From Hoverboards to Lift trucks: What you need to know about Lithium-ion batteries

Presented by:

Joern Tinnemeyer

EnerSys®
Power/Full Solutions

MODEX 2020
GEORGIA WORLD CONGRESS CENTER
ATLANTA | MARCH 9-12
MODEXSHOW.COM
powered by MHI

Presenter

Joern Tinnemeyer
Senior Vice President and
Chief Technical Officer
EnerSys

Forward Looking Disclaimer Statement

The following presentation includes forward looking statements and/or information based on EnerSys' current beliefs, expectations and assumptions, and are subject to a number of risks and uncertainties that could cause actual results to materially differ from those anticipated. Such risks include, among others, risks associated with competition, technology, development and implementation, intellectual property, penetration of existing markets, expansion into new markets, hiring and retaining high quality personnel and general economic conditions, including the risks described in EnerSys' most recent annual report on Form 10-K or quarterly report on Form 10-Q, along with other unforeseen risks. Nothing in this presentation should be interpreted as an update to the information and guidance provided during our most recent investor call, our most recent annual report on Form 10-K, quarterly report on Form 10-Q, and current reports on Form 8-K, as filed with the SEC.

The statements and information in this presentation are made as of the date of presentation, even if made available by EnerSys on its website or otherwise after the date of the presentation. EnerSys does not undertake any obligation to update or revise the statements or information to reflect subsequent events or circumstances.

Hoverboard Accidents Send 27K Kids to the Hospital in 2 Years

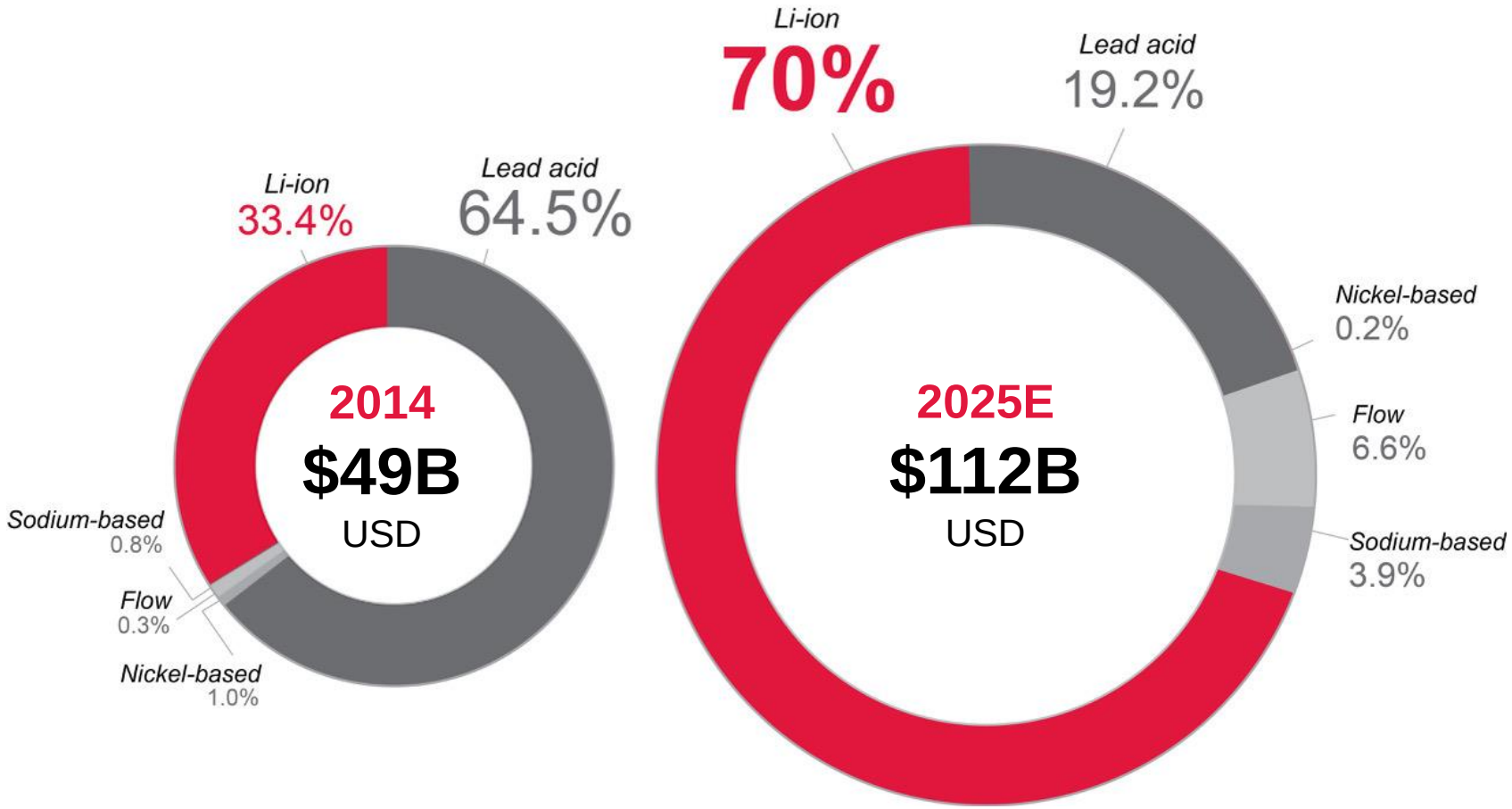
New research shows nearly 27,000 kids were sent to emergency departments from 2015 though 2016

Hoverboards recalled for fire and explosion risks — again

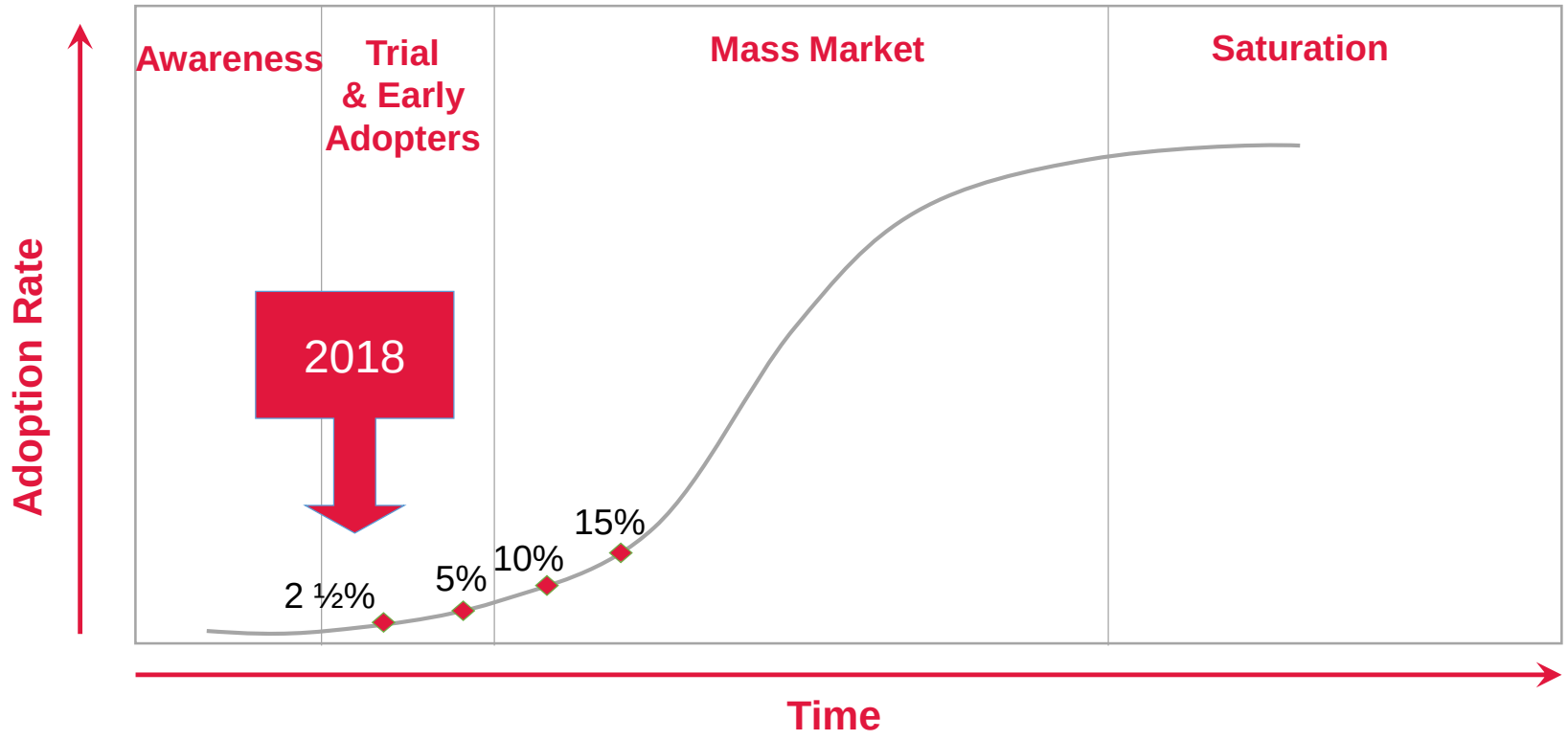
Brett Molina, USA TODAY Published 9:47 a.m. ET Nov. 15, 2017 | **Updated 11:24 a.m. ET Nov. 15, 2017**

A lithium solution for forklifts?

