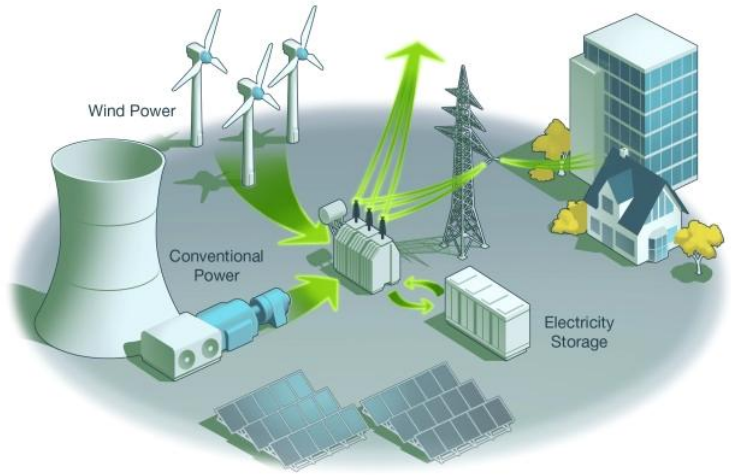

International Year of
CHEMISTRY
2011
BASF is a
Global Sponsor
Innovative materials for today‘s and future generations of batteries
Dr. Andreas Fischer
BASF SE
DPG AKE Herbstsitzung 2011, Bad Honnef, 21.10.2011
BASF
The Chemical Company

Overview

Batteries for Mobile Application

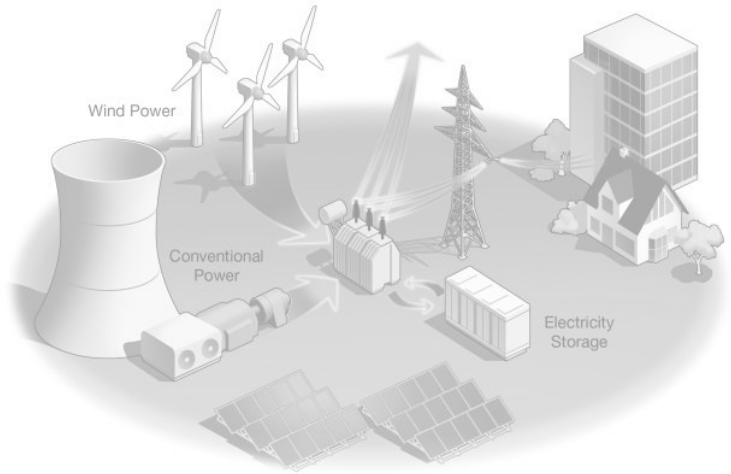
Batteries for Stationary Application



Overview

Batteries for Mobile Application

Batteries for Stationary Application



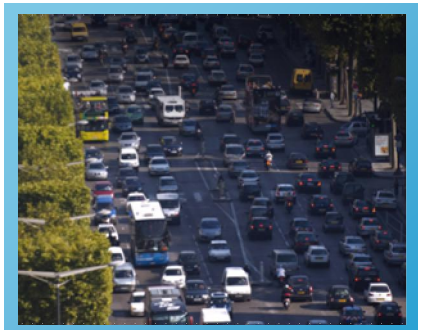
Global Challenges

… require new concepts

Growing population

Urbanization

Energy demand & climate protection



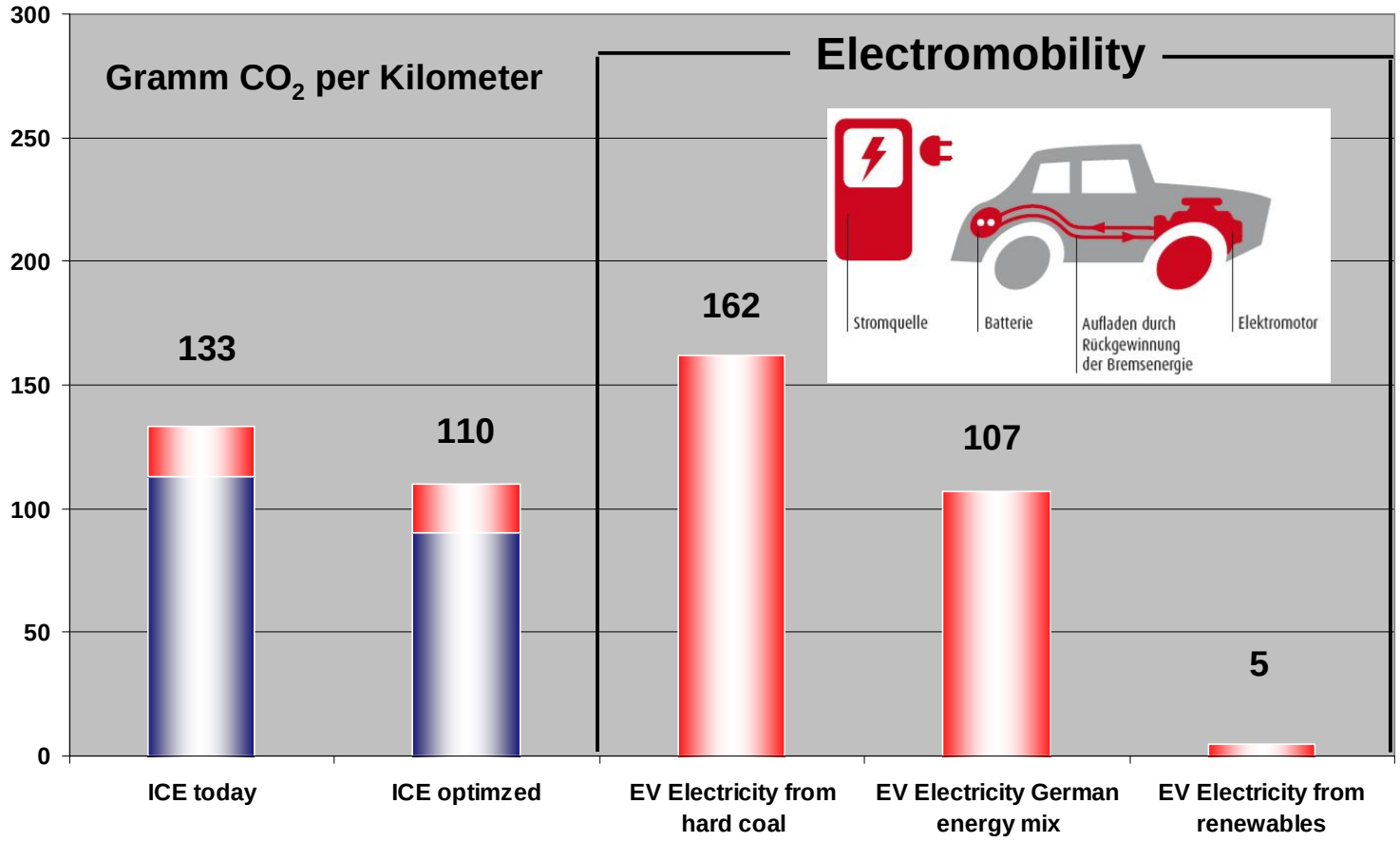
Globalization & Developing Markets

MEGATRENDS

New concepts for Mobility

- Energy efficient
- Low emission
- Affordable
- Suited for daily use

CO_2 emission by propulsion concept
Potentials for optimization



Assumption energy demand: 4,5 l/100 km ICE today, ICE optimized -20%, 18 kWh/100 km
Source: Studien UBA, Agentur für Erneuerbare Energien, BMU, IES, Stand: 9/2008.

The way to electromobility

Measures

Cheap renewable energy

- Development of efficient green technologies (wind, solar, etc.)
- Optimized grid integration

Smart and stable grids

- Grid expansion
- Grid management
- Low-loss transmission

Flexible energy storage

- New stationary storage systems (Batteries…)
- Utilization of car batteries for storage

Competitive Electric Vehicles

- Development of affordable high-performance battery technologies
- Energy efficient comfort elements and materials

Improved Battery Technology

Battery as key components in electric vehicles

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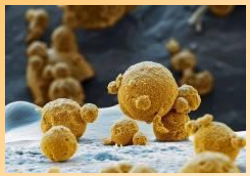
Materials	Components	Cells	Batteries	**Electric Car**
				

The battery determines characteristics of an electric vehicle
Range, Costs, Safety, …

The battery allows for differentiation and value creation
Challenging technology and chance for chemistry / engineering / OEMs

Materials are the heart of the battery cell
Chemistry plays a central role as materials supplier

Improved Battery Technology
Contributions of BASF

Goals: higher energy density, safety, and life time at lower costs

APPROACHES

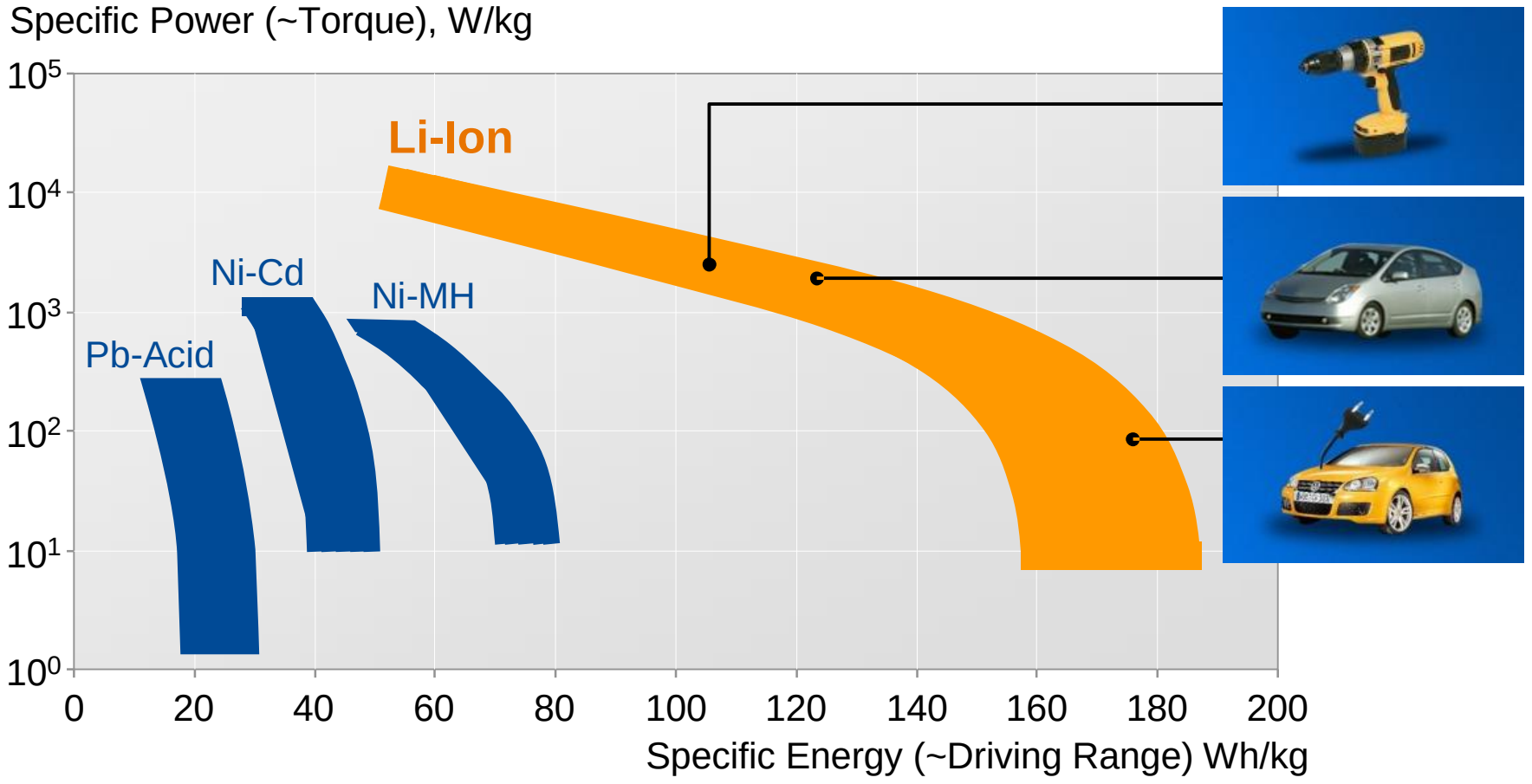
- Improved materials for components and cells
- Continued improvement of the Li-ion technology and development of new battery concepts

