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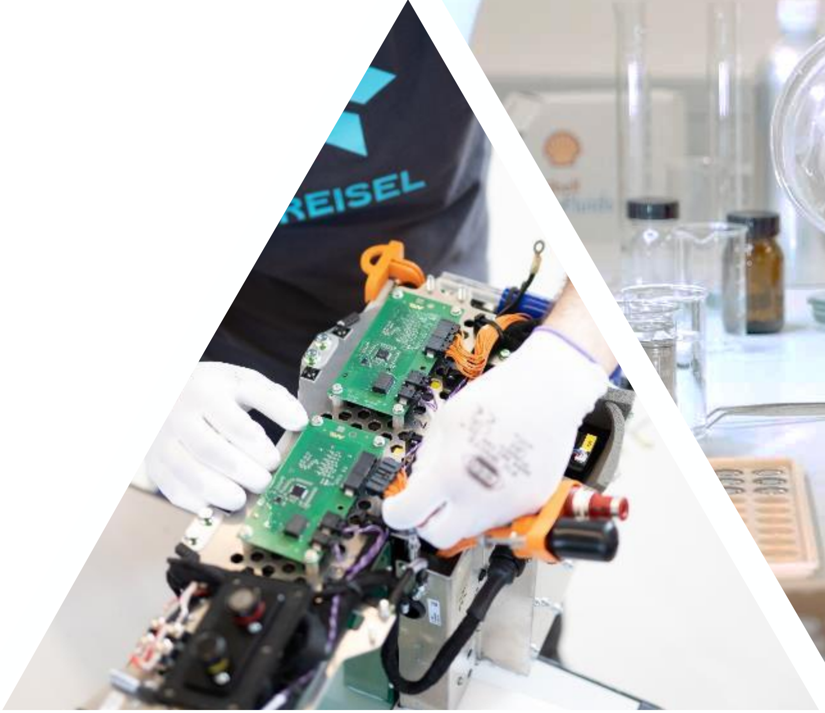
RESIDENTIAL BATTERY ENERGY STORAGE SYSTEMS



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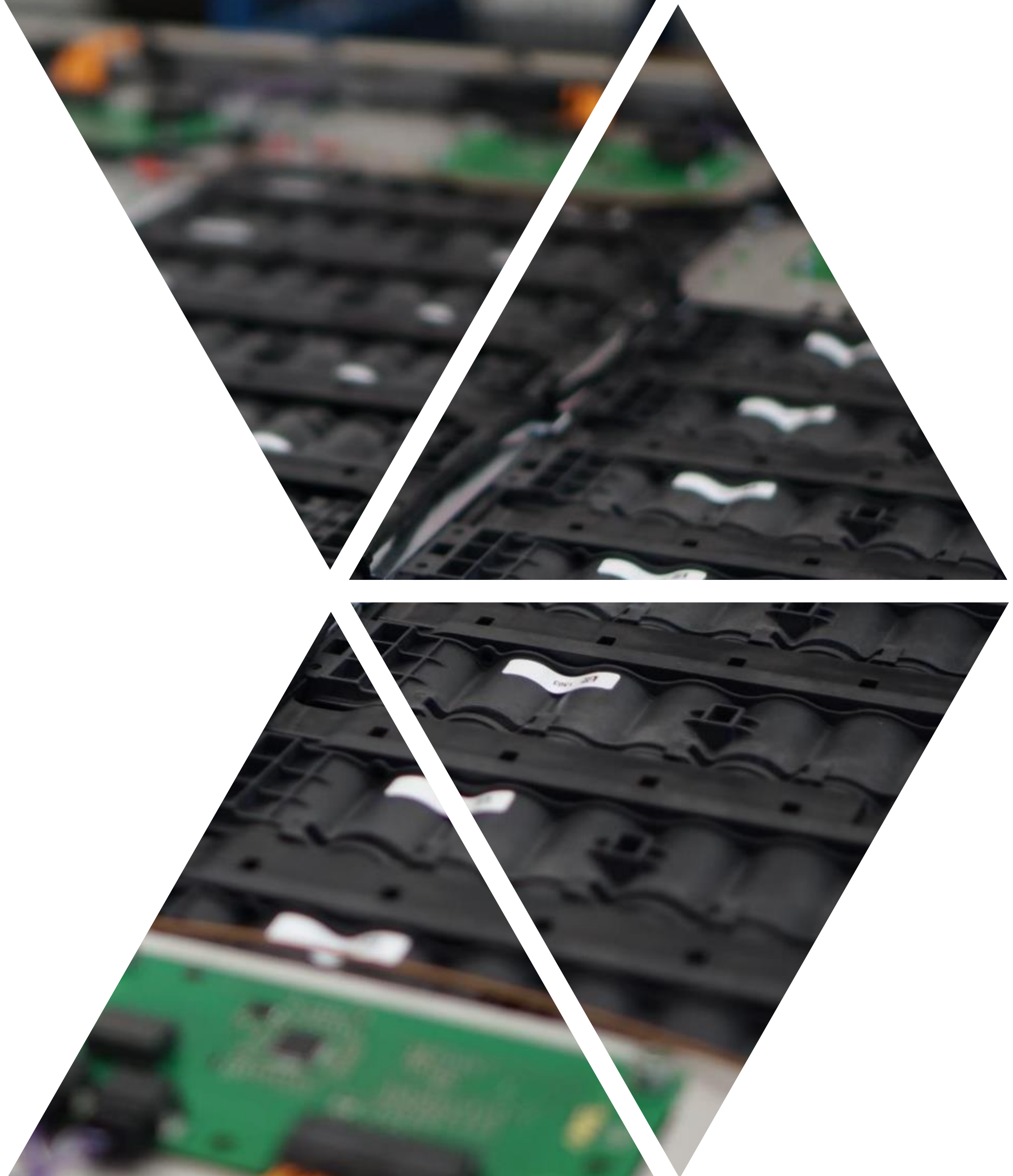
KREISEL

AGENDA

- About Kreisel Electric
- Technical aspects of battery
- An example use case
- Economic aspects of battery
- Summary



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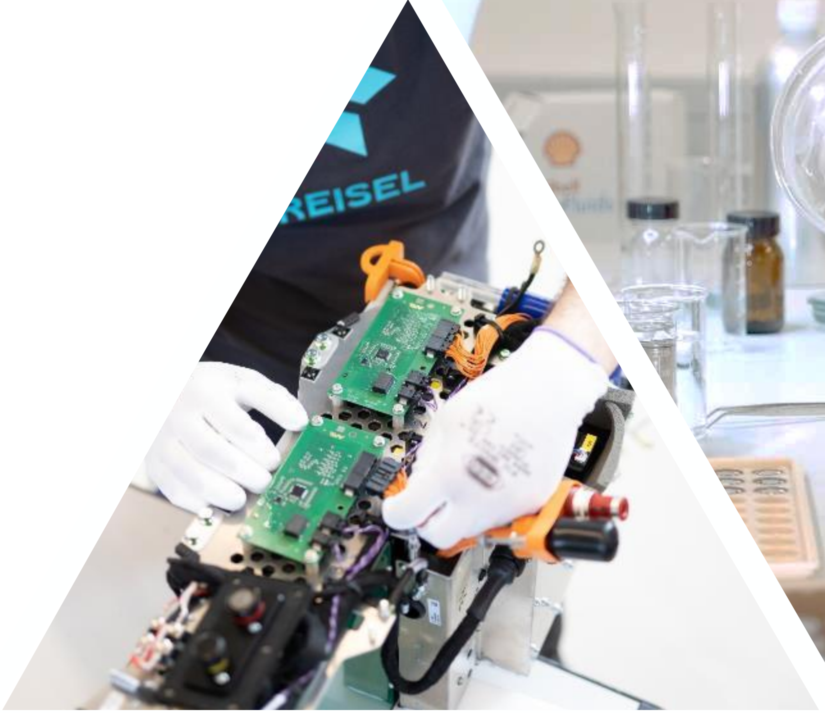
BATTERY TECHNOLOGY PIONEER

ABOUT KREISEL ELECTRIC



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BATTERY TECHNOLOGY PIONEER

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FIRST ELECTRIC CAR
conversion by the
KREISEL brothers

2013

2014

FOUNDING
KREISEL Electric
GmbH & Co KG

VW E-GOLF
with 130% more
battery capacity

2015

2016

G-WAGON
with true 150kW fast
charging capability

NEW HEADQUARTER
Rainbach i.M.

