T. Patey, R. Flueckiger, J. Poland, N. Prasad, O. Sologubenko; ABB Corporate Research, 4th of May 2015

Li-ion BESS for public transportation
Electric bus battery lifetime estimation

Power and productivity
for a better world™

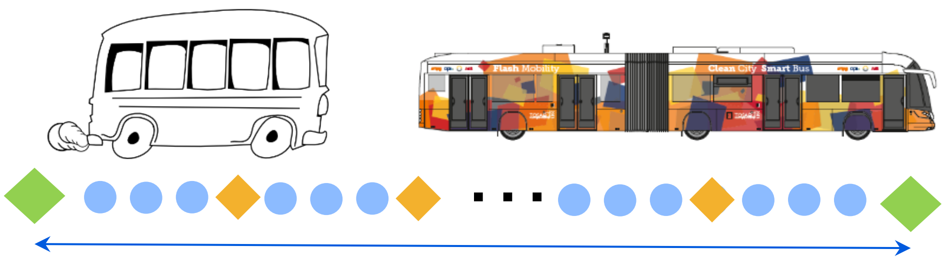
Li-ion BESS for public transportation
Outline

Introduction → Model → Case study → Conclusions

1) Introduction to electric bus lines
2) Electric, thermal, aging model of a battery
3) Case study - battery aging in an electric bus
4) Conclusions & Outlook

What a diesel-powered public transportation bus does
Product requirements of electric bus line

- **Introduction**
- Model
- Case study
- Conclusions



Terminal charge (100 kW)

Terminal stop (0-5 minutes)

20-30 s wait at busy stops during rush hour

"Typical"* line: 30-40 stops, 10-14 km in 30-50 min, 11-15 busy stops, 10-20 buses at 5-15 min intervals

"Opportunity" / flash charge (600 kW)

Diesel bus:

- Makes noise, CO_2, and particulate matter pollution
- Pay for personnel, infrastructure, and fuel (**$/litre**)
- Must be exception ready! (bus needed for other line, traffic, car blocks bus stop, etc)

Electric bus:

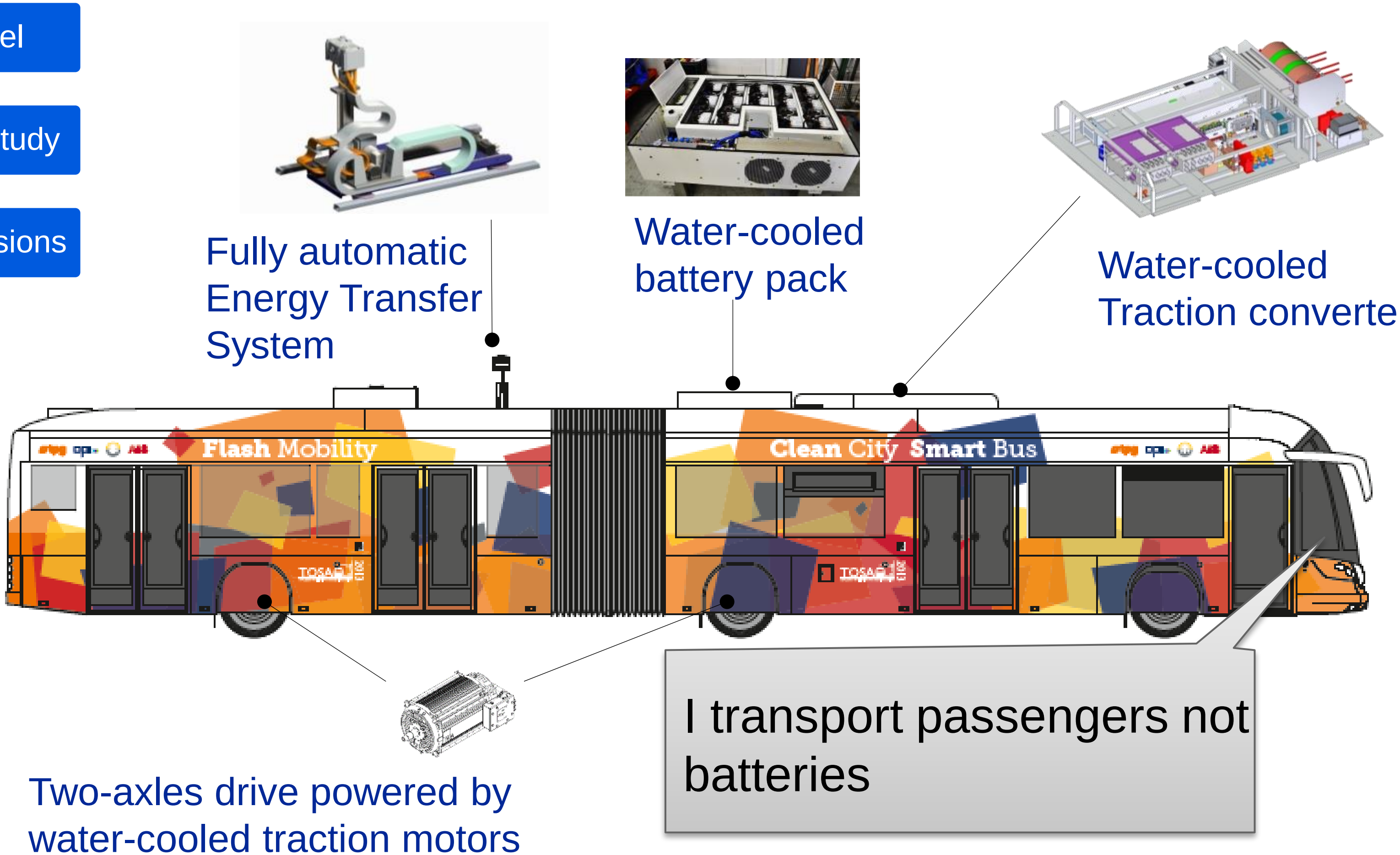
- Less noise and no local generation of CO_2 and particulate matter pollution
- Pay for personnel, infrastructure and electricity (**$/kWh**)
- Must be exception ready! (bus needed for other line, traffic, car blocks bus stop, etc)

→ design the battery for the line

*** There's no such thing as a "typical" bus line**

The electric bus – TOSA electic bus, Geneva, CH
Main components – battery as key component