ONGOING ACTIVITIES

- International Research Network with renowned scientists and comprehensive industry consortia
- Building a production plant for cathode materials
- Work on new generations of cell chemistry

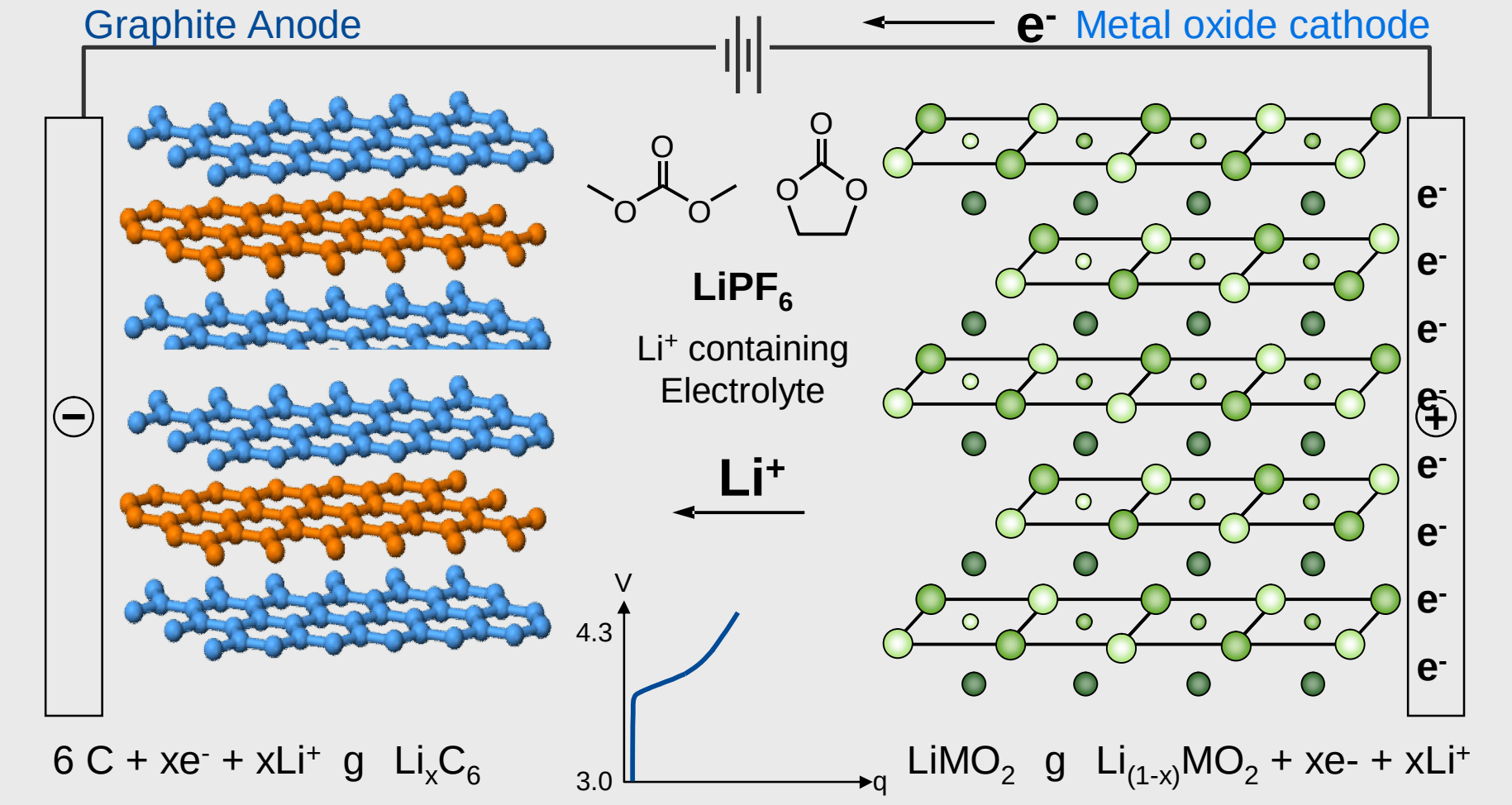
Comparing different battery technologies

Power versus energy



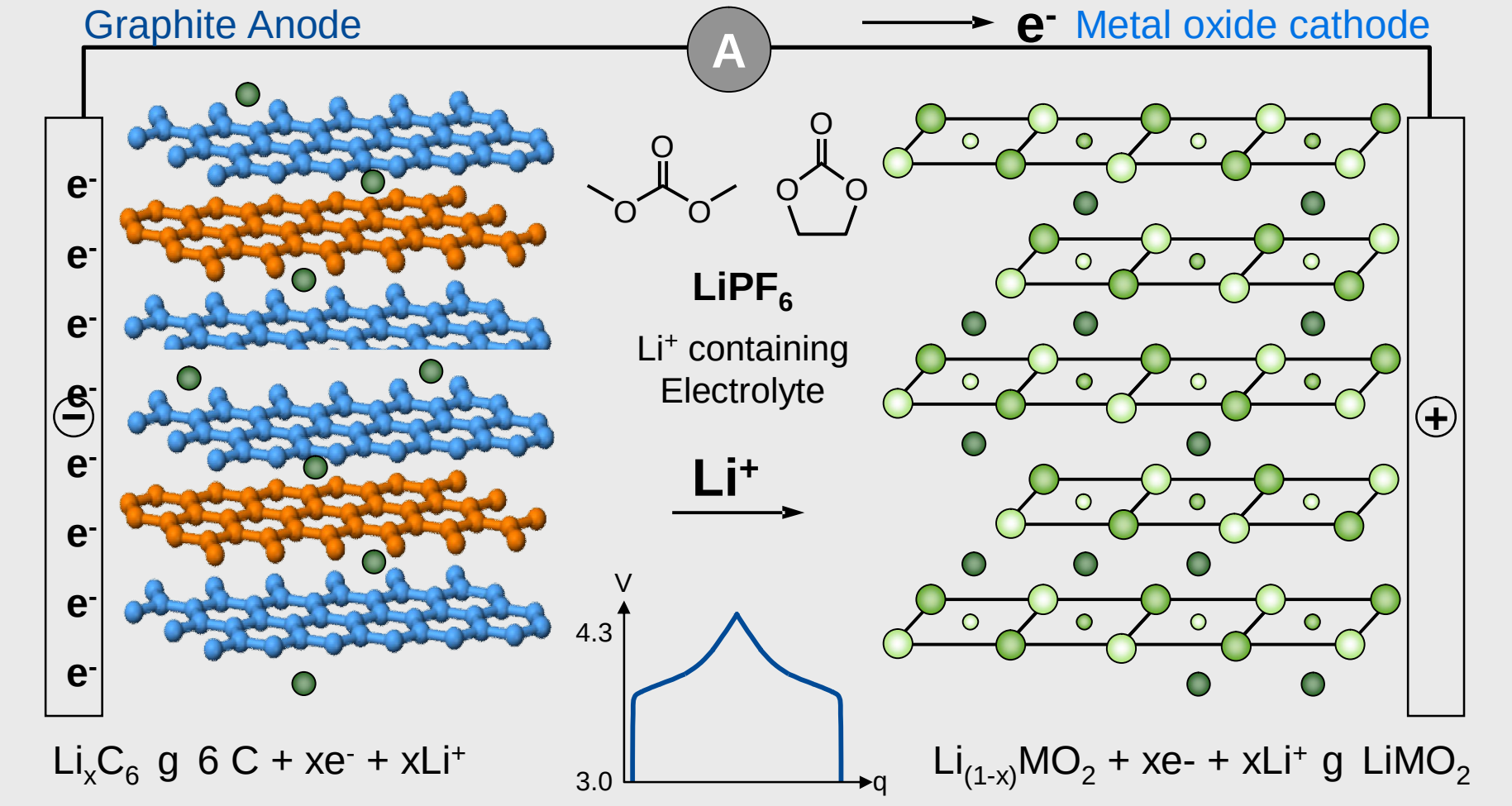
Lithium ion batteries

Working principle charging



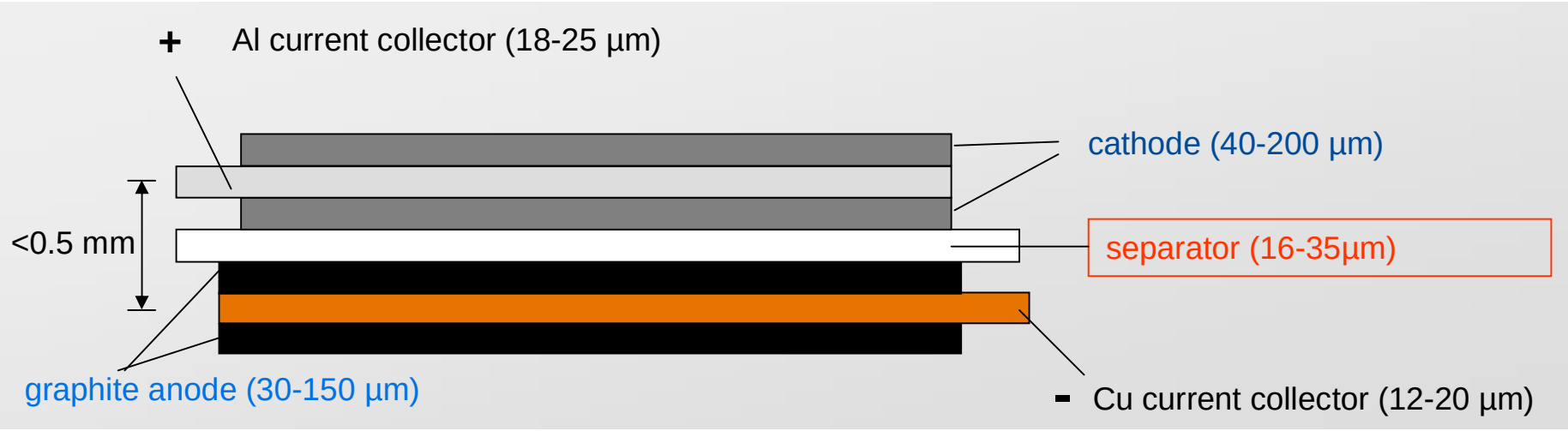
Lithium ion batteries

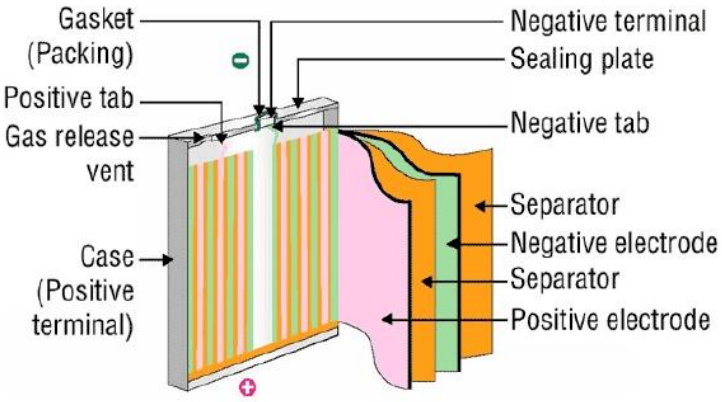
Working principle discharging



Lithium ion batteries

Cross section and schematic set up

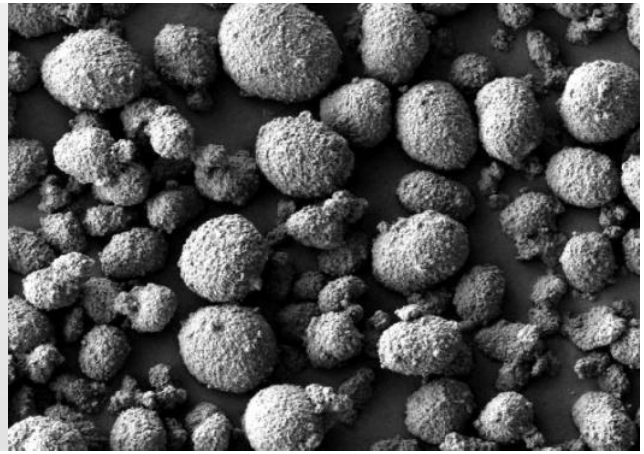


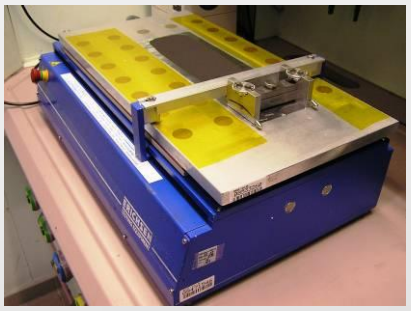


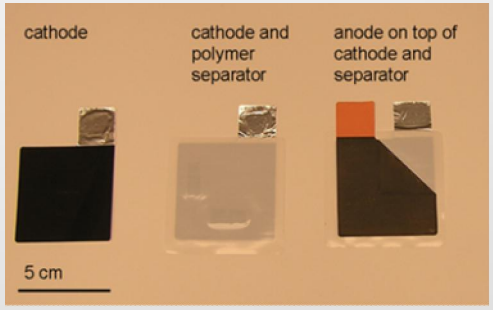
From raw material to lithium ion batteries

