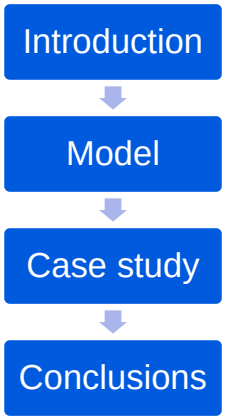
T. Patey, R. Flueckiger, J. Poland, N. Prasad, O. Sologubenko; ABB Corporate Research, 4th of May 2015

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

Power and productivity
for a better world™
ABB

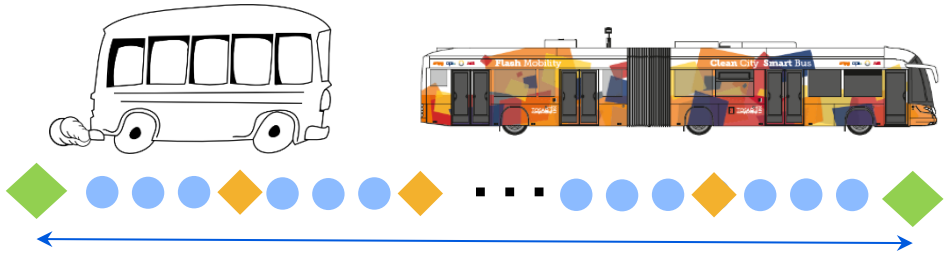
Li-ion BESS for public transportation
Outline



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



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

Terminal charge (100 kW)

Terminal stop (0-5 minutes)

20-30 s wait at busy stops during rush hour

"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**

© ABB

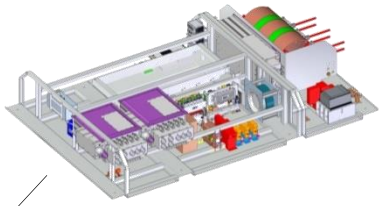
*** There's no such thing as a "typical" bus line**

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

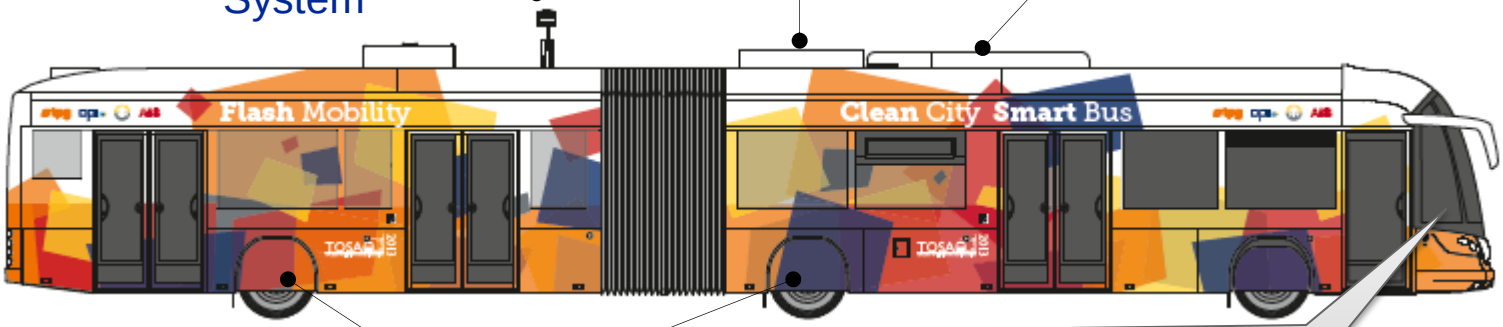
- Introduction
- Model
- Case study
- Conclusions

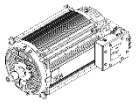
Fully automatic Energy Transfer System

Water-cooled battery pack



Water-cooled Traction converter





Two-axles drive powered by water-cooled traction motors

I transport passengers not batteries

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

- Introduction
- Model
- Case study
- Conclusions

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

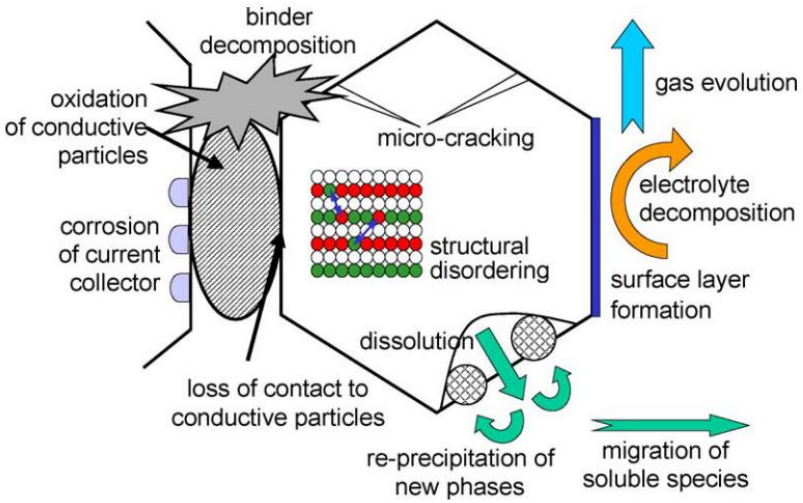
* Source: NZZ, March 7, 2015.