- Introduction
- Model
- Case study
- Conclusions



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Electric bus in Geneva
Line 23 to be converted from diesel to all electric*

- Introduction
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NZZ article March 7, 2015 reports:

- 15 second flash charge every 4 stops
- 94% of energy from renewable sources / emission free in the city
- Advantage of no overhead lines:
  - Aesthetics: no wires obstructing sight
  - Supporting infrastructure for a new line with battery buses is half the price (bus costs similar)*
- Time saved for opportunity charging – 15s x 13 stops = ~3 minutes

Elektrobus Tosa

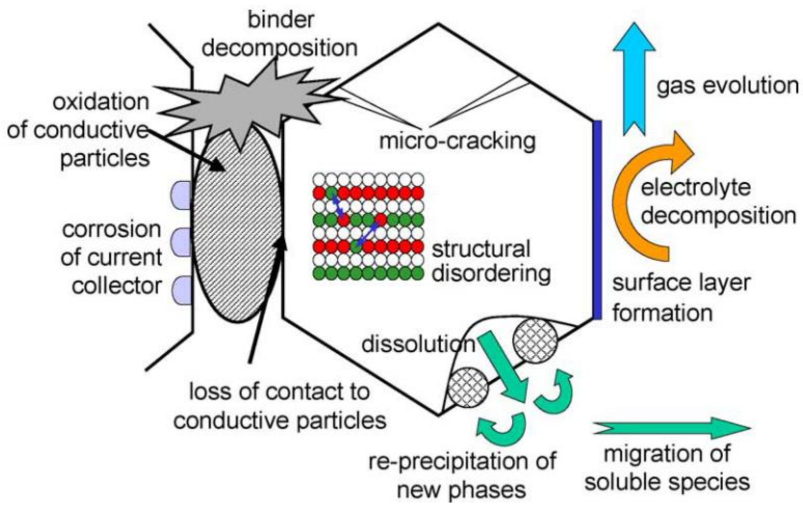
Genf tüftelt am Bus der Zukunft

* Source: NZZ, March 7, 2015.

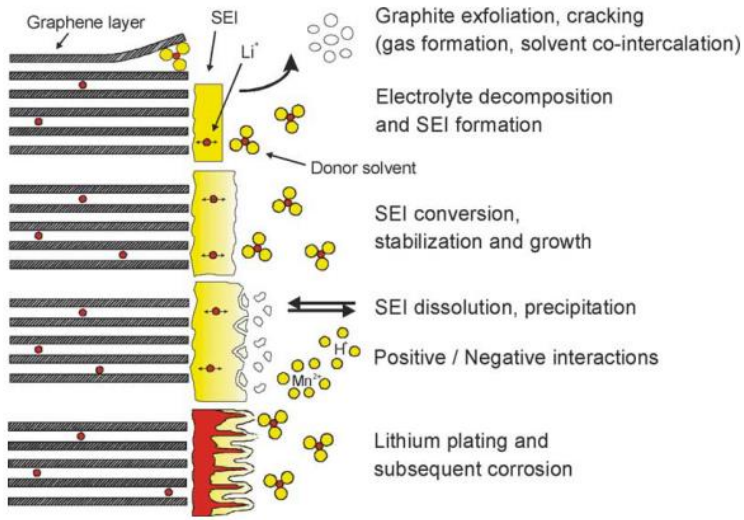
Map: Google Maps

Motivation for battery R&D
How to quickly estimate all these aging processes?

Aging at cathode



Aging at anode



- Key R&D question: How can we predict the net aging & performance impact of all the reactions above in an electric bus with reasonable accuracy?

→ A goal of battery R&D at ABB Corporate Research

Source of images: Vetter et al. (PSI), J. Power Sources, 2005

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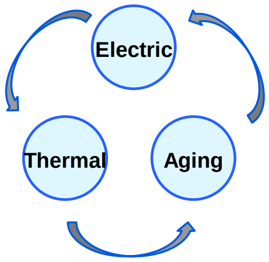
Electrical, thermal and aging model
Introduction



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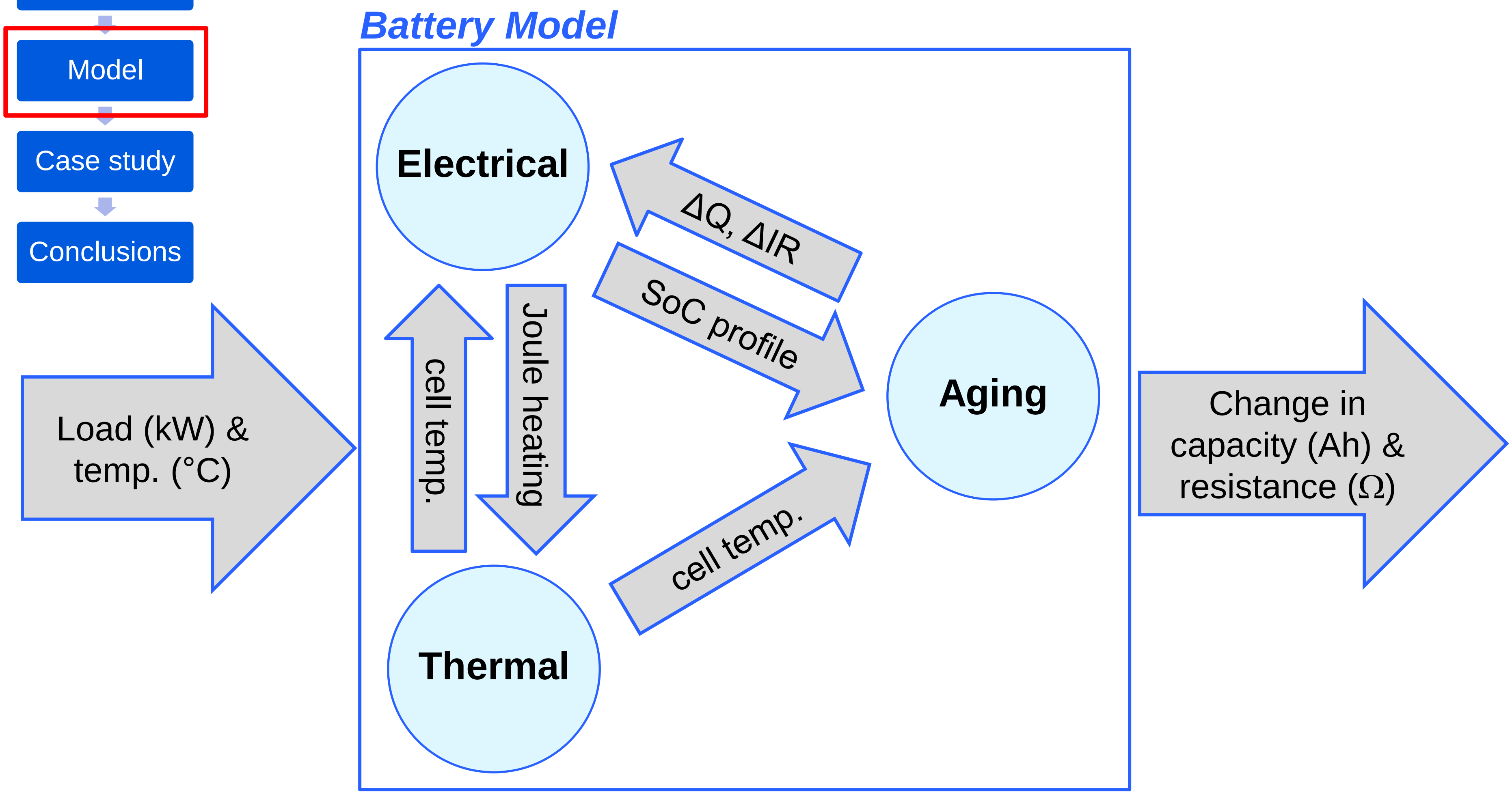
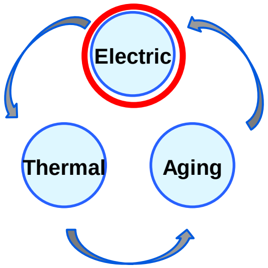


