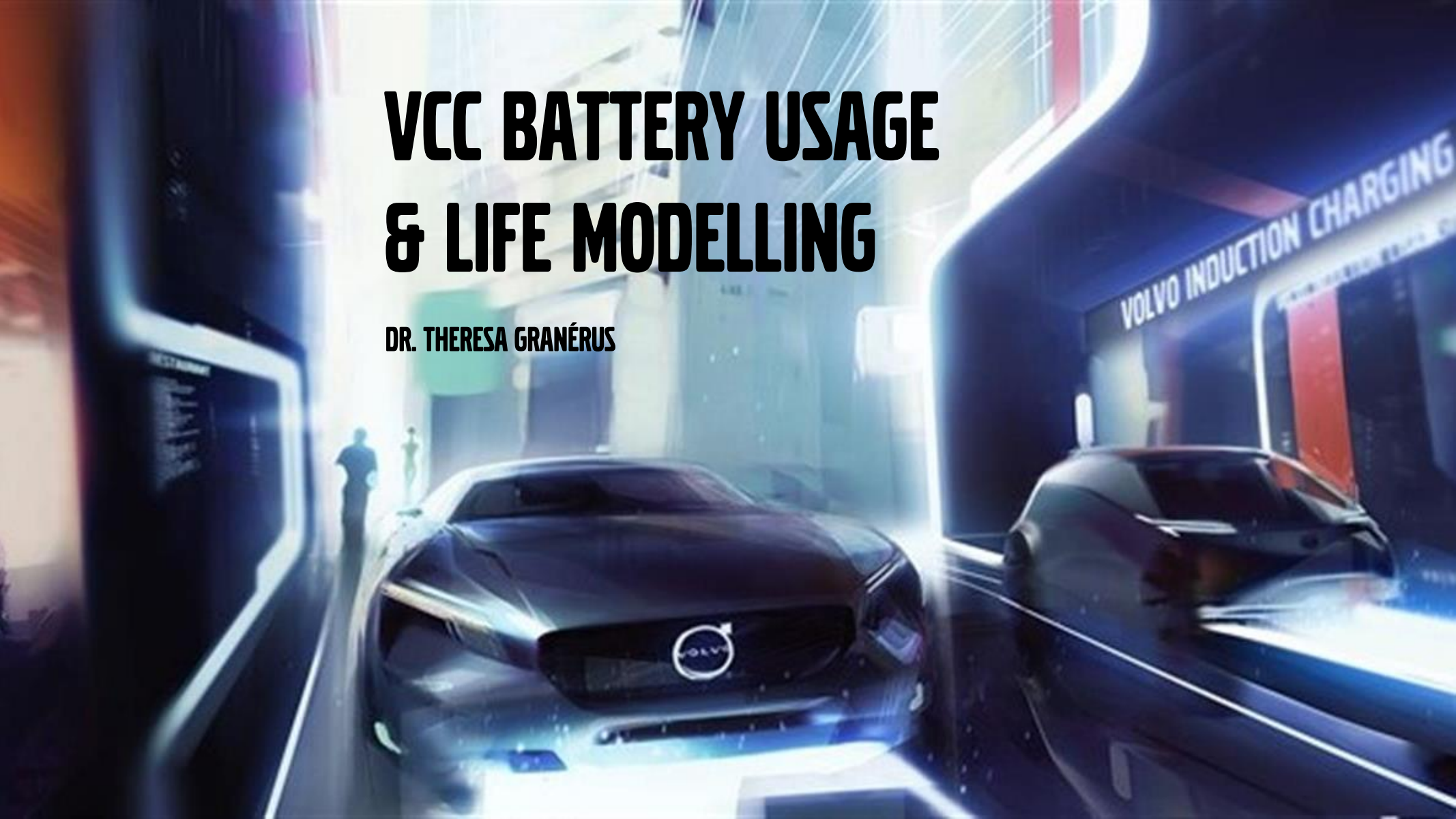
VCC BATTERY USAGE & LIFE MODELLING

DR. THERESA GRANÉRUS



BATTERY TECHNOLOGY

- The li ion technology for automotive applications continously undergoes rapid and frequent changes.