2017

CHIMERO
Battery
Integrated
Charger

2018

2018

START OF SMALL SERIES
1 000+ immersion cooled
batteries per year

2019

EXCLUSIVE PROVIDER
FIA World RX (Powertrain)
FIA WRC hybrid (Battery)

R&D PARTNERSHIP
R&D thermal
management

2020

JOHN DEERE
acquires majority
ownership of KREISEL

2021

2022

€50 MILLION PARTNERSHIP
KBP 63 for X Shore Eelex
8000 boats

PRODUCTION EXPANSION
3+ GWh capacity in
France & USA

2023

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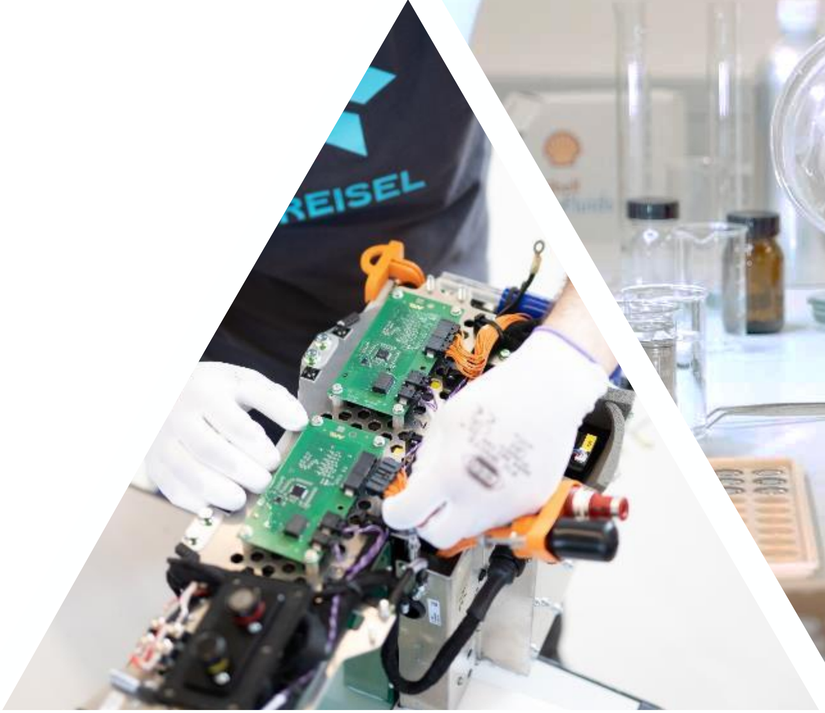
RESIDENTIAL BATTERY STORAGE SYSTEMS

TECHNICAL ASPECTS OF BATTERIES



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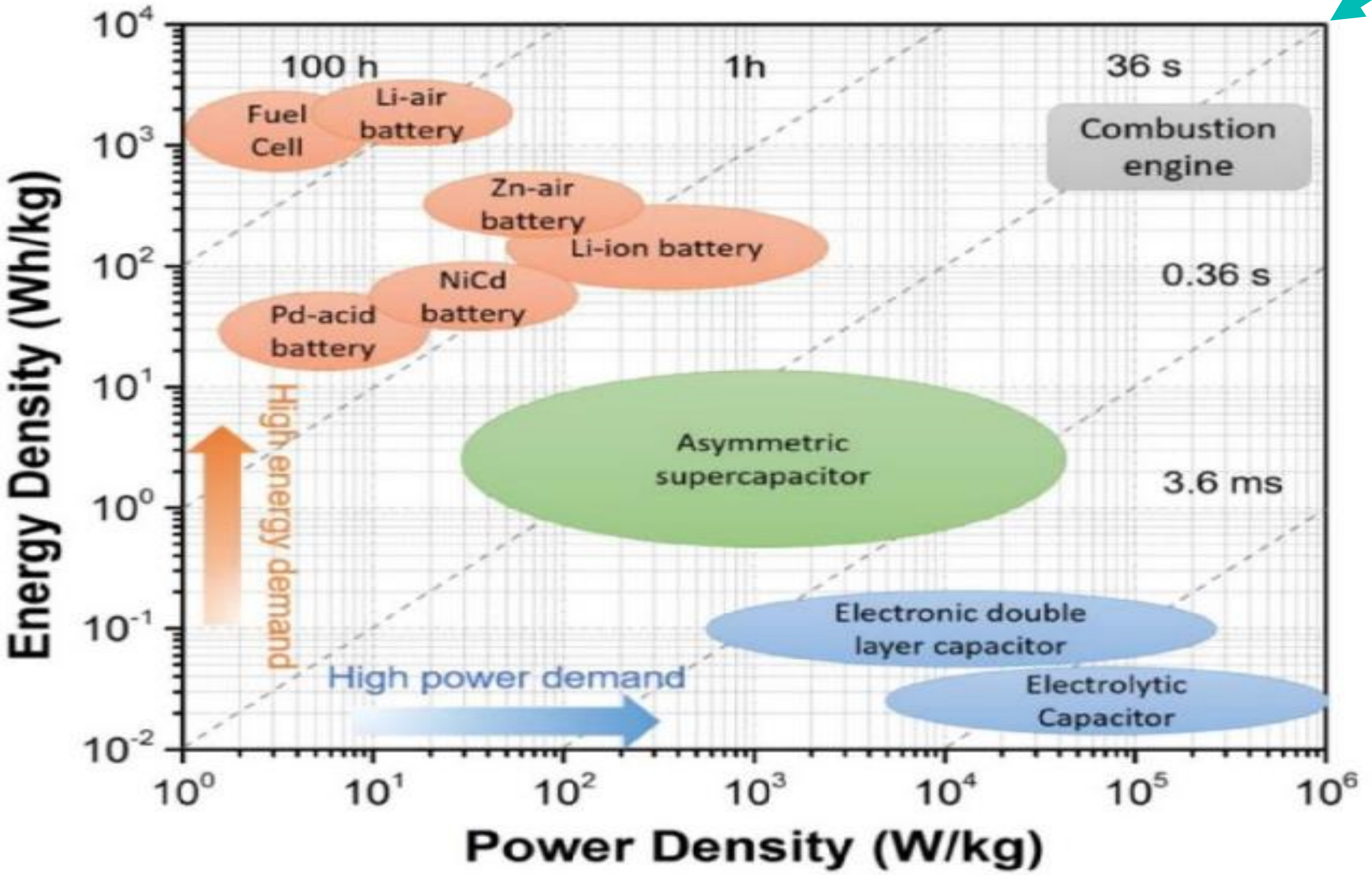
COMPARISON OF DIFFERENT ENERGY STORAGE DEVICES

IDEAL SOLUTION



Ref: The 2021 battery technology roadmap, IOP Science

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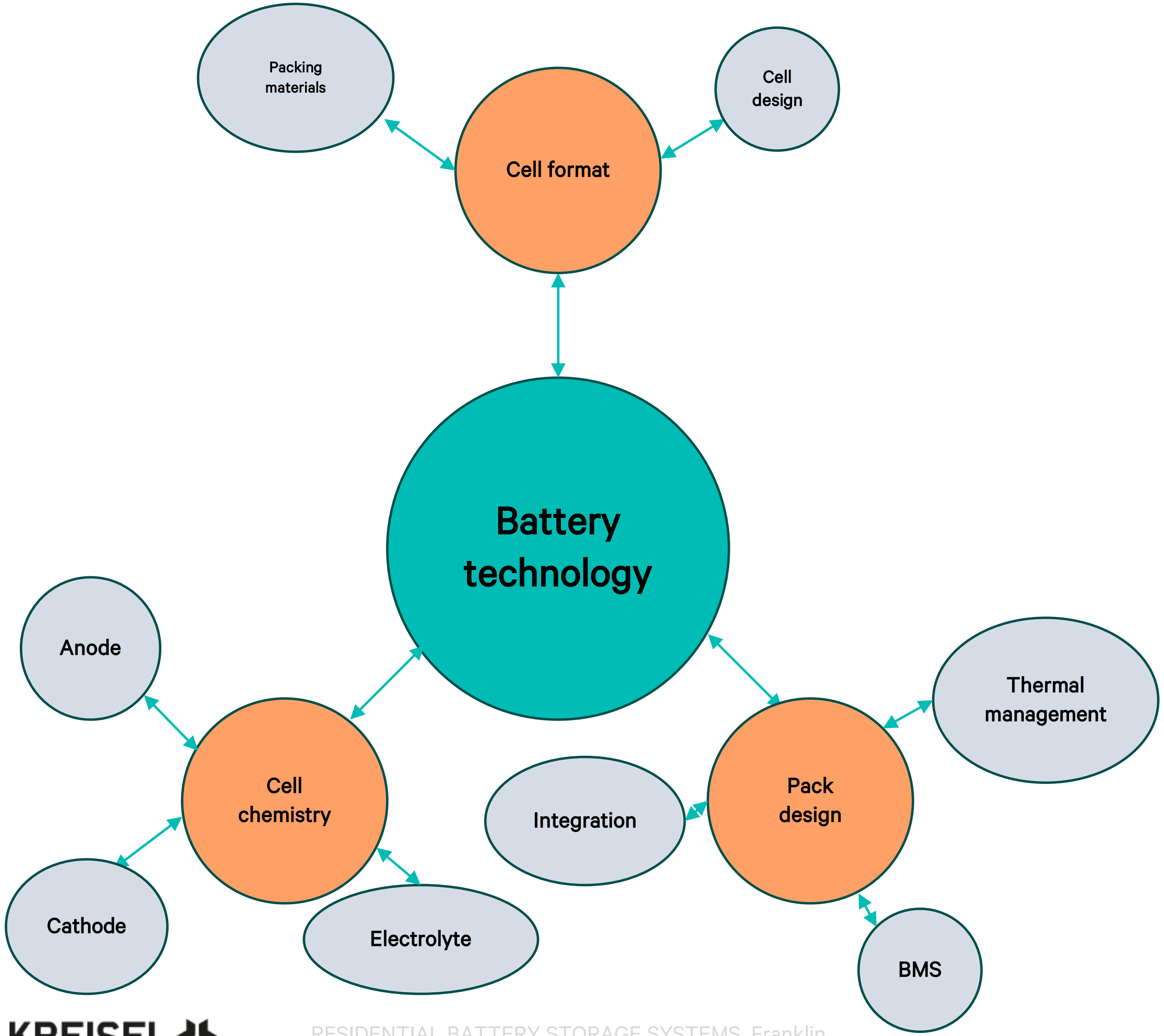
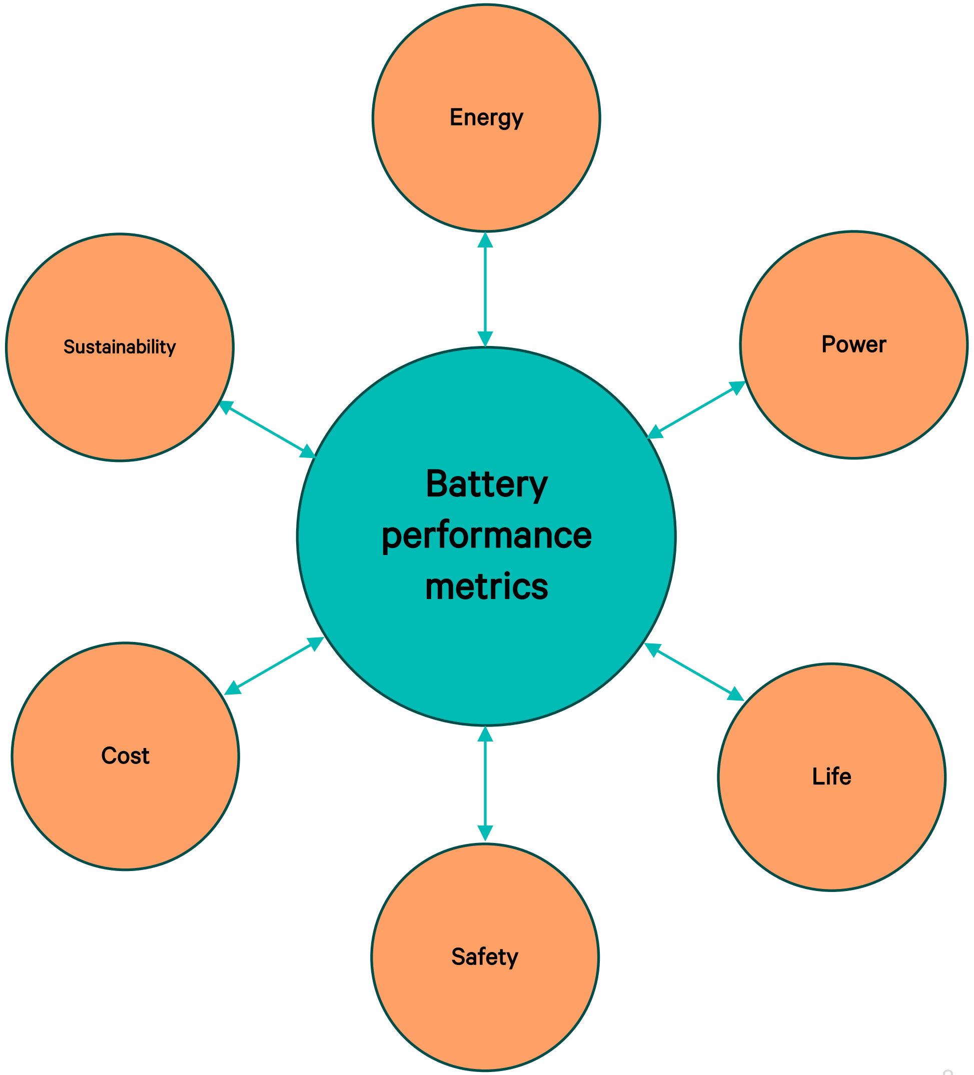
BATTERY TECHNOLOGY