Map: Google Maps

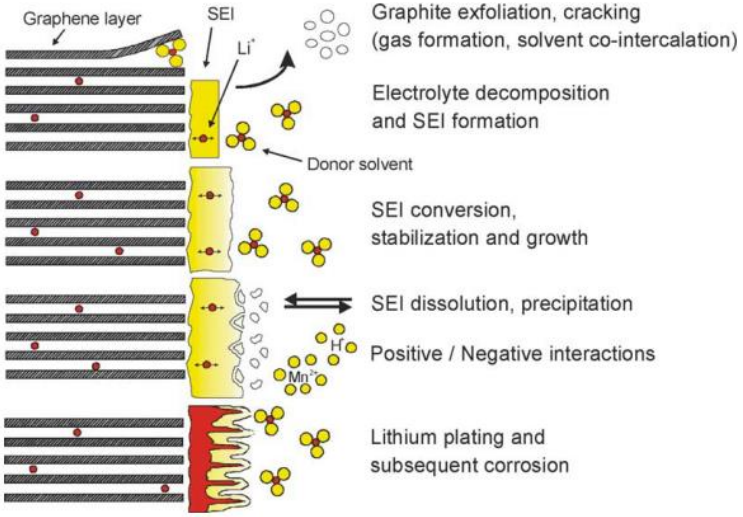
Motivation for battery R&D
How to quickly estimate all these aging processes?

- Introduction
- Model
- Case study
- Conclusions

Aging at cathode



Aging at anode

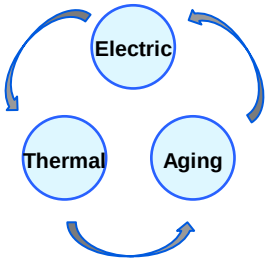


- Key R&D question: How can we predict the net aging & performance impact of all the reactions above in an electric bus with reasonable accuracy?

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

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

Electrical, thermal and aging model
Introduction



Introduction

Model

Case study

Conclusions

Battery Model

Electrical

ΔQ, ΔIR

SoC profile

cell temp.

Joule heating

Aging

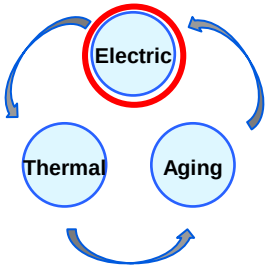
cell temp.

Thermal

Load (kW) & temp. (°C)

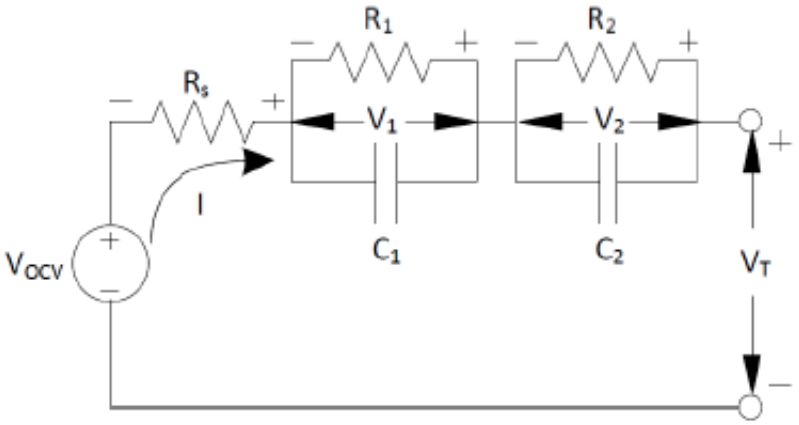
Change in capacity (Ah) & resistance (Ω)

Electrical model
Record data and fit to electric model



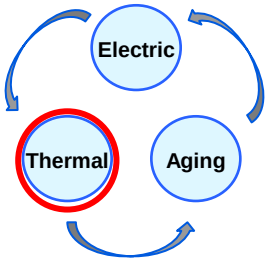
- Introduction
- Model
- Case study
- Conclusions

- 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.



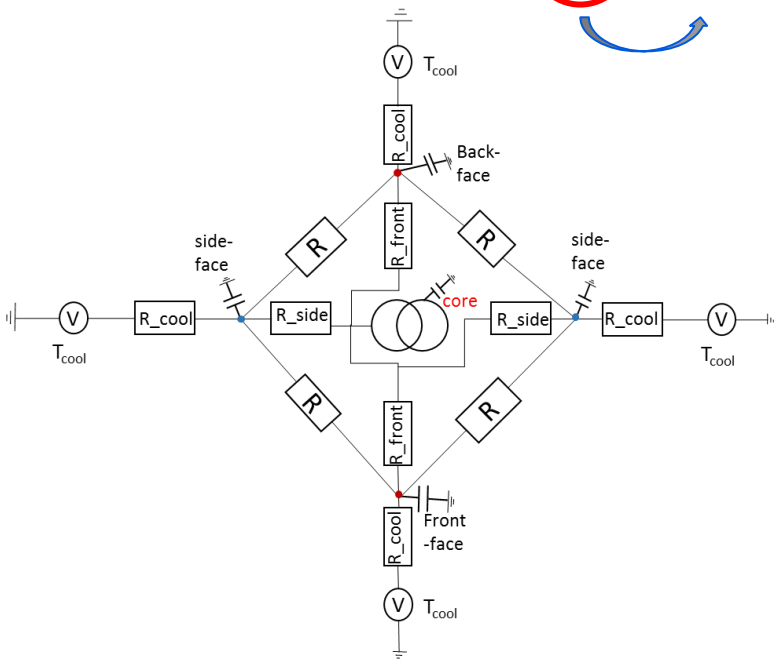
© ABB

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



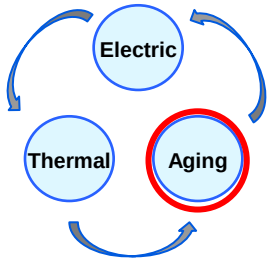
- Introduction
- Model
- Case study
- Conclusions

- 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).