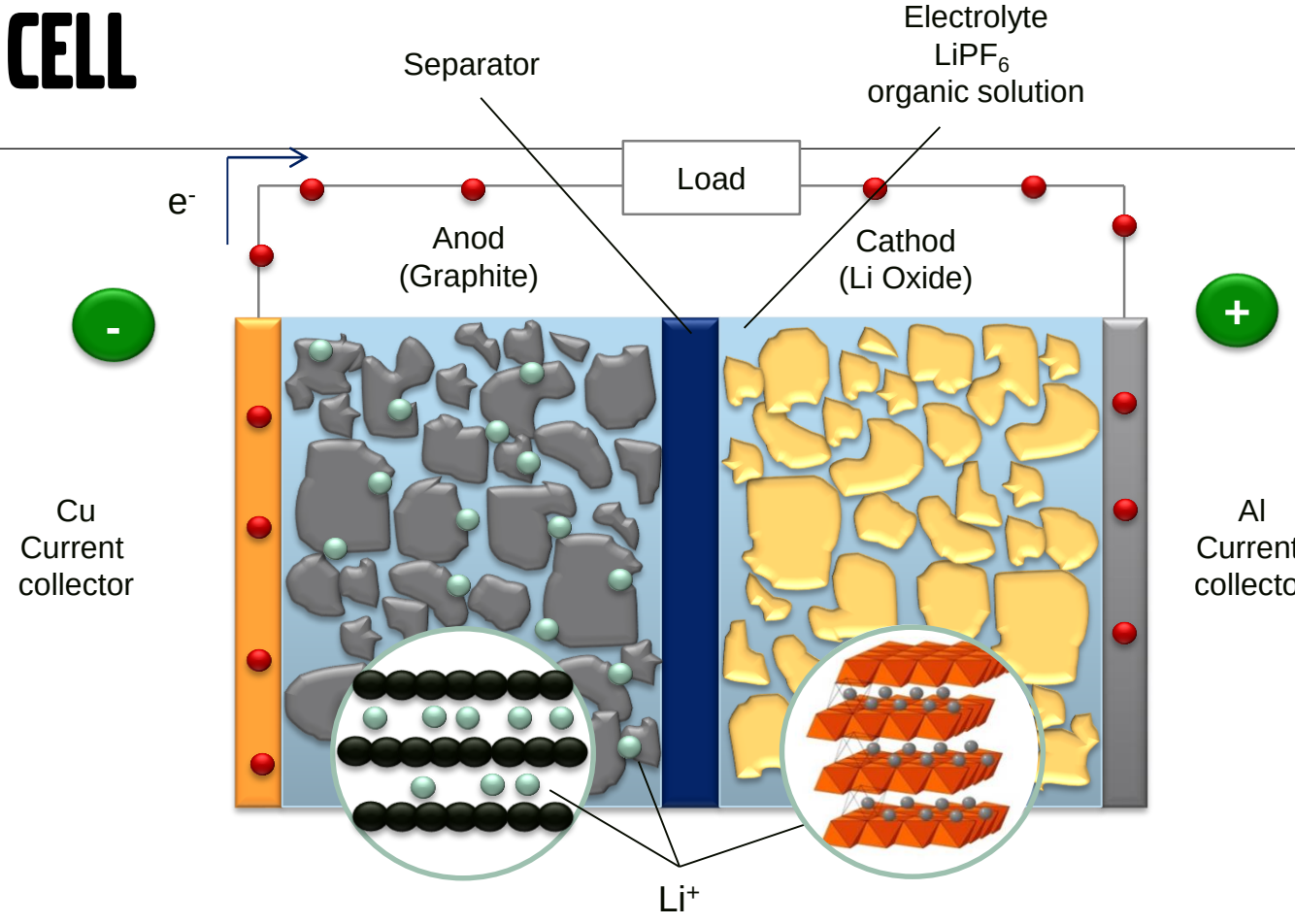
- Mastering the battery technology is an enabler for a succesfull electrification strategy with reliable performance & solid profitability.

- Cell technology competence is a must for an optimized battery utilization to be able to deliver competitive electrical range, fuel economy and performance for different applications.

BATTERIES DON'T DIE – THEY GET MURDERED

- Too aggressive usage will lead to premature battery end of life.
- Volvo Life Requirements
- Difficult to predict battery health over time.
- A verified adaptive usage strategy and functionality is crucial to minimize the risk for premature battery end-of-life.