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CELL FORMAT

Prismatic cells

+Volumetric energy density
+Structural integrity
+Advanced safety features
- Low gravimetric energy density
- Higher production costs
- High amount of energy released under failure
- Poor thermal control

Applications: EV, Grid energy storage Off-highway etc…

Pouch cells

+Good gravimetric energy density
+Customizable size & low cost
+High efficiency
- Swelling
- No safety features
- No solid housing

Applications: Smart phones, Drones, laptops etc..

Cylindrical cells

+Standard cell sizes & flexible pack sizes
+Good thermal control
+Low amount of energy released under failure
+Low cost, mass production etc..
- Low efficiency
- Low volumetric energy density
- Complex monitoring system

Applications: EVs, tools, toys, automotive industry, Grid storage system etc..

Picture ref: onecharge.biz

CELL CHEMISTRIES

Innovations in the battery industry affect all cell components.

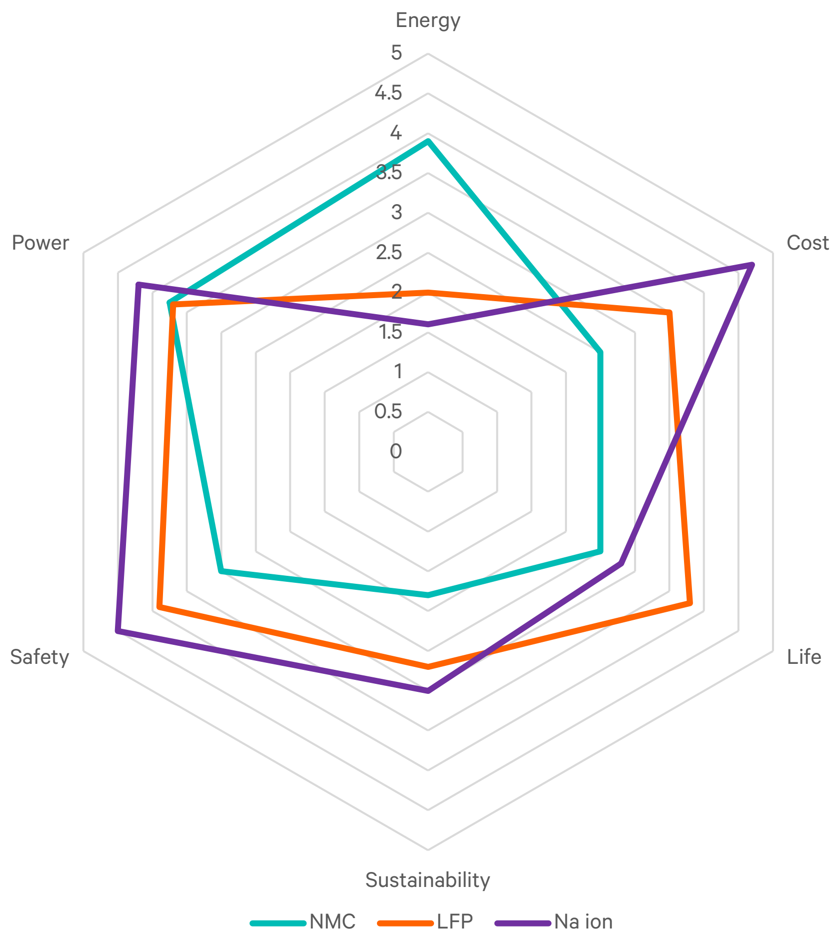
Common battery chemistries and form factor available

	2010s		2020s		2030s	
1 Cathode	LCO[1]	LMO[2] LFP[3] NMC[4]/NCA[5]	LFP[3] NMC[4]/NCA[5]	LFP[3] NMC[4]/NCA[5] LMFP[6]/LMNO[7]	NMC[4]/NCA[5] LMFP[6]/LMNO[7] Sulphur	LMFP[6]/LMNO[7] Sulphur
2 Separator/ electrolyte	Polymer/liquid	Polymer/liquid	Polymer/liquid	Polymer/liquid	Polymer/liquid Advanced liquid Semi-solid	Advanced liquid Semi-solid Solid
3 Anode	Graphite	Graphite	Graphite	Graphite Graphite and silicon	Graphite and silicon Lithium metal Silicon anode	Lithium metal Silicon anode
4 Casing	Cylindrical	Cylindrical Pouch	Prismatic Cylindrical Pouch	Prismatic Cylindrical Pouch	Cylindrical Pouch Prismatic	Cylindrical Pouch

[1]Lithium cobalt.
[2]Lithium manganese oxide.
[3]Lithium, iron, phosphate.
[4]Lithium, manganese cobalt.
[5]Lithium, nickel, cobalt, aluminum oxide.
[6]Lithium manganese iron phosphate.
[7]Lithium, manganese nickel oxide.
Source: McKinsey Battery Insights, 2022

Ref: Mckinsey battery insights

CELL CHEMISTRY COMPARISON



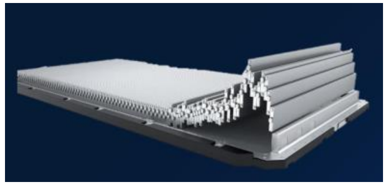
NMC:

- Nickel manganese Cobalt
- Most advanced technology
- High energy density,High cost
- Low sustainability, Safety measures needed
- Applications: Electric vehicles, Motor sport, Off road vehicles

Ref: Tesla

LFP:

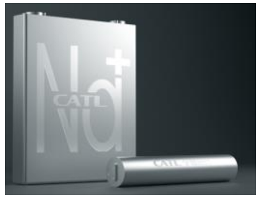
- Lithium Iron Phosphate
- Can be designed smartly to overcome its disadvantages
- Superior safety, Low cost, Good sustainability,Excellent life cycle
- Low energy density
- Applications: Electric vehicles, Energy storage applications, Off road vehicles



Ref: BYD

Na ion:

- Sodium Ion
- Research in progress, long way to go
- Superior safety, Low cost, Good sustainability,Excellent life cycle
- Low energy density, Challenges in commercialization
- Applications: Energy storage applications



