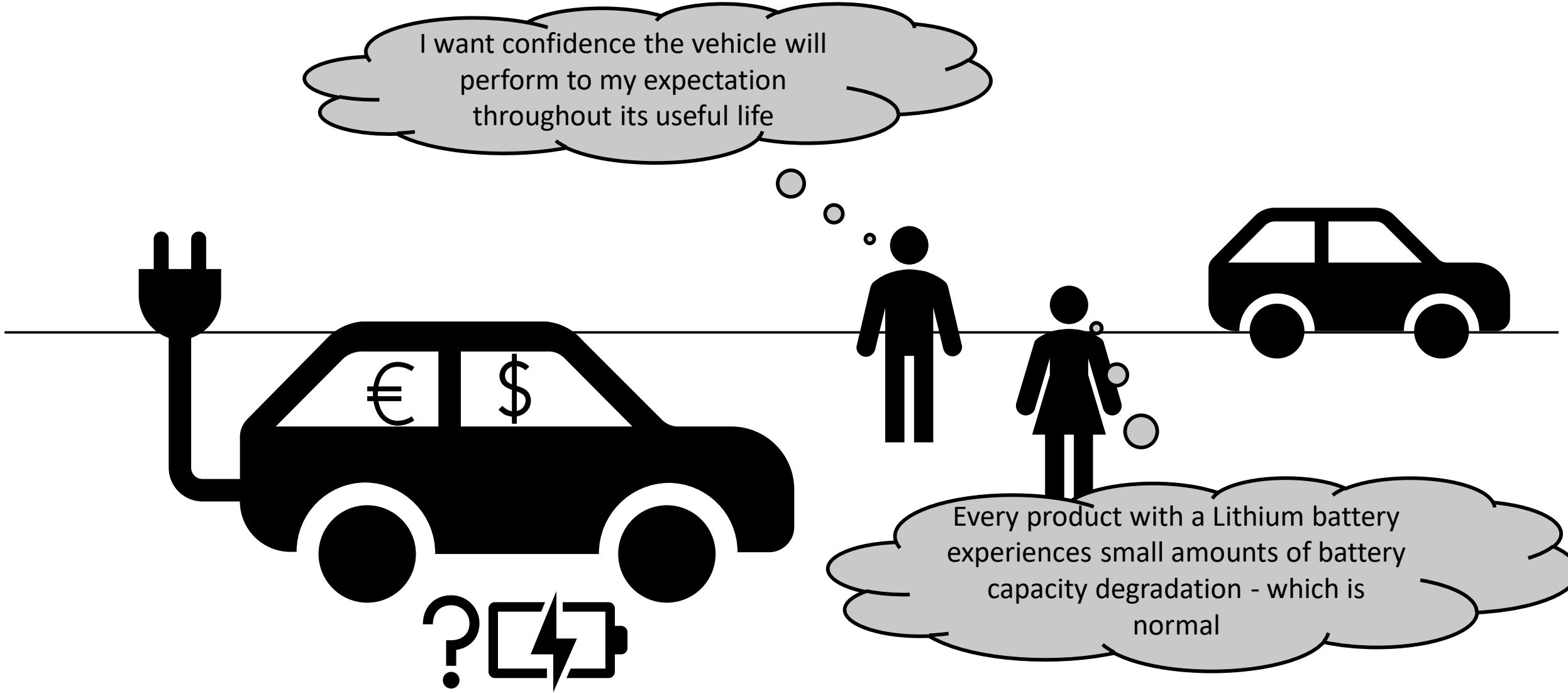
Focus on the Customer:
Ways to Think about Electric Vehicles as they Age:



Focus on the Customer:
Ways to Think about Electric Vehicles as they Age:

Primary Requirement:

A customer requires their vehicle to get them from A->B. (Distance)

What is different about EV's in providing this requirement (vs ICE vehicles)?