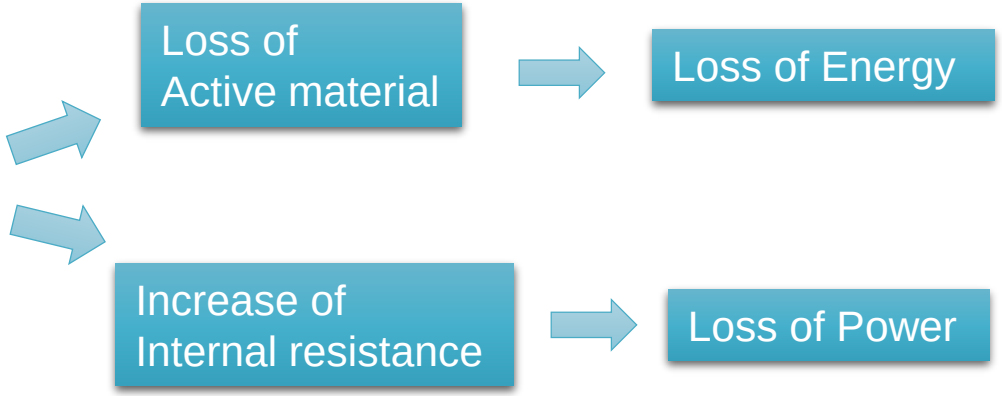
LI ION CELL



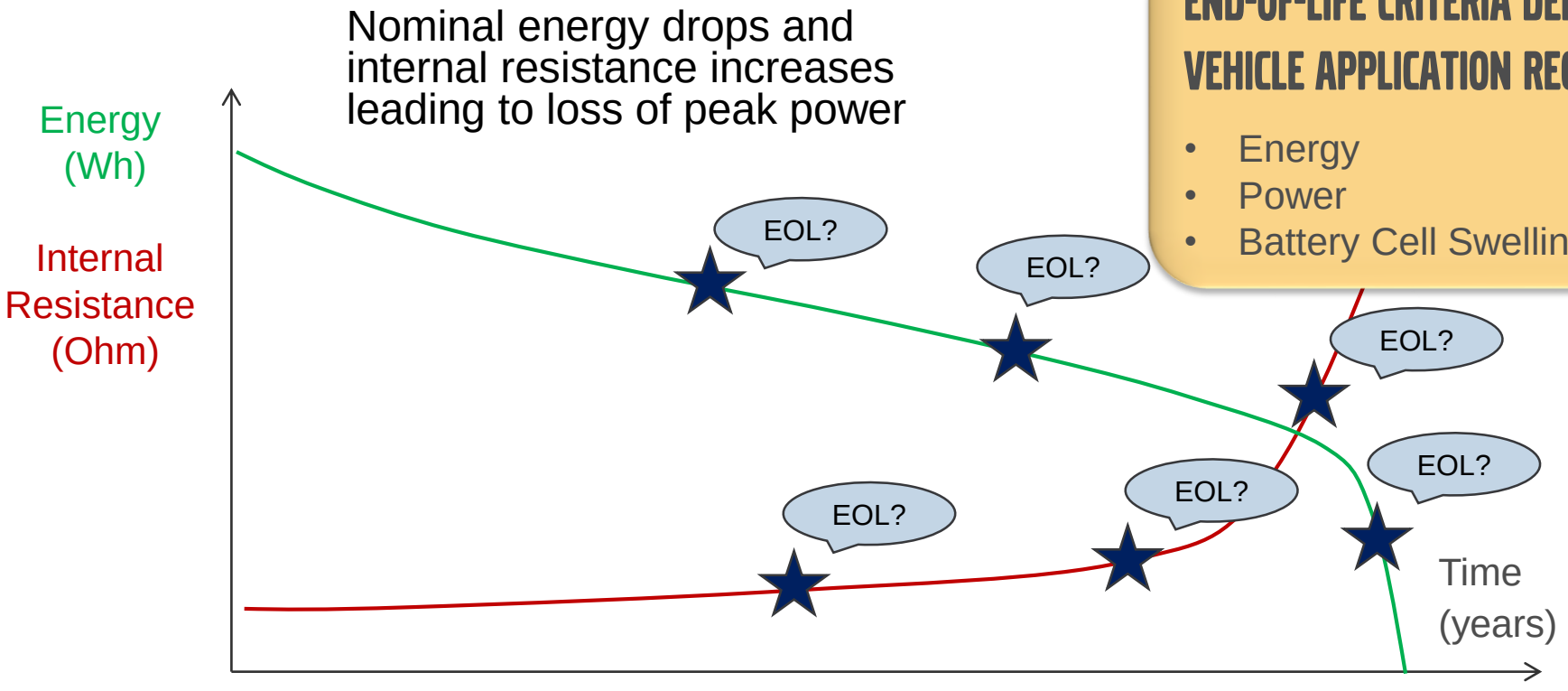
Discharge process

DEGRADATION MECHANISMS

- Loss of cyclable Li
- Dissolution of active material in anod/cathode
- Structural disordering (cracking of particles etc)
- Loss of conductivity in electrods or electrolyte
- Loss of contact with current collectors
- Growth of surface layer



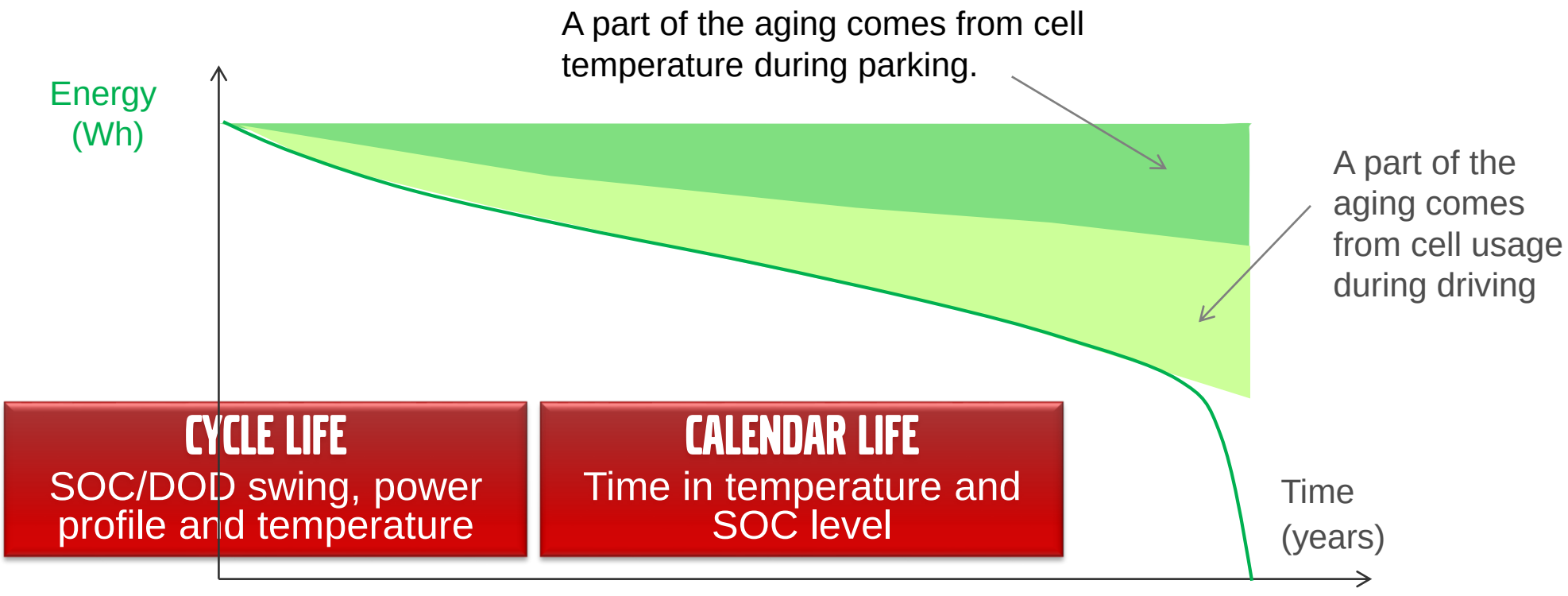
BATTERY AGEING BEHAVIOUR OVER TIME



END-OF-LIFE CRITERIA DEPENDS ON THE VEHICLE APPLICATION REQ. RELATED TO

- Energy
- Power
- Battery Cell Swelling

CYCLING & CALENDAR AGEING



FACTORS AFFECTING DEGRADATION

CYCLE LIFE
SOC/DOD swing, power profile and temperature

CALENDAR LIFE
Time in temperature and SOC level

	Battery Usage*	Degradation Factors
1	Driving distance (week/weekend)	Energy throughput
2	Driving behavior	C-rate
3	SOC window	DOD (depth of discharge)
4	Charging behavior	SOC levels
5	Charging protocol (normal/fast charging)	C-rate & SOC levels
6	Temperature (driving/charging/parking)	Temperature & SOC levels

*Not in degradation order

DIFFERENT APPLICATIONS

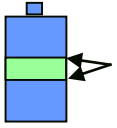
HEV BATTERY MAIN REQUIREMENTS:

Short duration power for regen and boost. Fuel economy improvement through regen and ICE down size.