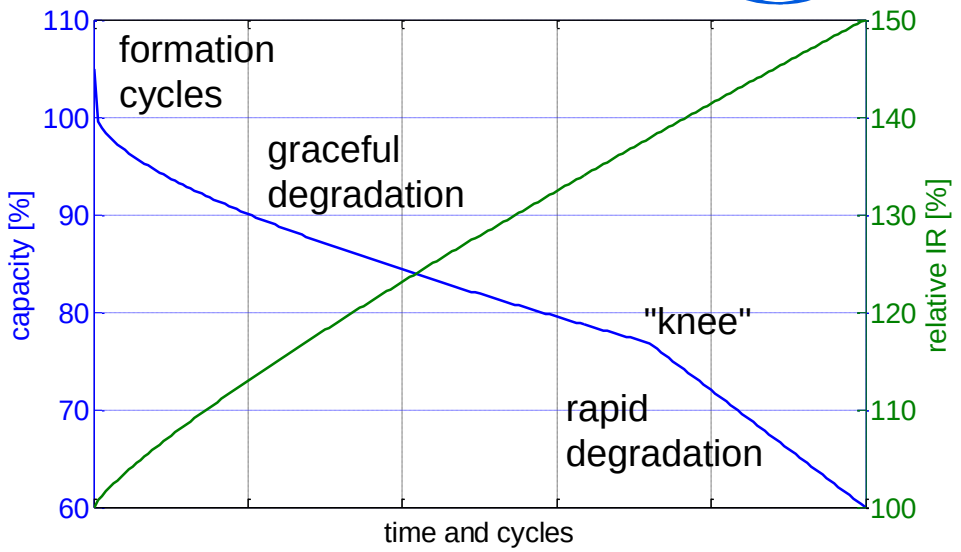
© ABB

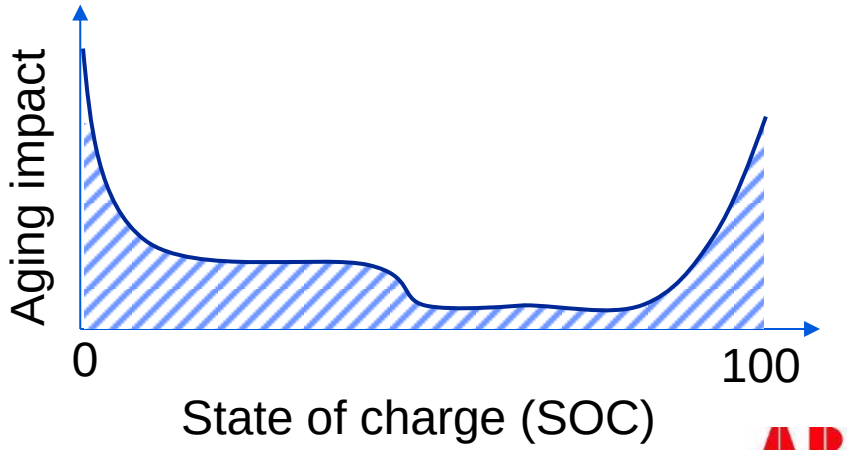
Aging model: semi-empirical approach
Conduct battery experiments and fit data



Introduction
Model
Case study
Conclusions

- 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).





© ABB

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

- Introduction
- Model
- Case study
- Conclusions

Case study details:

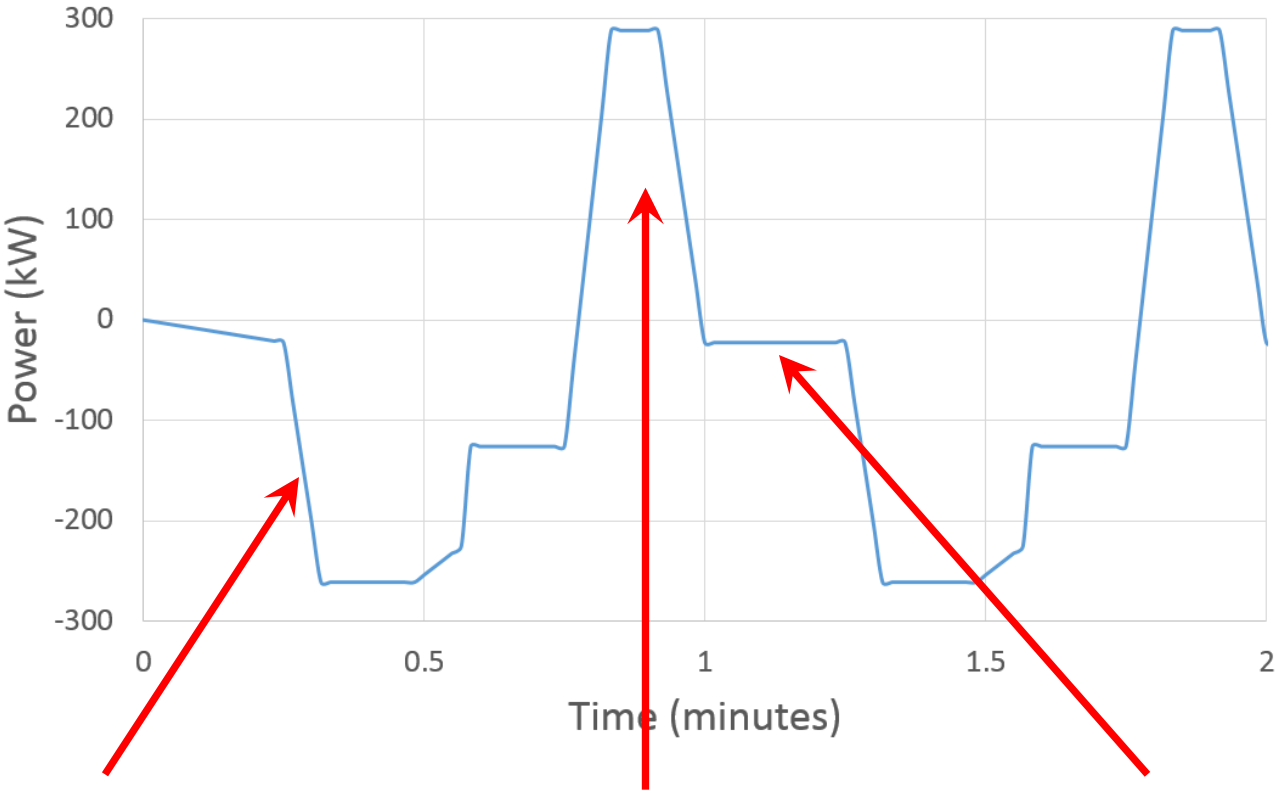
- 43 kWh, 300 kW Li-ion battery.
- 10 full journeys per day, 365 d/y for 10 y.
- Lithium titanate (LTO) as anode.