The battery will degrade gradually, depending on factors such as:

1. Magnitude and Quantity of Battery Discharges
2. Resting and Usage Temperature

Additionally, the battery has cold temperature limitations if not properly conditioned before customer usage

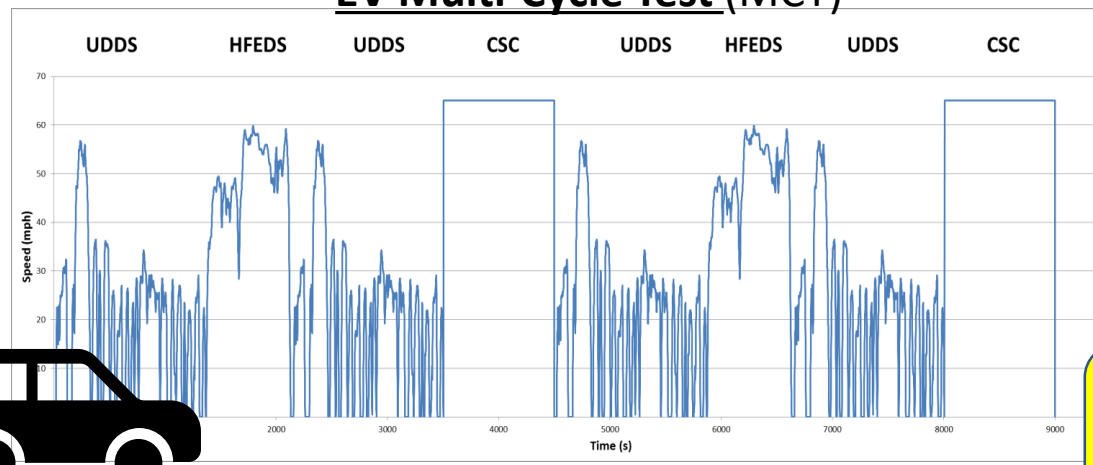
Focus on the Customer:
Ways to Think about Electric Vehicles as they Age:

In order to give the customers a realistic expectation of how the electric vehicles will perform in the marketplace, global governments utilize controlled test cycles that provide a customer a window into a new EV's performance at time of purchase.

For example, the Society of Automotive Engineers provides SAE J1634 Test Standard for Electric Vehicles:

*example using Metric Label

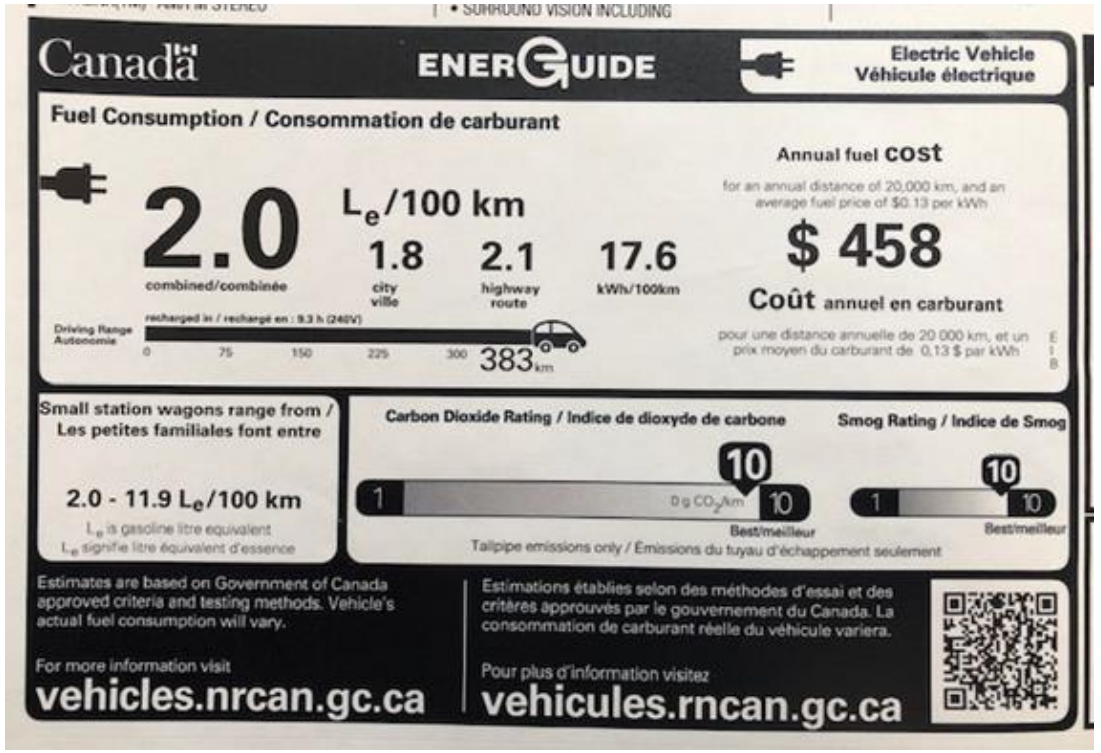
EV Multi-Cycle Test (MCT)