Preparation steps

- Synthesis of cathode material
- Preparation of slurry
- Electrode coating
- Calendering
- Pouch cell preparation
- Electrochemical characterization



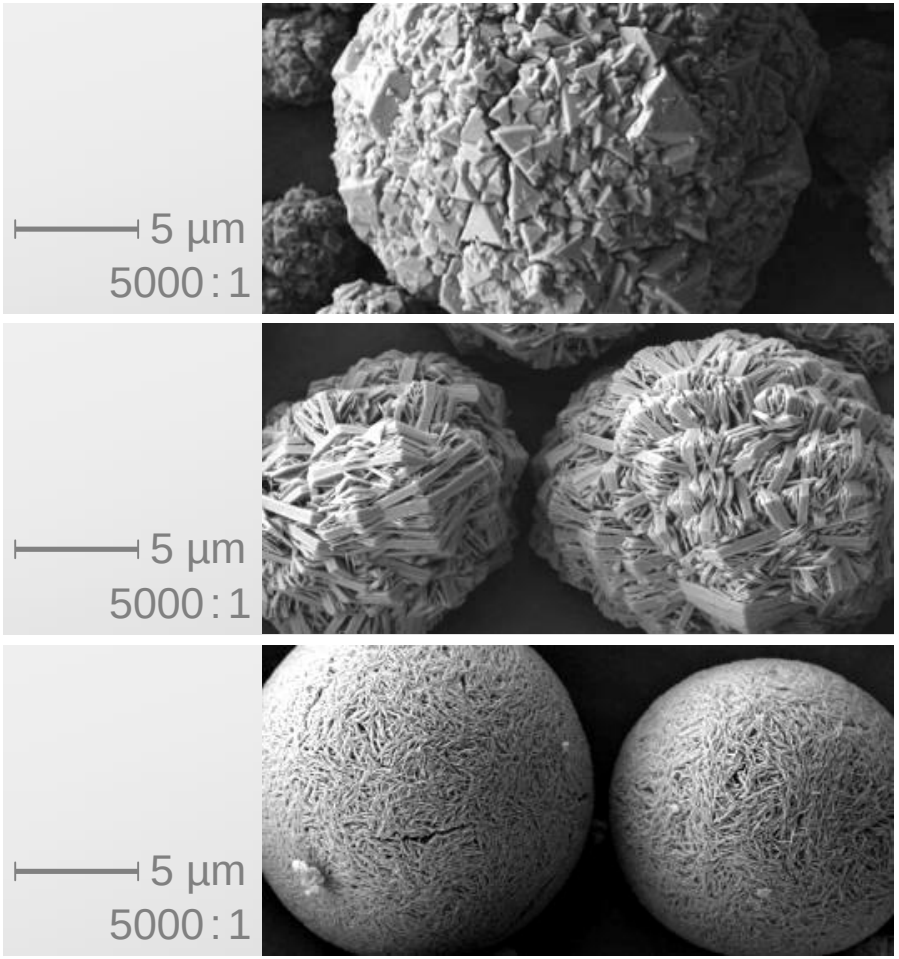




Lithium ion batteries

Cathode materials roadmap

- BASF has licensed a broad NCM $Li_{1+x}(NiCoMn)_{1-x}O_2$ patent portfolio from ANL.
- Standard NCM-111 will become first BASF product, standard voltage NCM-xyz will follow.
- High-Energy HE-NCM and High-Voltage HV-spinel materials as well as Li iron phosphates LFP are in the pipeline.

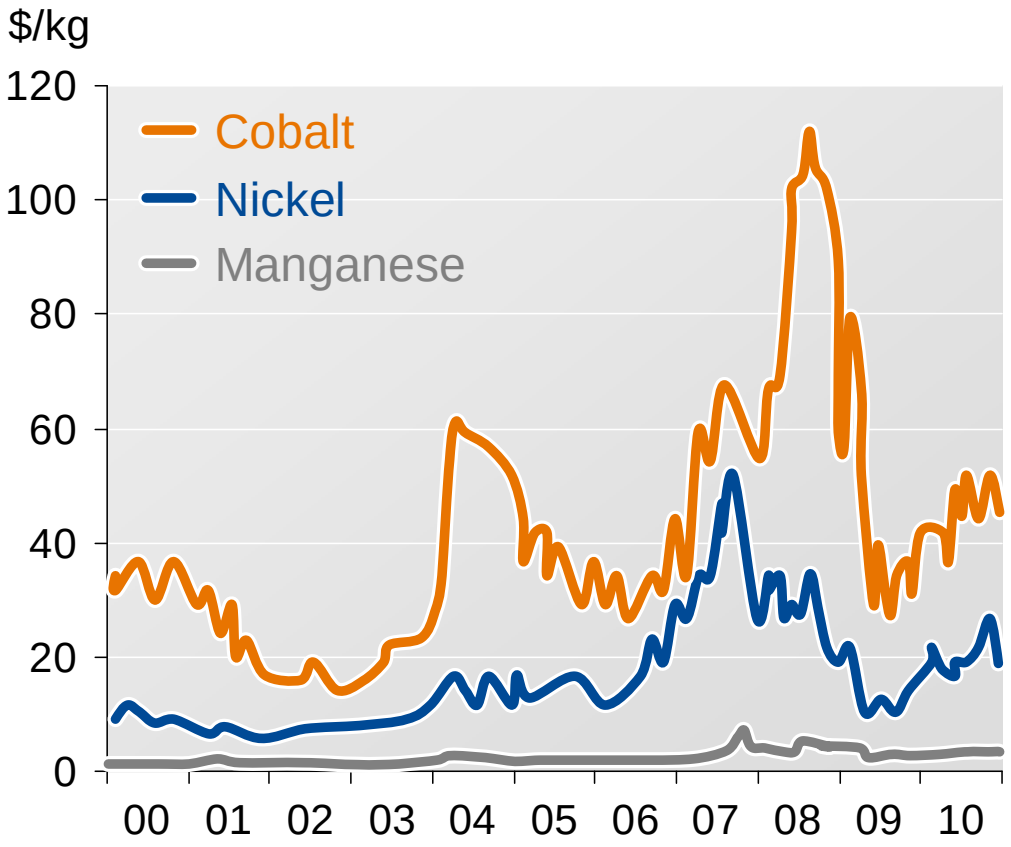


Metal Prices

Historic Development

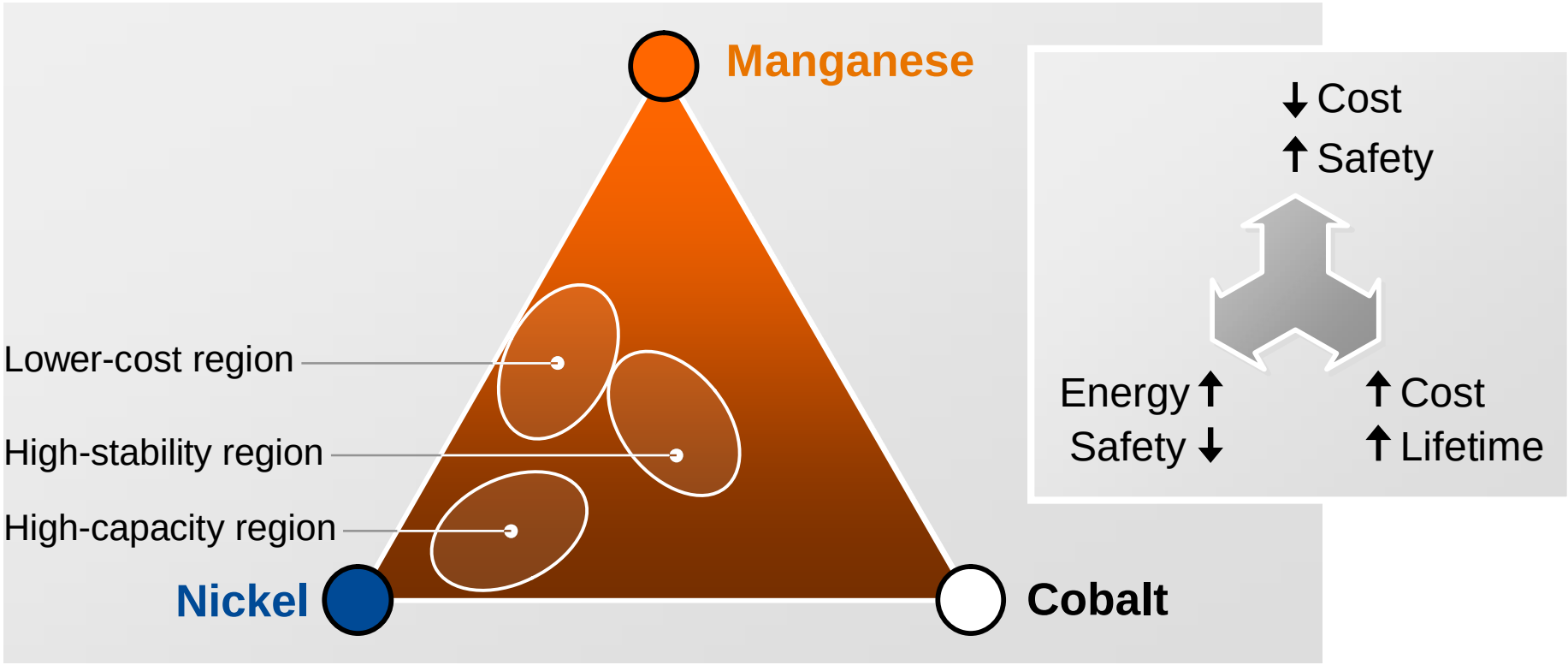
Key Facts

- Metal prices dominate cathode cost
- Cobalt content drives total metal cost
- Metal prices are heavily fluctuating