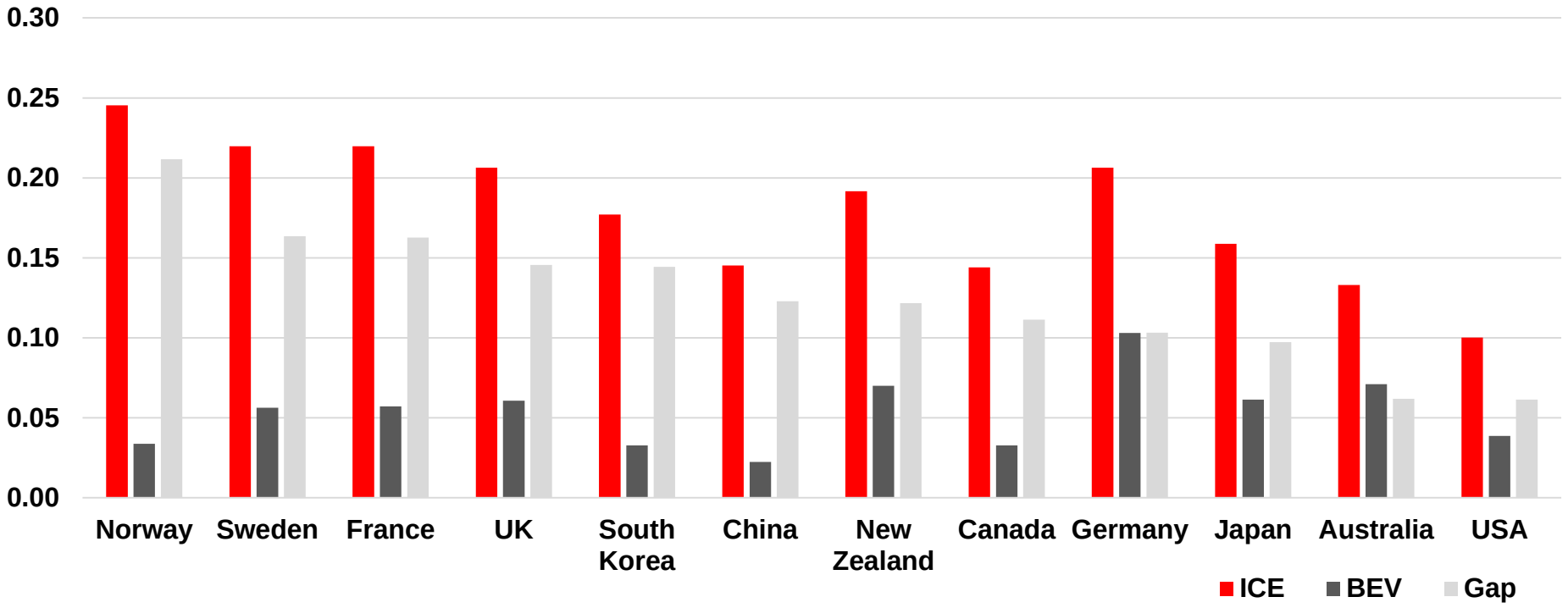
Global Market for Lithium in All Applications



Evolution: Adoption Status



Economic Drivers



Vehicle Energy Cost (USD per mile)

How does it work?

Limited Success to Date for Industrial Lithium

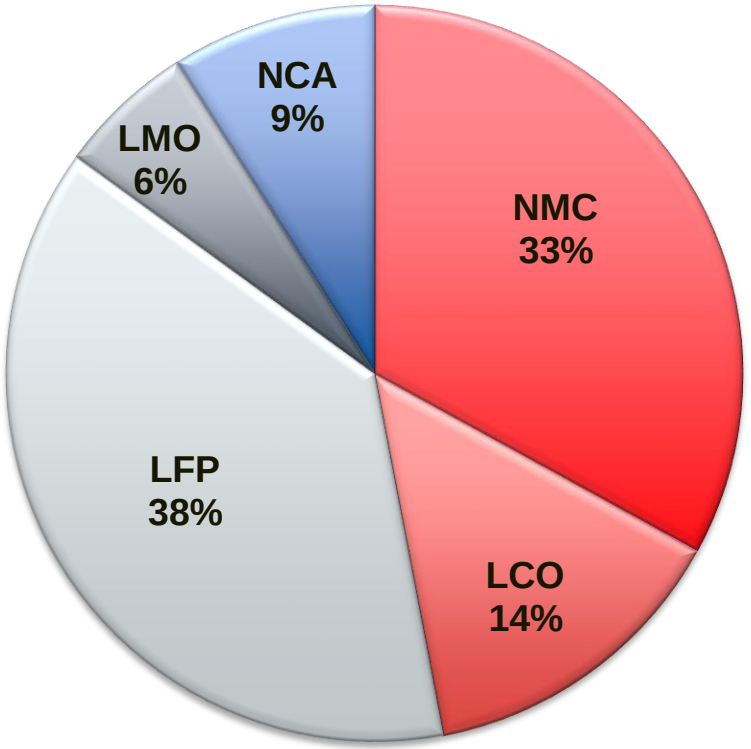
Yesterday 	Today 
x Most cells produced economically were small format	✓ Extensive usage of large format cells

Limited Success to Date for Industrial Lithium

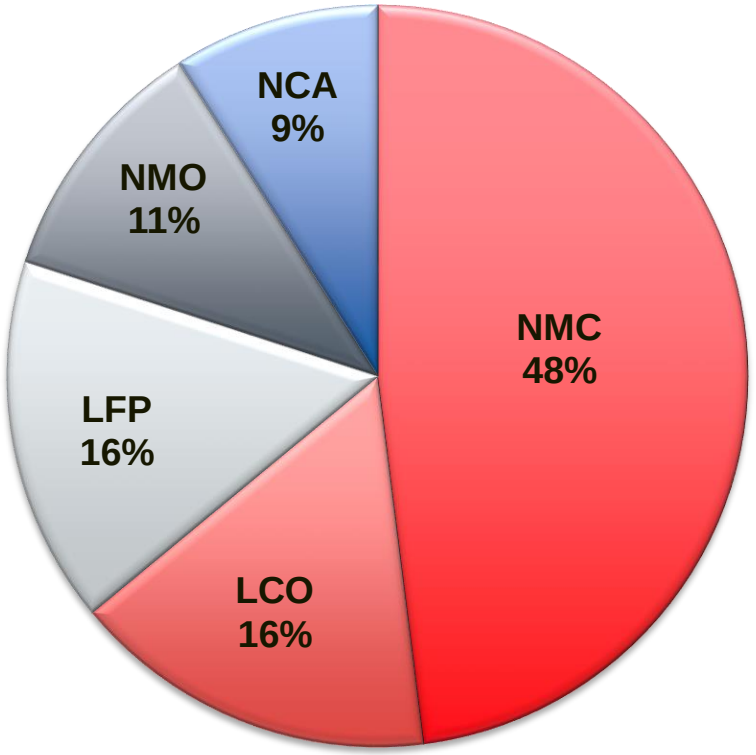
Yesterday 	Today 
x Most cells produced economically were small format	✓ Extensive usage of large format cells
x Limited variation available – only consumer LCO was produced at high volume	✓ Advanced NMC with high energy density

Lithium Distribution

Cathode active materials 2017: >250,000 Tons



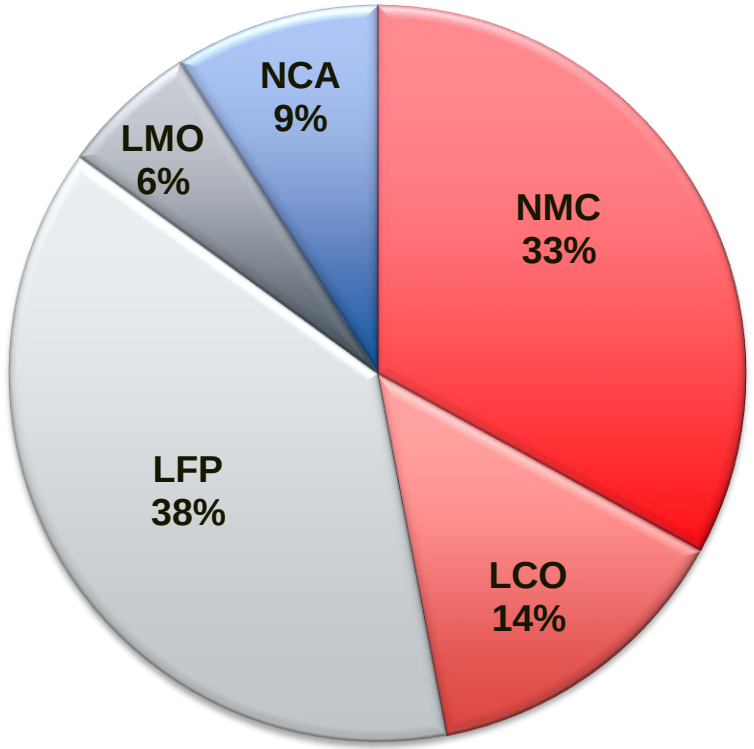
Cathode active materials 2025: 600,000 Tons



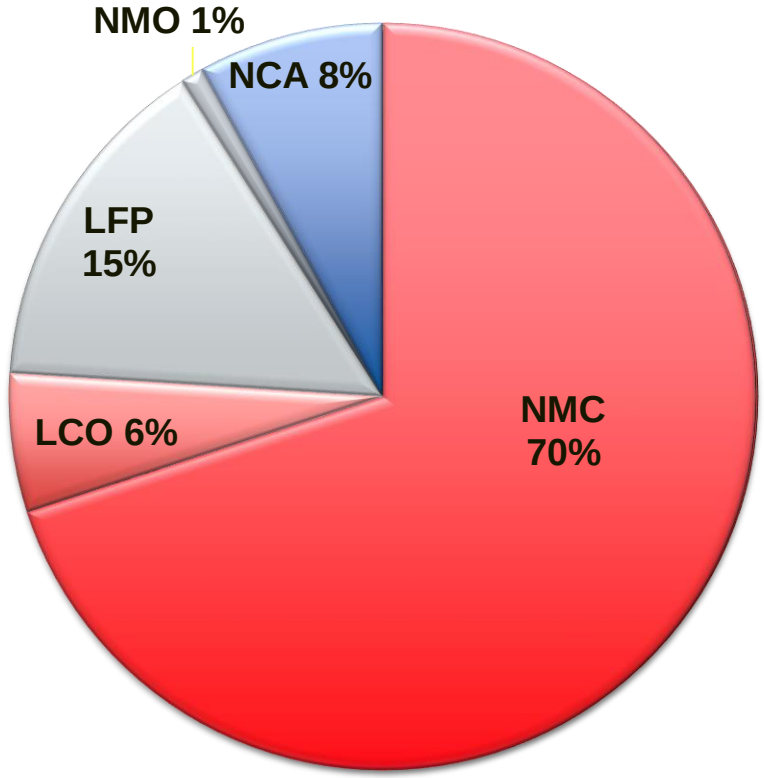
Source: Avicenne 2019

Lithium Distribution

Cathode active materials 2017: >250,000 Tons



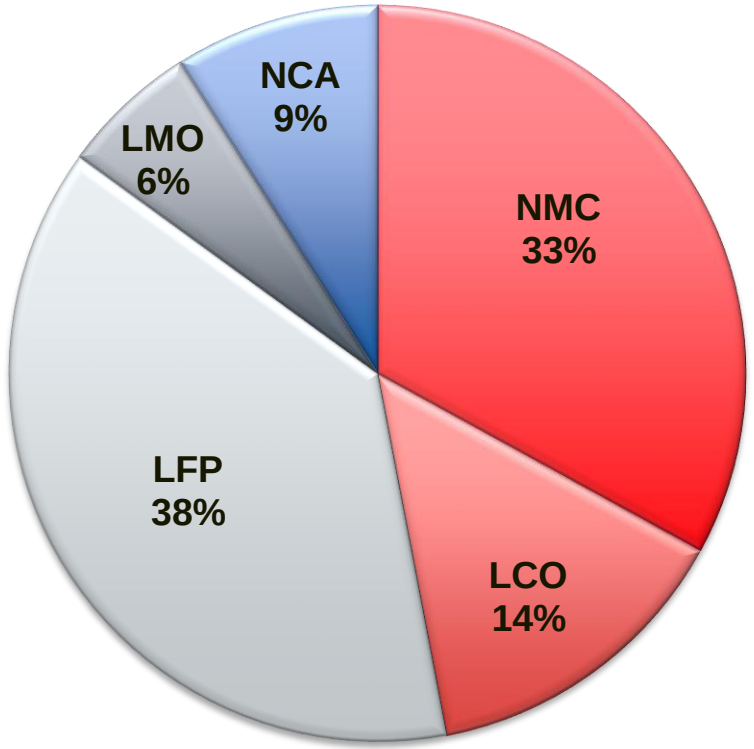
Cathode active materials 2025: 875,000 Tons