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

© ABB

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

- Introduction
- Model
- Case study
- Conclusions



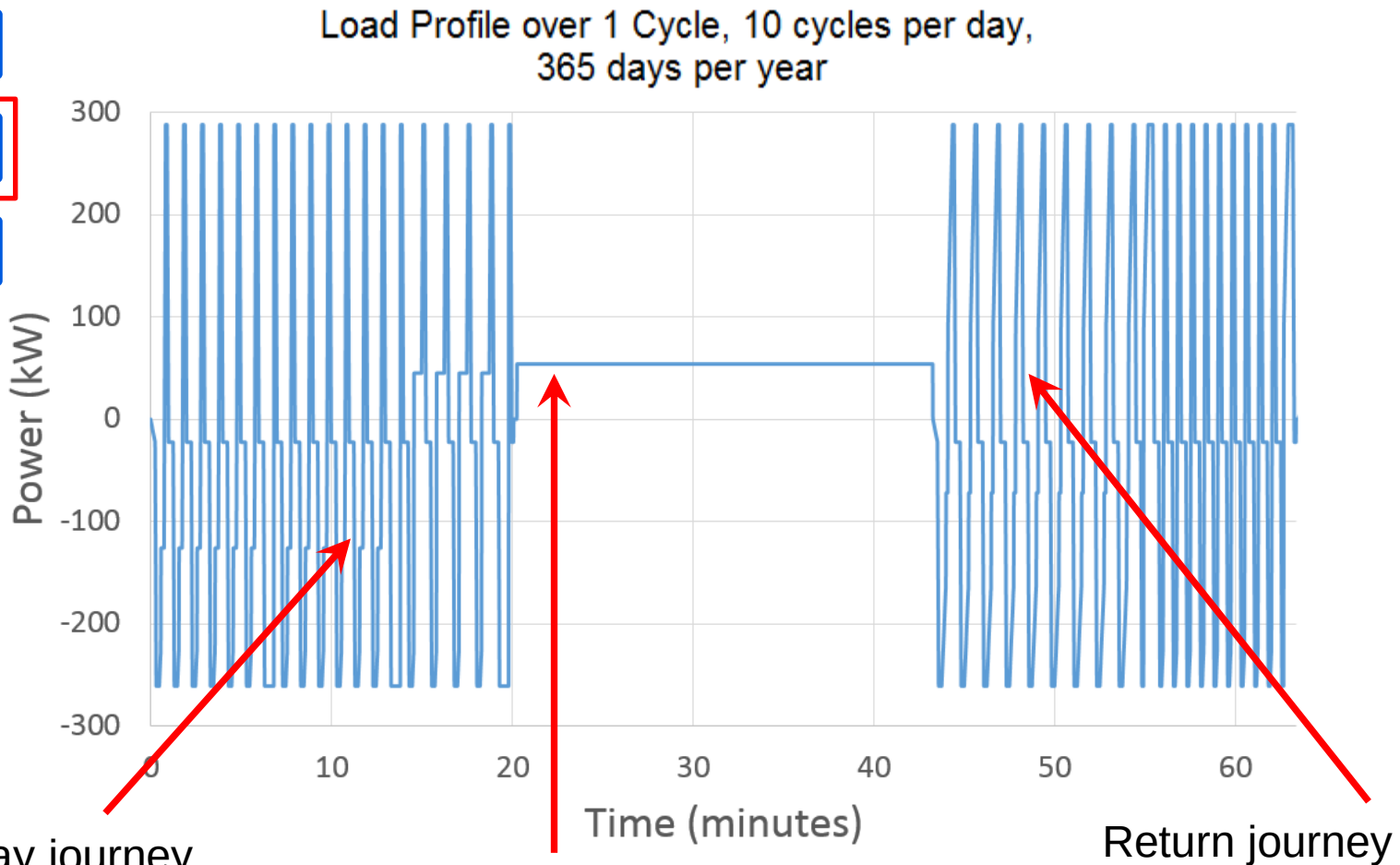
Bus accelerates, coasts, slows down

Bus performs regenerative breaking

Auxiliary power during bus stop

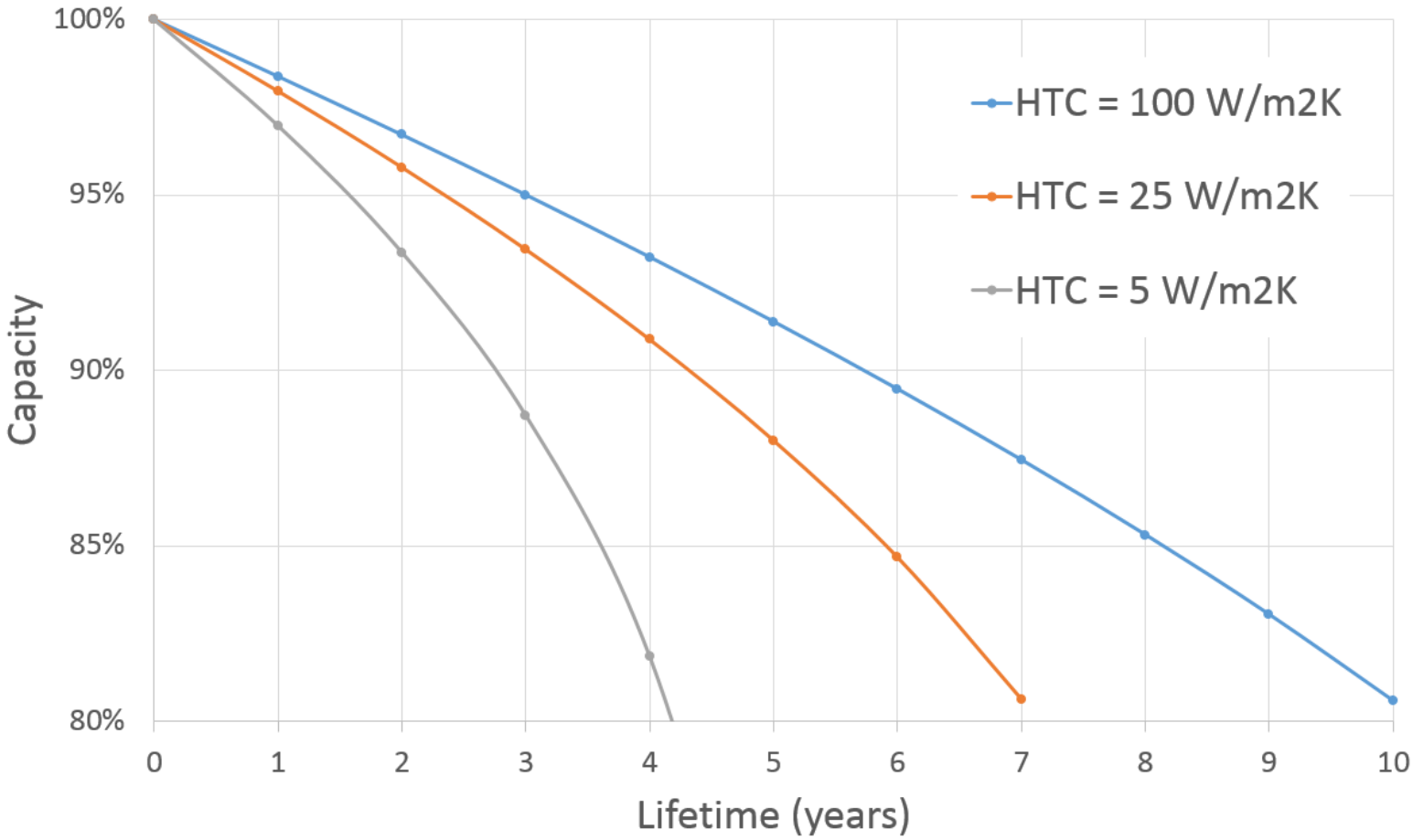
Load profile: away and return journey of load profile
What is the aging impact of cooling?