Chemical Composition

NCM Cathodes – Commercially Relevant Areas

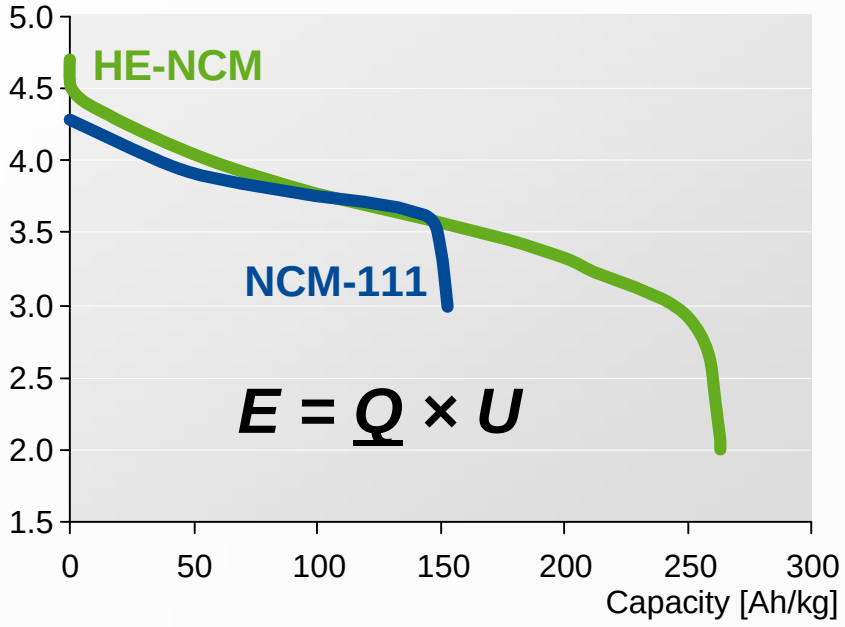


Lithium ion batteries

Cathode materials with higher energy density

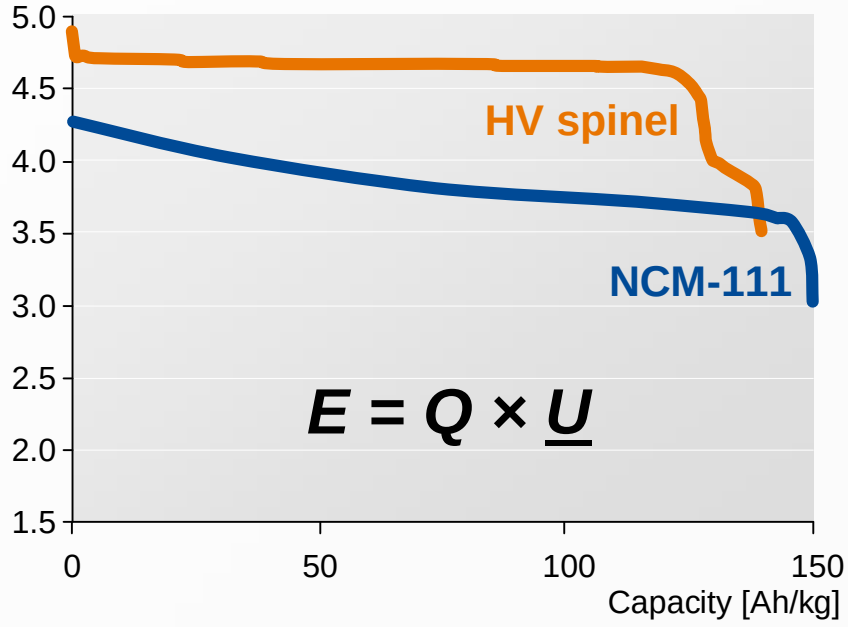
Marked capacity increase at slightly lower voltage **“High Energy”**

Discharge profiles
BASF HE-NCM vs. BASF NCM-111



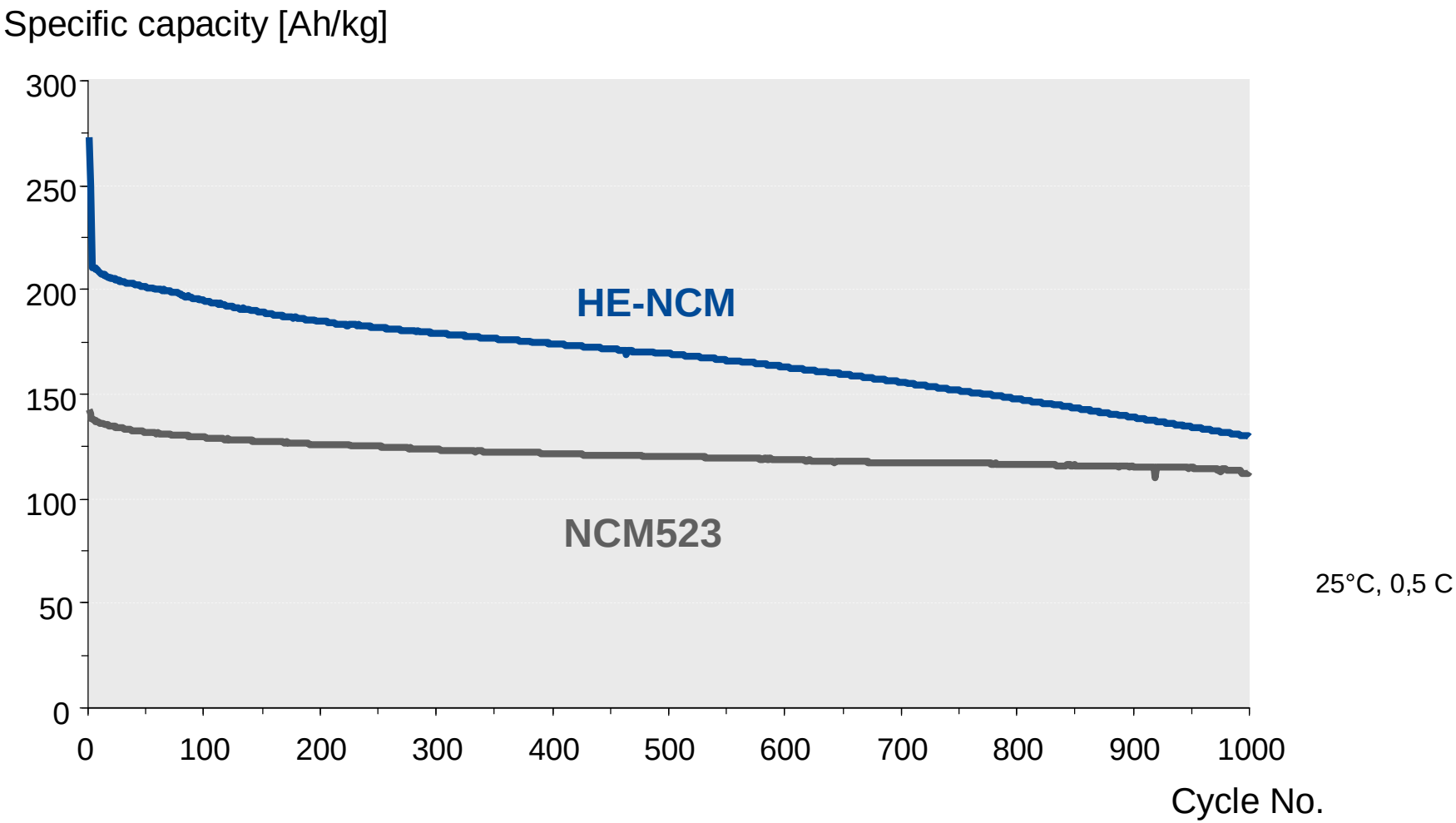
Marked voltage increase at slightly lower capacity **“High Voltage”**

Discharge profiles
BASF HV spinel vs. BASF NCM-111



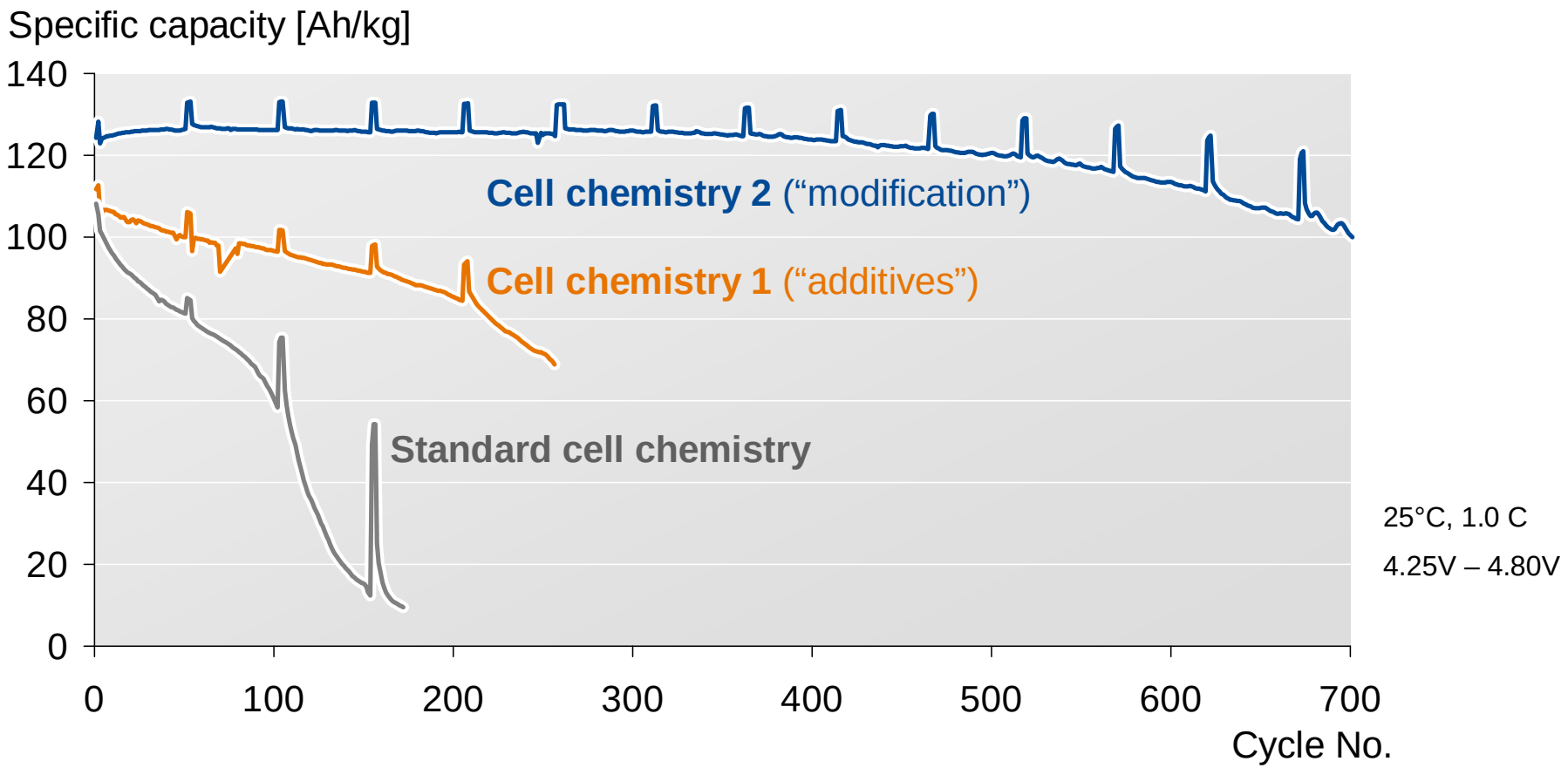
BASF's HED™ HE-NCM *vs.* graphite

Cycling stability in Swagelok cells



BASF's HED™ HV-spinel *vs.* graphite

Cycling stability in pouch cells



Requirements for next generation electrolytes

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Performance

- Improved energy and power density
- Conductivity / Rate capability
- Higher voltage window
- Low temperature behavior