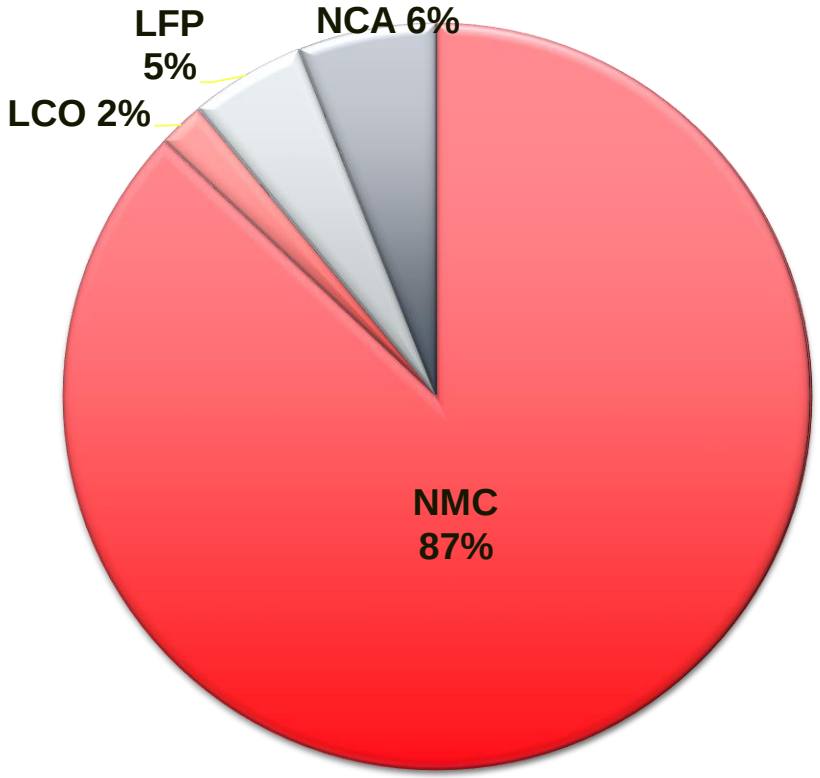
Source: Avicenne 2019

Lithium Distribution

Cathode active materials 2017: >250,000 Tons



Cathode active materials 2030: 1,670,000 Tons

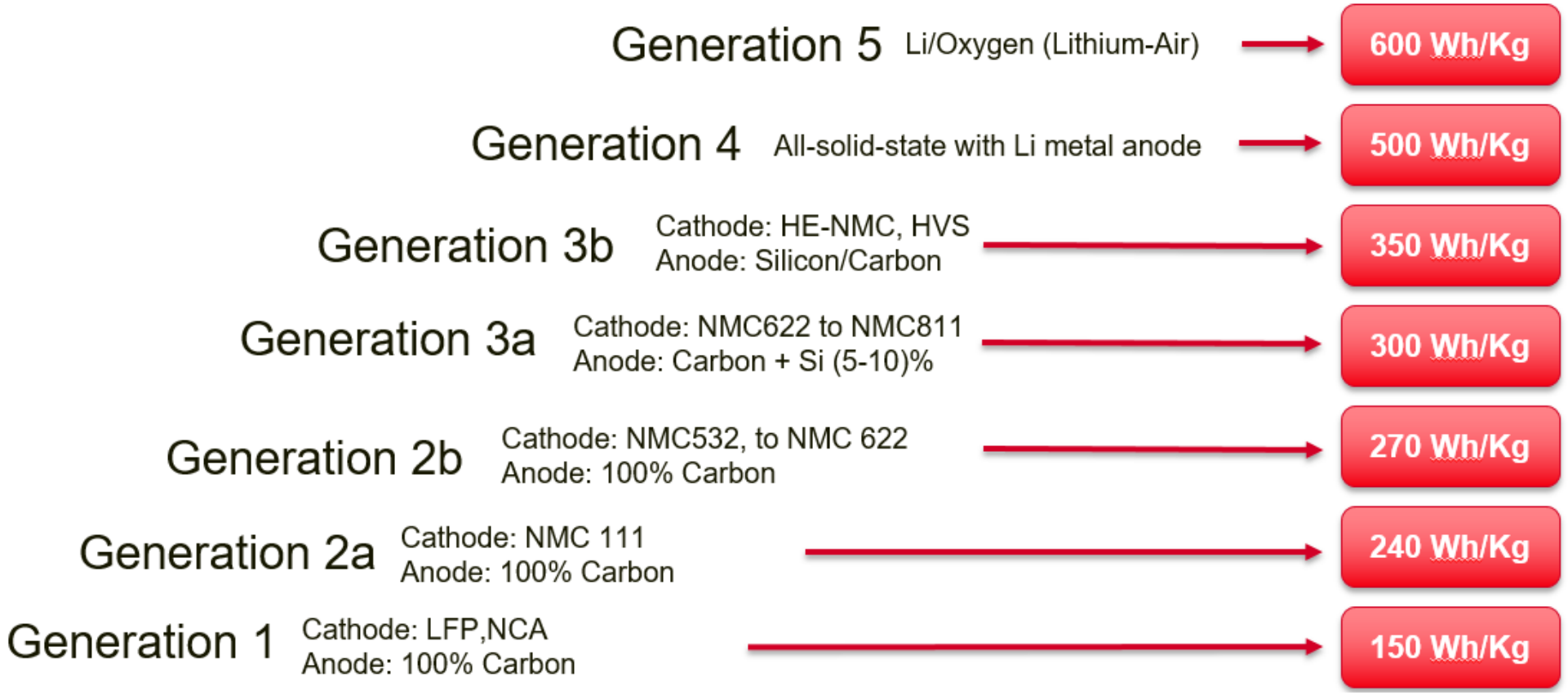


Source: Avicenne 2019

Limited Success to Date for Industrial Lithium

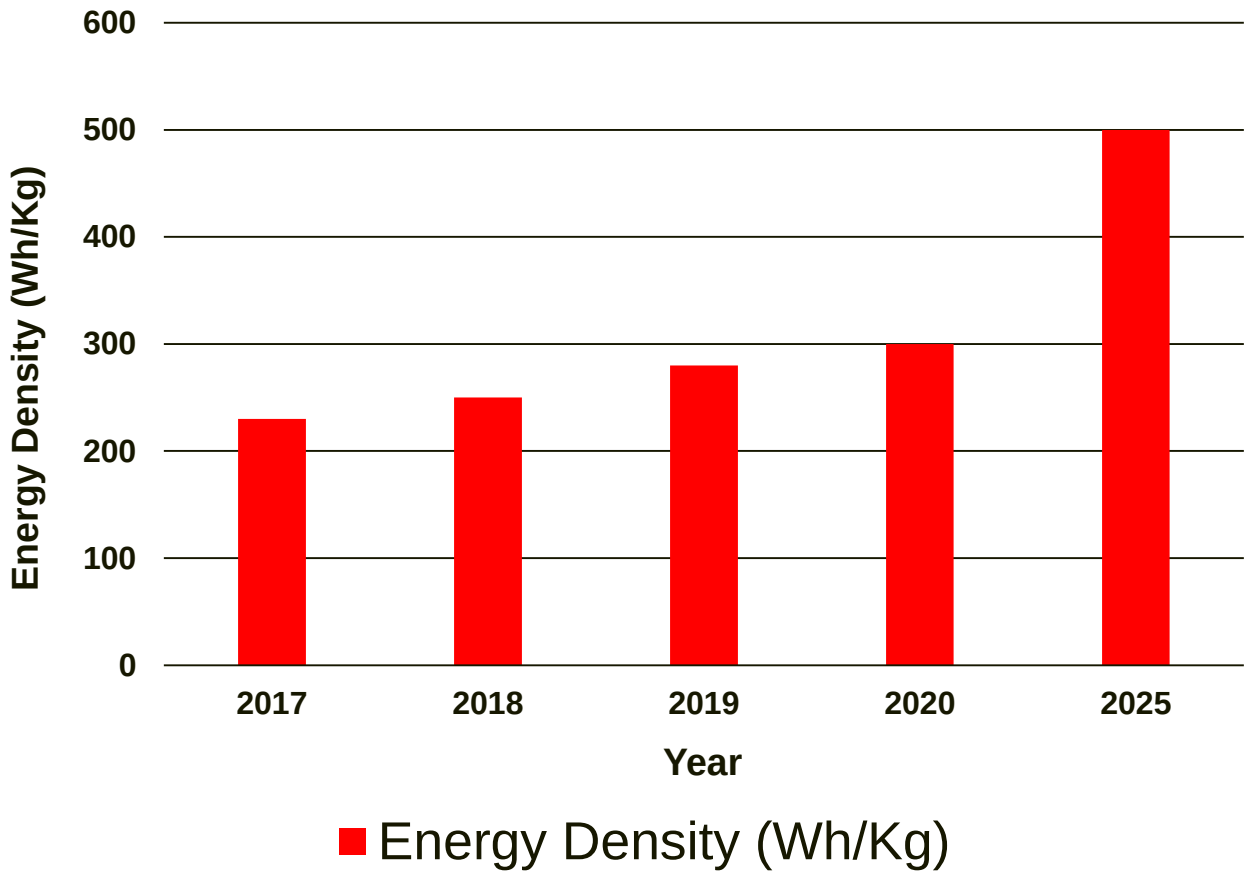
Yesterday 	Today 
x Most cells produced economically were small format	✓ Extensive usage of large format cells
x Limited variation available – only consumer LCO was produced at high volume	✓ Advanced NMC with high energy density
x 18650 cell cost was valued at 300 USD/KWh	✓ Automotive OEMs are pushing the battery industry to offer increasingly lower pricing