Electrical model
Record data and fit to electric model



- Introduction
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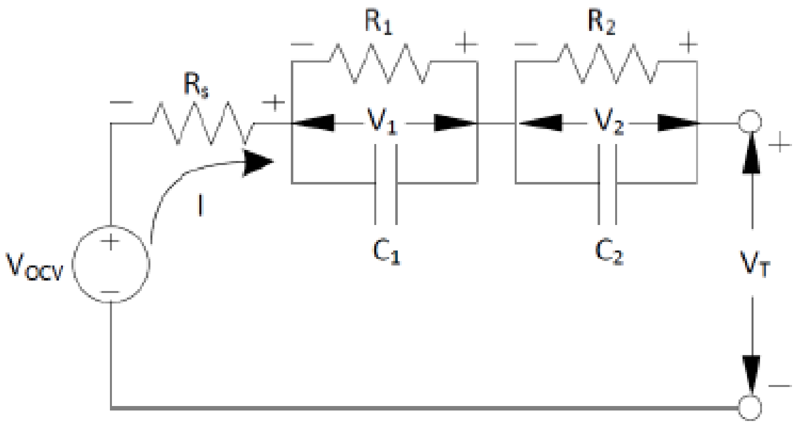
- Create an electrical model of the battery (right).
- Power pulse and open circuit voltage experiments.
- Calculate R,C parameters that describe overvoltages.
- Modify R,C parameters as battery ages.



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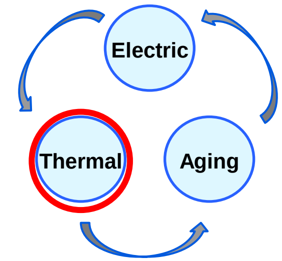
Thermal network model
Measure thermal properties and calculate T_{avg}



Introduction

Model

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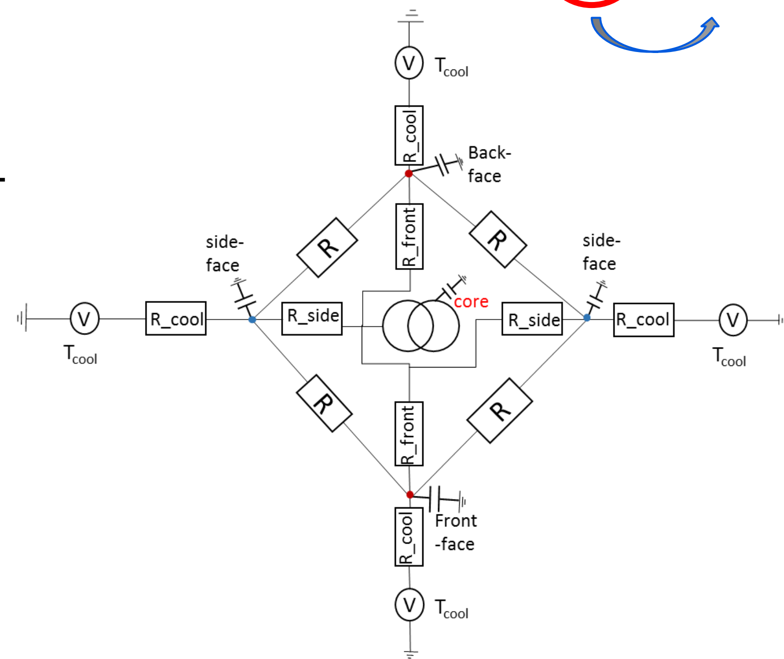
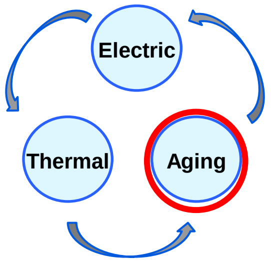
- Thermal network model is analagous to electrical network: T ~ voltage, heat transfer ~ current
- Critical step #1 - calculate the cell's internal electrical resistance.
- Critical step #2 - Measure the cell's heat capacity (J/kg/K) and conductivity (K/W).