PHEV/EV BATTERY MAIN REQUIREMENTS:

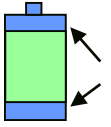
Energy for electrical drive range & power to follow the traffic. Fuel economy improvement through the use of grid energy.

HEV



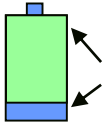
~ 60-40% SOC

PHEV



~ 90-15% SOC

LONG RANGE EV



~100-10% SOC

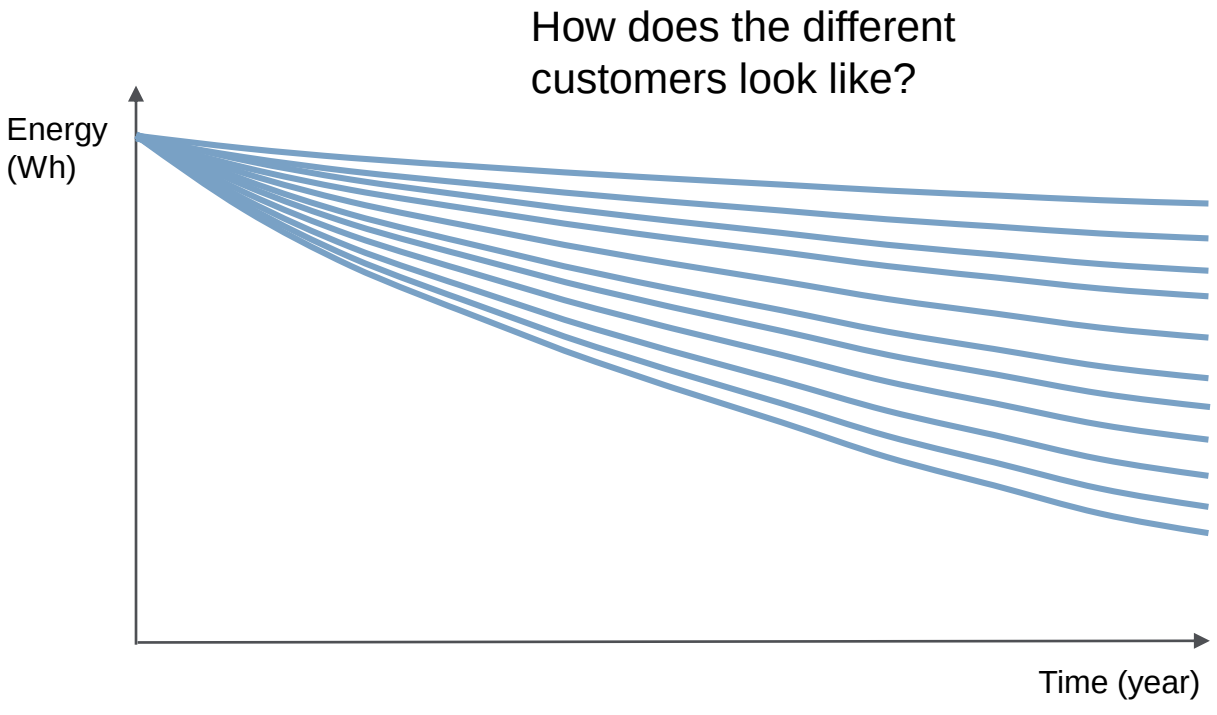
10 YEAR LIFE REQ

> 60 000 cycles

~ 6 000 cycles

~ 600 cycles

LARGE SPREAD IN DEGRADATION



FOR EVERY VEHICLE:

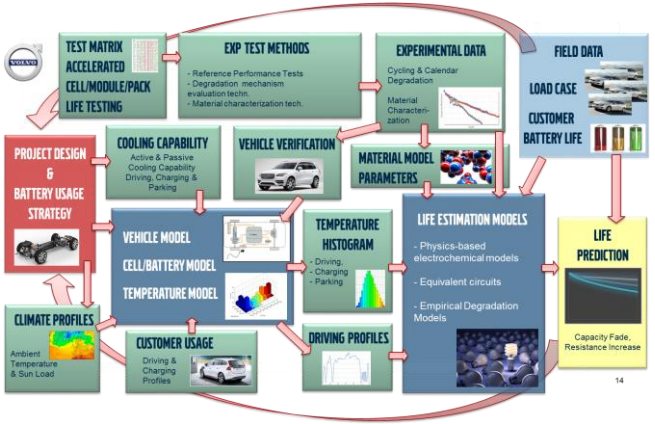
- Large spread in customer usage.
- Large spread in battery degradation.

Large number of different applications for light and heavy vehicle gives a large spread in usage and degradation.

VOLVO BATTERY LIFE MODEL PROCESS

DEVELOP AND VERIFY

- The battery design
- Usage strategies for optimal battery utilization
- Specific functionality and algorithms for battery usage



CUSTOMER BENEFIT:

Optimized Battery Utilization gives Electrified Vehicles with Competitive Customer Attributes to a Lower Cost

TEST MATRIX ACCELERATED CELL/MODULE/PACK LIFE TESTING

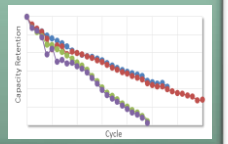
TEST METHODS

- RPT
- Degr. mech. evaluation techn.
- Material characterization tech.