Effects of New Technologies



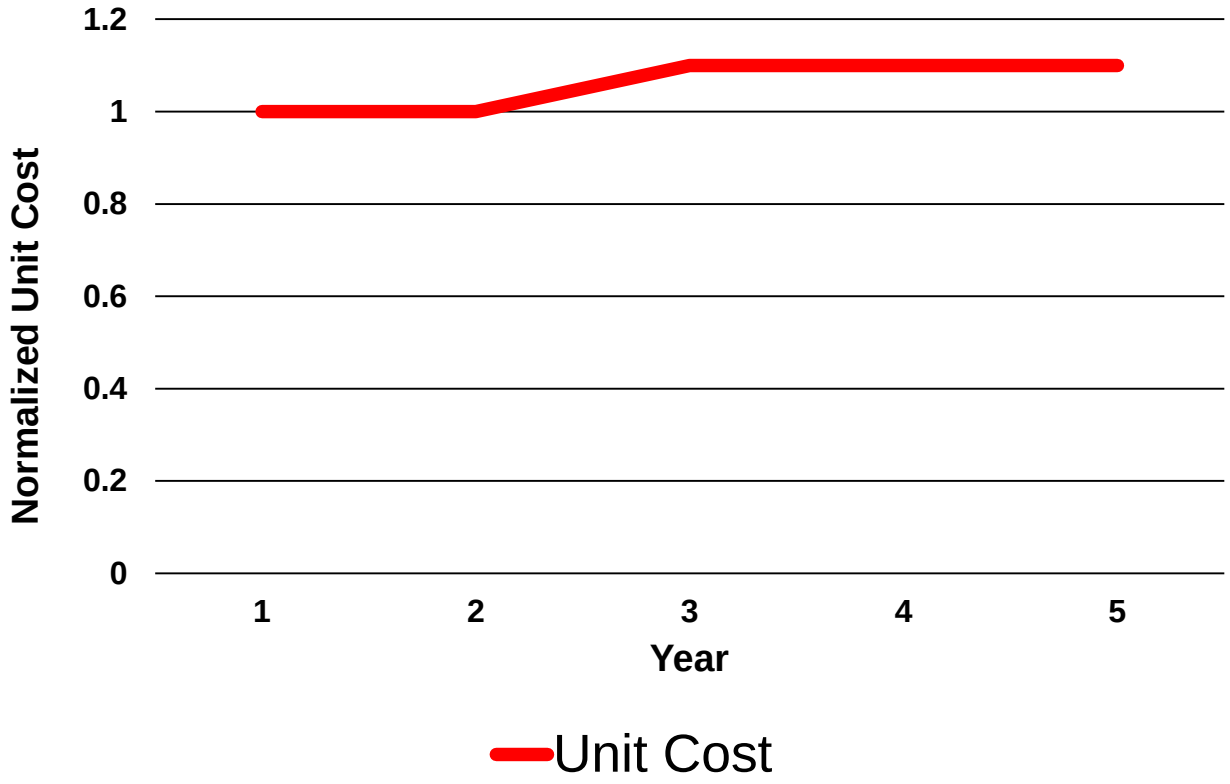
Typical LA: (30-40) Wh/Kg

Lithium Price Evolution



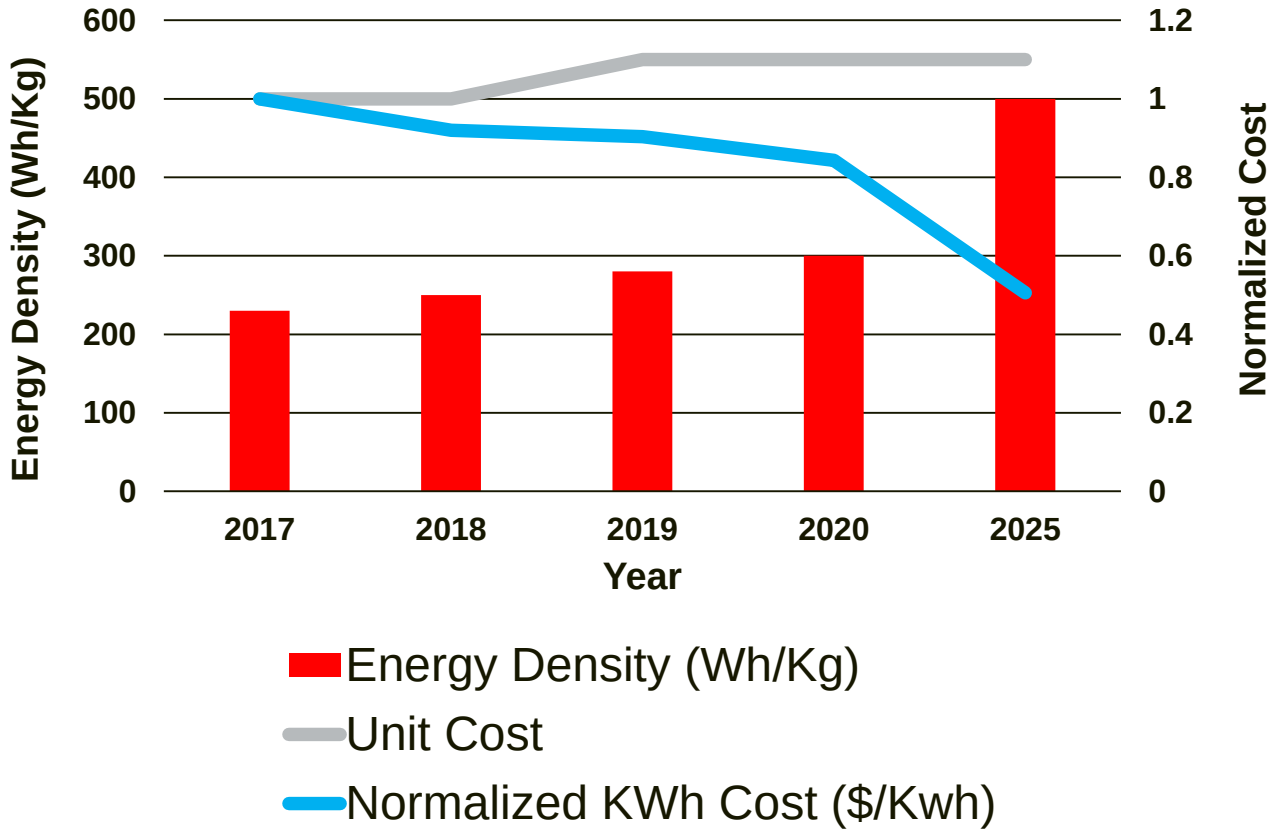
- Continuous increase in energy density
- Technology transition from NMC(111)->NMC(811) for the cathode
- Anode natural carbon -> synthetic carbon with SiOx additive
- Solid state cells

Lithium Price Evolution



- Same package content, price will stay relatively similar
- Energetic high Ni content may require enhanced safety cost
- Does not consider size optimization

Lithium Price Evolution



- Impact of changes in cell technology alone will cause cost ($/KWh) to fall by 50% in the next 7 years
- Safety, production capability and cycle life will continue to improve

The Price Estimate is Conservative!

“We have pricing of $145/KWh at the cell level”

– GM, Oct 23, 2015

“Our pack costs will be less than $100/KWh by 2020”

– Lei Zhang, Envision Energy, Dec 4, 2018

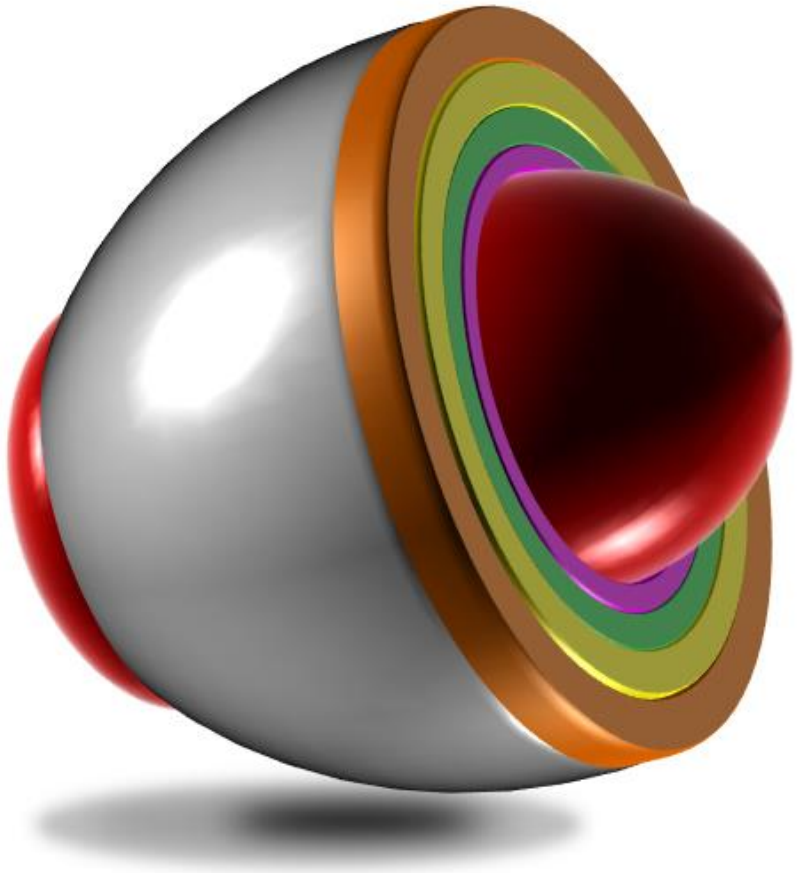
“We think at the cell level probably we can do better than $100/KWh by the end of the year”

