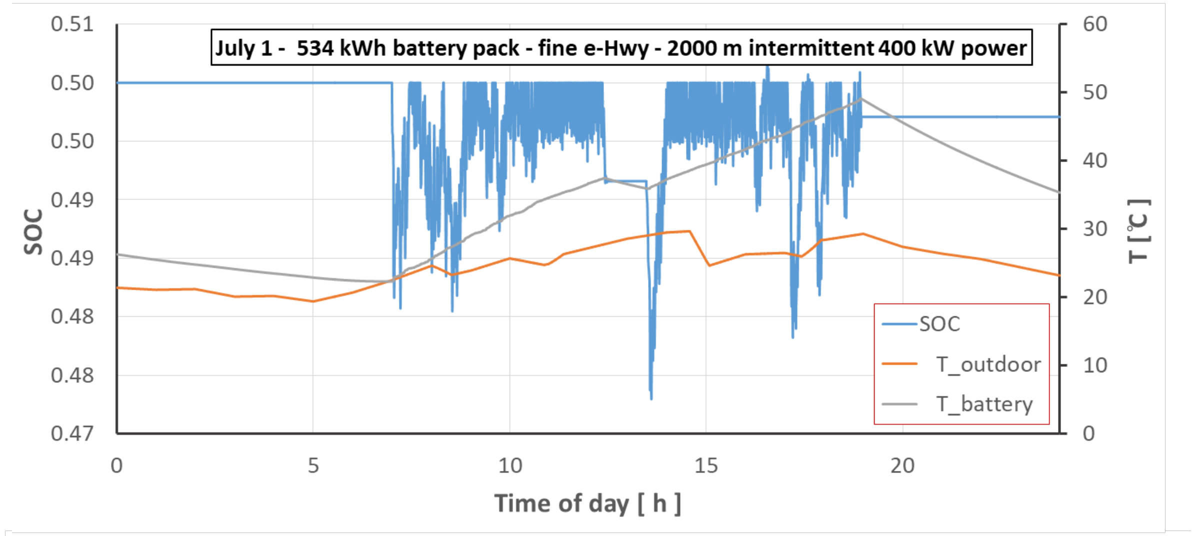
eHwy – Detailed Parameter Tracking over 24 h period

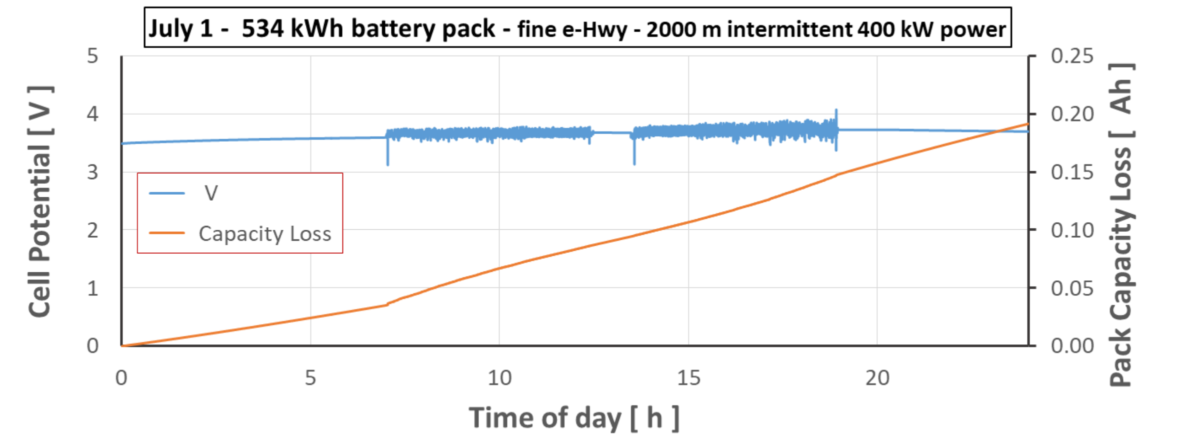
January 1st – no DWPT – 1 MW rchg – 16 banks