4. Cold Test

5. Hot Test

5.5 HOURS to Compete test!



Focus on the Customer:
Ways to Think about Electric Vehicles as they Age:

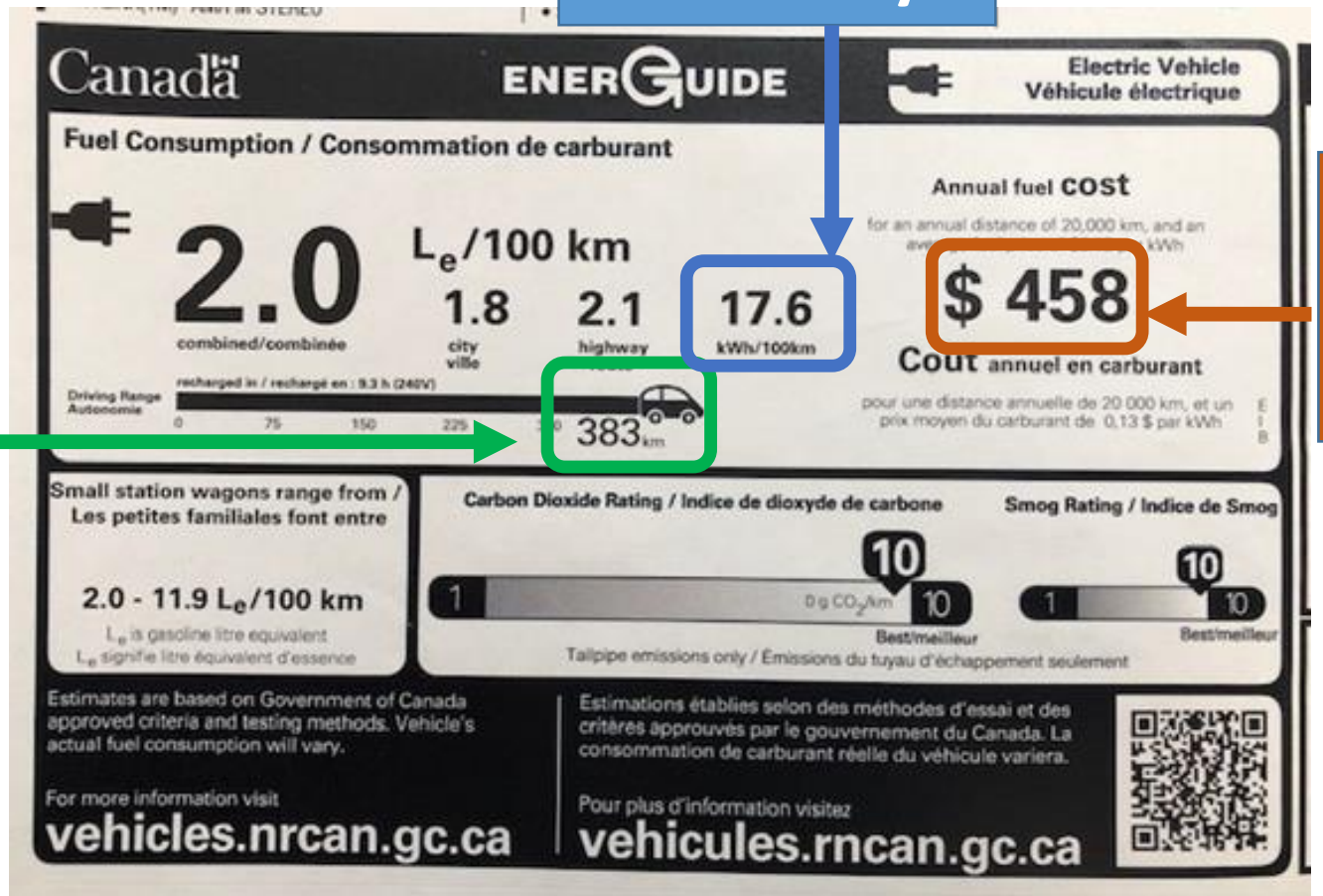
A vehicle performance labels is required on each vehicle.