EXPERIMENTAL DATA

Cycling & Calendar Degradation

Material Characteri-zation



FIELD DATA

LOAD CASE

CUSTOMER BATTERY LIFE

PROJECT DESIGN & BATTERY USAGE STRATEGY

THERMAL CAPABILITY

Active & Passive Thermal Capability Driving, Charging & Parking

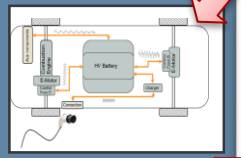
VEHICLE VERIFICATION

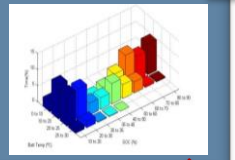
MATERIAL MODEL PARAMETERS

VEHICLE MODEL

CELL/BATTERY MODEL

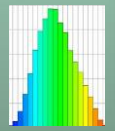
TEMPERATURE MODEL





TEMPERATURE HISTOGRAM

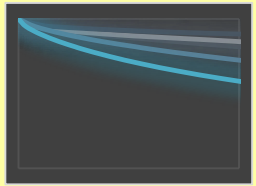
- Driving,
- Charging
- Parking



LIFE ESTIMATION MODELS

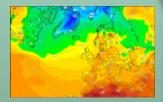
- Physics-based electrochemical models
- Equivalent circuits
- Empirical Degradation Models

LIFE PREDICTION



Capacity Fade, Resistance Increase

CLIMATE PROFILES



Ambient Temperature & Sun Load

CUSTOMER USAGE

Driving & Charging Profiles

DRIVING PROFILES

DRIVING ASSUMPTIONS FOR CUSTOMERS

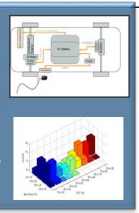
COOLING CAPABILITY
Active & Passive Cooling Capability Driving, Charging & Parking

VEHICLE VERIFICATION

VEHICLE MODEL

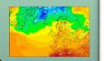
CELL/BATTERY MODEL

TEMPERATURE MODEL



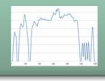
TEMPERATURE HISTOGRAM
- Driving,
- Charging
- Parking

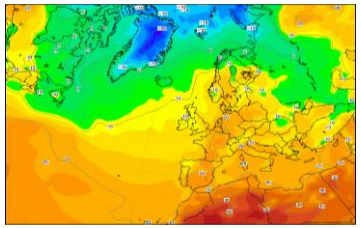
CLIMATE PROFILES
Ambient Temperature & Sun Load

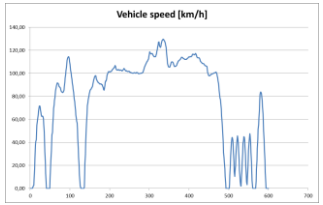


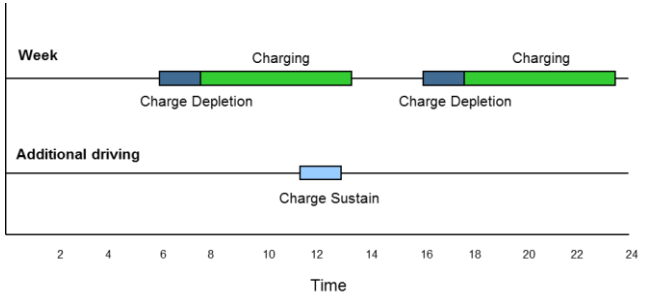
CUSTOMER USAGE
Driving & Charging Profiles

DRIVING PROFILES



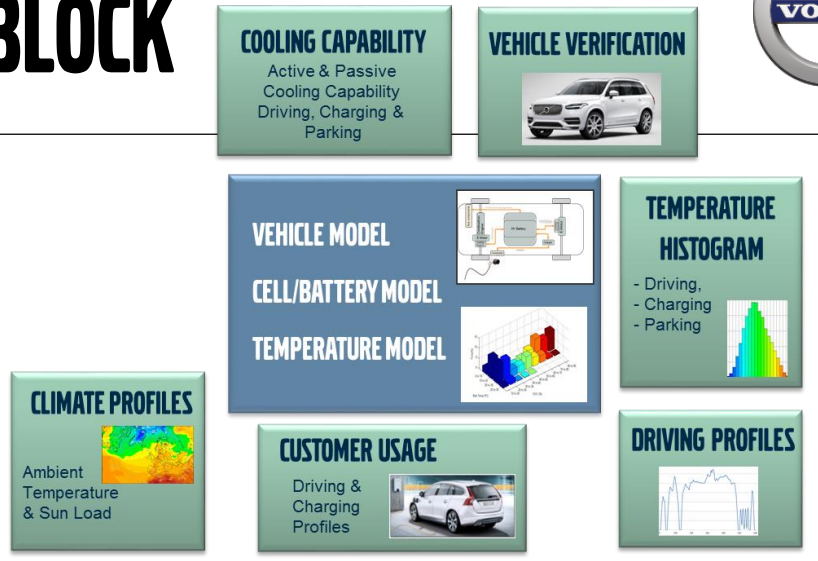


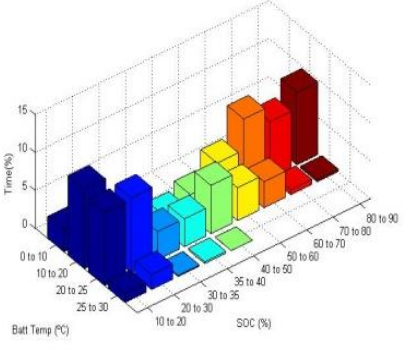




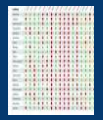
BATTERY TEMPERATURE MODEL BLOCK

- Complete Vehicle models to validate the vehicle attributes such as the performance.
- Cell models (equivalent circuit model) and battery system models simulating the battery controls.
- Temperature models including thermal strategies and thermal capability for active and passive cooling/heating.