Long-term stability

- Cycle life
- Self discharge

Safety

- Flammability
- Overcharge protection
- Thermal runaway

Unfortunately improving one characteristic often leads to worsening another

Lithium ion batteries

Cathode material and electrolyte from BASF used

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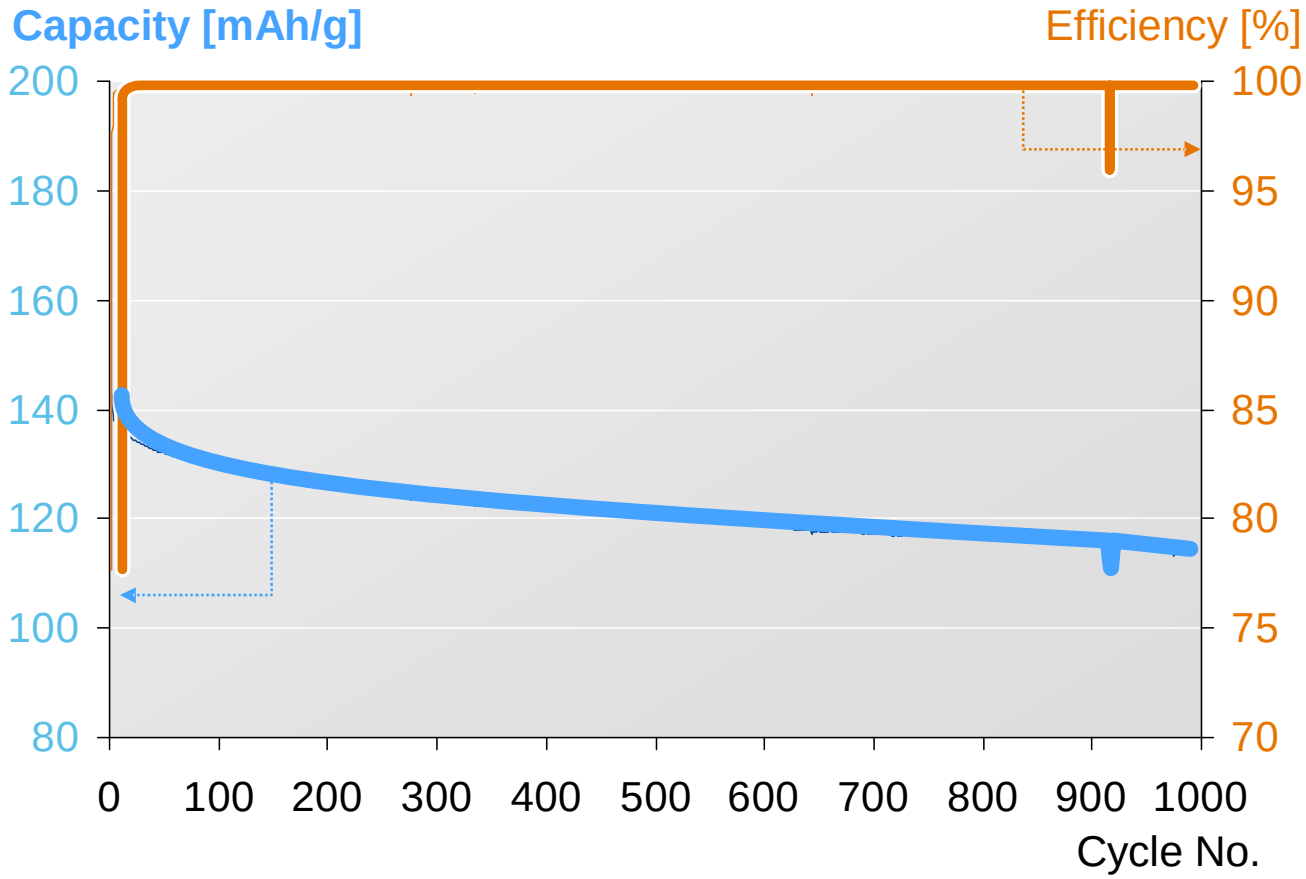
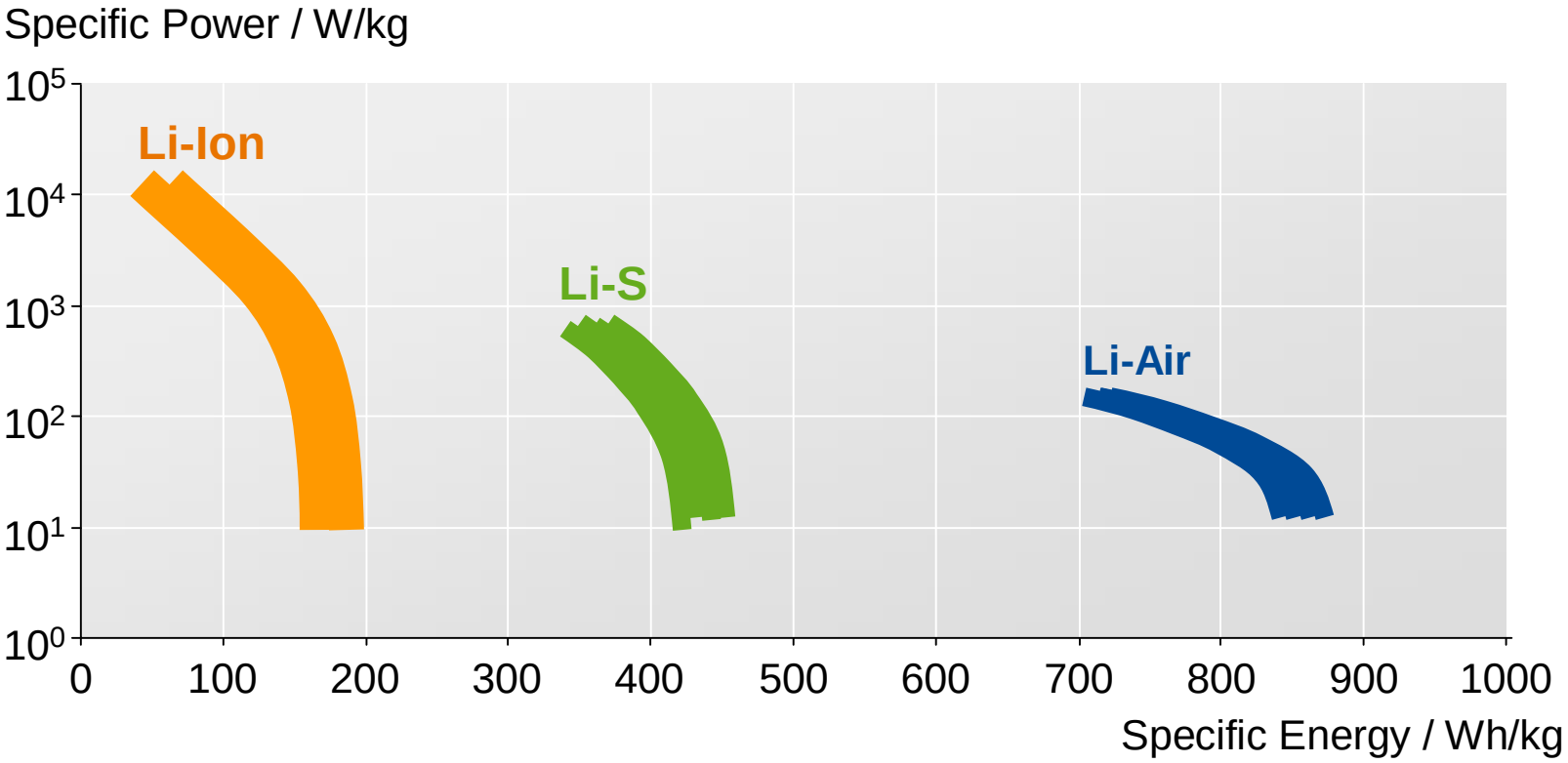
High cycle stability successfully demonstrated



Cell type:	Pouch cell
Cathode:	**NCM523 (BASF)**
Anode:	Graphite
Electrolyte:	**Carbonates (BASF)**
Charge:	4.2V, CCCV, 0.5C
Discharge:	3.2V, CC, 0.5C
Formation:	0.1C at 1st & 2nd Cycle
Temperature:	Room temperature

From Li-Ion to Li/S and Li/Air:

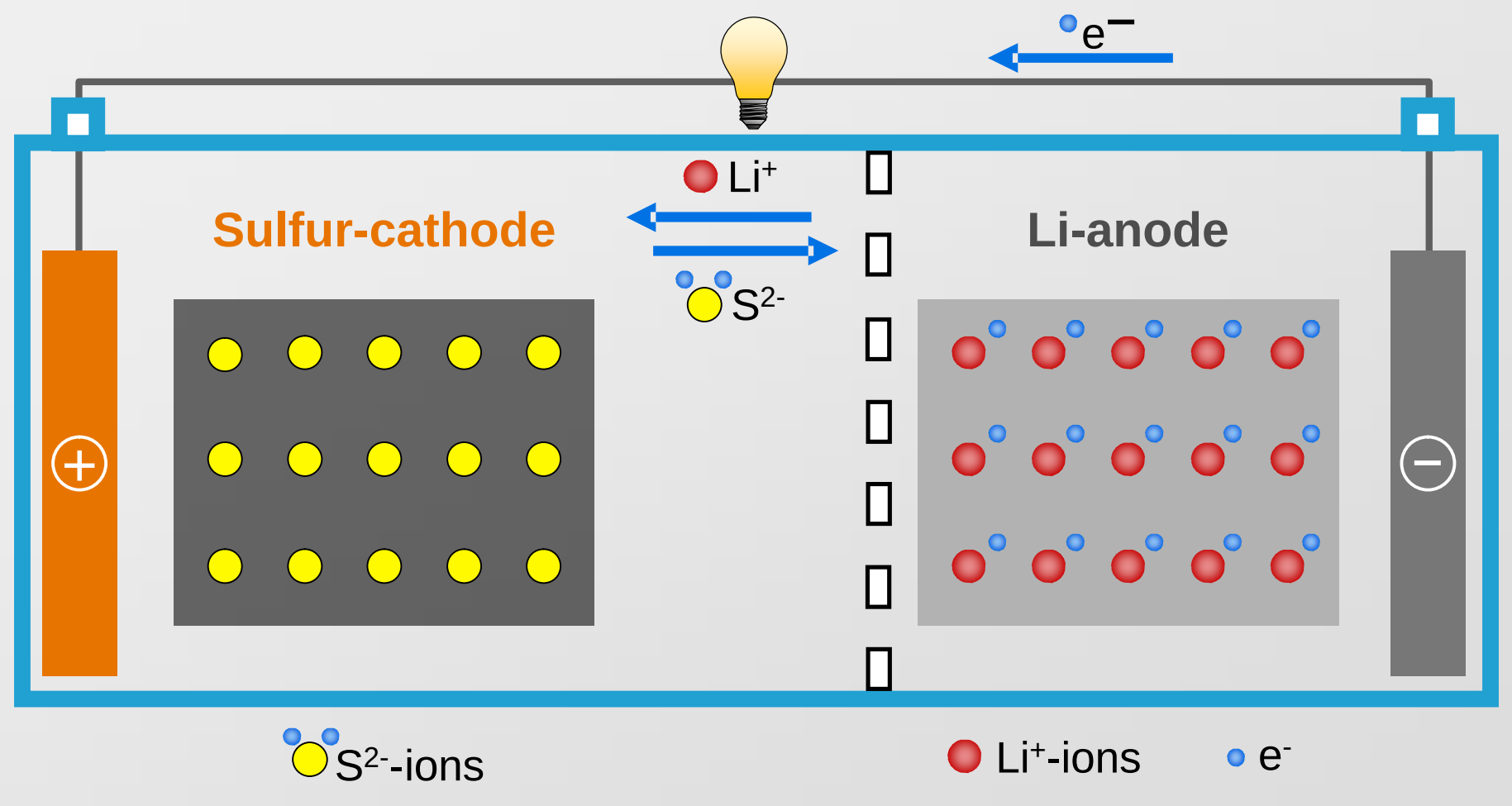
The next Generation of Batteries



BASF battery research focuses on advanced Li-Ion and “next Generation” systems

Lithium/Sulfur batteries

Working principle – Discharge



Lithium/Sulfur batteries

Advantages and Challenges

Advantages

- High gravimetric **energy density**
- **Low cost** and abundant raw materials
- Operability at **low temperatures**

Challenges

- **Cycle life** yet too low
- **Self discharge** yet too high
- **Safety** must be guaranteed
- Fast **charging capabilities** are essential