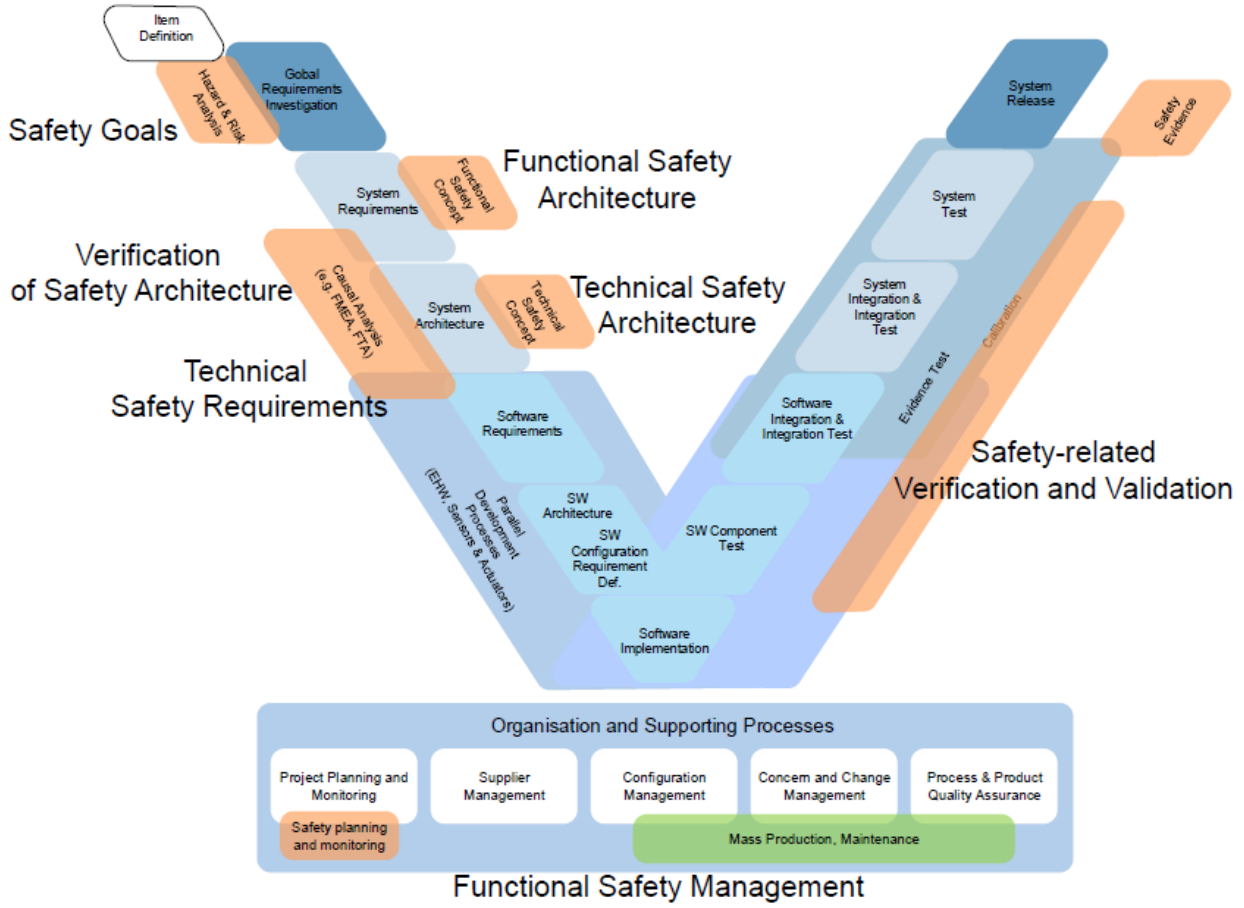
– Elon Musk, Tesla, June 1, 2018

Limited Success to Date for Industrial Lithium

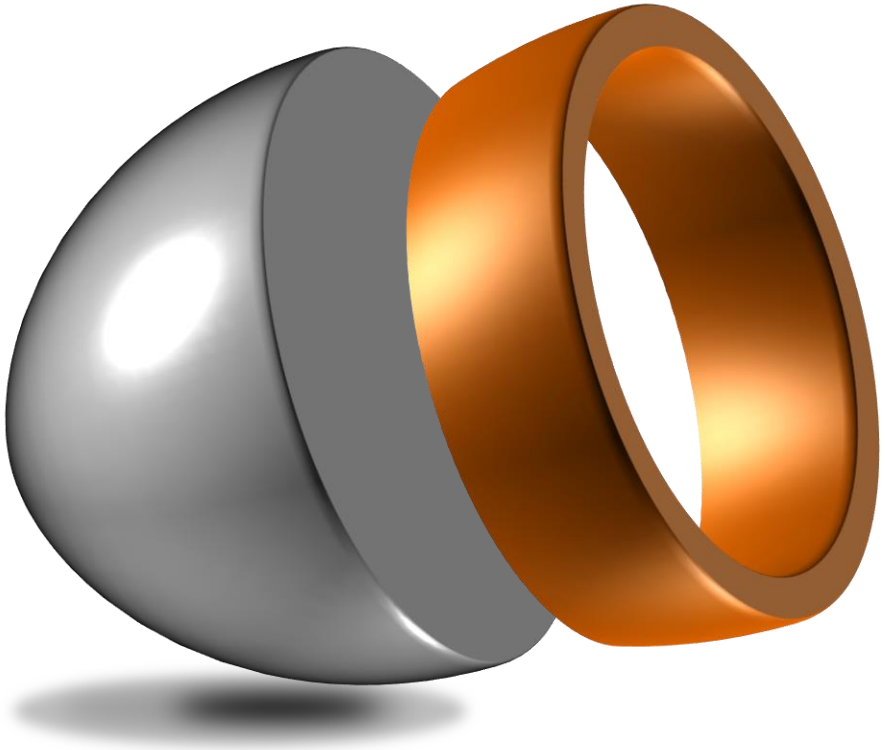
Yesterday 	Today 
x Most cells produced economically were small format	✓ Extensive usage of large format cells
x Limited variation available – only consumer LCO was produced at high volume	✓ Advanced NMC with high energy density
x 18650 cell cost was valued at 345 USD/KWh	✓ Automotive OEMs are pushing the battery industry to offer increasingly lower pricing
x Safety strategy primitive with limited monitoring	✓ Functional safety hardware topology complying with ISO26262 coupled with enhanced cell safety designs

Safe Design through Layers



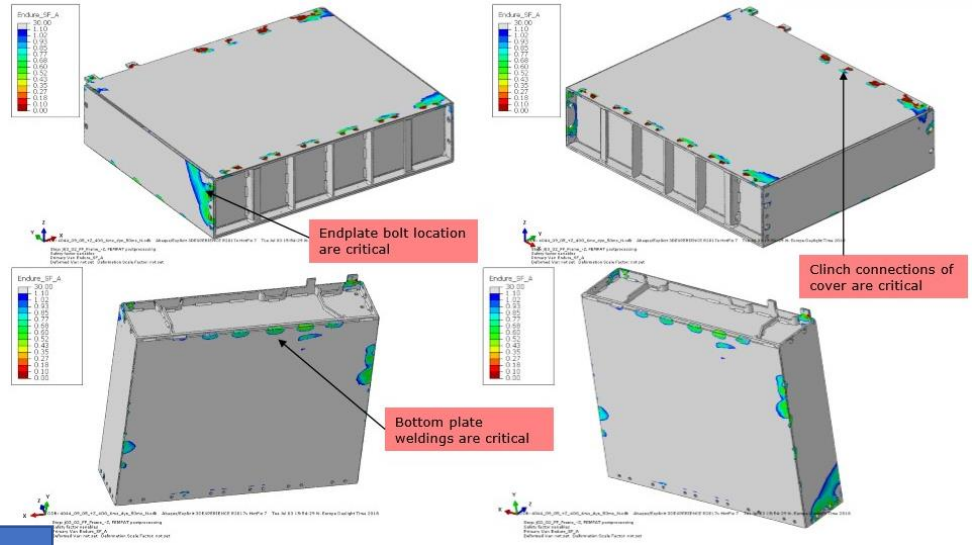


Mechanical Safety System

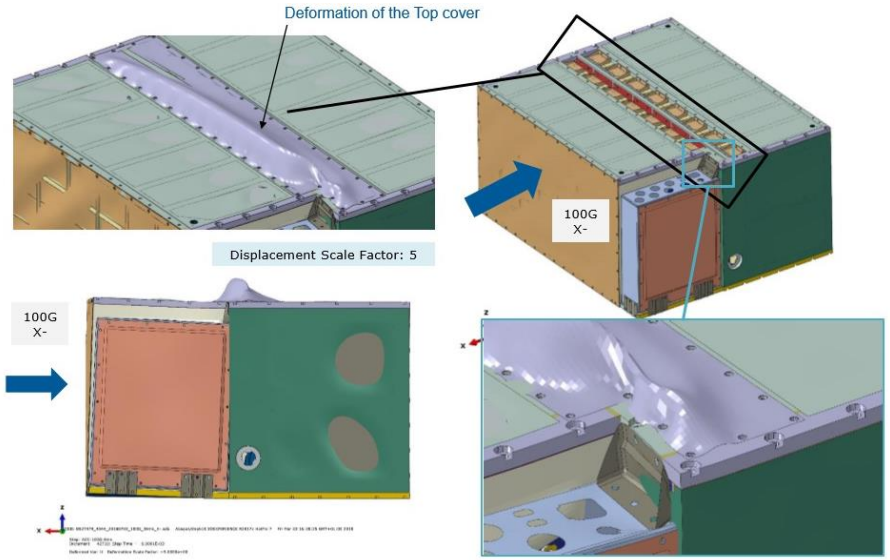


Mechanical Integrity

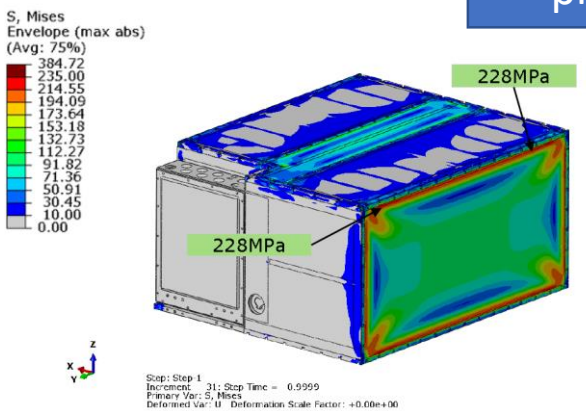
Durability

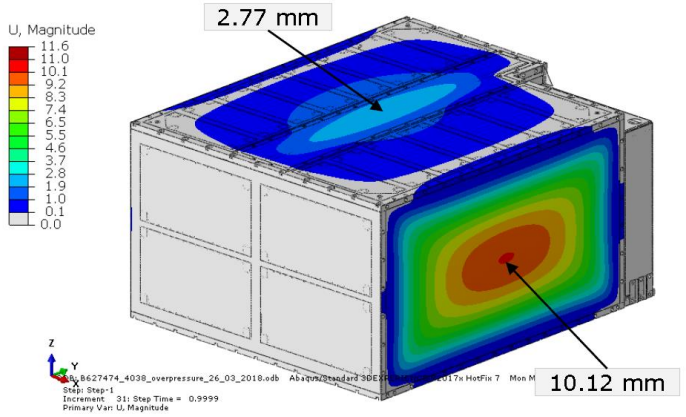


Shock Loads



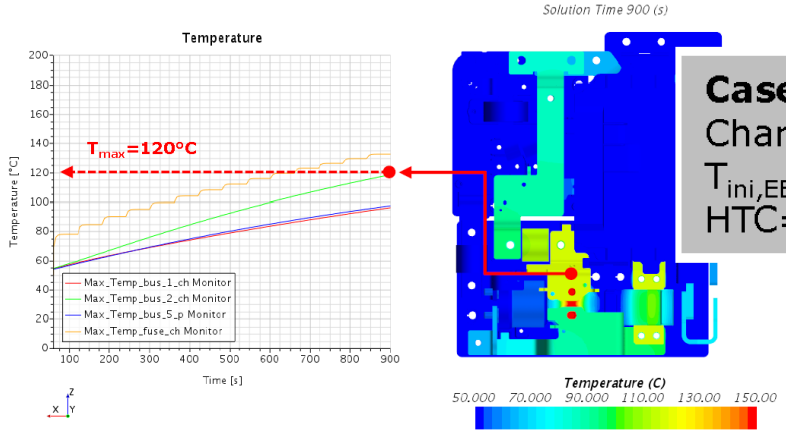
Internal pressure





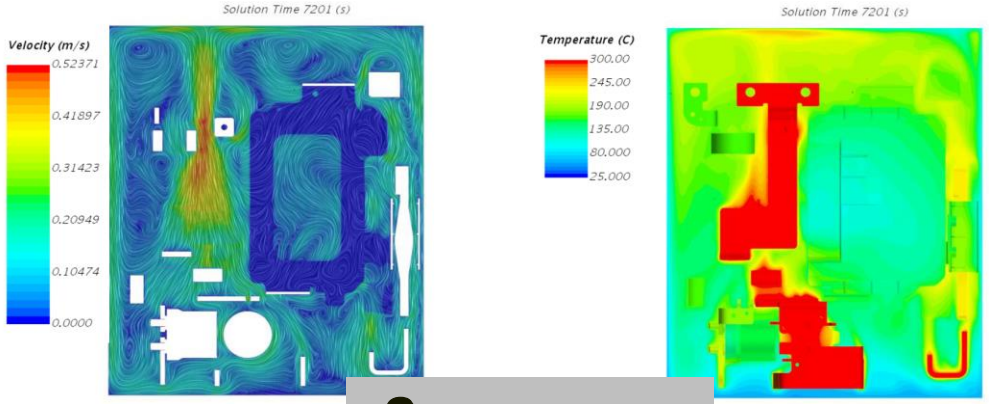
Thermal Behavior

B-Sample



Case:
Charge: 480A, 900 s
$T_{ini,EE}$: 50°C, $T_{ini,Air}$: 40°C
HTC=5 W/m²-K, no air