TEST MATRIX ACCELERATED CELL/MODULE/PACK LIFE TESTING



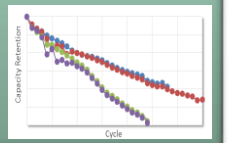
TEST METHODS

- RPT
- Degr. mech. evaluation techn.
- Material characterization tech.

EXPERIMENTAL DATA

Cycling & Calendar Degradation

Material Characteri-zation



FIELD DATA

LOAD CASE

CUSTOMER BATTERY LIFE

PROJECT DESIGN & BATTERY USAGE STRATEGY

THERMAL CAPABILITY

Active & Passive Thermal Capability Driving, Charging & Parking

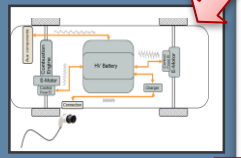
VEHICLE VERIFICATION

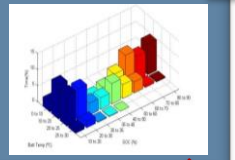
MATERIAL MODEL PARAMETERS

VEHICLE MODEL

CELL/BATTERY MODEL

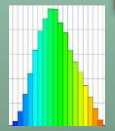
TEMPERATURE MODEL





TEMPERATURE HISTOGRAM

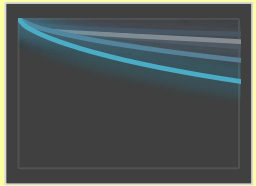
- Driving,
- Charging
- Parking



LIFE ESTIMATION MODELS

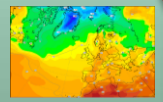
- Physics-based electrochemical models
- Equivalent circuits
- Empirical Degradation Models

LIFE PREDICTION



Capacity Fade, Resistance Increase

CLIMATE PROFILES



Ambient Temperature & Sun Load

CUSTOMER USAGE

Driving & Charging Profiles

DRIVING PROFILES

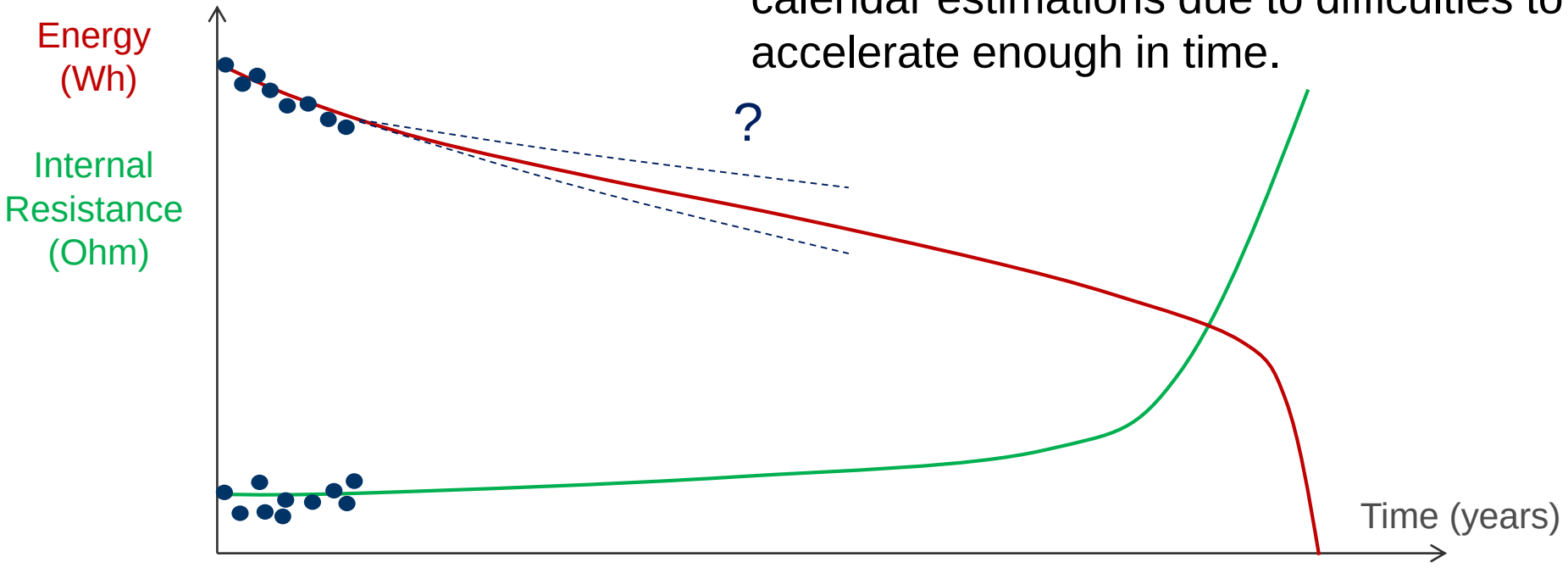
TEST METHODS

- The life tests need to be accelerated.
- It is important that the accelerated test methods must not introduce additional degradation mechanisms that would not occur in normal cutomer usage.
- Cycle testing are accelerated by cycling 24/7 using higher C-rates and higher temperatures. Calendar testing are accelerated by higher temperatures and different SOC levels.
- Additional complexity introduce uncertainties:
  - Degradation is path dependent, i.e. depends on test order.
  - Infinite number of cycle & calendar ageing combinations for customer usage.

TESTING ARE VERY TIME AND RESOURCE CONSUMING INDEPENDENT OF LIFE MODEL USED

DIFFICULT TO PREDICT THE LIFE PERFORMANCE

Large uncertenties especially for calendar estimations due to difficulties to accelerate enough in time.



TEST MATRIX ACCELERATED CELL/MODULE/PACK LIFE TESTING

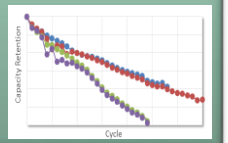
TEST METHODS

- RPT
- Degr. mech. evaluation techn.
- Material characterization tech.