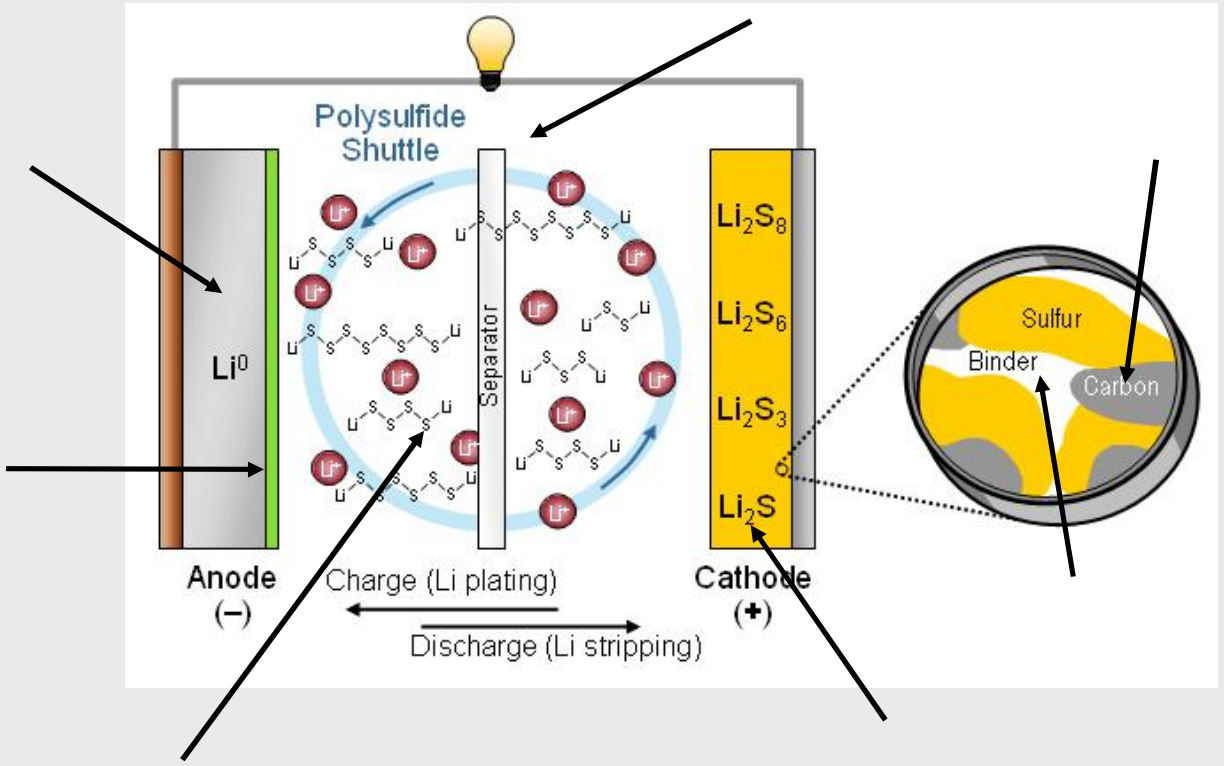
High potential
but challenges to be solved

Lithium/Sulfur batteries

Joint Development with Sion Power Corporation

- Sion Power is a global leader in the development of a new generation of high-energy, rechargeable lithium sulfur batteries and is located in Tuscon, Arizona.
- In 2009 BASF and Sion Power agreed on a joint development program on Li/S battery materials
- The collaboration targets the development of materials to improve Li/S batteries' life and energy density

Field of work

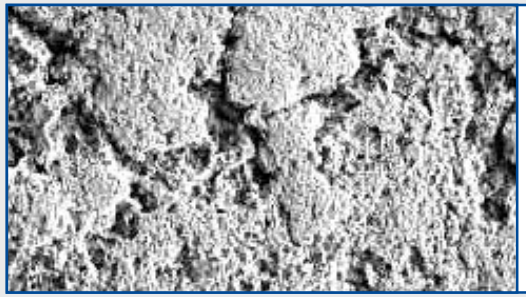


u ***Several parts and components need further optimization and improvement***

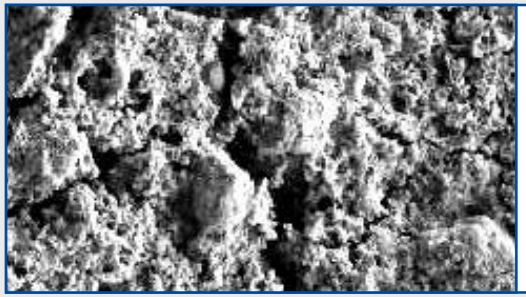
Lithium/Sulfur batteries

Cathode development

Evaluation of special cathode preparation techniques as spraying, doctor blading, screen printing



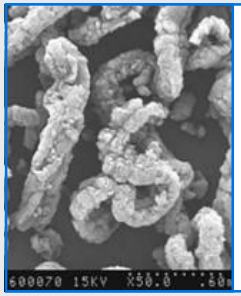
Smoother sprayed **BASF** cathode



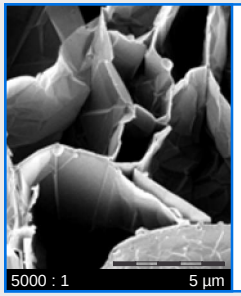
Mud cracks on **standard** cathode

New cathode additives (e.g. expanded graphites, graphenes)

Graphite



Expanded Graphite



"Micropockets" for sulfur uptake

u ***Improved sulfur utilization and structural stability***

Lithium/Sulfur batteries

Cathode development

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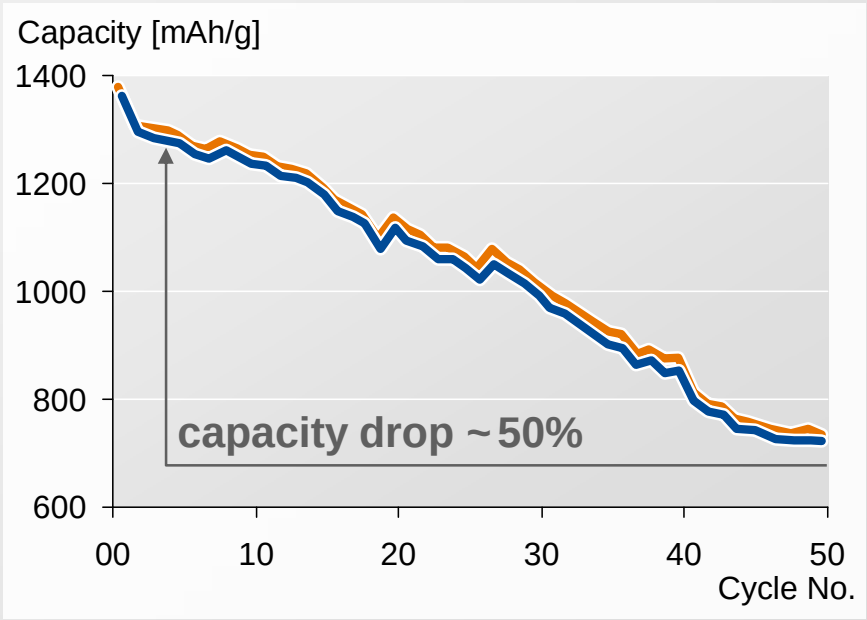
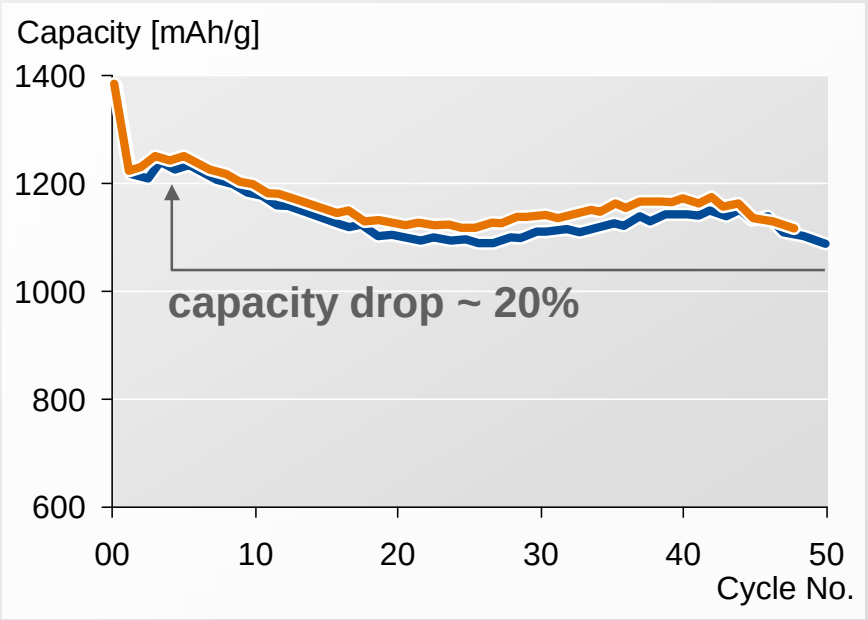
State of the art Li/S battery
with **PTFE** binder



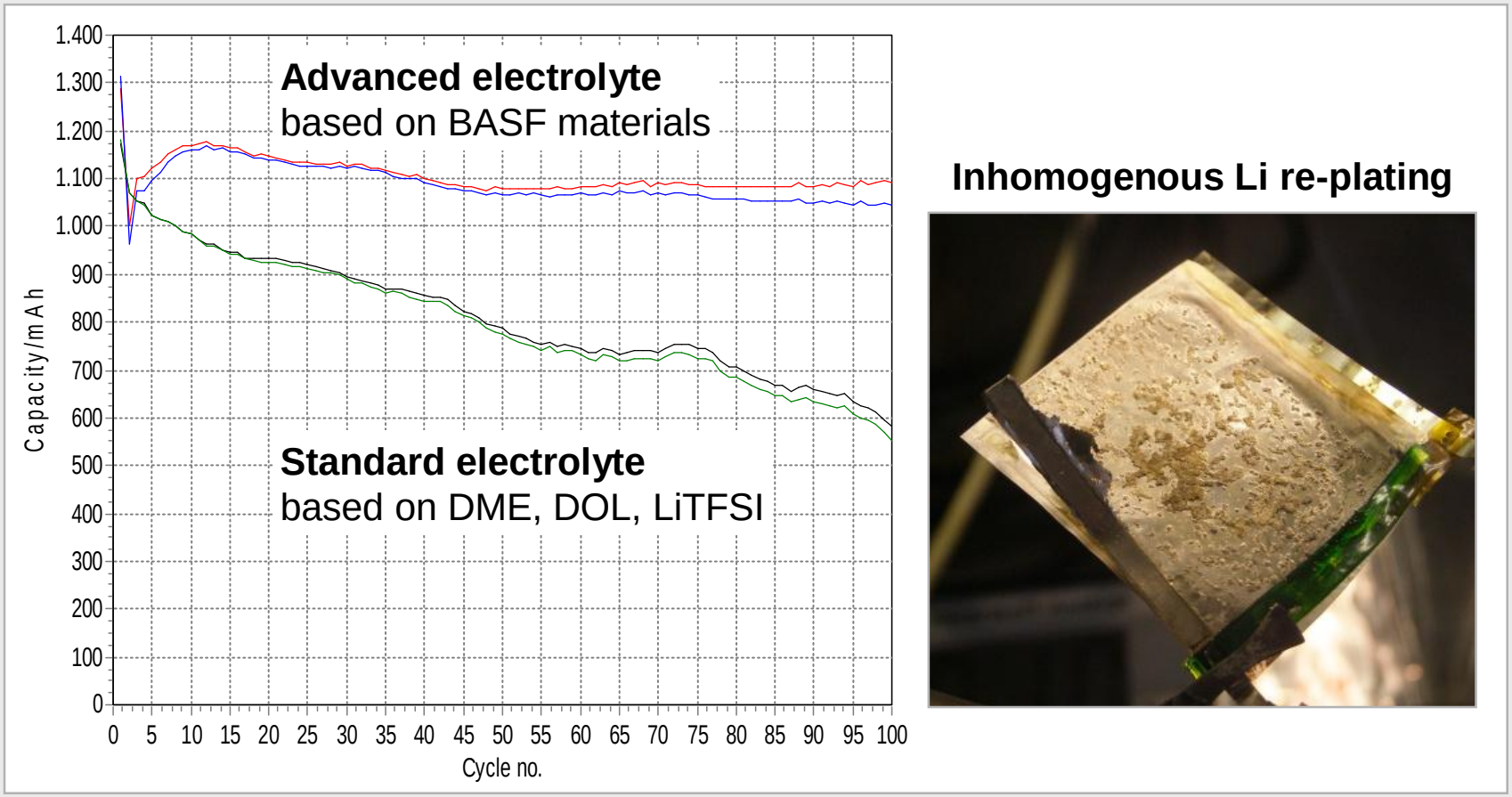
Li/S batteries
with **advanced** BASF binder