- Introduction
- Model
- Case study
- Conclusions



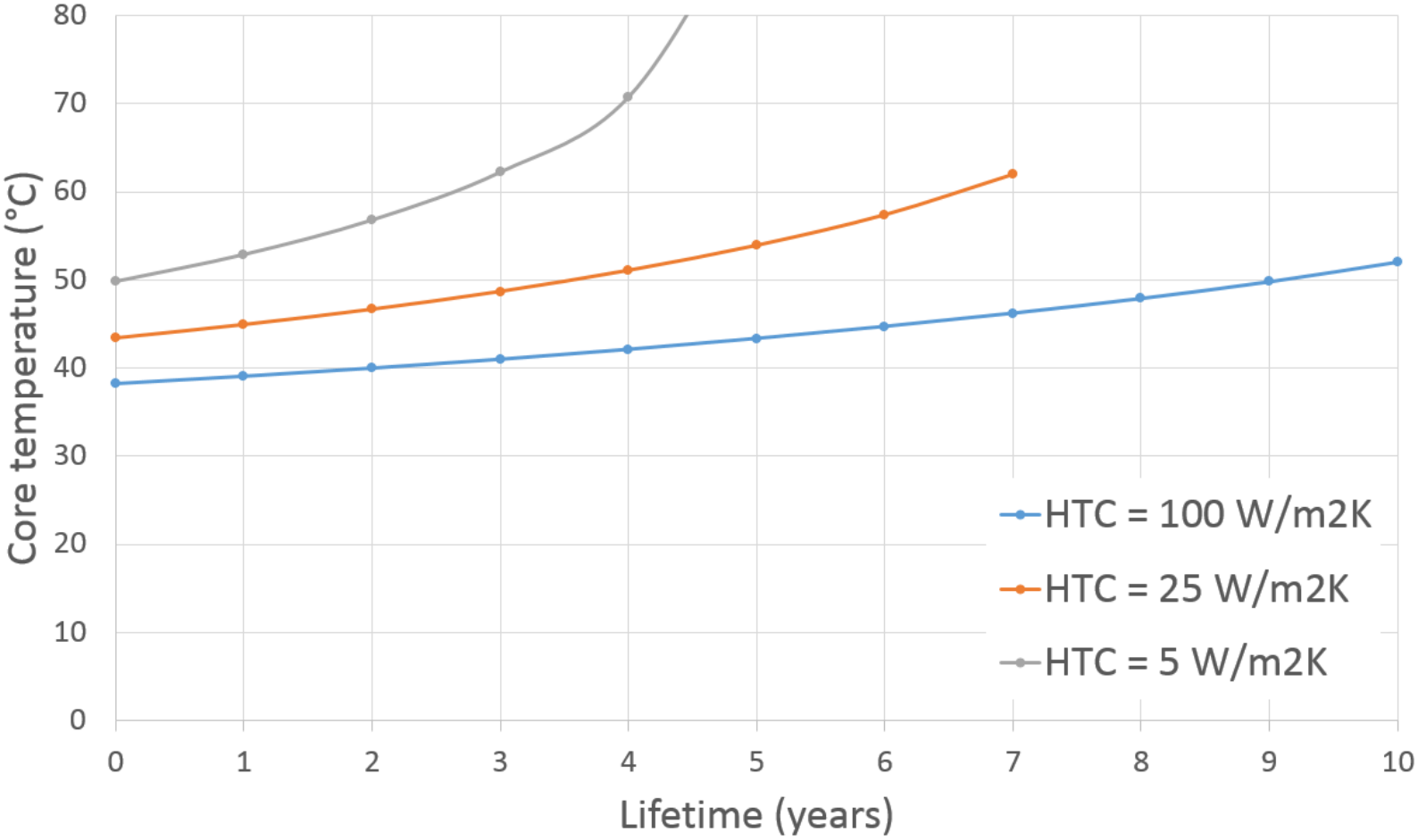
Heat transfer coefficient (HTC) impact on aging
What is the aging impact of cooling?

- Introduction
- Model
- Case study
- Conclusions

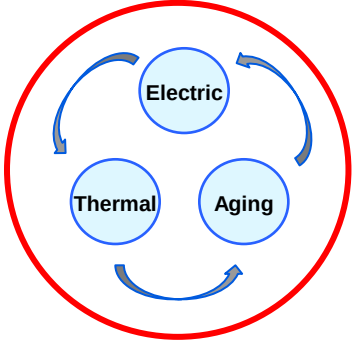


Heat transfer coefficient (HTC) impact on temperature
What is the aging impact of cooling?