Aging model: semi-empirical approach
Conduct battery experiments and fit data



Introduction

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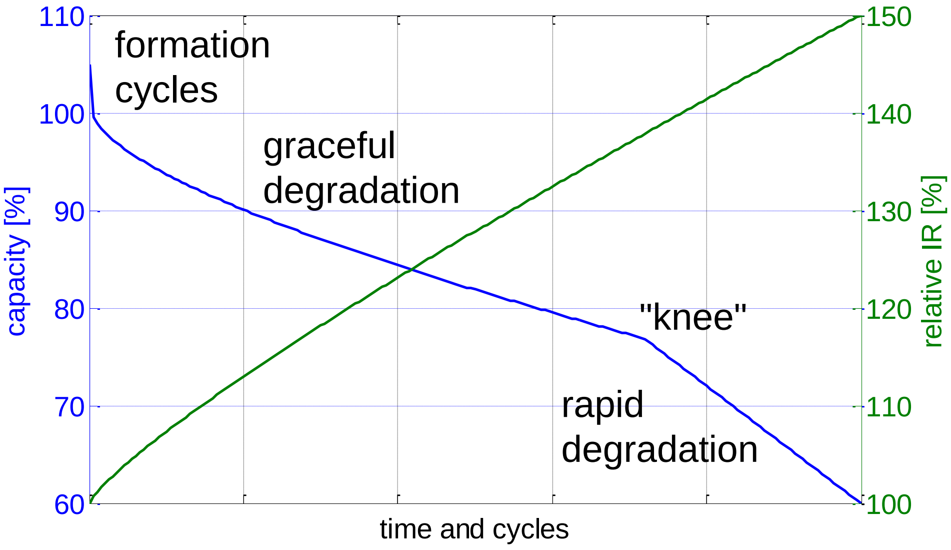
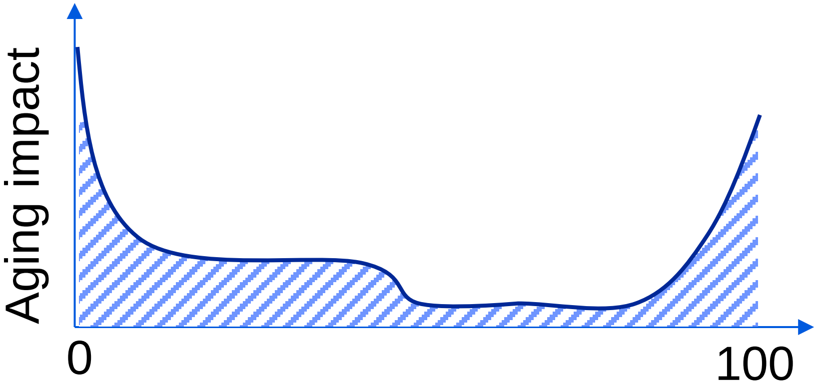
- A battery degrades due to time (calendar) and use (cycling).
- Critical step #1 – predict the temperature.
- Critical step #2 – predict impact of Ah throughput (ΔSOC, right).





Case study of electric bus, similar to TOSA, Geneva
Geneva, Switzerland

Introduction
Model
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Conclusions

Case study details:

- 43 kWh, 300 kW Li-ion battery.
- 10 full journeys per day, 365 d/y for 10 y.
- Lithium titanate (LTO) as anode.

→ **Key design question: how does cooling influence the aging of the battery?**

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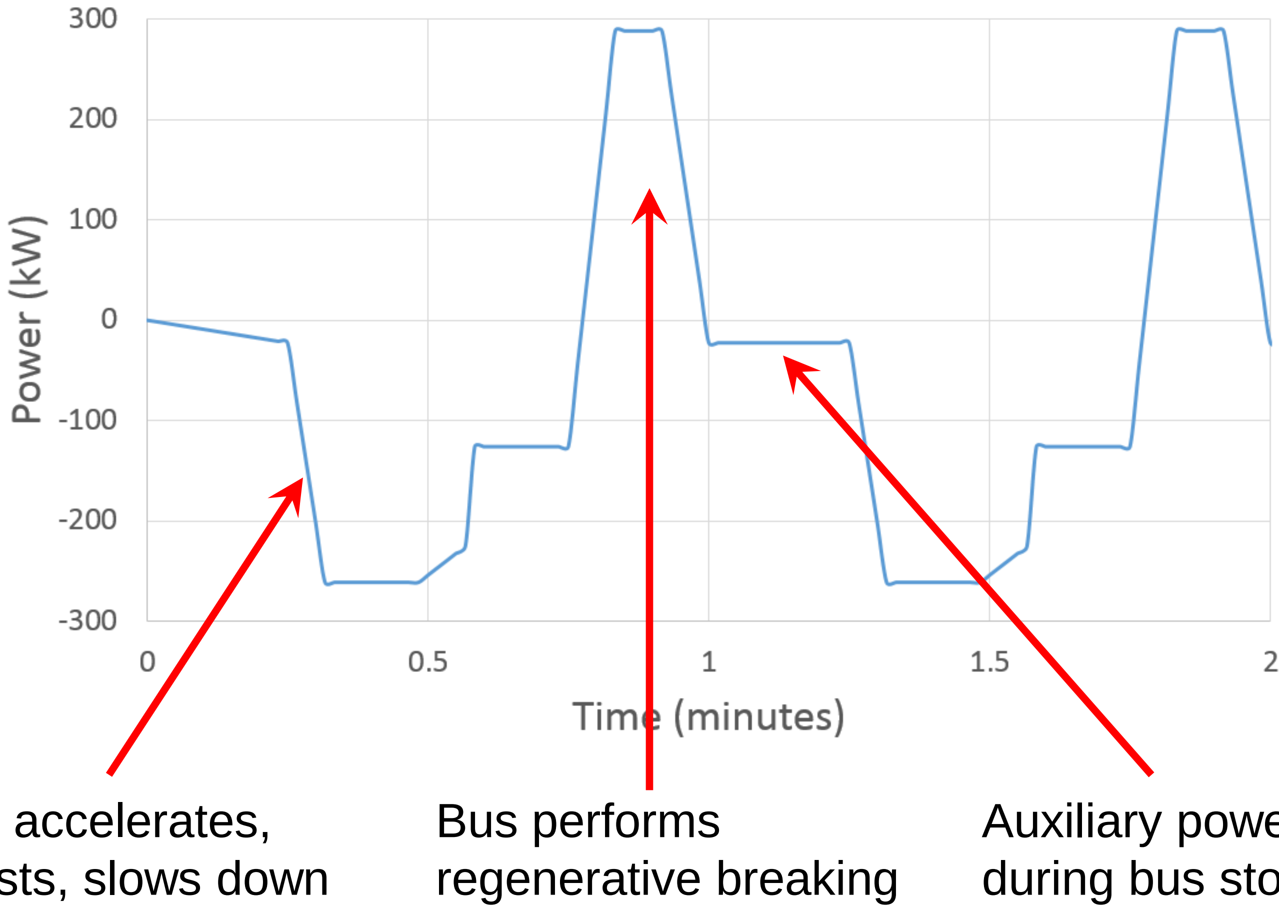
Load profile: acceleration & regenerative breaking
What is the aging impact of cooling?