It focuses on the three important aspects for a customer:

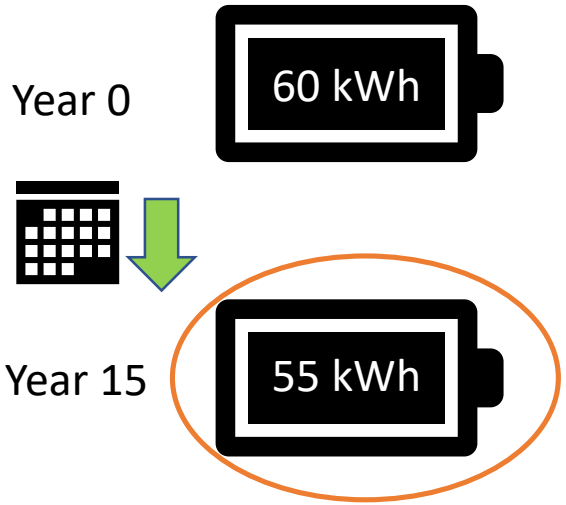
Energy Usage Efficiency

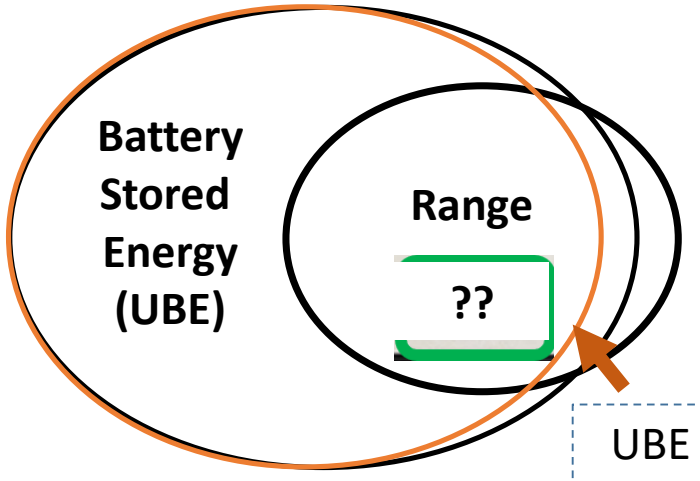
Range

Cost of Operation (per year)

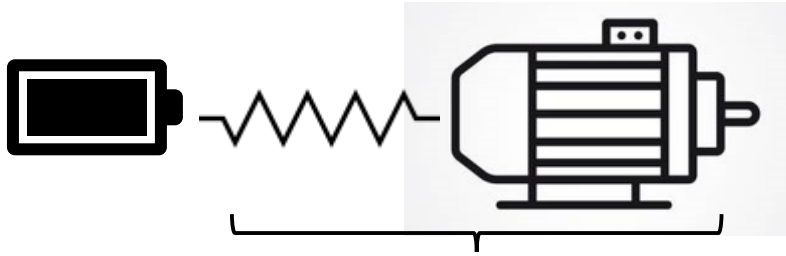


Focus on the Customer:
Ways to Think about Electric Vehicles as they Age:





Propulsion System Energy Usage Efficiency



Other vehicle components that affect range

UBE slowly lowers, directly affecting range, However, observed range differences in the field cannot always be attributed to the battery –better to look at just the energy