Ref: CATL

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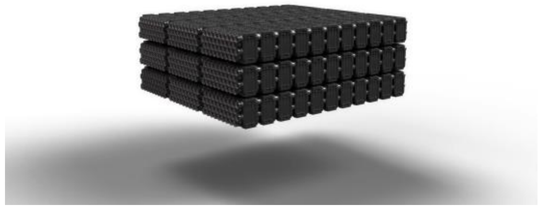
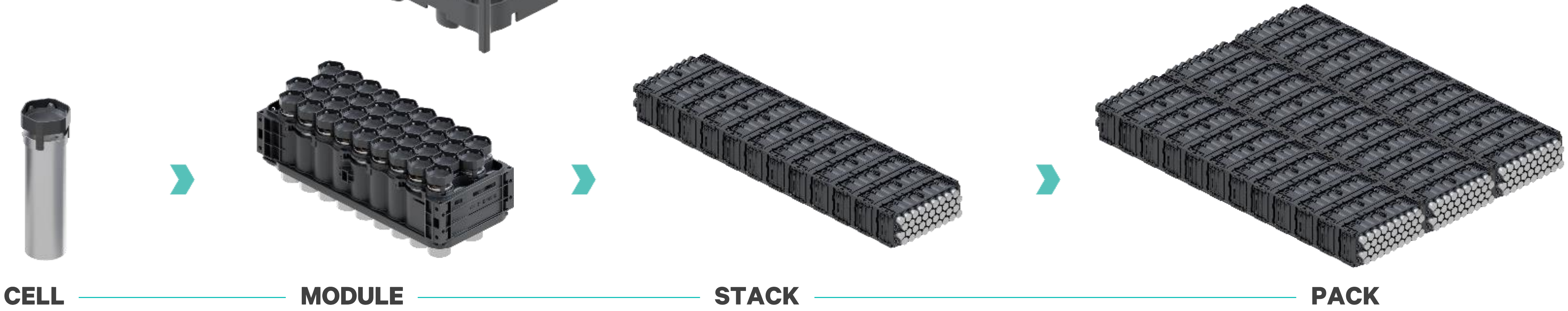
PACK DESIGN



DESIGN TO COST

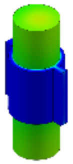
- Favourable cost at cell level
- State of the art processes lead to 2nd source ability of all parts
- Compact assembly
- Economic industrialization



IMMERSION COOLING

KREISEL IMMERSION COOLING

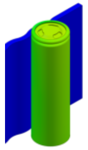
- Most **ENERGY EFFICIENT** cooling type: non-conductive liquid is in direct contact with the cell
- Unique low **TEMPERATURE SPREAD OF <1°C** throughout the module



SIDE WALL COOLING

- Increased jelly roll temperature
- **TEMPERATURE SPREAD: PACK >5°C**

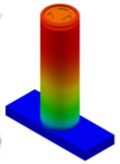
Panasonic
TOYOTA



BASE PLATE COOLING

- High cell temperature at the top; low on the base
- **TEMPERATURE SPREAD: PACK >5°C**

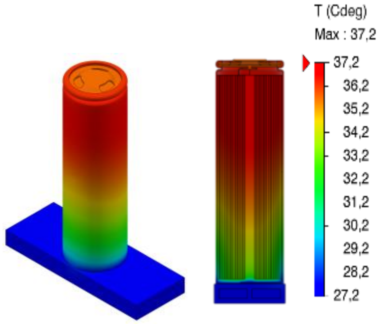
AKASOL
ROMEO



COOLING TECHNOLOGY COMPARISON

BASE PLATE COOLING

Significantly increased temperature differences



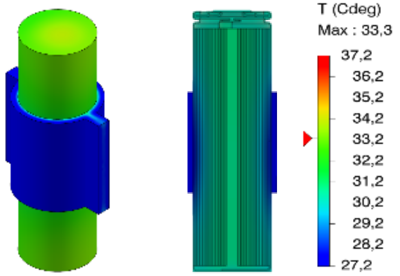
346 mm²

Heat transfer area
Liquid temperature
Pressure drop
Pump power required **HIGH**
Lifetime

V.S.

KREISEL IMMERSION COOLING

Superior cooling performance



+500%
HEAT TRANSFER AREA

1.880 mm²

- **+ 500 %** Heat transfer area
- **- 15 %** Liquid temperature
- **- 50 %** Pressure drop
- **- 50 %** Pump power required
- **+ 20 %** Lifetime

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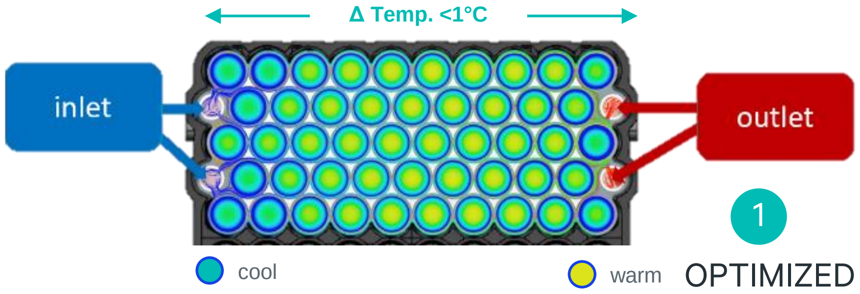
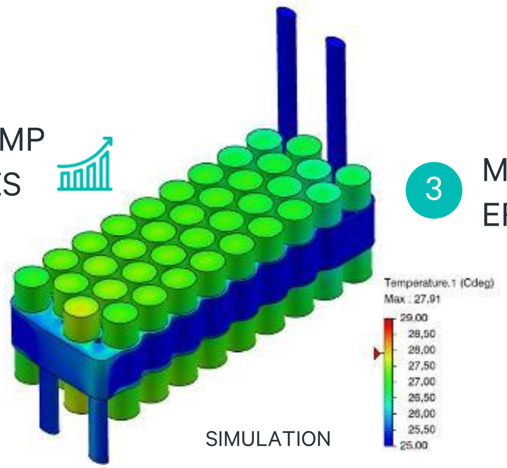
TECHNOLOGY ADVANTAGES

2 MIN. TEMP SPREAD **(ΔT)**



1 OPTIMIZED END TEMP

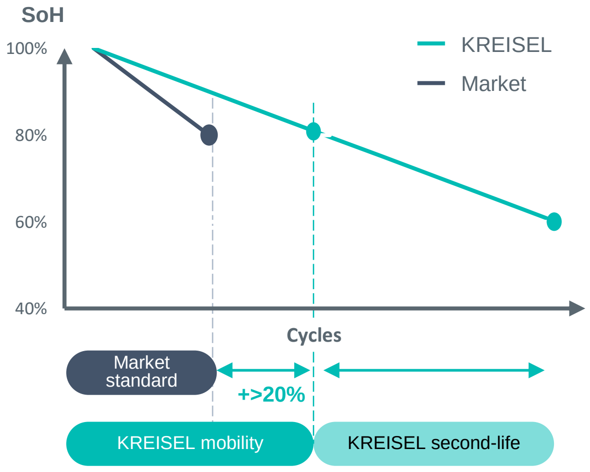
FAST TEMP CHANGES



3 MAX. COOLING EFFICIENCY

UNSURPASSED LIFETIME

- Battery state of health (SOH) is determined by the weakest cell in the module
- The **UNIQUE LOW TEMPERATURE SPREAD** ensures that all cells are stressed equally and thus **PROLONGS BATTERY LIFE**
- Better thermal management and safety enable **SECOND-LIFE APPLICATIONS BELOW 80% SOH**

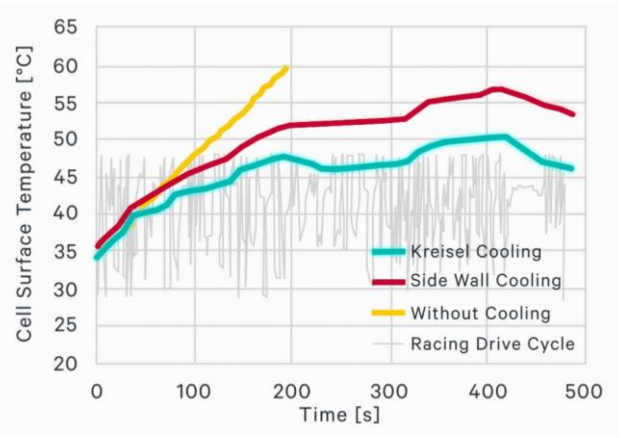


Estimation at defined cycle of 1C charge & 1C discharge

ULTIMATE PERFORMANCE

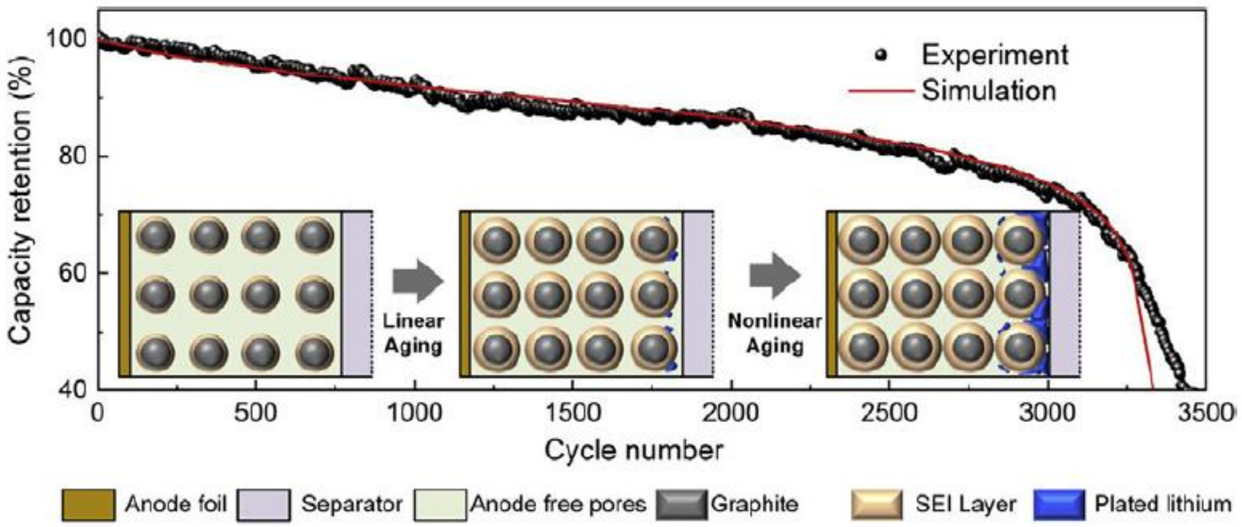
- Rapid heating and maintaining the optimal temperature is **KEY FOR FAST CHARGING** and KREISEL is the industry leader in thermal management
- **IMPROVED PERFORMANCE** in particularly **HOT/COLD CLIMATES**, which EVs traditionally struggle with