- Introduction
- Model
- **Case study**
- Conclusions



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Load profile: away and return journey of load profile
What is the aging impact of cooling?

- Introduction
- Model
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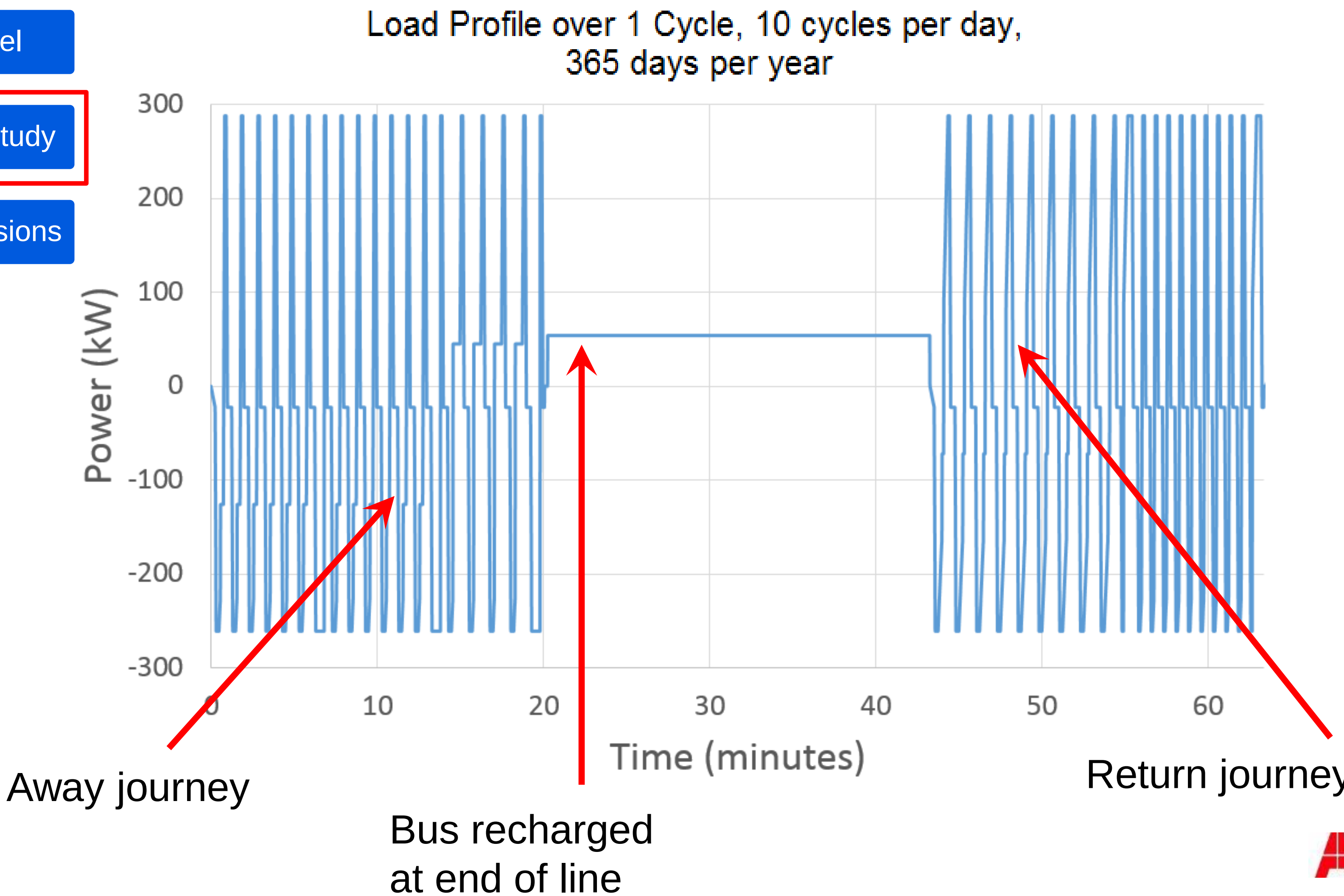