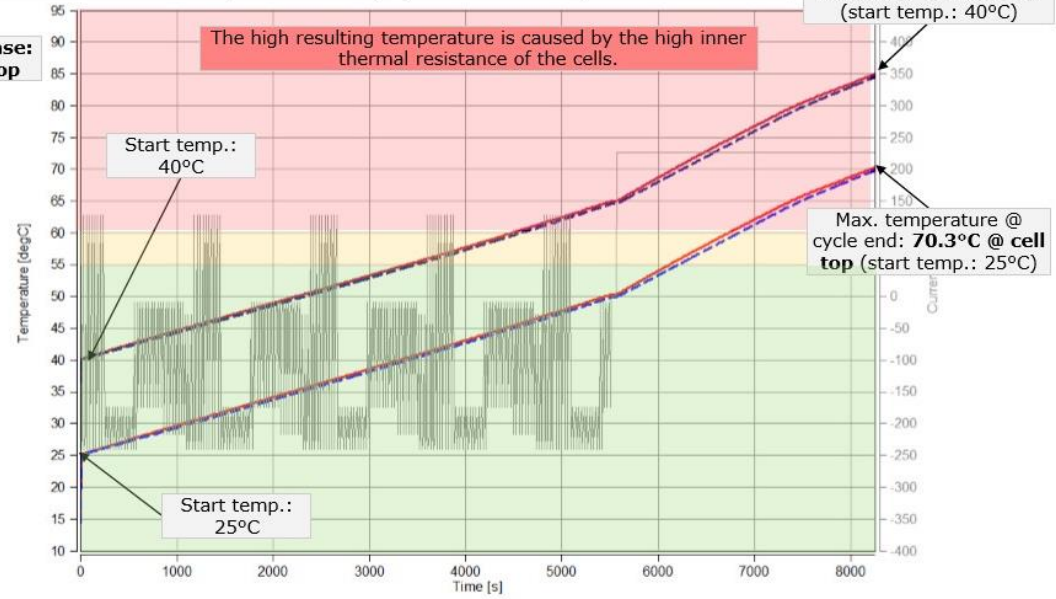
Current paths



Case:
Charge: 640A

2 different simulations were performed:
- Start temperature: 25°C
- Start temperature: 40°C

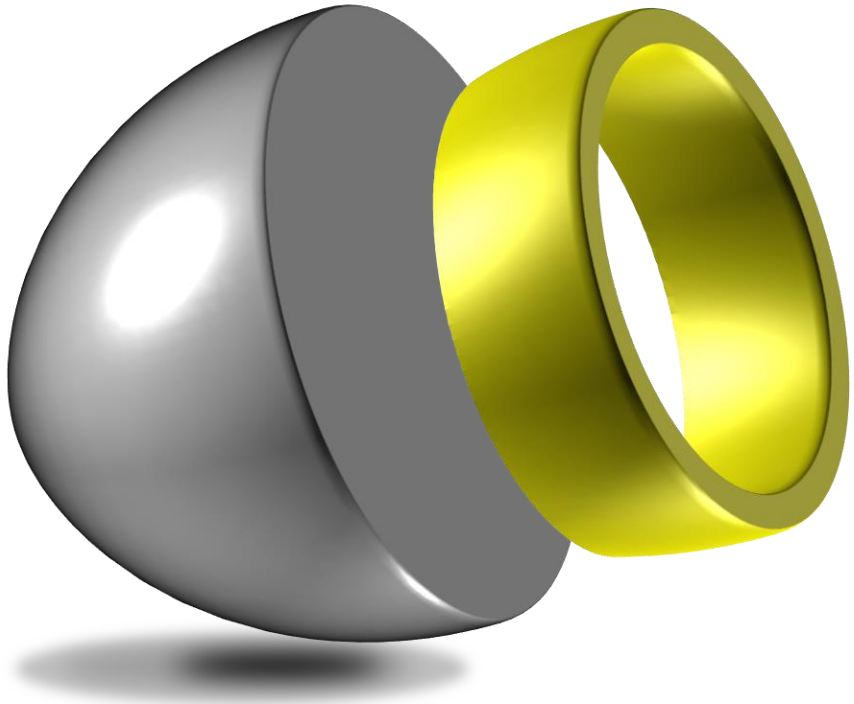
Minimum and maximum cell temperatures are displayed → bus bar temperatures not included

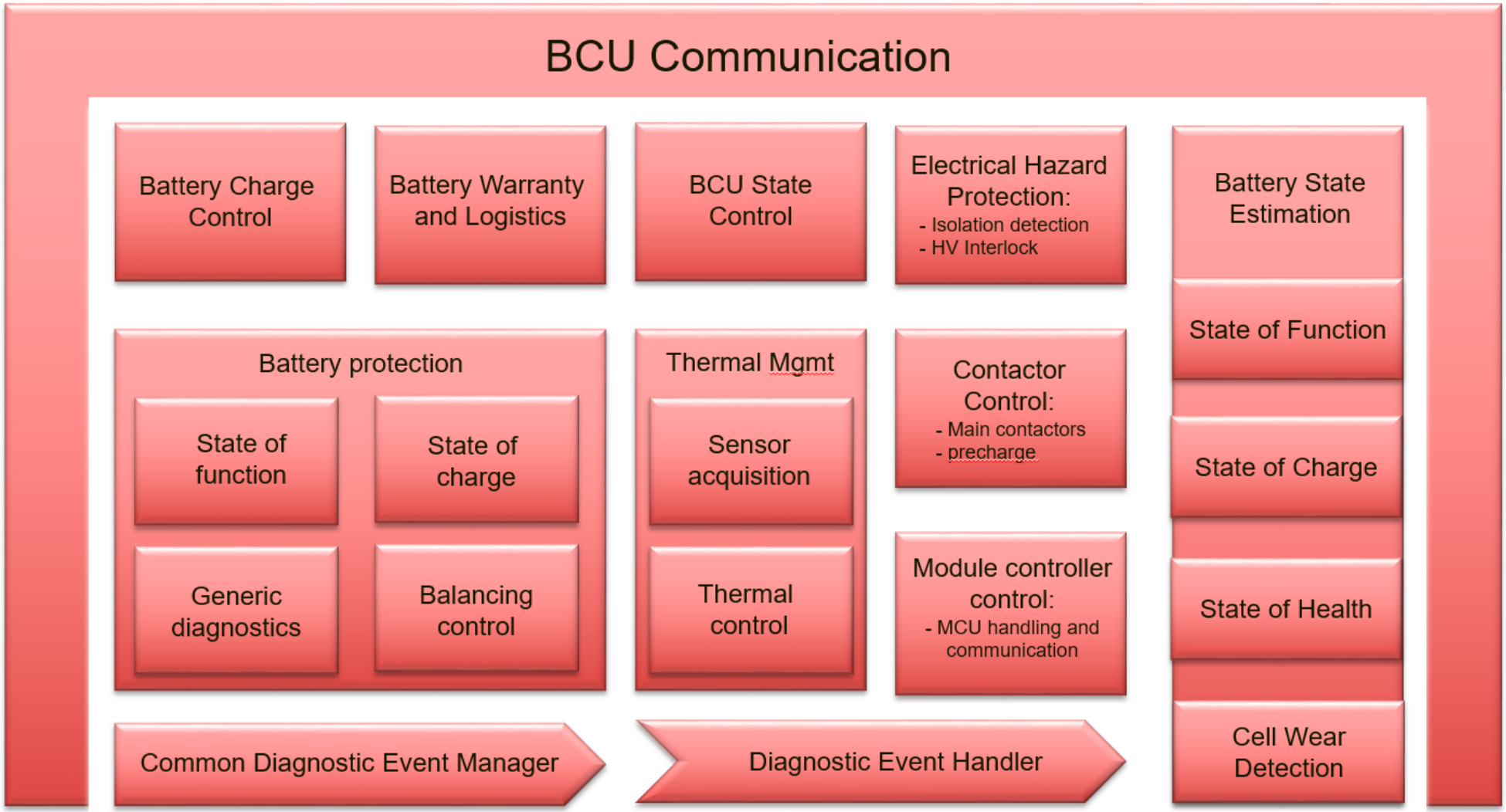


The minimum and maximum temperatures in the module are displayed for the two simulations with different starting temperatures.