- Introduction
- Model
- Case study
- Conclusions



Conclusions on battery model



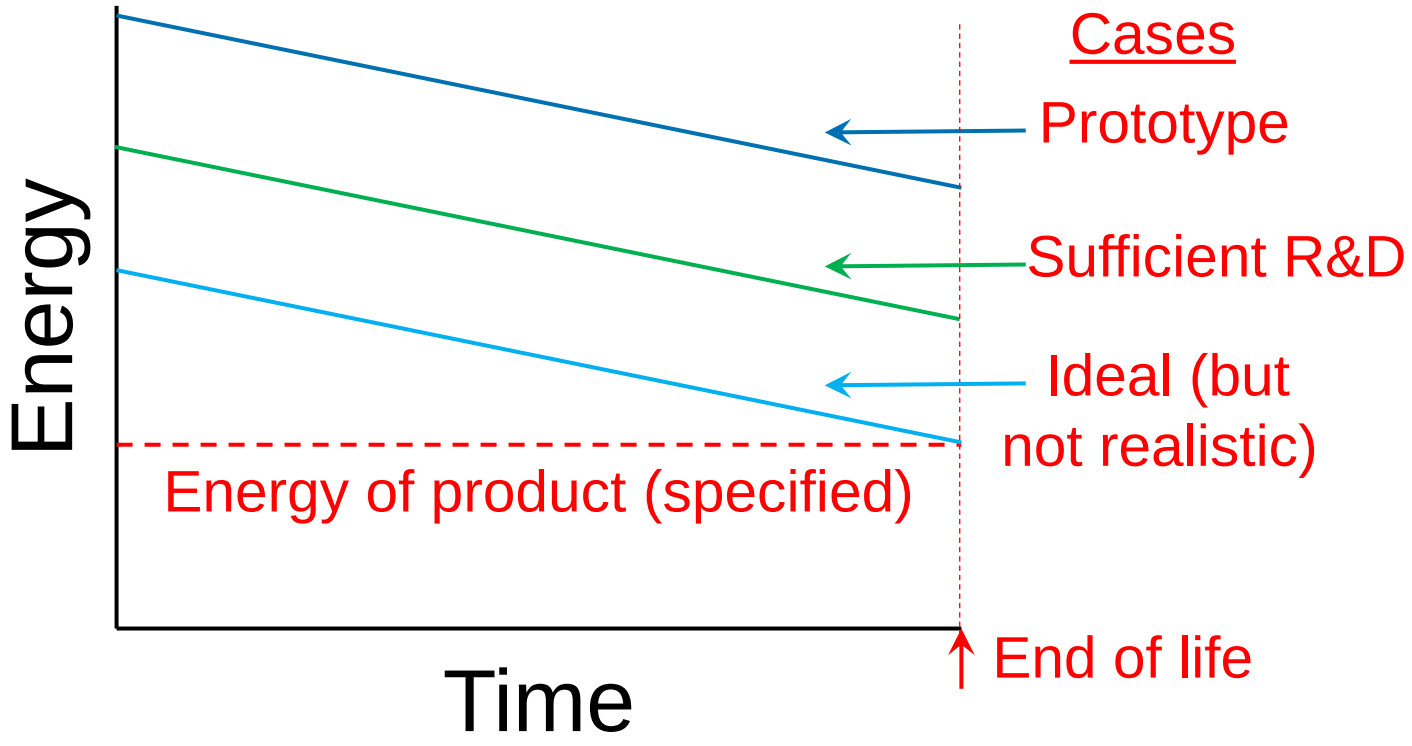
Introduction
Model
Case study
Conclusions

- 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.