Range

Energy Usage Efficiency

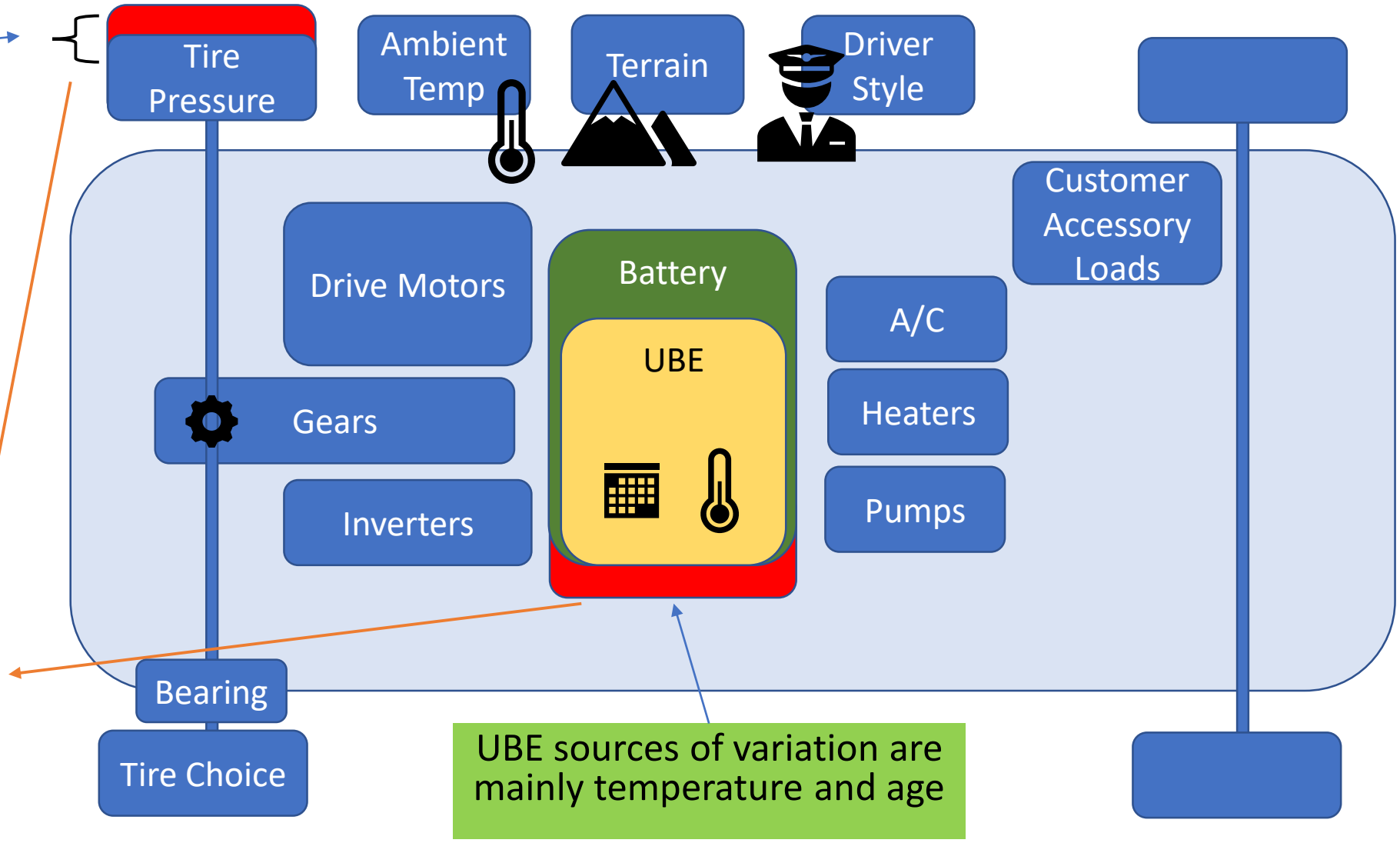
- The Testing procedures can identify these two attributes by using controlled test cycles
- The Battery undoubtably affects RANGE and Kwh/100km (energy deployment efficiency) of the propulsion system as a whole
  - However when considering how the vehicle performs over useful life – the battery is the only component that we know of that follows a noteworthy degradation path that *would affect a ZEV adoption decision*.
    - (the Propulsion System Energy Usage efficiency oval should stay relatively constant across useful life)
    - The battery UBE lowers over time, as indicated by the orange Oval

Range vs UBE Debate:
Which Provides better Battery Durability Insight?