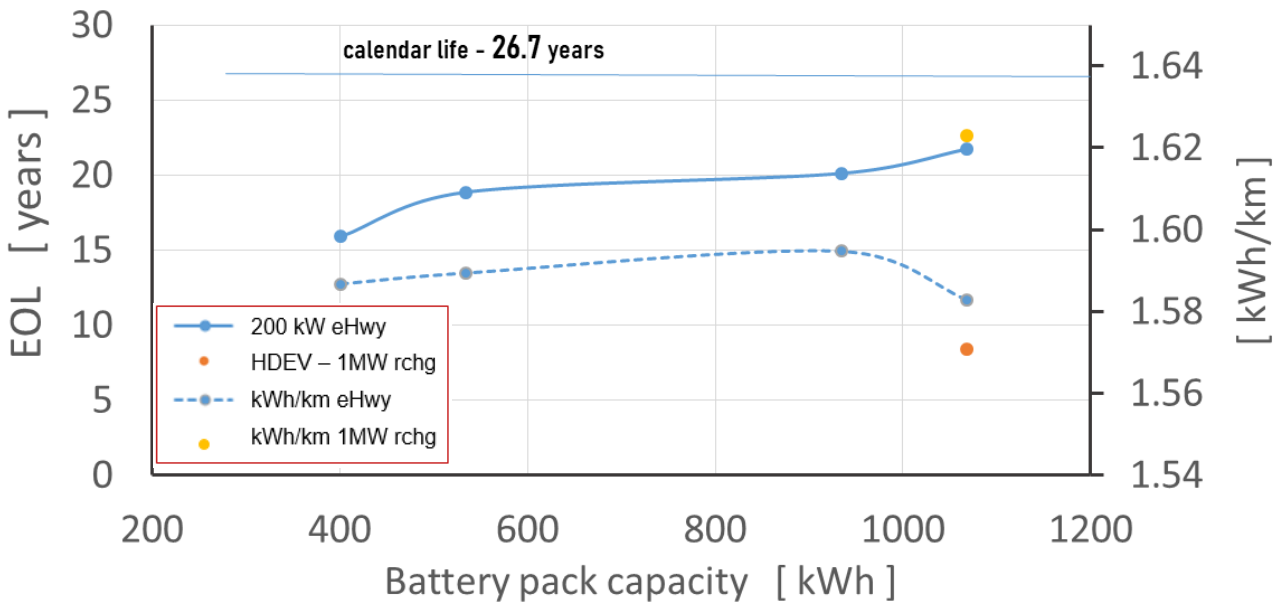
July 1st – 2 km on/off DWPT – 8 banks





eHwy – Preliminary Results: Lifetime Estimates and Energy Use

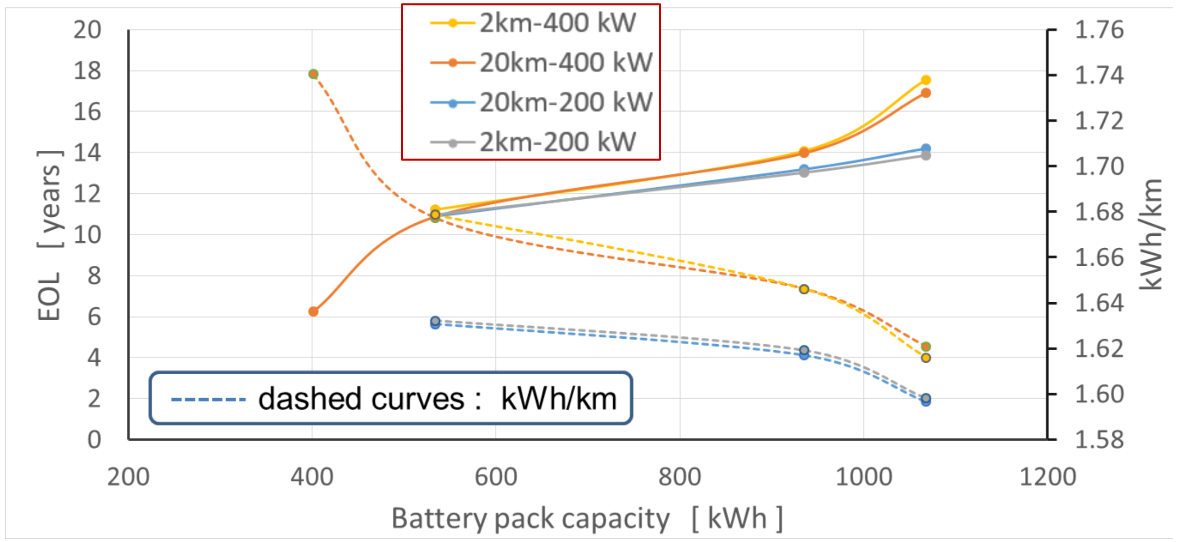
Reference case : 16 bank 1068 kWh battery, 1MW rchg