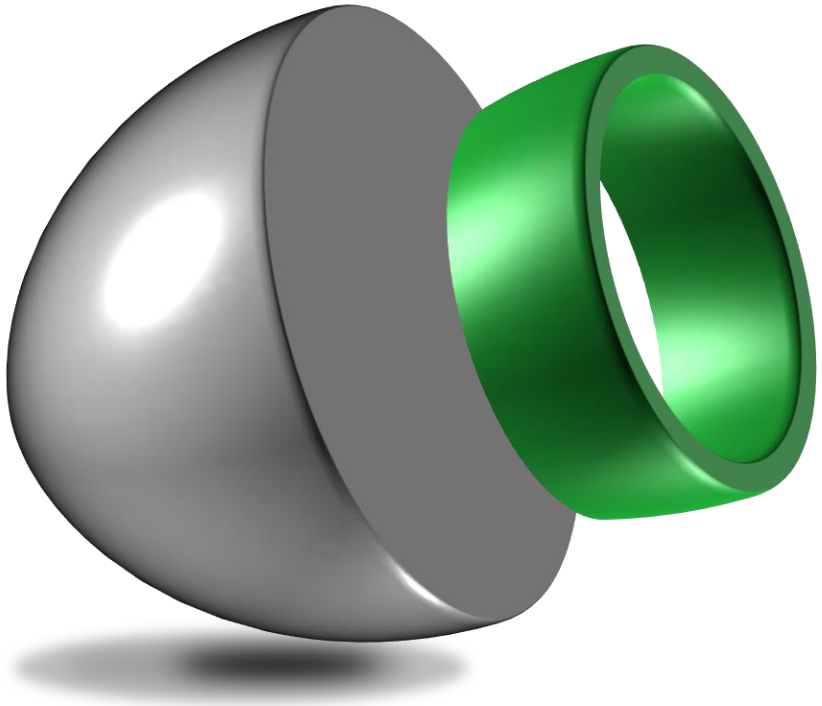
Cell temperatures

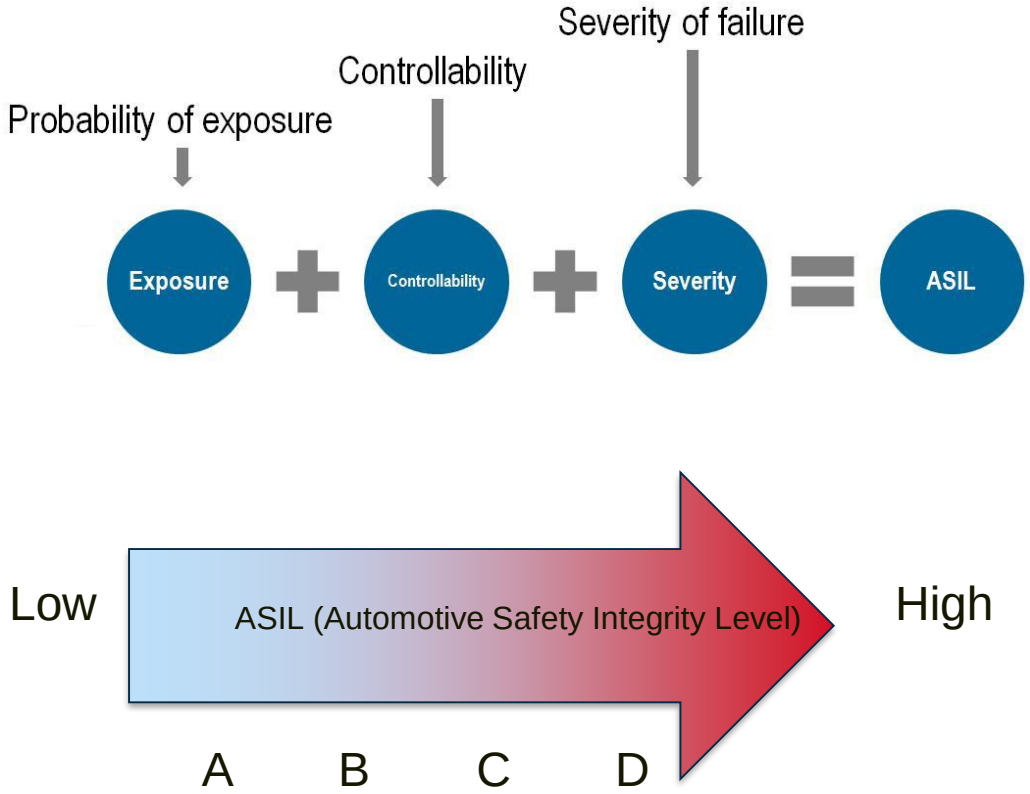
Application Level Software

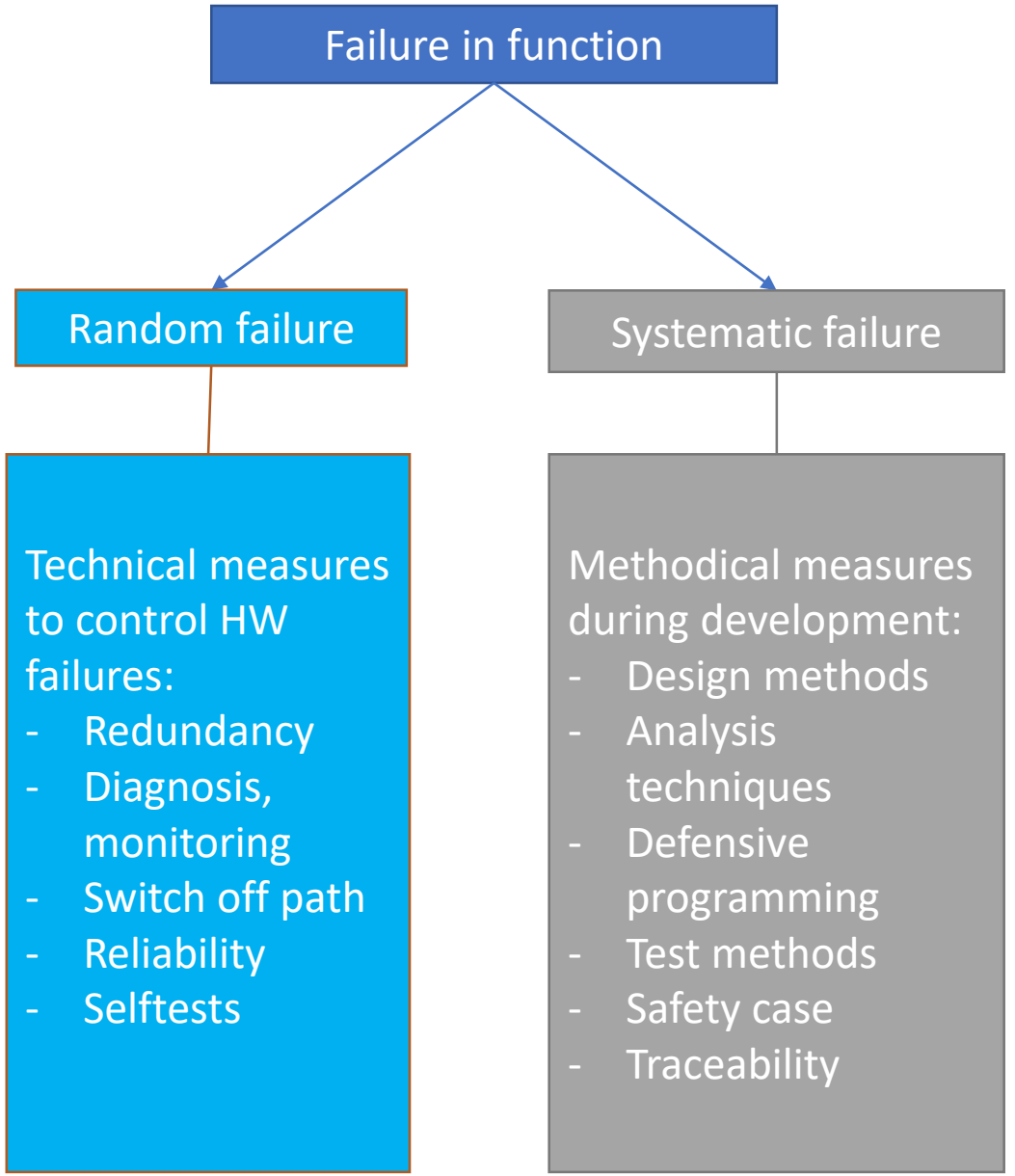




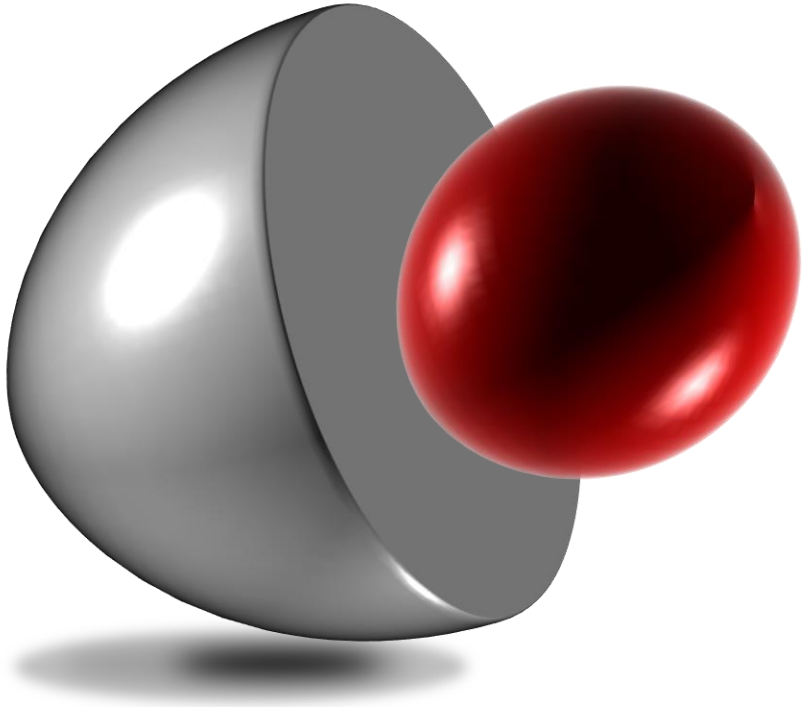
FuSa Layer





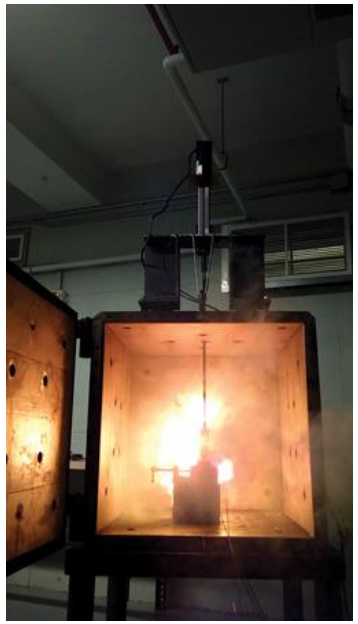


Cell Layer



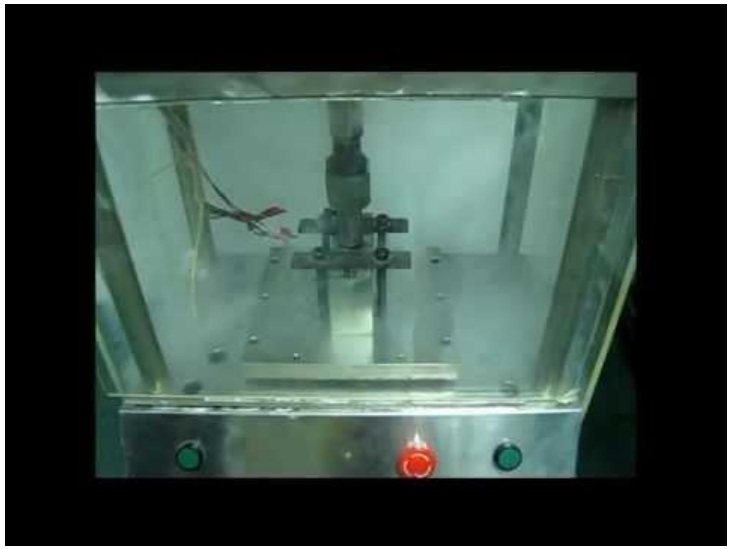
Safety of NMC

LFP



Poor Test

NMC



Good Test

Test Item	Test Condition	Hazard Level
Over Charge	• 100% SoC, RT • 1C charge 1h or voltage of one cell reaches 1.5 times of charged end voltage	2
Over Discharge	• 100% SoC, RT • 1C DC 90 min, rest 60 min	2
Nail	• 100% SoC, RT • Nail Diameter: 8mm, velocity 25+/- 5m/s, through cell	4
Crush	• 100% SoC, RT • Crush head: 75mm, crush to 30% displacement or 0V or crush force reaches 200 KN	3
Hot Box	• 100% SoC, RT • Heating from RT to 130+/- 2^{o}C at a rate 5^{o}C/min. Keep temperature for 30 min	3
Short	• 100% SoC, RT • External resistance<5mΩ, hold for 10 min	2
Drop	• 100% SoC, RT • 1.5m height to concrete floor with terminals downward, 1h rest	2