Higher structural stability results in better cycle life

Lithium/Sulfur batteries

Electrolyte development



Inhomogenous Li re-plating

u ***New electrolytes and additives for improved Li re-plating***

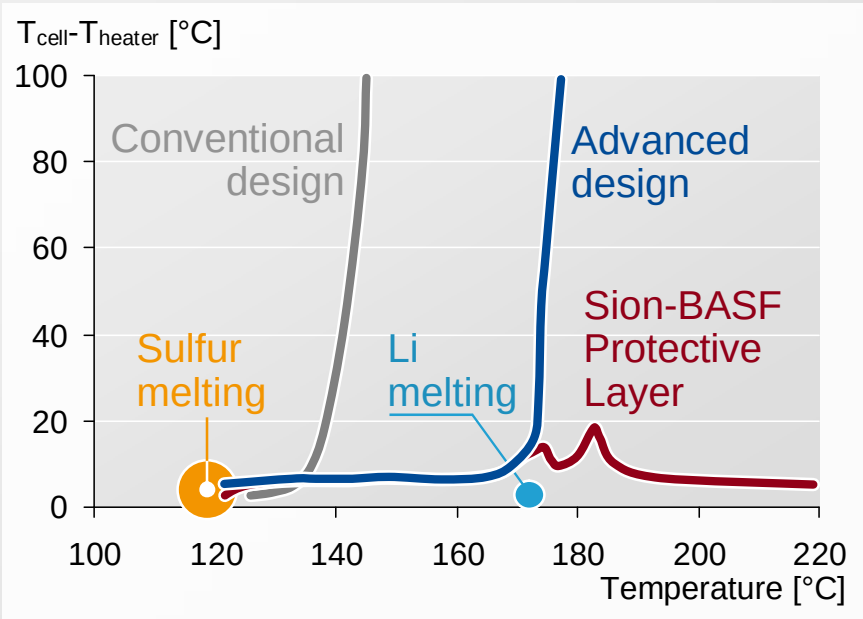
Lithium/Sulfur batteries

Safety

Safety issues

- At 180 °C
  lithium and sulfur are liquid
  g fast reaction
- Special protection needed

Li/S batteries
with BASF polymer layer



BASF protective polymer layer enhances safety of Li/S cells

Energy efficient comfort elements and materials

Examples

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The Chemical Company

Special requirements in EVs because of limited energy availability

1 **Light weight construction**
e.g. fibre-reinforced composites

2 **Heat management**
reflecting paints/shields,
high performance insulating materials

3 **Energy by sun light**
Organic Photovoltaics

4 **New lighting systems**
LEDs

5 **Innovative cooling systems**
Magneto caloric

Energy efficient comfort elements and materials – light weight construction

Contributions of BASF

BASF
The Chemical Company

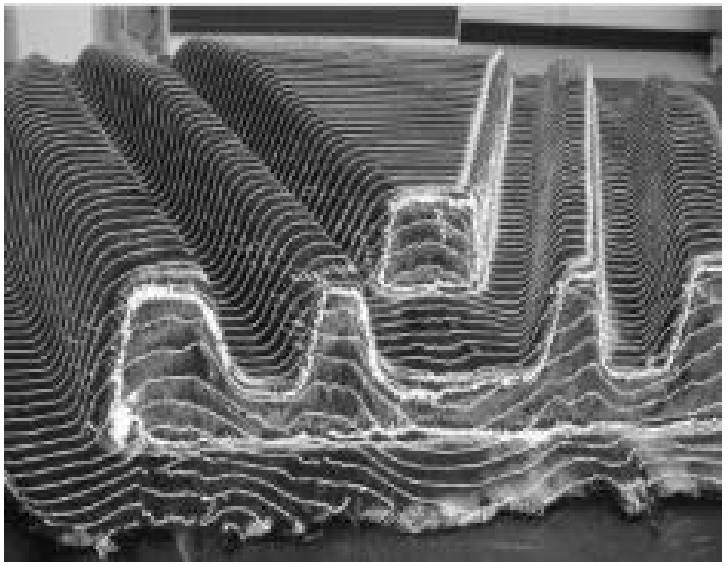
Goals: Energy saving and increased range

APPROACHES

- Use of polymer based light weight materials
  Saving potential of 150 kg per car
- Use in several construction elements
  largest impact in load bearing elements like chassis

ONGOING ACTIVITIES

- Evaluation of new material concepts and technologies
  Sandwichstructures, fibre-reinforced composites…
- Use of high-performance polymers
  Polyamides, Polyurethanes…



Energy efficient comfort elements and materials – heat management

Contributions of BASF

BASF
The Chemical Company

Goals: Energy saving and increased comfort

APPROACHES

- New heat relecting pigments
  for shields, paints and interior
- Use of high performance insulating materials
  Isolation of cabin and engine compartment

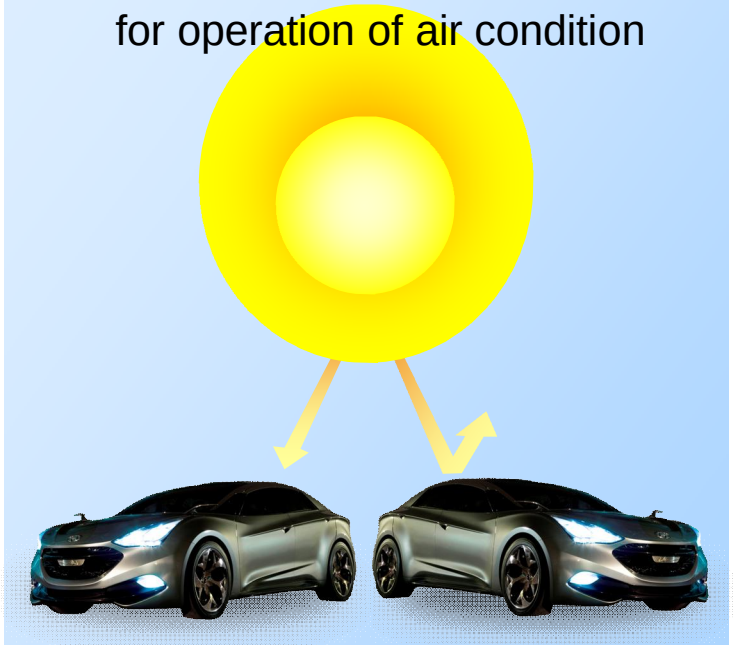
ONGOING ACTIVITIES

- Intense research and development
  on innovative pigments and new insulating materials
- Insulating materials
  Polymer foams