Some have a concern of entire propulsion system degrading over useful life:

Each contributor to EV range has variation

- Range is affected by all of the components/factors noted in this example vehicle



When an auditor pulls a random vehicle out of service, one has to consider all the possible errors coming together on the test vehicle to affect EV range

UBE sources of variation are mainly temperature and age

UBE vs Range

Auditing an *aged vehicle* and focusing on EV Range adds unnecessary variation risk. Focusing on UBE makes job of analyzing the *battery contribution* to the propulsion system much easier.

All the variation attributed to other aging components may be small in and of themselves, but may sum to cause a possible effect on the range ***on that particular vehicle***

However – even while UBE is a better choice, it is still is NOT a panacea

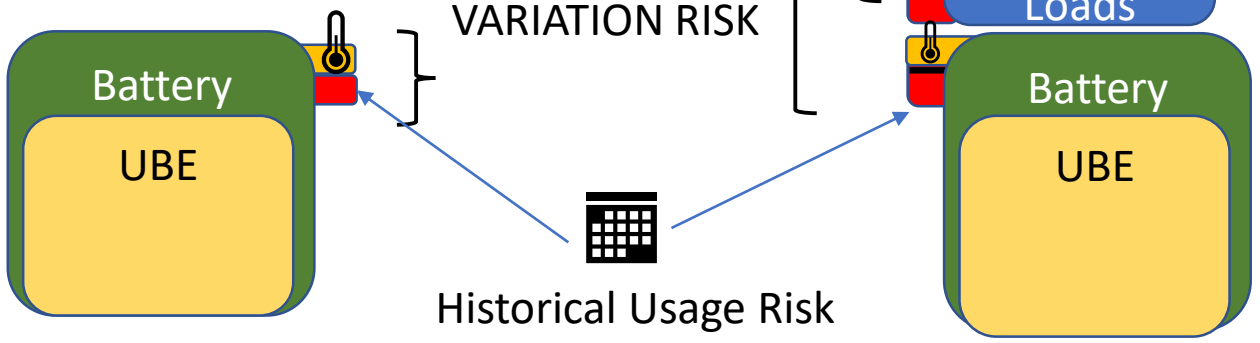
Even though an auditor can control for the testing Temperature of a battery pack – and knows the "vehicle age" and "odometer". The testing agency is unlikely to know or have controlled the usage history of that particular battery pack (the battery may have been abused by unmitigated hot soak temps, etc.)

Therefore, even if only UBE is adopted, it would be ill-advised to make any conclusions on an experiment with a low sample size on vehicles with an unknown history

Therefore larger testing programs would be required to audit larger and larger fleets

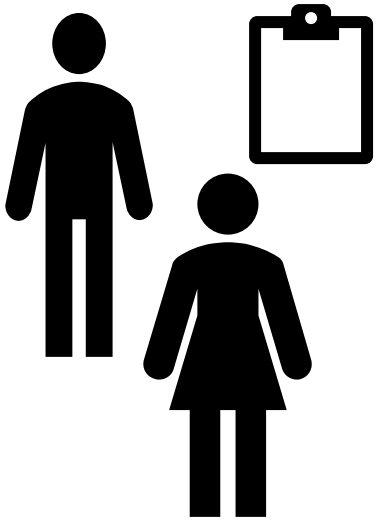
➔ very costly

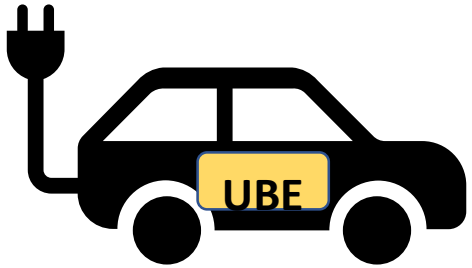
SOH: This has led to the conclusion that a standardized "UBE based" SOH variable is of value to both consumers and regulators. J1979 Scan Tool data can be retrieved at lower cost than dyno testing programs, and can also be used by customers considering used EV's for purchase consideration etc.