EXPERIMENTAL DATA

Cycling & Calendar Degradation

Material Characteri-zation



FIELD DATA

LOAD CASE

CUSTOMER BATTERY LIFE

PROJECT DESIGN & BATTERY USAGE STRATEGY

THERMAL CAPABILITY

Active & Passive Thermal Capability Driving, Charging & Parking

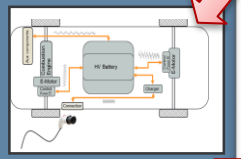
VEHICLE VERIFICATION

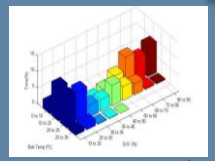
MATERIAL MODEL PARAMETERS

VEHICLE MODEL

CELL/BATTERY MODEL

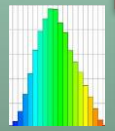
TEMPERATURE MODEL





TEMPERATURE HISTOGRAM

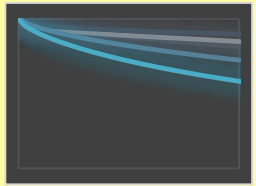
- Driving,
- Charging
- Parking



LIFE ESTIMATION MODELS

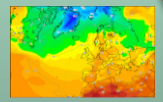
- Physics-based electrochemical models
- Equivalent circuits
- Empirical Degradation Models

LIFE PREDICTION



Capacity Fade, Resistance Increase

CLIMATE PROFILES



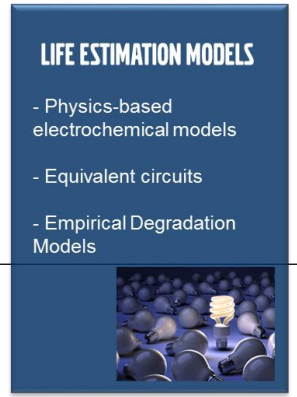
Ambient Temperature & Sun Load

CUSTOMER USAGE

Driving & Charging Profiles

DRIVING PROFILES

LIFE ESTIMATION MODELS

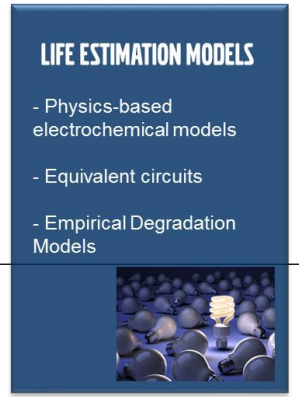


PHYSICS-BASED ELECTROCHEMICAL MODELS

Model degradation mechanisms and electrochemical reactions and dependency. Needs a large amount of material characterization for model parameterisation.

Time and resource consuming, and computational demanding.

LIFE ESTIMATION MODELS

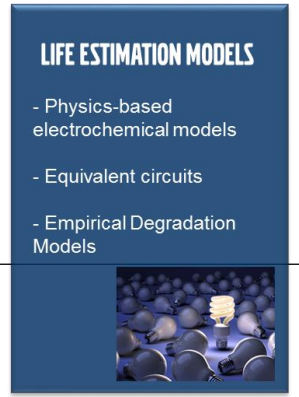


PHYSICS-BASED ELECTROCHEMICAL MODELS

EMPIRICAL DEGRADATION MODELS

Without detailed knowledge of the electrochemical design, the models can be parameterised using experimental cycle and calendar life tests. Needs extensive testing. Only valid in the defined set of operation conditions.

LIFE ESTIMATION MODELS



PHYSICS-BASED ELECTROCHEMICAL MODELS

EMPIRICAL DEGRADATION MODELS

EQUIVALENT CIRCUIT MODELS

Semi-empirical models with different complexity that partly explain the ageing mechanisms. Can be used in complete vehicle simulations. Cover a wider range of operation conditions. Still needs an extensive testing to parameterise.

TEST MATRIX ACCELERATED CELL/MODULE/PACK LIFE TESTING

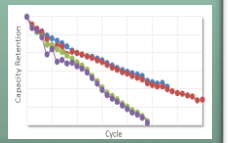
TEST METHODS

- RPT
- Degr. mech. evaluation techn.
- Material characterization tech.

EXPERIMENTAL DATA

Cycling & Calendar Degradation

Material Characteri-zation



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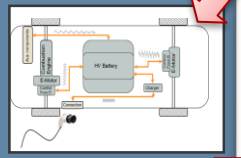
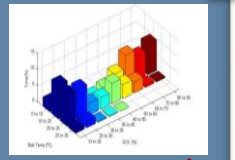
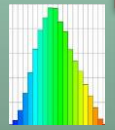




TEMPERATURE HISTOGRAM

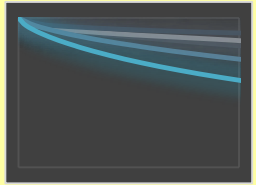
- Driving,
- Charging
- Parking



LIFE ESTIMATION MODELS

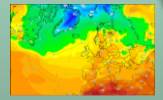
- Physics-based electrochemical models
- Equivalent circuits
- Empirical Degradation Models