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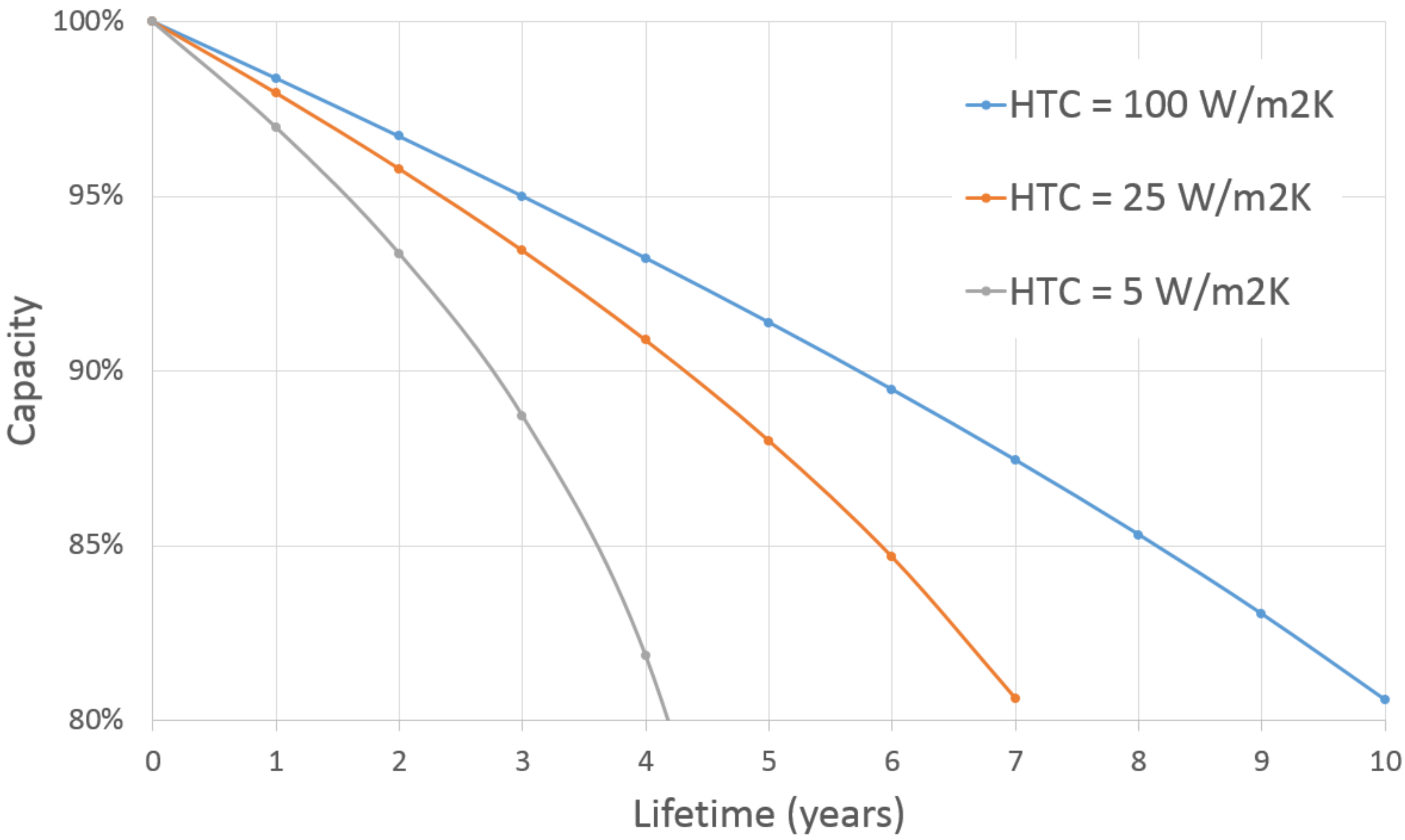
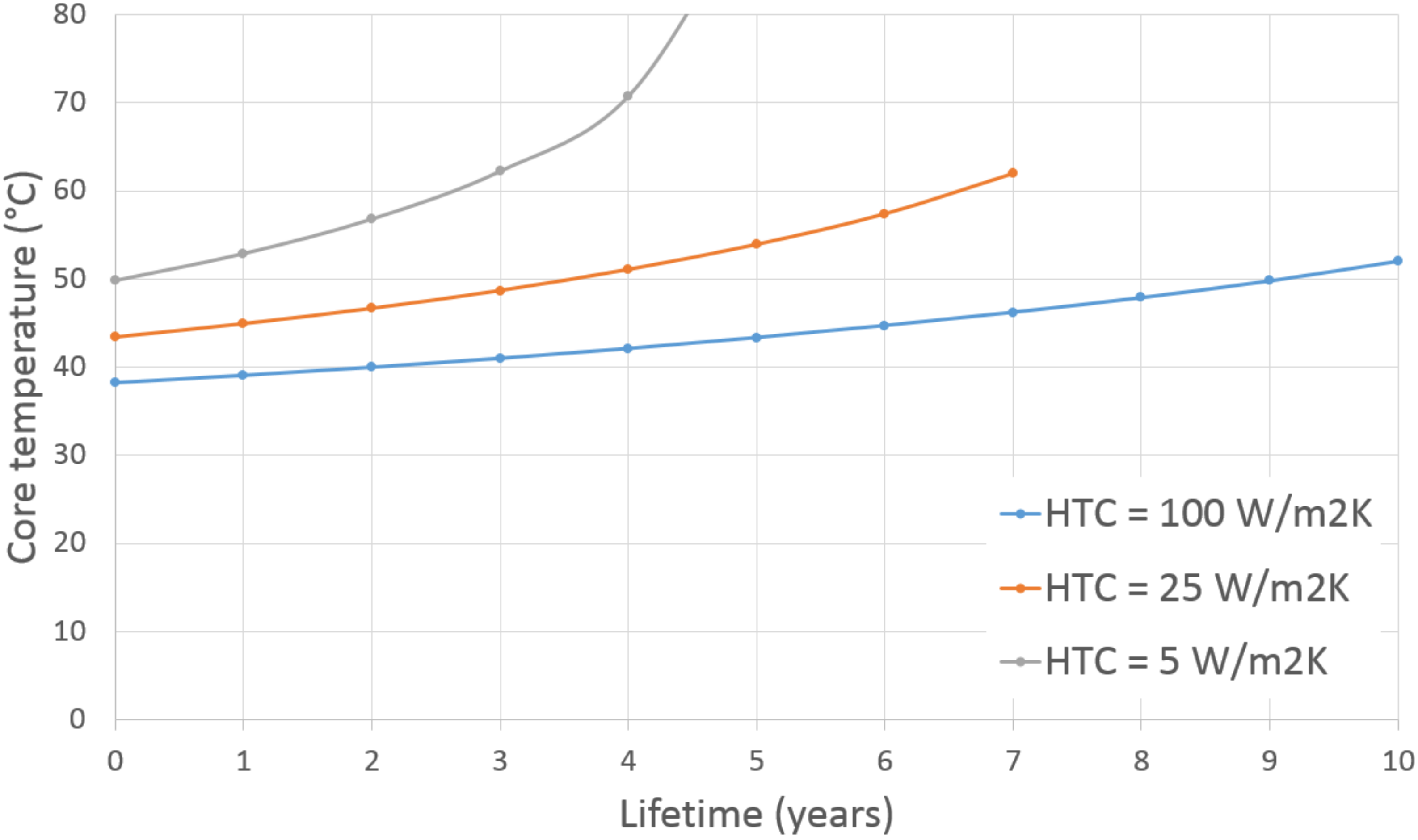
Heat transfer coefficient (HTC) impact on aging

What is the aging impact of cooling?

- Introduction
- Model
- **Case study**
- Conclusions



Heat transfer coefficient (HTC) impact on temperature
What is the aging impact of cooling?