eHwy: full electrification at 200 kW

- >15 year EOL for 4 bank pack, more for larger ones
- Slight efficiency benefit, increases with pack size

2 km and 20 km intermittent intervals
200 kW and 400 kW eHwy power provision



- increased eHwy power benefits EOL for large packs
- smaller intermittent intervals provide slight EOL gain
- larger packs perform more efficiently

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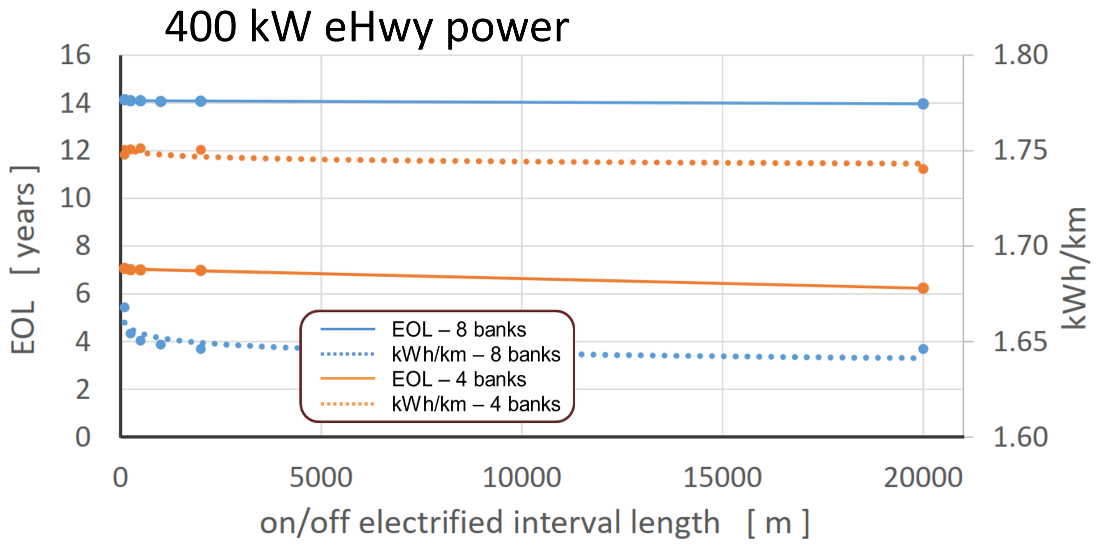
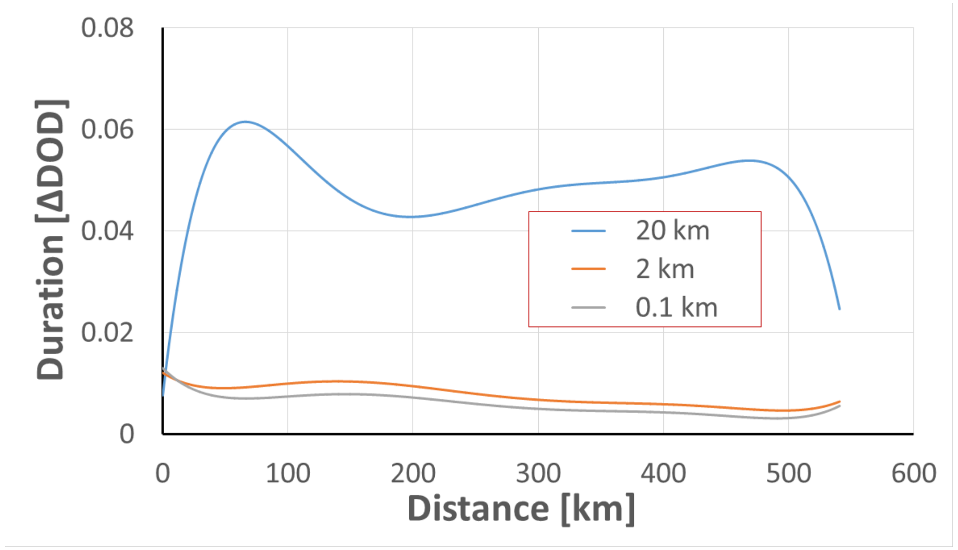
eHwy – Impact of eHwy Intermittency Interval Lengths - effect on duration factor