LIFE PREDICTION



Capacity Fade, Resistance Increase

CLIMATE PROFILES



Ambient Temperature & Sun Load

CUSTOMER USAGE

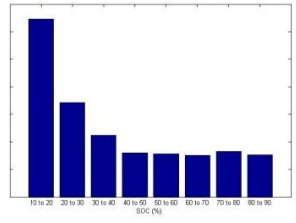
Driving & Charging Profiles

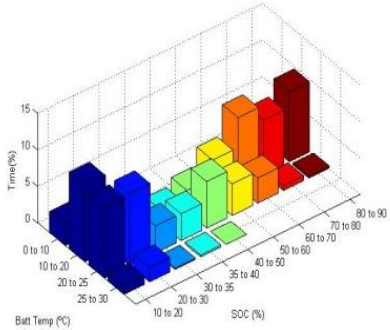
DRIVING PROFILES

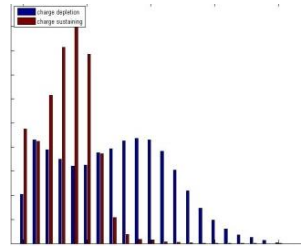
FIELD DATA

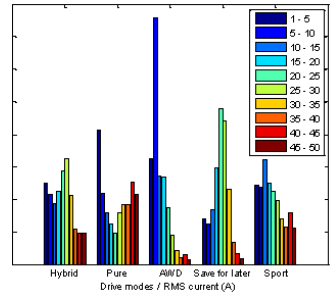
EVALUATE BATTERY LIFE DUE TO DIFFERENT CUSTOMERS USAGE

- Customer driving profiles (distance, speed, mode)
- Customer charging profiles (time, rate)
- Climate profiles (ambient temp. & sun load)
- Battery usage (SOC, RMS current, temp.)
- On-board diagnostic for battery health







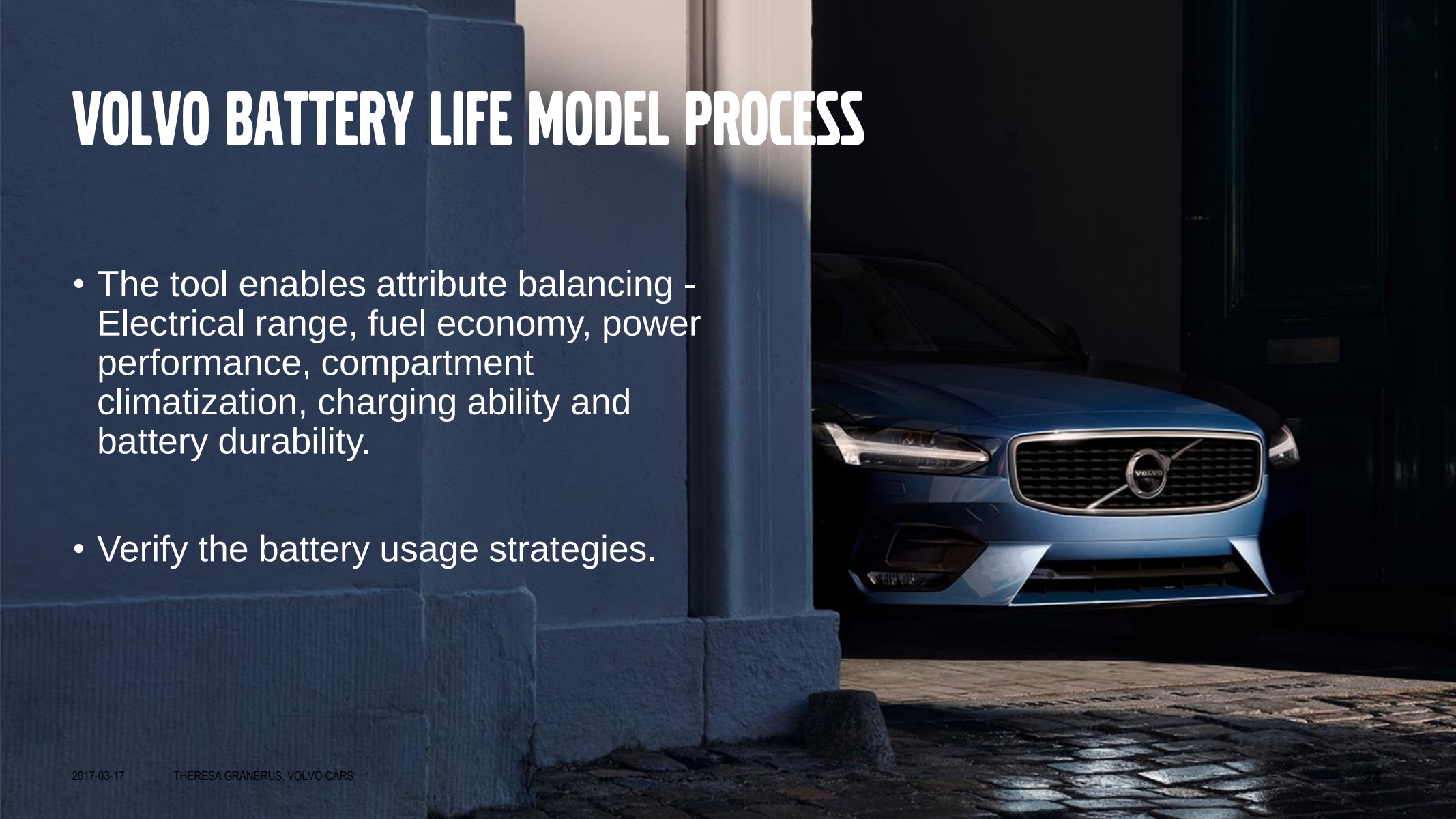


TAKES TIME TO VALIDATE THE LIFE MODELS BY FIELD DATA

VOLVO BATTERY LIFE MODEL PROCESS

- The tool enables attribute balancing - Electrical range, fuel economy, power performance, compartment climatization, charging ability and battery durability.

- Verify the battery usage strategies.



SUMMARY

The li ion technology still undergoes rapid and frequent changes with new chemistry every second year. New life models are needed in the future for post li-ion technologies.

Battery aging and understanding the degradation mechanisms is extremely complex.

Life testing is very time and resource consuming. Large test matrixes and testing for several years are needed for confident results for model parameterization.

No standardized accelerated ageing test methods are available.

Life estimation models are still under development and contains a number of uncertainties. Large spread in degradation due to different customer usage and different applications make the models complex.

Takes time to receive information from the real customers to verify the models.


THANK YOU