Nürburgring testing event



AGEING OF BATTERIES

- Calendric ageing
  - SEI layer growth
  - Structural and chemical decomposition of the cathode
- Cyclic ageing
  - SEI layer growth
  - Lithium plating



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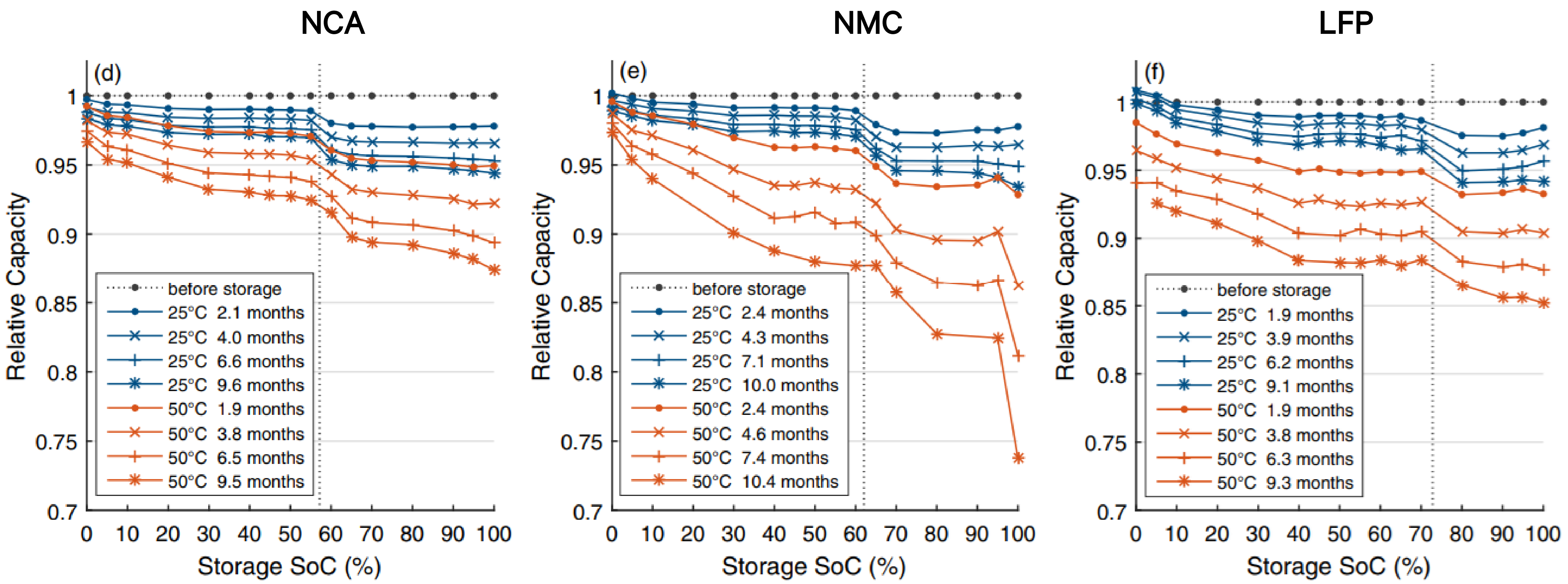
CALENDRIC AGEING



Ref: Peter Keil et al 2016 J. Electrochem. Soc. 163 A1872

Take aways:-

- Store the battery at low temperatures
- Store the battery at low SOC

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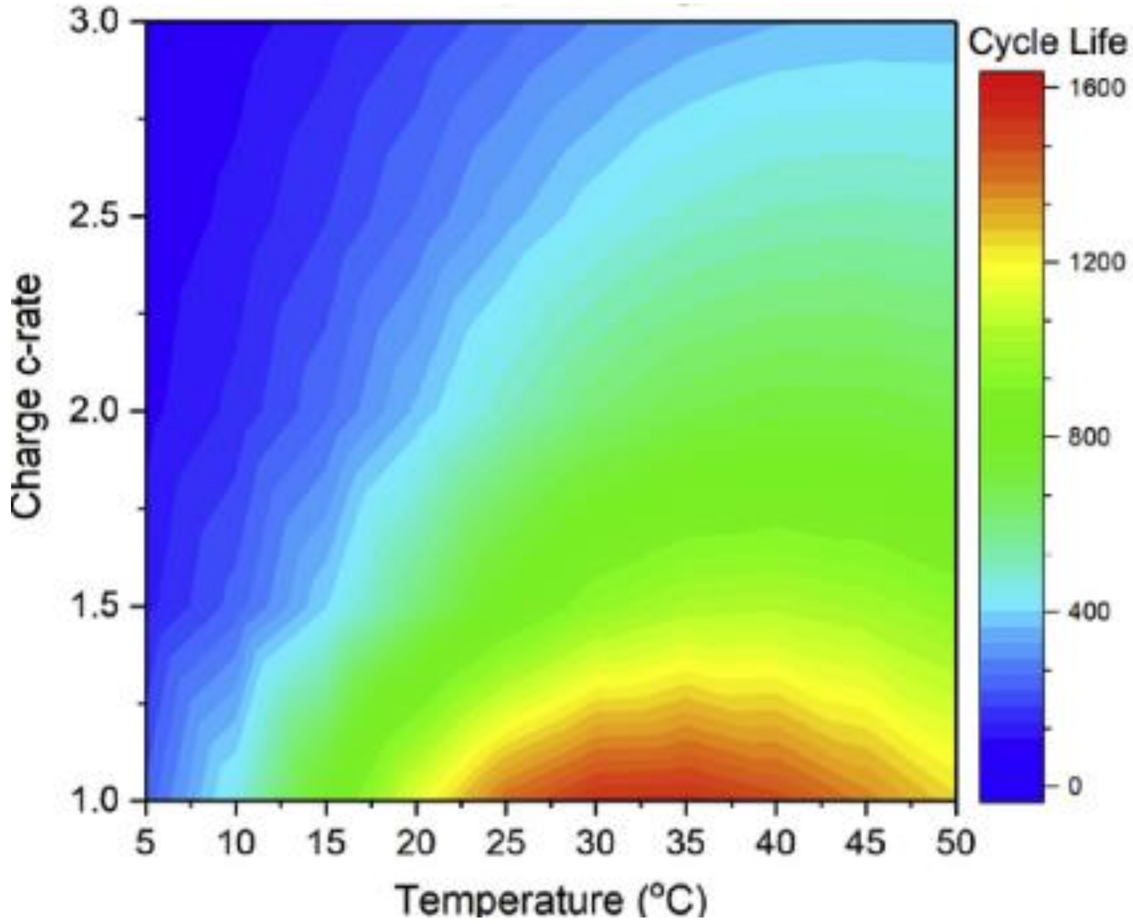
CYCLIC AGING



Ref: Yang et al, Understanding the trilemma of fast charging, energy density and cycle life of lithium-ion batteries, Science direct

Cycle definition:-

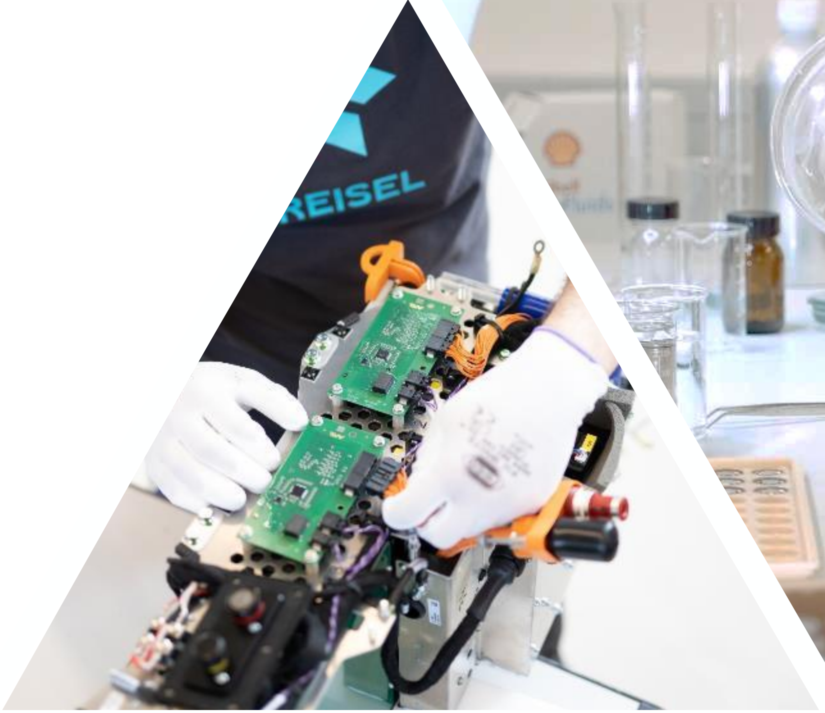
- Standard [CCCV] profile charging
- Wait between charging and discharging 5 mins
- Discharging at 1C
- Wait between each cycle – 5 mins