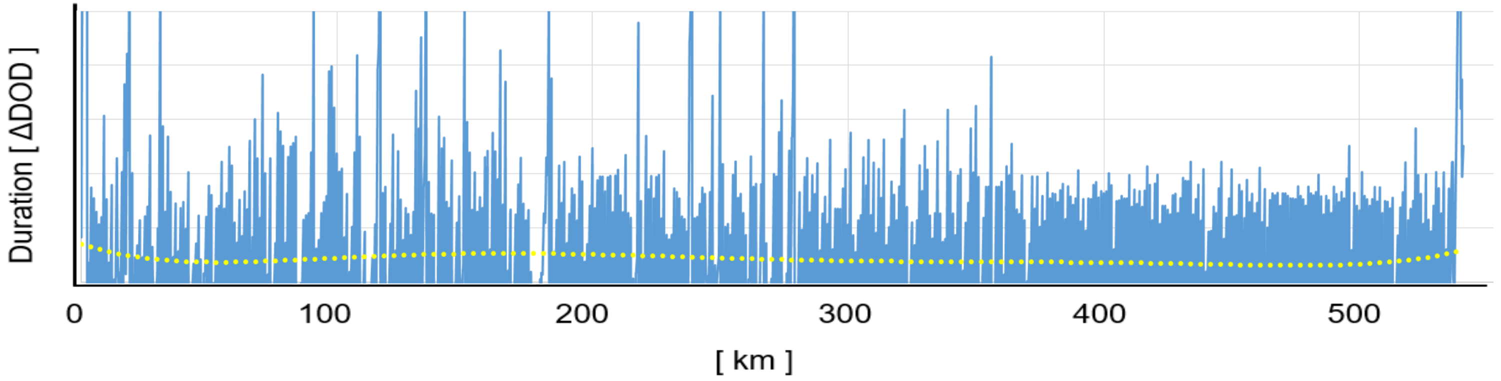
- Small EOL benefit for 4-bank packs at shorter on/off electrified intervals