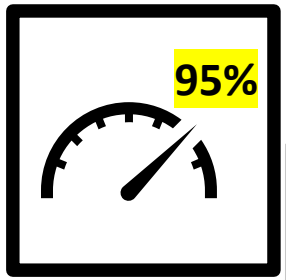


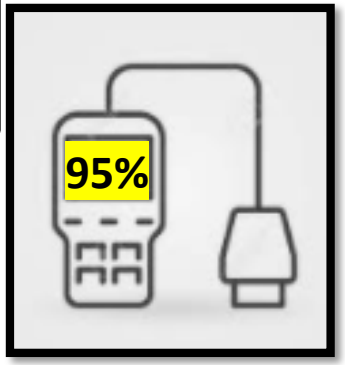
Case 1: Just UBE: (Present day in Production for some manufacturers)

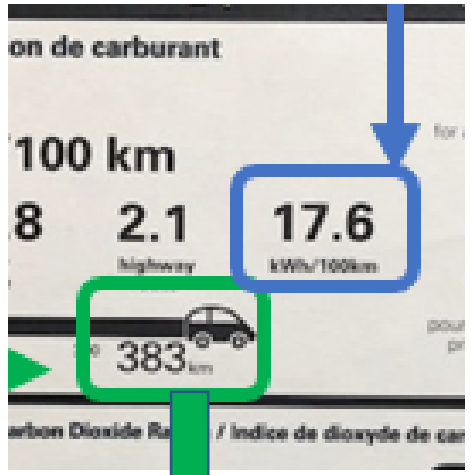
Even though UBE has the least variation, it requires the customer/regulator to do a mental transformation to make it applicable for actual usage (% UBE → Distance)











- A customer wishes to make a purchase decision on a 5 year old used EV
- Regulator Seeks to audit an EV

Customer accesses their **Traction Battery Pack Performance Retention Rate Parameter via J1979** (0xB2) or UDS (0xF4B2)

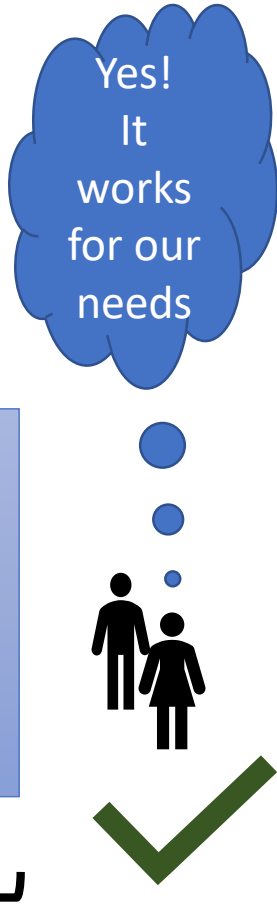
Customer notes 95% of original capacity is available and assesses if battery is appropriate for their usage:

95% of 383 km →

~364 km Combined Range (@10 years)

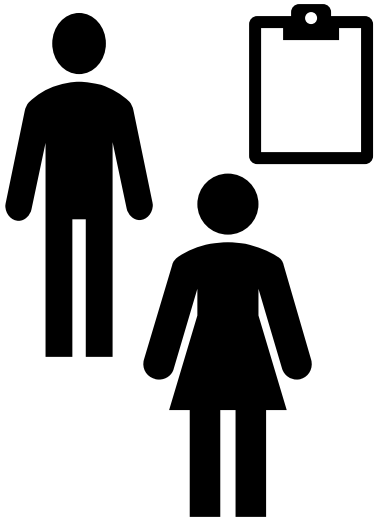
CALCULATED AND PROVIDED BY VEHICLE

CALCULATED BY USER



Case 2: Just UBE w/ Estimated Range (simplest calculation):

Manufacturers provide an estimate of the range *had the customer tested the vehicle on the applicable cert cycle with that given battery.*



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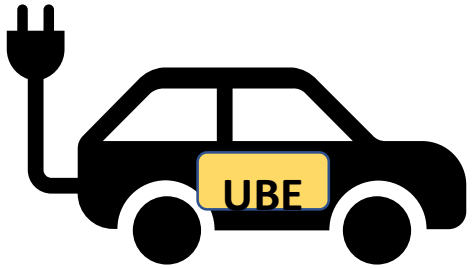