Take aways:-

- Higher the charging rate, faster the ageing
- Operate the battery at optimum temperature

RESIDENTIAL BATTERY STORAGE SYSTEMS

AN EXAMPLE USE CASE



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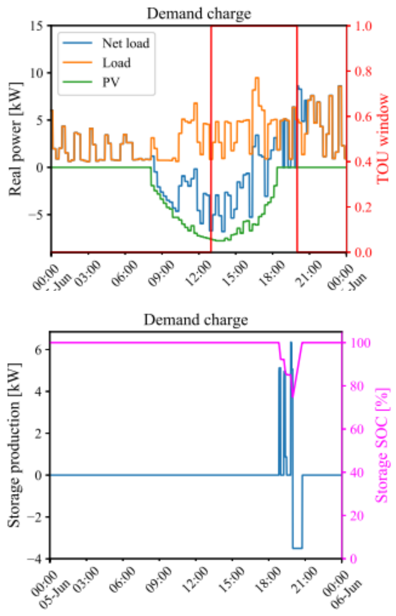
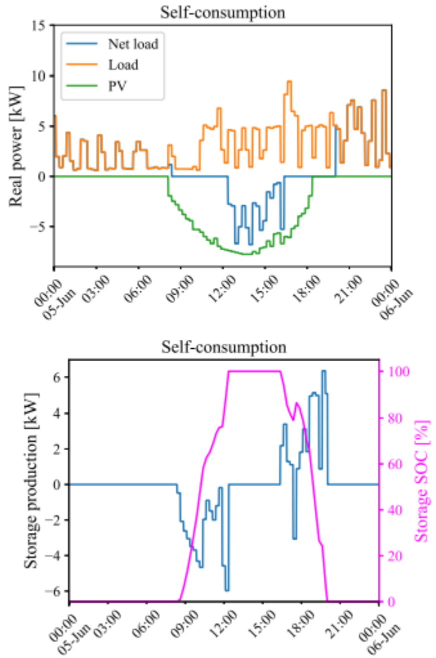
THREE OPERATION MODES

Demand charge reduction



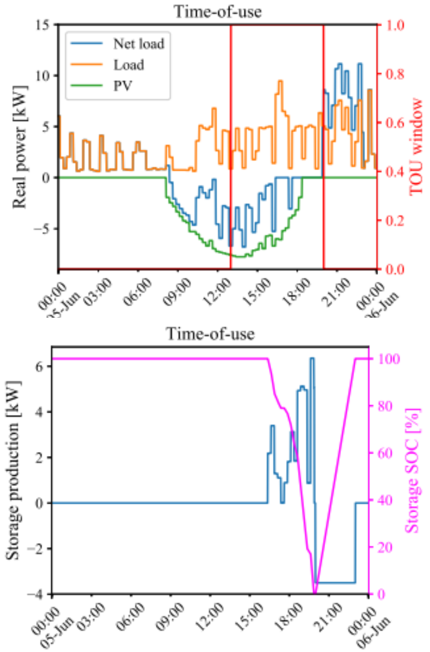
Controller discharges only after the energy threshold set within the TOU window over a 30-minute period is reached

Self consumption



Controller follows the net load profile, thereby consuming excess PV generated solar energy

Time of use mode



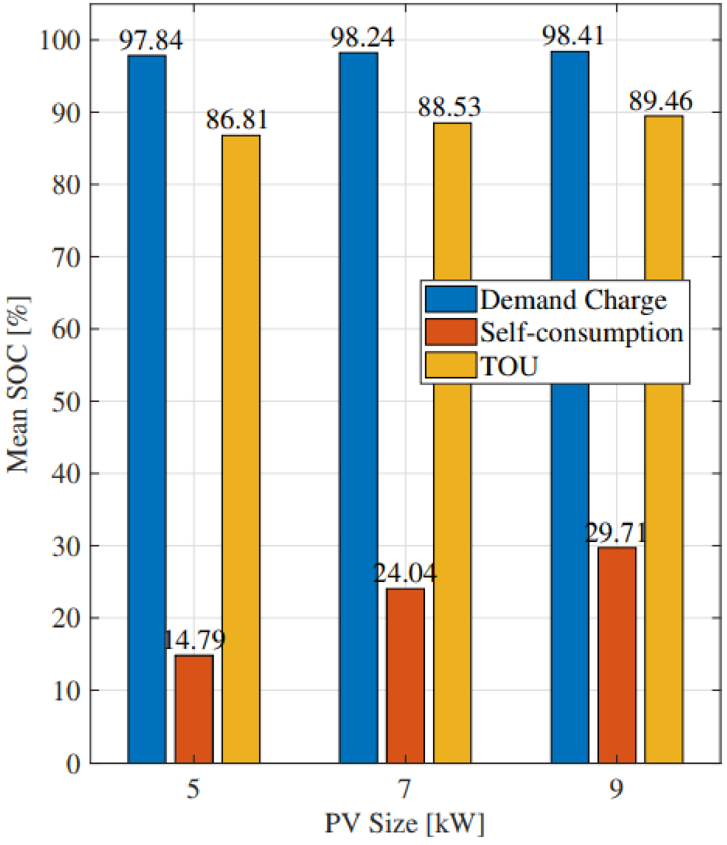
Controller dispatches the energy storage capacity during the TOU window and charges at the end of the window

TOU → Time of Use

Ref: Analysis of Degradation in Residential Battery Energy Storage Systems for Rate-Based Use-Cases, NREL

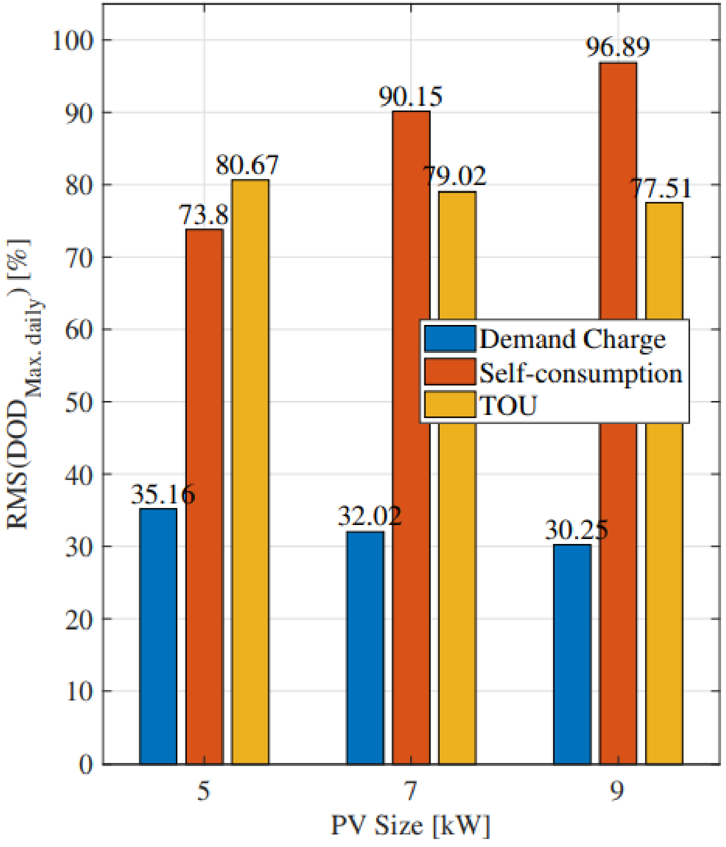
BATTERY BEHAVIOUR FOR THREE OPERATION MODES

SOC – State of Charge



(a) Mean SOC

DOD – Depth of Discharge



(b) RMS of maximum daily DOD

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Ref: Analysis of Degradation in Residential Battery Energy Storage Systems for Rate-Based Use-Cases, NREL