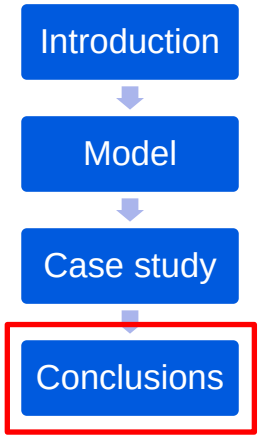
© ABB

Battery R&D
Sizing of prototypes and developed battery

- Introduction
- Model
- Case study
- Conclusions



Conclusions

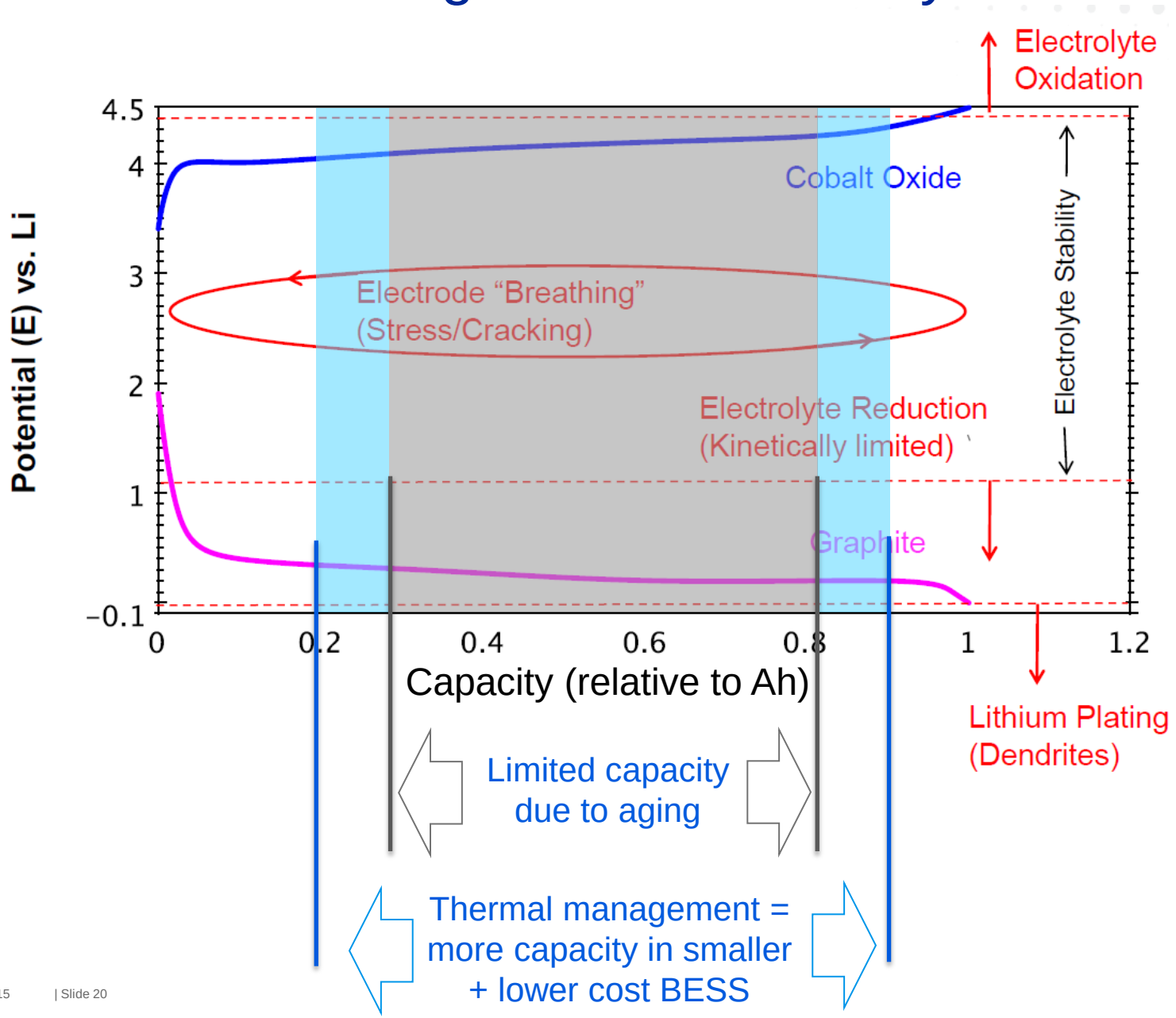


- Design the battery for the public transportation line and the bus.
- Models support battery design, but it must be combined with experience and field data.
- Batteries will increasingly be used in ABB products and systems
  → Lifetime knowledge critical for reliability
  → Continued collaboration with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

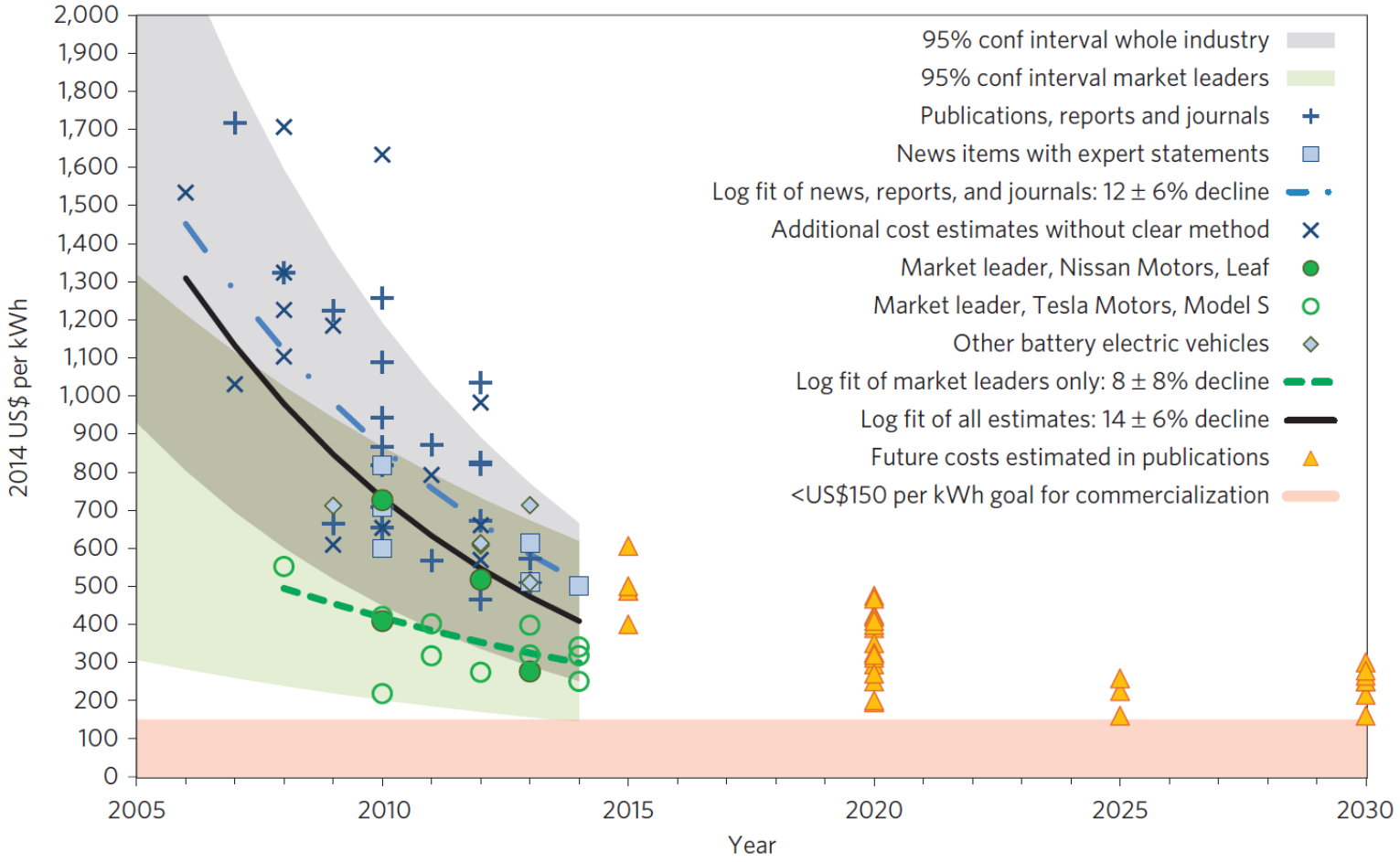
© ABB

Power and productivity
for a better world™

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

© ABB

Battery energy storage
Overview and future batteries