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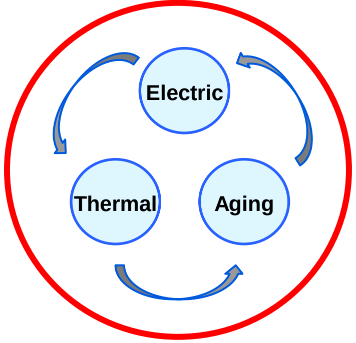
Conclusions on battery model



- For long lifetime of 10 years, liquid-cooling is needed to manage aging and core temperature.
- Battery modelling acts as design guideline and not “perfect” forecast (especially for prototypes).
- Model components are interdependent. For example:
  - Electric model determines resistance.
  - Thermal model calculates temperature (based on resistance).
  - Aging model highly depends on temperature (Δ10°C = ca. x2 more aging), and modifies R.

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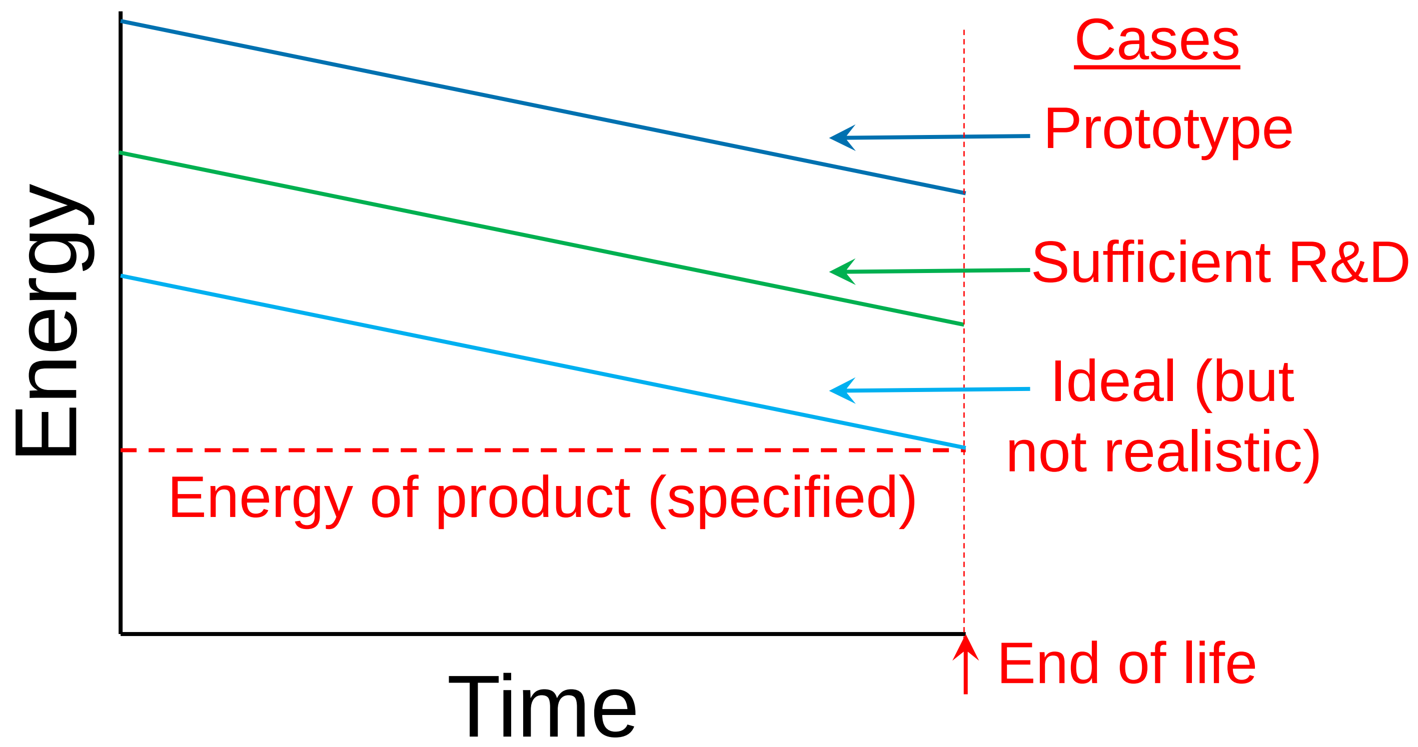
Battery R&D
Sizing of prototypes and developed battery

- Introduction
- Model
- Case study
- **Conclusions**



Conclusions

Introduction

Model

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Conclusions

- Design the battery for the public transportation line and the bus.
- Models support battery design, but it must be combined with experience and field data.
- Batteries will increasingly be used in ABB products and systems
  → Lifetime knowledge critical for reliability
  → Continued collaboration with Academia