BATTERY [10kWh] LIFE

Demand charge reduction mode

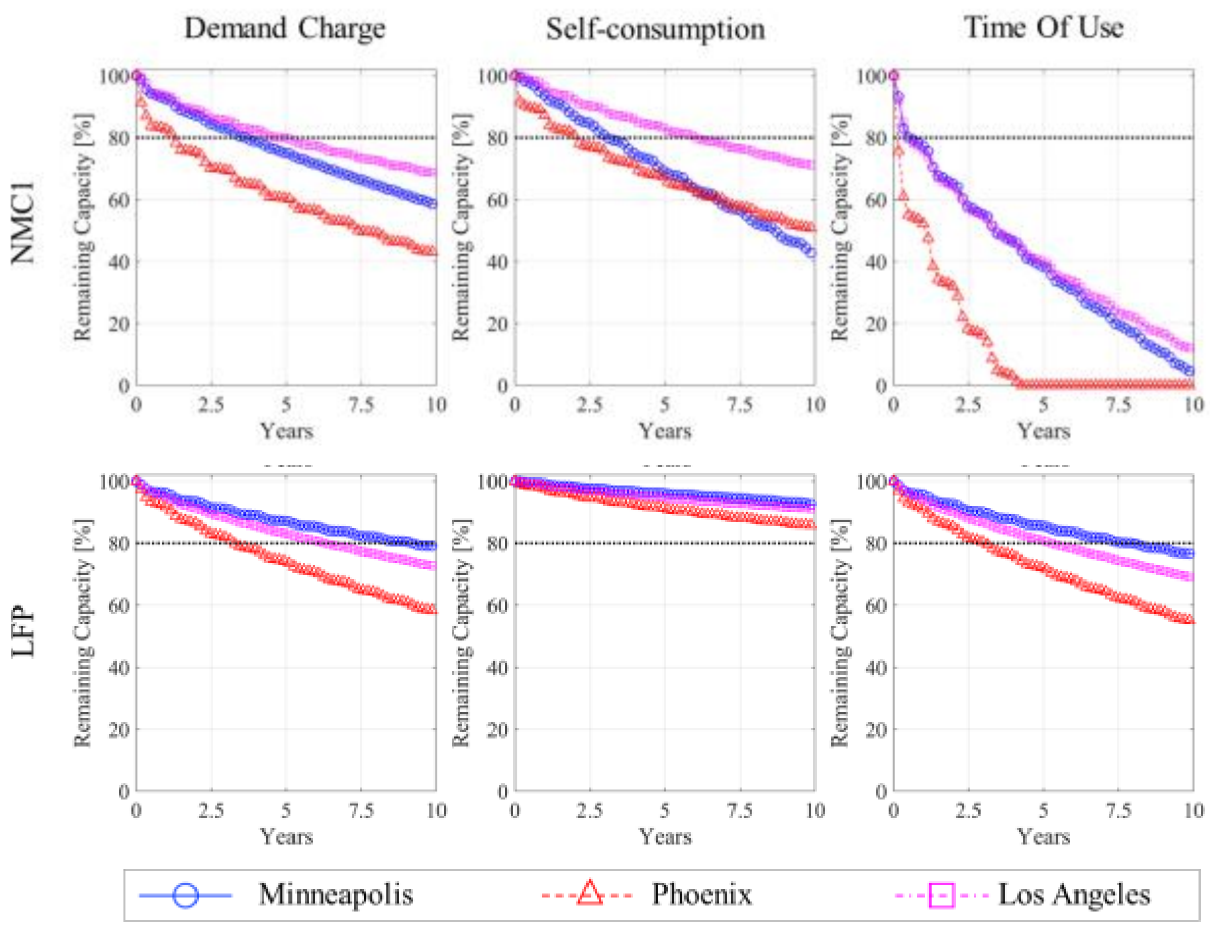
- Battery is stored at higher SOC and cycled at low DOD
- Calendric ageing is dominant over cyclic ageing
- Low ambient temperatures → slow calendric ageing
- 18°C seems optimum temperature

Self-consumption mode

- Battery is stored at low SOC and cycled at high DOD
- Cyclic ageing is dominant over calendric ageing
- Low ambient temperatures → not optimum for cyclic agein
- LFP chemistry favours this mode

Time of Use mode

- Battery is stored at high SOC and cycled at high DOD
- NMC chemistry shows poor ageing characteristics for this mode
- Better thermal management strategy for this NMC chemistry could help to prolong the battery life



Yearly average temperature 6°C | Yearly average temperature 25°C | Yearly average temperature 18°C

Take away: LFP chemistry based battery operating under low yearly average temperatures and under self-consumption mode is the optimum energy storage system.

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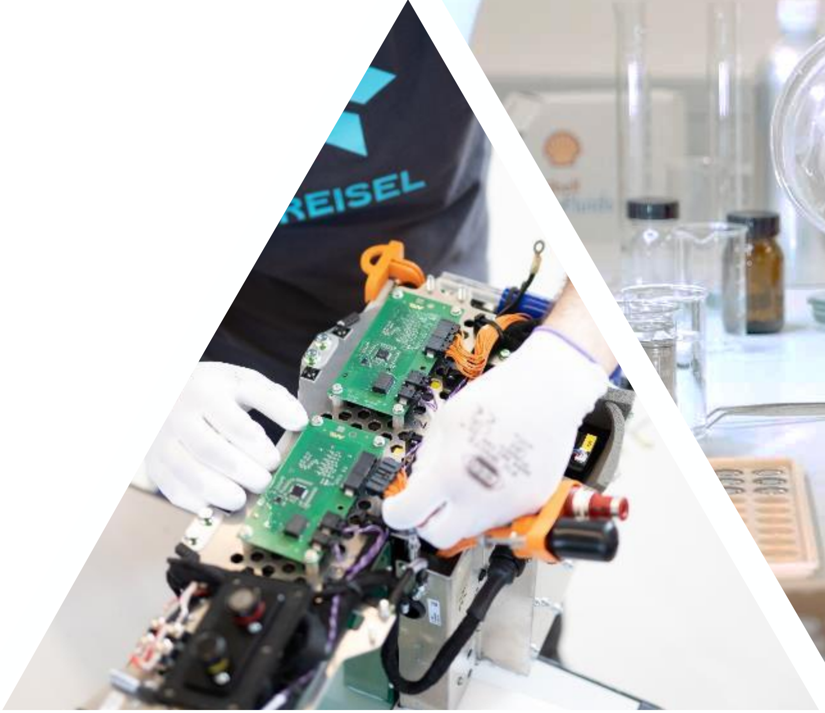
RESIDENTIAL BATTERY ENERGY STORAGE SYSTEM

ECONOMIC ASPECTS OF BATTERIES



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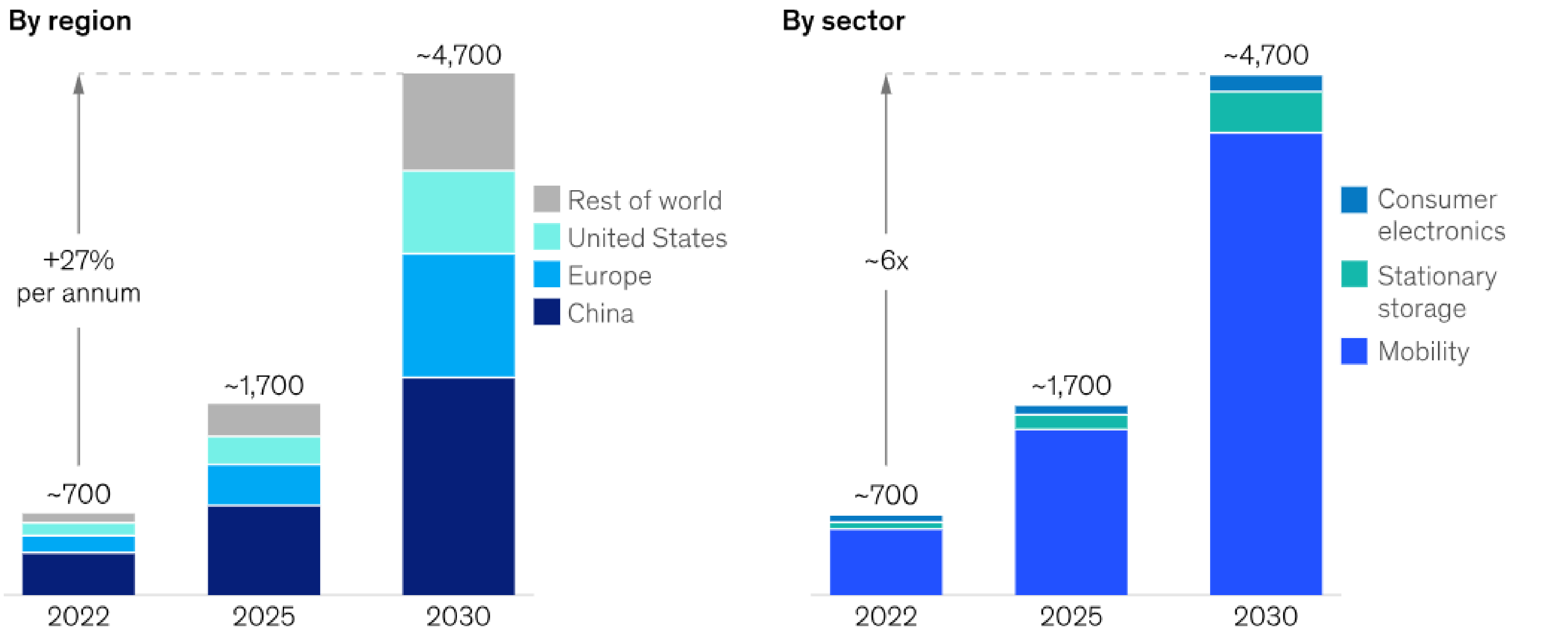
DEMANDS OF LI-ION BATTERY