Longer intervals: prolonged discharge; larger recharge margin

Intervals < 2000m : limited scope for benefit

<u>ΔDOD data:8-bank 500 m interval case:</u>

polynomial represents ΔDOD level



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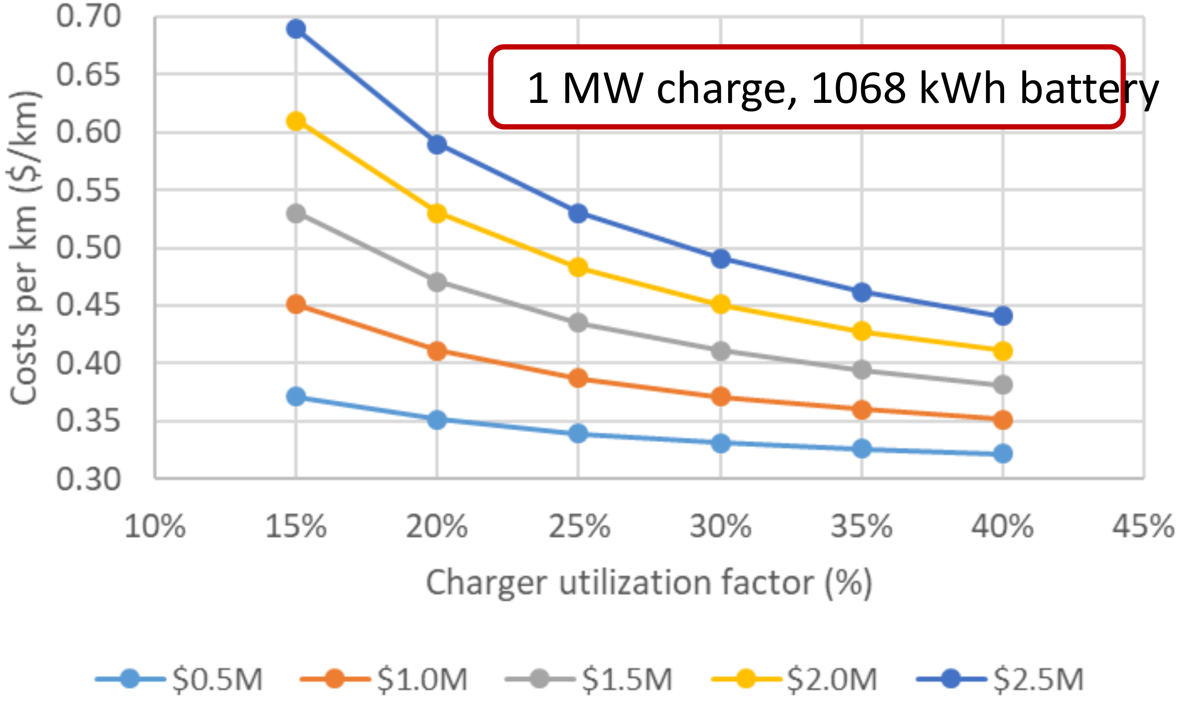
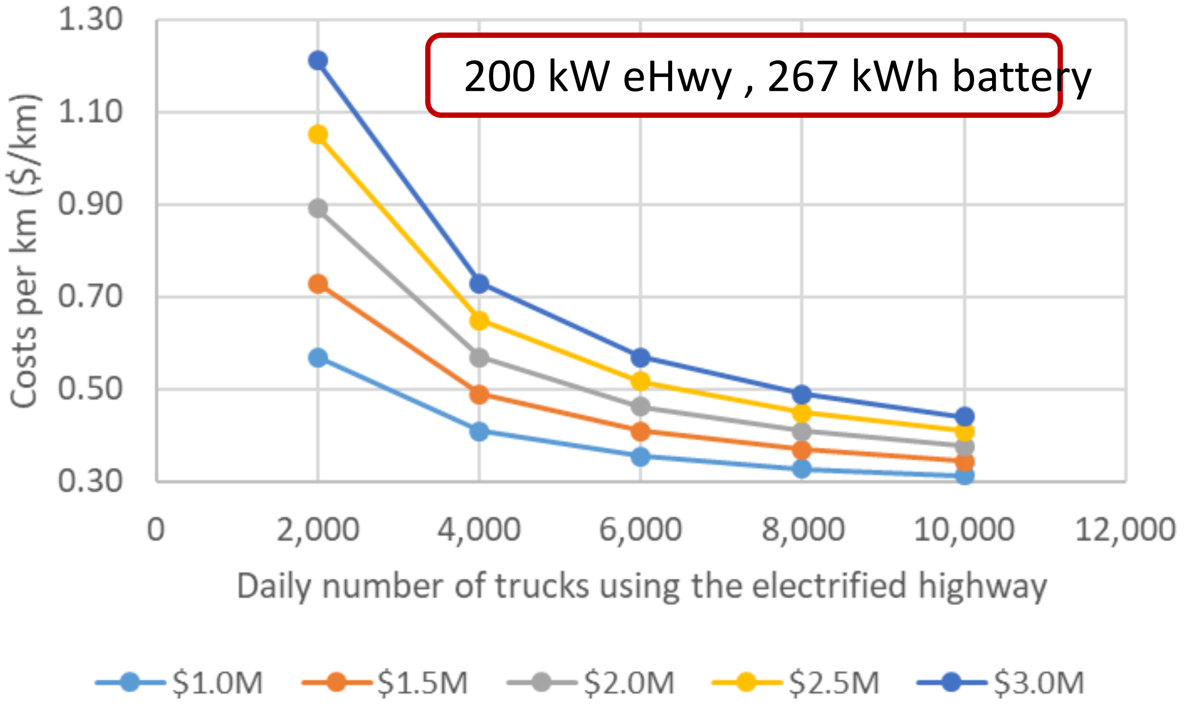
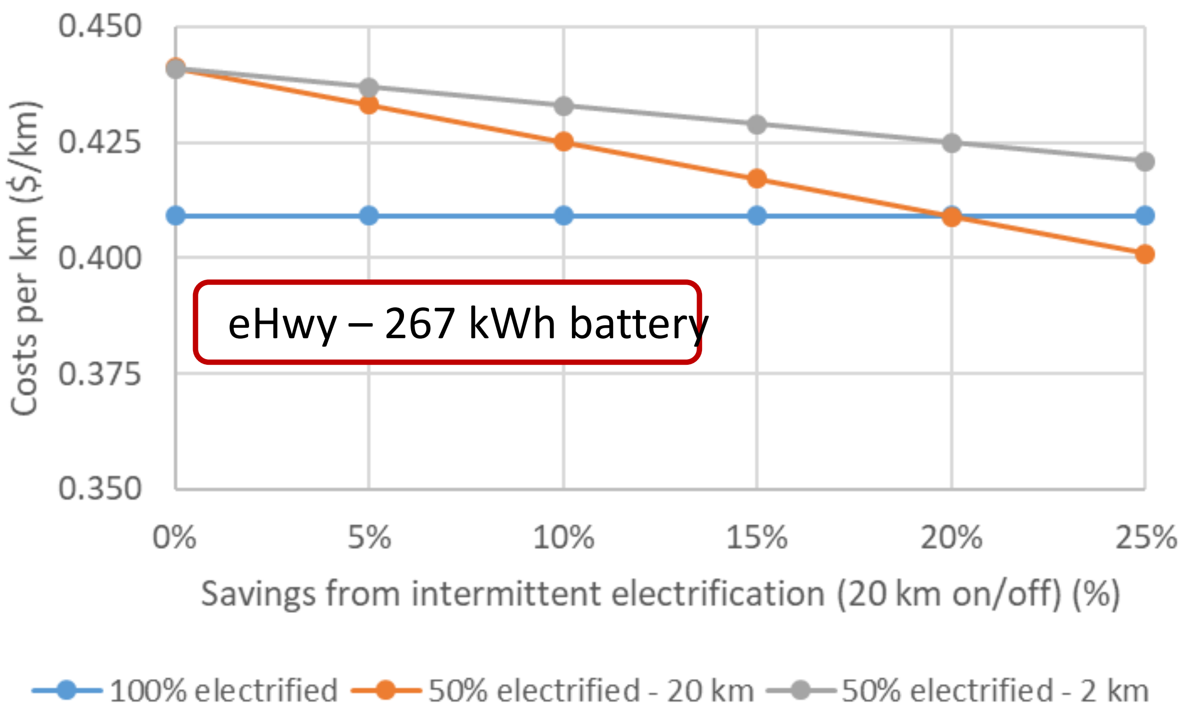
Economics – 1MW charging vs eHwy ($/km)