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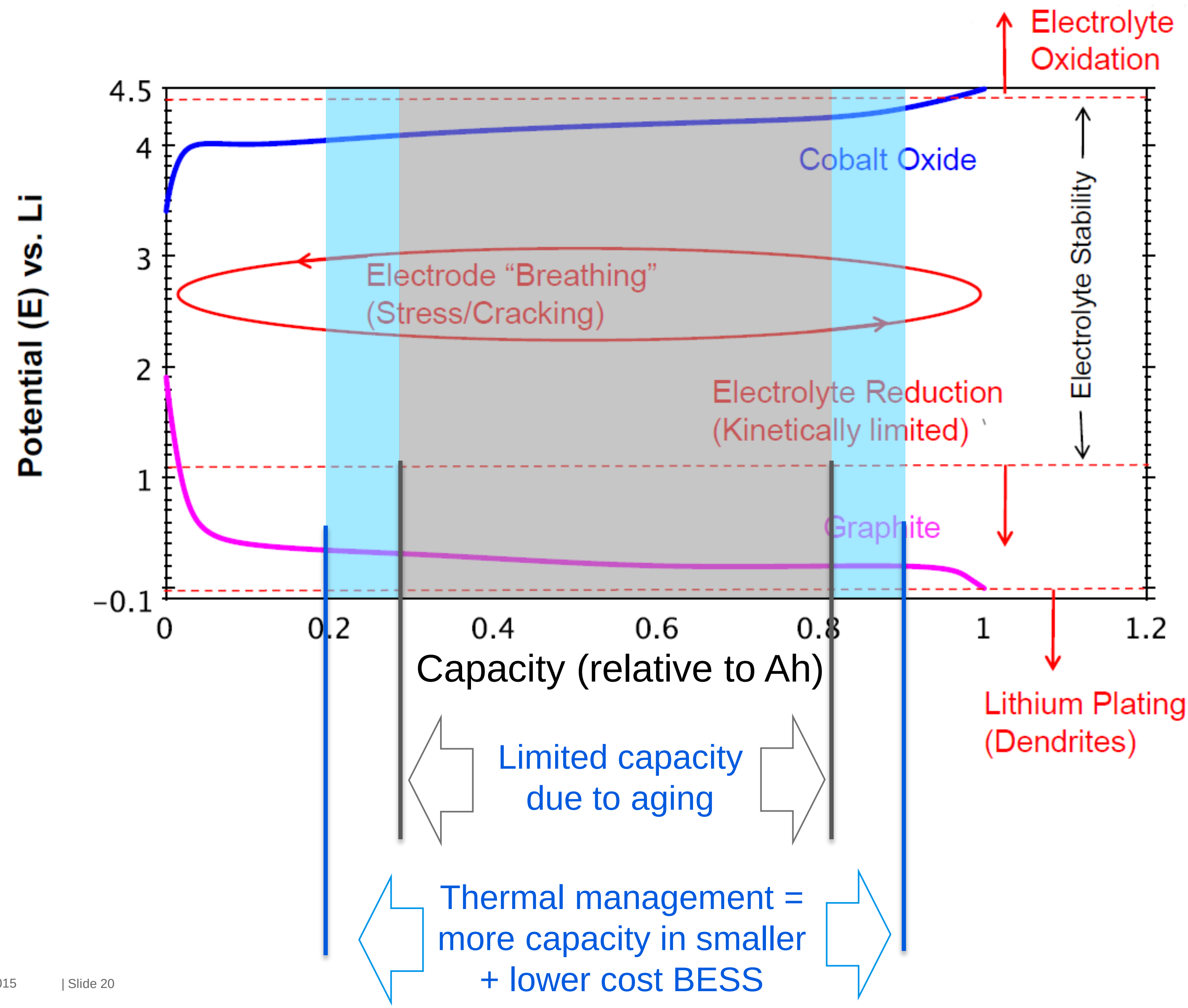
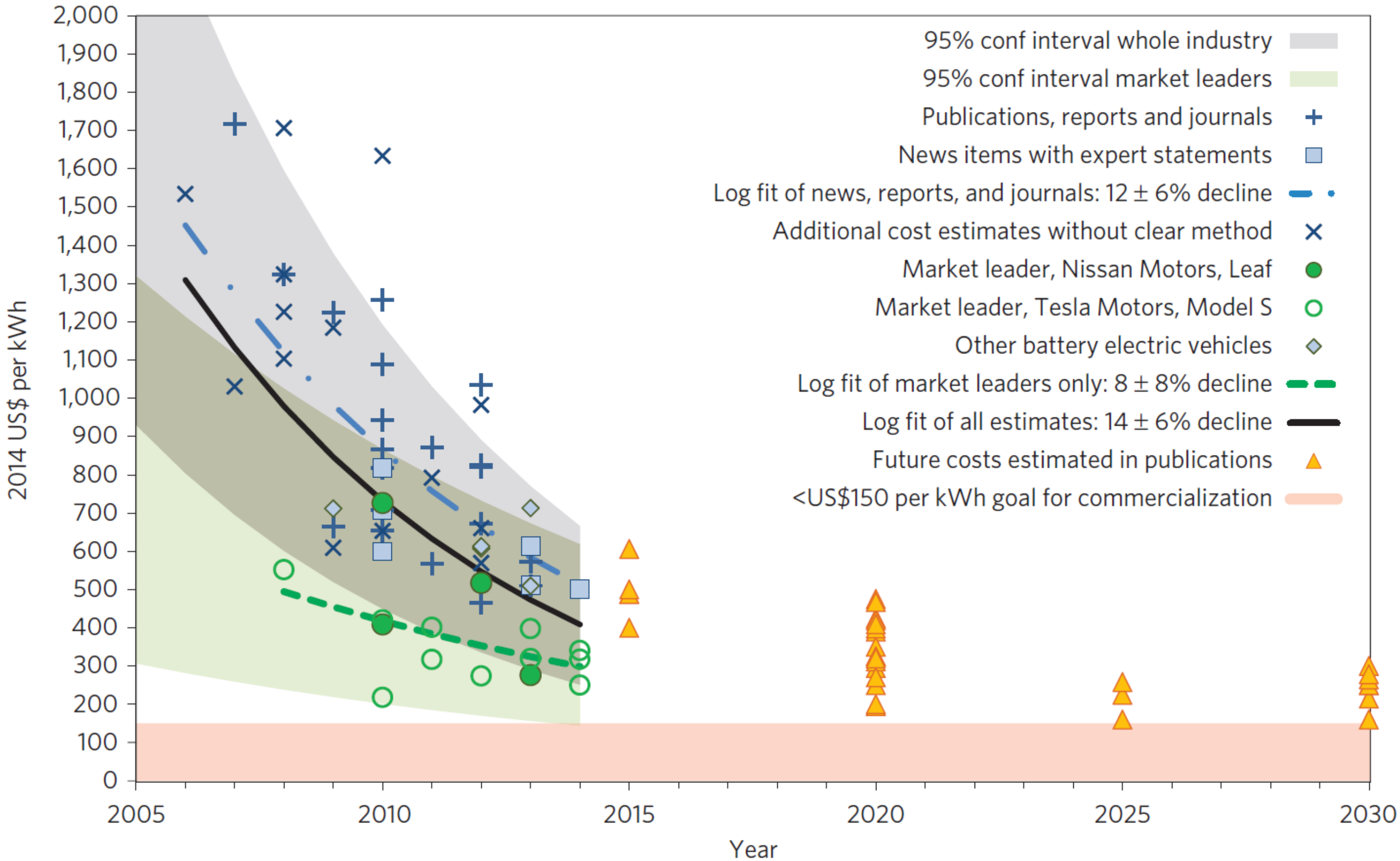
Operation and sizing of a Li-ion battery



Rapid falling cost of LIB packs in EVs
The impact of learning curves – 8% annual decline*



*Source: Nykvist, B. and Nilsson, M., Nature Climate Change, 23 March 2015

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Battery energy storage
Overview and future batteries