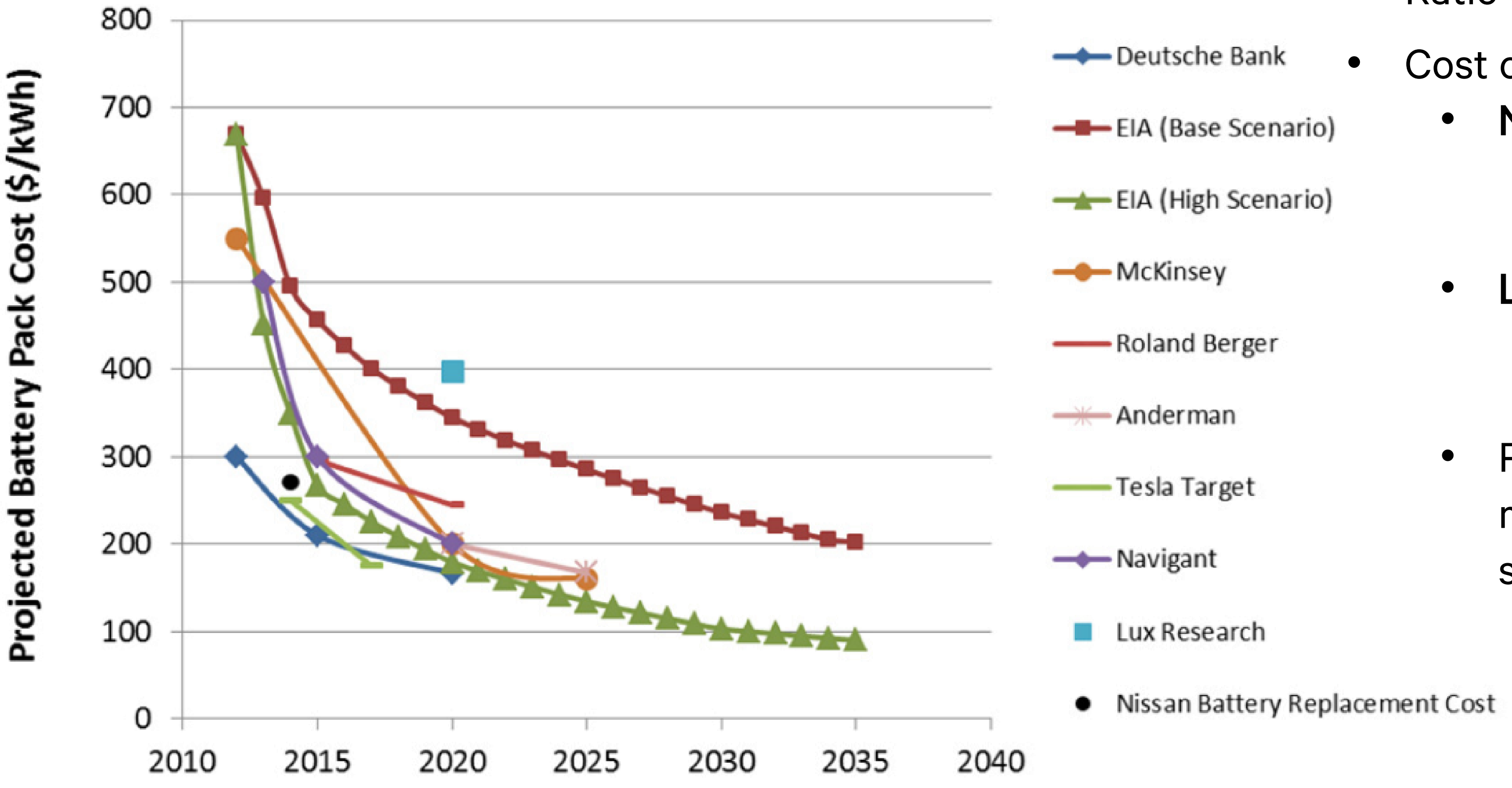
Global Li-ion battery cell demand, GWh, Base case



[1]Including passenger cars, commercial vehicles, two-to-three wheelers, off-highway vehicles, and aviation.
Source: McKinsey Battery Insights Demand Model

Ref: Mckinsey battery insights

COST OF BATTERY PACK



Ref: NREL

- Cost of battery pack (NMC)[-2] → 150 - 250 $/ kWh
- Cost of battery pack (LFP) is ~20% lower than that of NMC[-1]
- Ratio of cell cost to battery cost[-2] → 0.8
- Cost of battery energy storage system
  - **NMC based**
    - Tesla power wall* (13 kWh) [-3] → 650 $/ kWh
    - Varta (12 kWh) [-3] → 1135 $/ kWh
  - **LFP based**
    - LG ESS (9.6 kWh)[-3] → 883 $/ kWh
    - BYD B box (11 kWh)[-3] → 600 $/ kWh
  - Price varies based on the features (thermal management, inverters etc...) comes with the system.

[-1] https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/

[-2] Cost, energy and carbon footprint benefits of second life electric vehicle battery use

[-3] https://www.energiespeicher-online.shop/

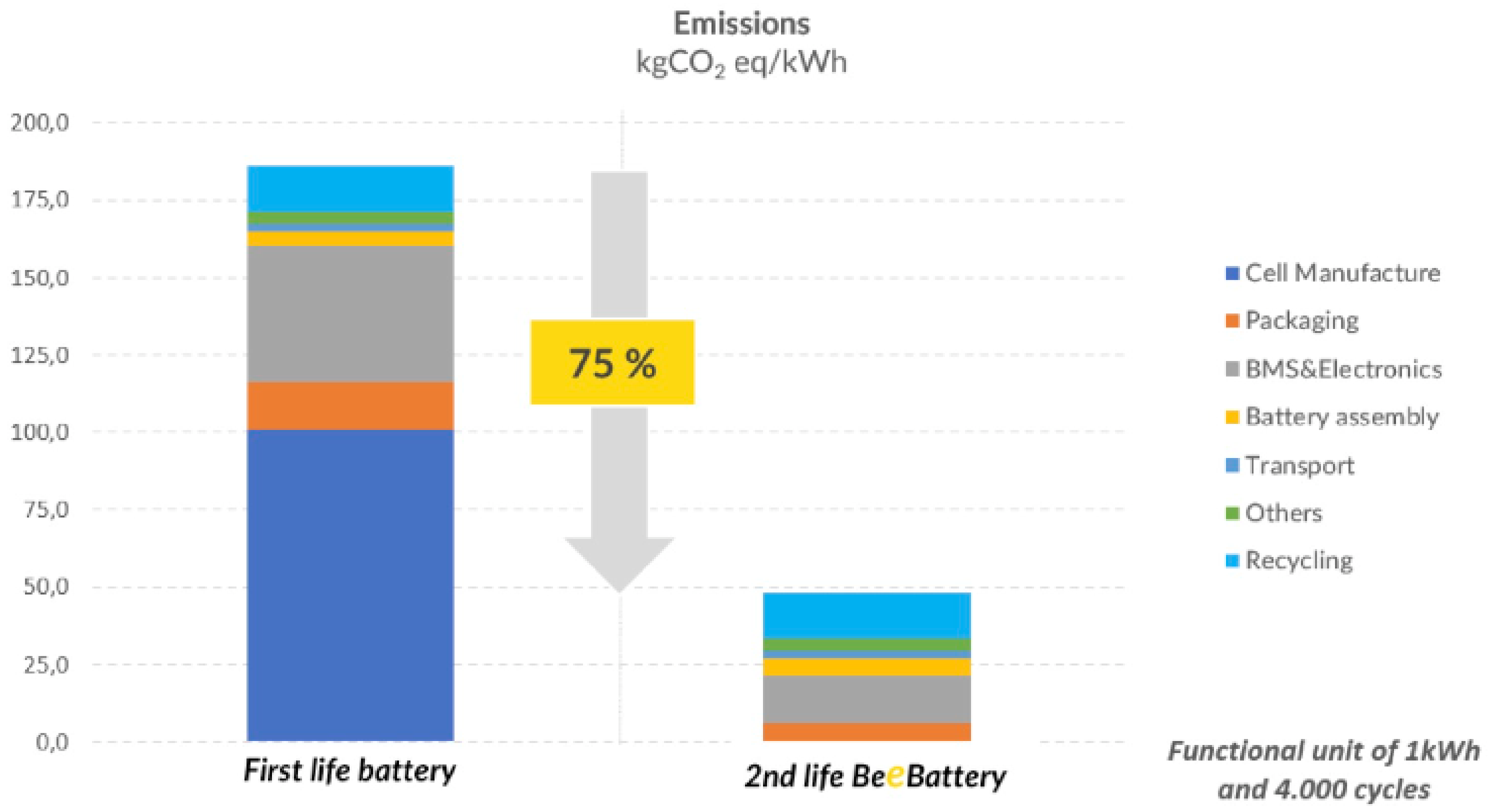
COST OF SECOND LIFE BATTERY[-2]

	Cost Range per kWh ($)	Average cost per kWh ($)
Cost of new battery pack	150 – 250[-2]	200
Value of retired battery pack	*19 – 131[-2]*	*75*
Cost of repurposing (collection, testing, refabrication etc..)	*25 – 49[-2]*	*37*
Cost of second life battery (NMC)	44 – 180[-2]	112
Cost of second life battery (LFP)	35 – 144	90
Cost of thermal management unit, inverters/converters etc…	200 – 400	300
Cost of second life battery energy system (NMC)	**244 - 580**	**412**
Cost of second life battery energy system (LFP)	**235 – 544**	**390**

Average cost of new battery energy storage system 10 kWh → 5000 $ (NMC) / 4000 $ (LFP)
Average cost of second life battery energy storage system 10 kWh → 4120 $ (NMC) / 3900 $ (LFP)

[-2] Cost, energy and carbon footprint benefits of second life electric vehicle battery use

CO_2e OF NEW AND SECOND LIFE BATTERY



Ref: https://beeplanetfactory.com/en/2021/01/06/second-life-and-emissions-reduction/

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SUMMARY

- Favourable cell chemistry for residential battery storage applications
    1. LFP
    2. NMC
- Ageing of the battery is a main technical challenge
    - To minimize calendric ageing
        - Store the battery at low temperature
        - Store the battery at low SOC
    - To minimize cyclic ageing
        - Operate at optimum temperature for given operation mode → Thermal management is important
        - Charge the battery at slow rate
        - Use of LFP is better than NMC
        - Match the PV and Battery size
- Cost of battery
    - Price is dropping every year
    - LFP is cheaper than NMC
    - Second life battery is almost half of the price of new battery at the given year
- Carbon footprint of second life battery is 75% lower than new battery

THANK YOU

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