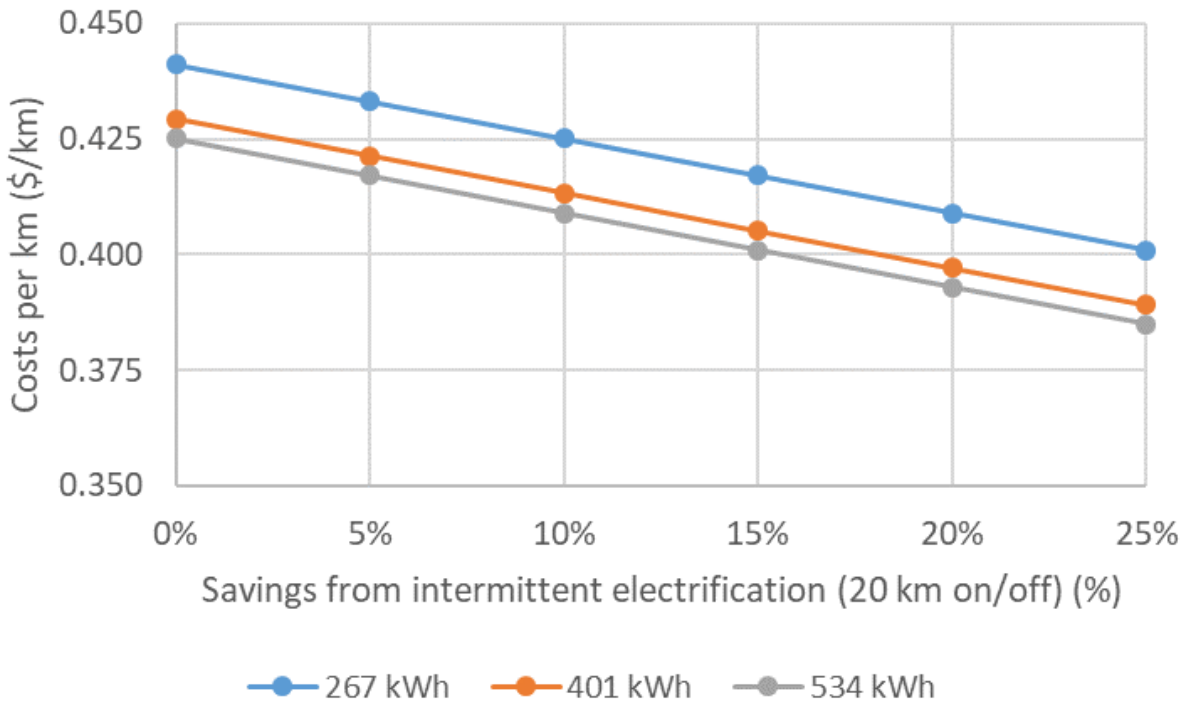




- Strong sensitivity to initial investment costs
- Significant benefit with higher utilization levels, notably for eHwy

Economics – Intermittency Effects for eHwy





- High construction savings required for intermittent configuration to be favored
- Durability of larger battery packs shows cost benefit on eHwy

Economics – Cost breakdown for various scenarios

Mid-level capital costs assumed

Per km costs for different cost components

	MegaWatt charging	100% electrified highway		50% electrified (20 km on/off)		50% electrified (2 km on/off)	
Battery size (kWh)	1,068	267	534	267	534	267	534
Battery use	$ 0.048	$ 0.006	$ 0.010	$ 0.016	$ 0.015	$ 0.015	$ 0.014
Capital costs	$ 0.102	$ 0.161	$ 0.161	$ 0.136	$ 0.136	$ 0.148	$ 0.148
Electricity	$ 0.243	$ 0.242	$ 0.241	$ 0.264	$ 0.250	$ 0.266	$ 0.250
Total	$ 0.394	$ 0.409	$ 0.412	$ 0.417	$ 0.401	$ 0.429	$ 0.413

- Energy requirements similar for all cases, so efficiency improvements would benefit eHwy most
- Optimal on-off interval length could be determined for eHwy cases
- Time flexibility much greater for eHwy cases, dollar-value for this not attributed here

eHwy – Notes on Preliminary Results

eHwy project has provided the motivation and context to incorporate temporal and current mode degradation drivers into HDEV usage simulations.

- Electrified highways significantly increase HDEV battery life, but total energy consumption is similar to 1 MW recharging

- Electrified highways allow battery packs < 50% of the size required for 1MW recharge service

- It was observed that 200 kW eHwy power provision was slightly more energetically efficient than power provided at 400 kW

- Economics of electric highway and MegaWatt charging concepts are still uncertain. It is not possible yet to indicate which concept is most cost effective

eHwy – Next steps? Building on Preliminary Project Results

eHwy impactful factors:

- battery size
- eHwy Power level
- route elevation
- investment costs

Requires further study:

- Intermittent electrification
- Interval lengths
- Economics

Insight gained: Discharge mode is minor degradation driver, and is dominant mode in present eHwy study.

Question: Are there ways to better involve recharging in eHwy context?

Future research: Road sections with a constant high load demand will stress the battery in terms of prolonged durations. For example, trips over mountain passes would be a promising situation to better exploit intermittency effects to preserve battery health.


Thank you / Merci / Takk skal du ha