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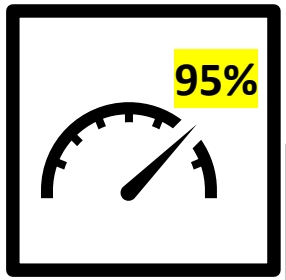
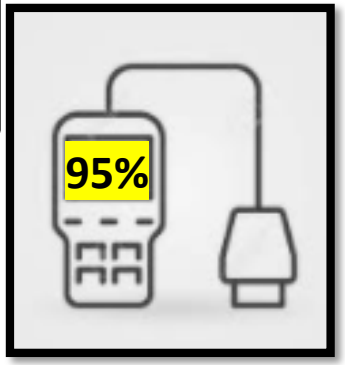
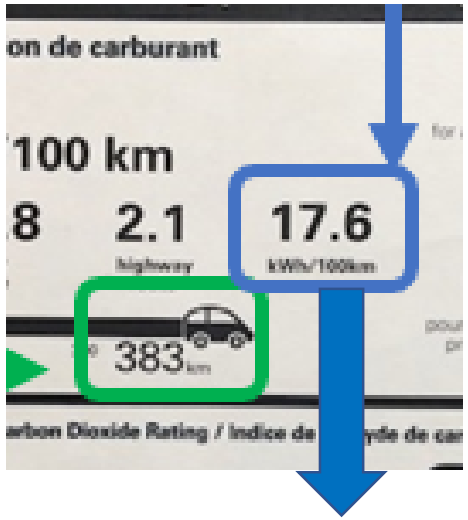




Customer notes 95% of original capacity is available and assesses if battery is appropriate for their usage:

2 CYCLE J1634 MCT



57 kwh / 17.6 J1634 2cycle rate
= 323 km

57 kwh / 16.9 WLTP rate (10% better)
= 337 km

57 kwh / TBD xxxx rate
= ____ km

BATTERY UBE w/ new Vehicle

This number will represent the range if the battery was put in a new "As certified vehicle"…

It does not include gradual aging of entire vehicle system….

323 km

337 km

TBD km

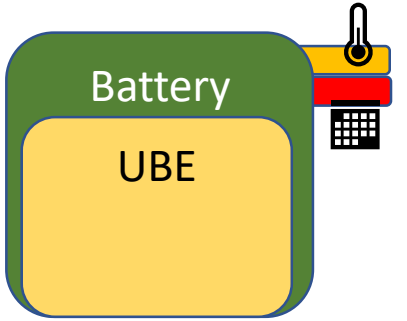
CALCULATED AND PROVIDED BY VEHICLE

Which is better for a customer: Range value vs UBE

- Providing a Range value to a Customer vs UBE has its advantages as outlined earlier in this presentation. (customer doesn't need to do the math)
- However, providing a range estimate could be misinterpreted by regulators if they choose to confirm the test. i.e., the value represents an estimation of the range if a battery with a given UBE *were to be installed and tested on a NEW vehicle*.
- Vehicle efficiency and Range are linked, and attempts by regulators to enforce battery deterioration by range on heavily aged vehicles will cause ambiguous results.
  - The older vehicles become, the more variation will be added to the vehicle range by unrelated vehicle components.
- Government could begin an effort to generate large sample size estimates of a deterioration factor that can be used to adjust the vehicle model in bringing UBE →estimated range. (similar to data supporting 0.7 USA '5 cycle adjustment factor') This could then be used by manufacturers to adjust their range estimate accordingly as a function of calendar age/vehicle odometer.

  → This data will be SLOW to arrive as there aren't any mass market Lithium EV's nearing the 10 yr AND 160,000 km point yet.

Conclusions/Recommendations



- In order to characterize any system and make useful conclusions based on our observations, a test needs to minimize sources of error
- The other hardware used in Electric vehicles has been deployed in other vehicles and industrial applications (pumps, motors, power electronics, etc.) and none share the degradation profile we expect to see from Lithium based energy storage.
- As highlighted in this presentation, range is one of the least advisable observables to garner the state of the battery because of compounding sources of variation on the vehicle (but is better for a customer – because they have a better chance of understanding it, as long as sufficient disclaimers are made about it's value)
- Monitoring Usable Battery Energy (UBE) keeps the focus narrowly on the battery itself (which is the focus of this workgroup) – and minimizes the complication of additional noise factors.
- If degradation of parts of the propulsion/vehicle system become a concern, they can be studied in a similar controlled manner to reduce noise factors.