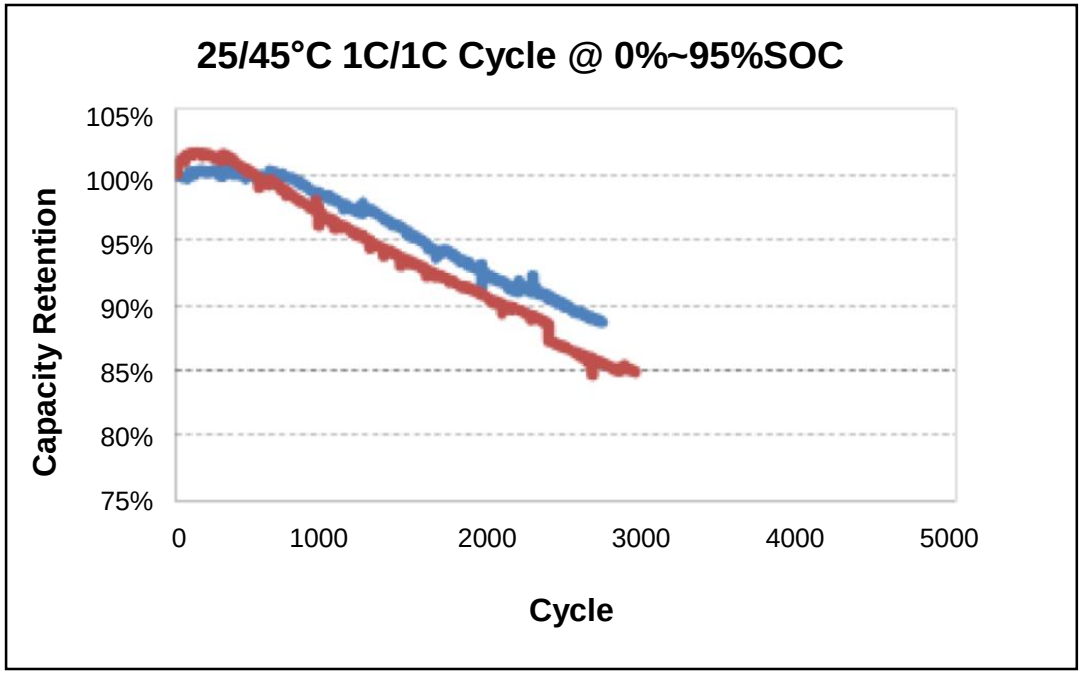
Limited Success to Date for Industrial Lithium

Yesterday	Today
x Most cells produced economically were small format	✓ Extensive usage of large format cells
x Limited variation available – only consumer LCO was produced at high volume	✓ Advanced NMC with high energy density
x 18650 cell cost was valued at 345 USD/KWh	✓ Automotive OEMs are pushing the battery industry to offer increasingly lower pricing
x Safety strategy primitive with limited monitoring	✓ Functional safety hardware topology complying with ISO26262 coupled with enhanced cell safety designs
x Low cyclic capability increases cost of ownership and limits applications	✓ High cyclic capability (+5000) at 75% BoL @ 80% DoD

Cycle Life

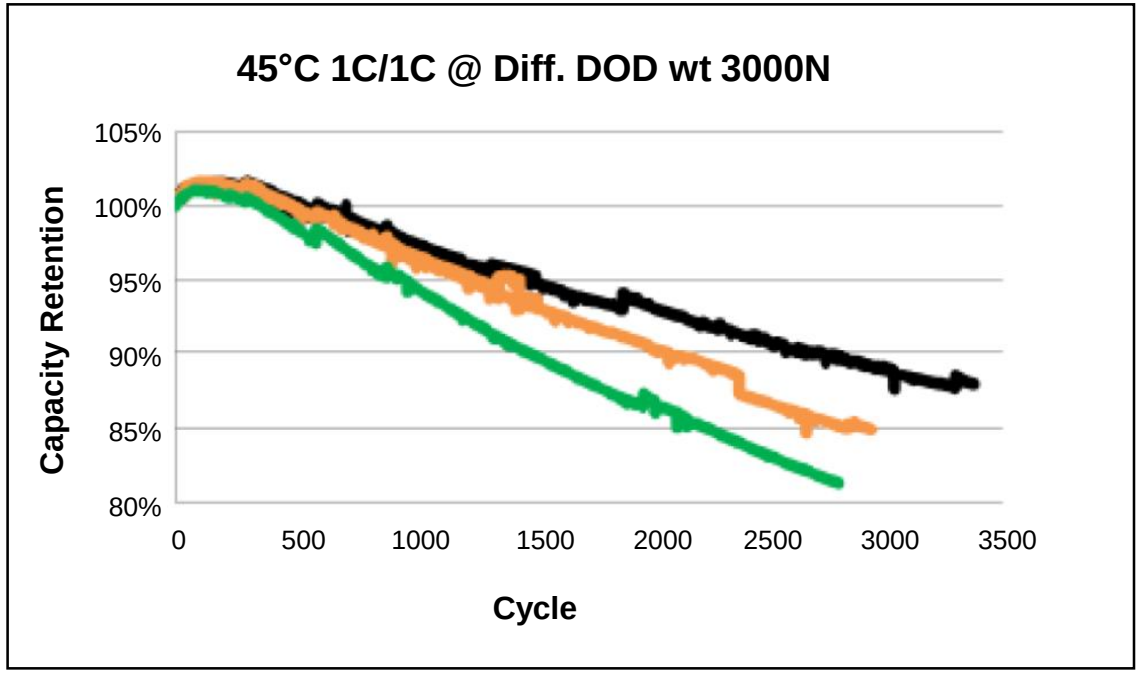
Test Condition: 25°C/45°C 2.8V~4.13V(0%~95%SOC), 1C/1C Cycle

25°C 45°C



Test Condition: 45°C, Diff. DOD 1C/1C Cycle

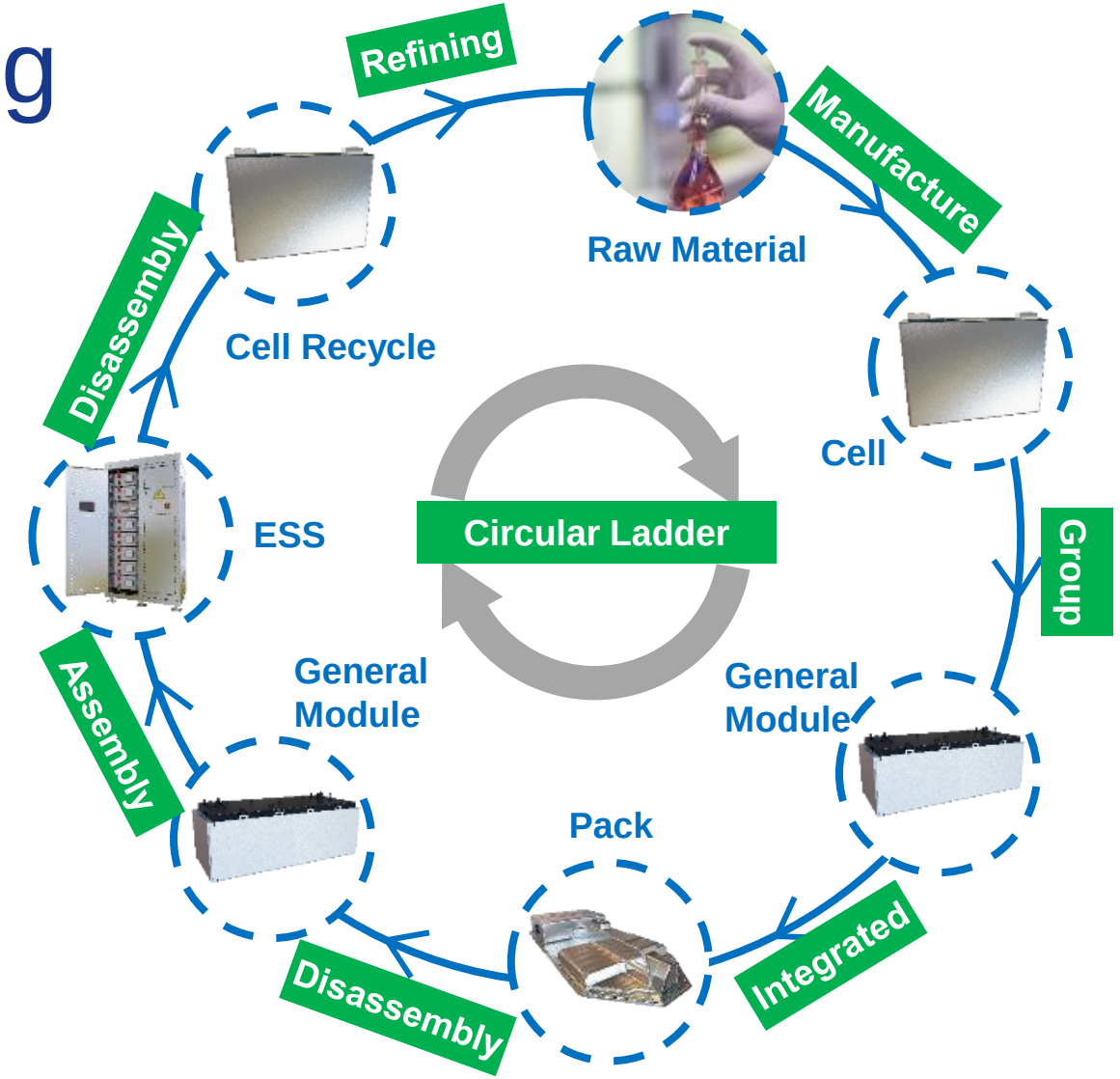
90%SOC 95%SOC 100%SOC



Recycling

LFP?

Recycling



For more information

Speaker name: joern.tinnemeyer@enersys.com
Website: www.enersys.com

Visit MODEX Booth 7632