EVs today

up to 35% of energy demand

for operation of air condition



In-cabin temperature

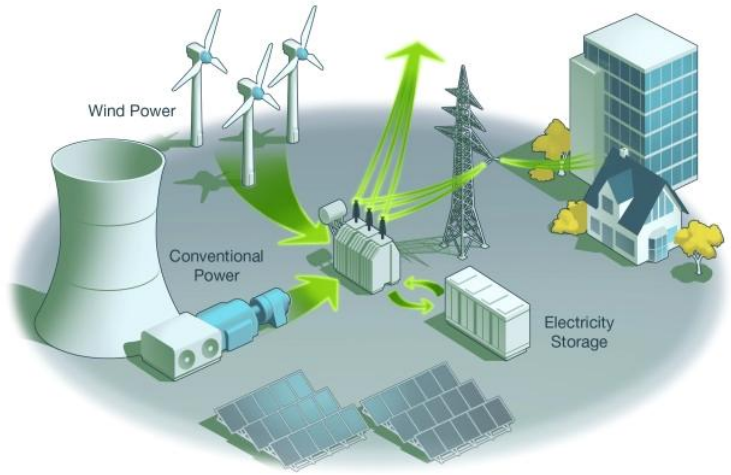
today
up to 60 °C

in the future
20-30 °C

Overview

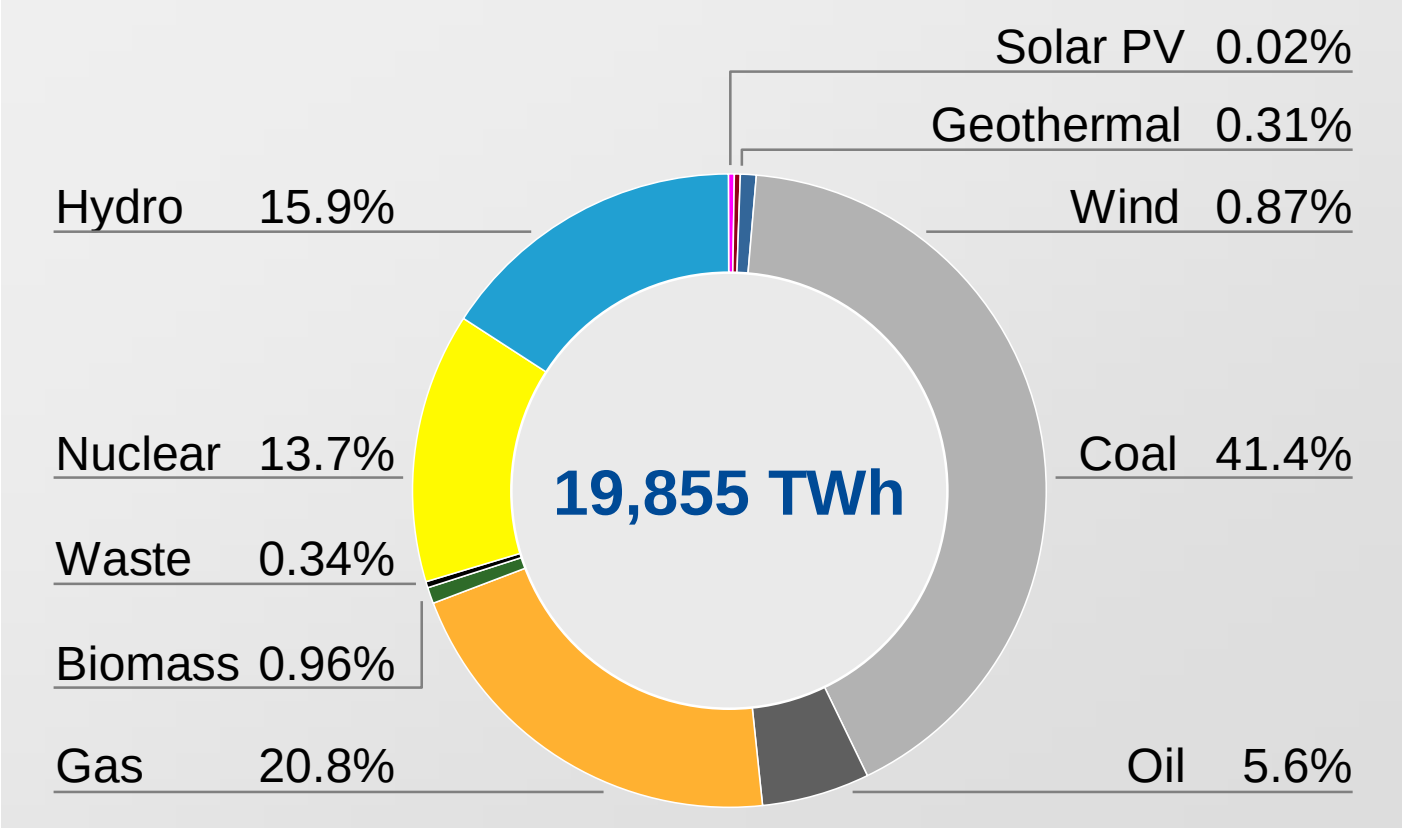
Batteries for Mobile Application

Batteries for Stationary Application



Energy Production

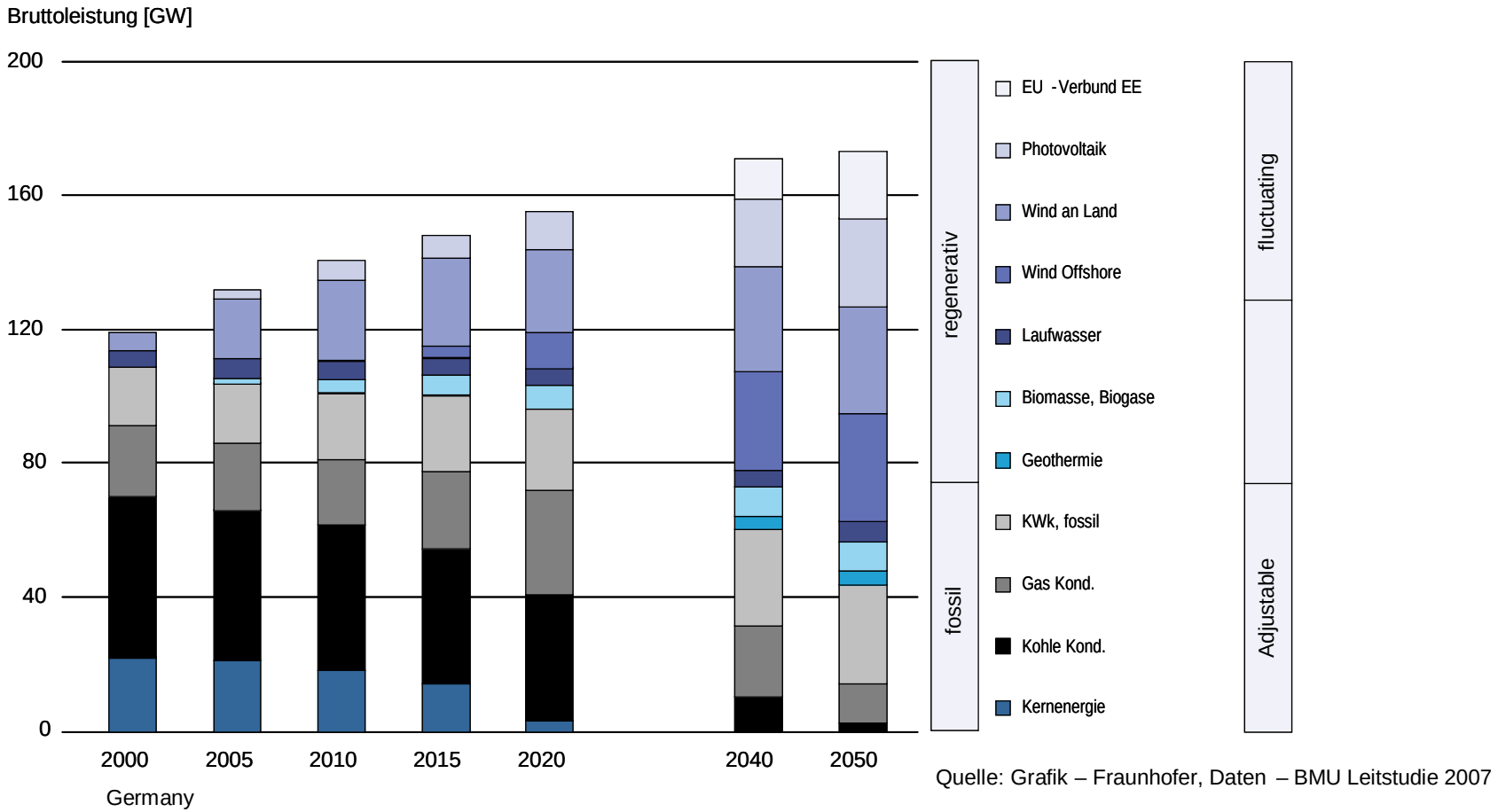
Worldwide Energy Mix 2007



Source: IEA Energie Statistics

Energy production
Changing the energy mix

Today: 1 / 6 fluctuating / adjustable
Year 2050: 2 / 1 fluctuating / adjustable

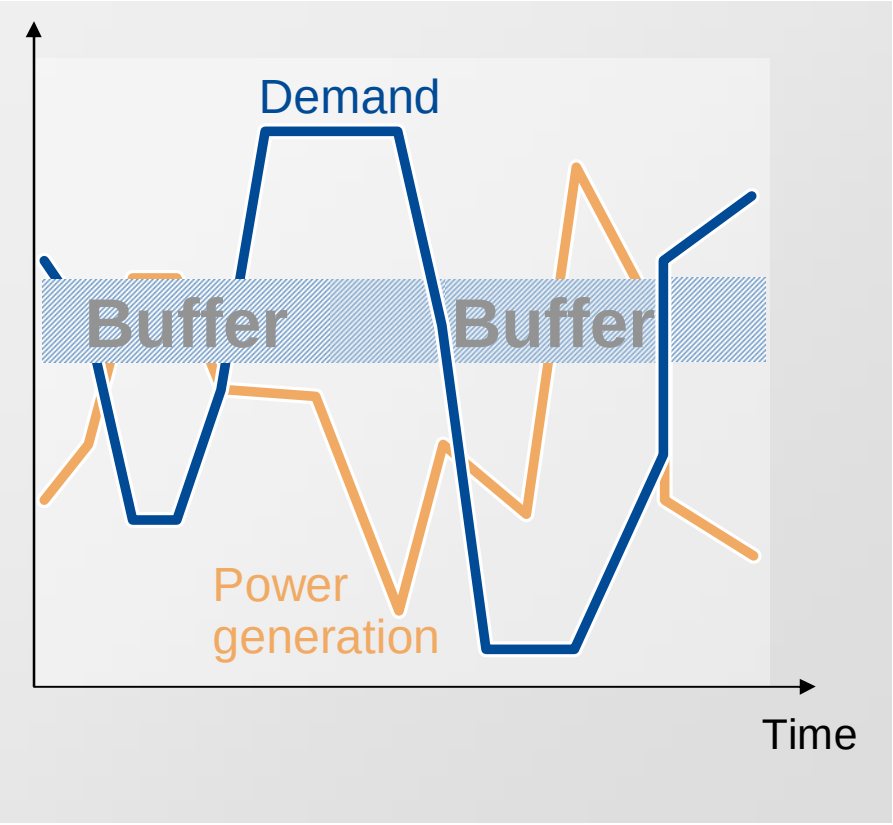


Quelle: Grafik – Fraunhofer, Daten – BMU Leitstudie 2007

Energy production

Renewables need storage

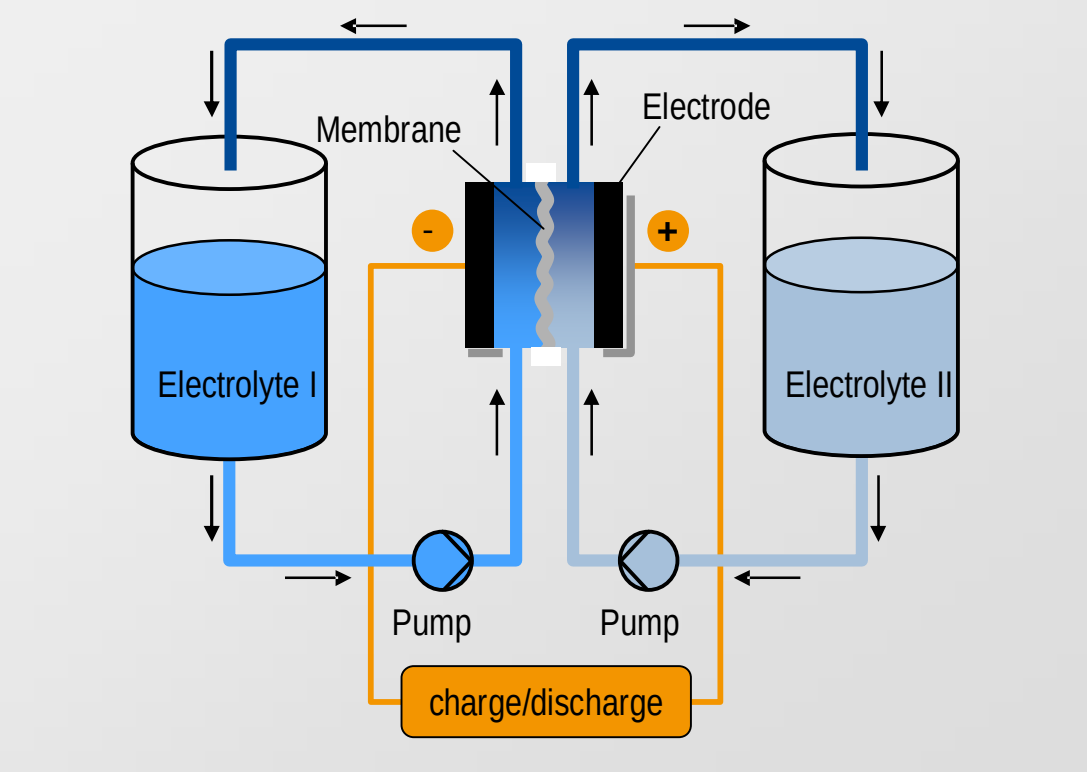
Wind and solar are fluctuating and so does the energy harvest.
Consumption is fluctuating as well but not accordingly.



What are alternatives to buffers:

- Gas peaker plants as back-up
- Grid expansion and distribution
- Steering demand by smart metering

Redox-Flow Battery



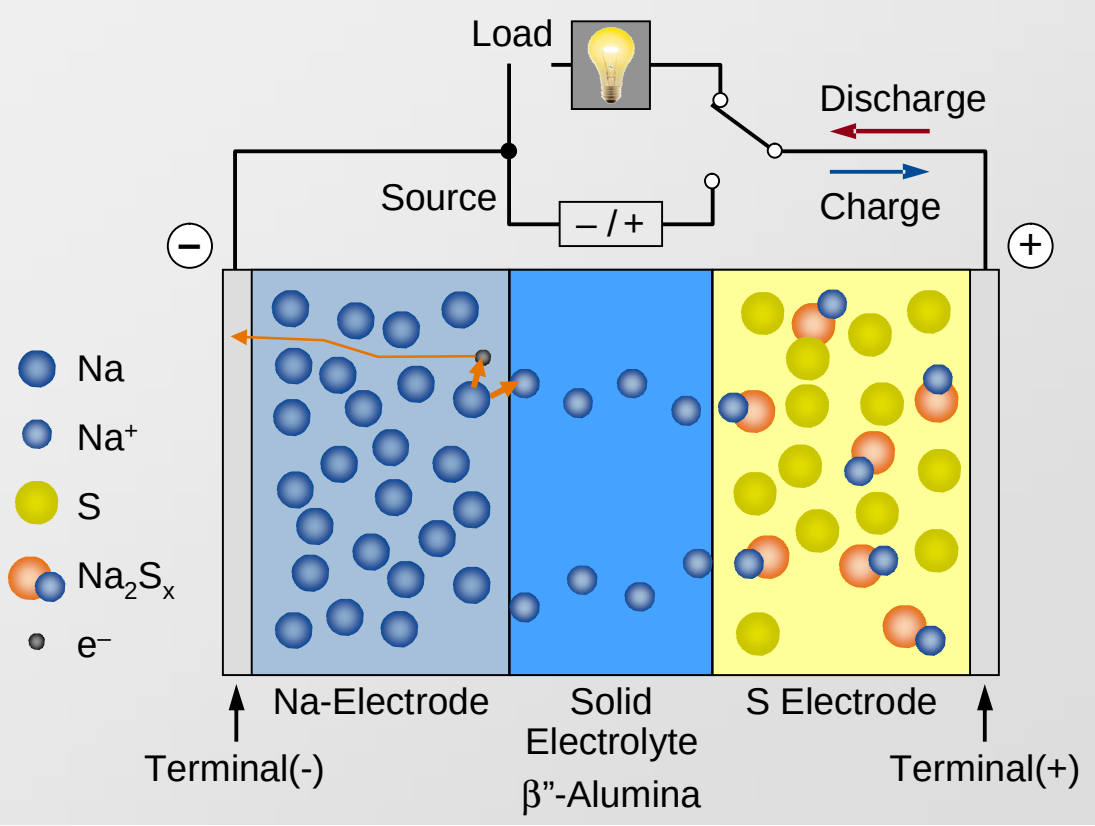
$$VO^{2+} + H_2O \; D \; VO_2^{+} + 2H^{+} + e^{-}$$

$$V^{3+} + e^{-} \; D \; V^{2+}$$

1.3 Volt
3.02 kg V / kWh

Source: Prof. Dr. Dirk Uwe Sauer RWTH Aachen

Sodium-Sulfur Battery



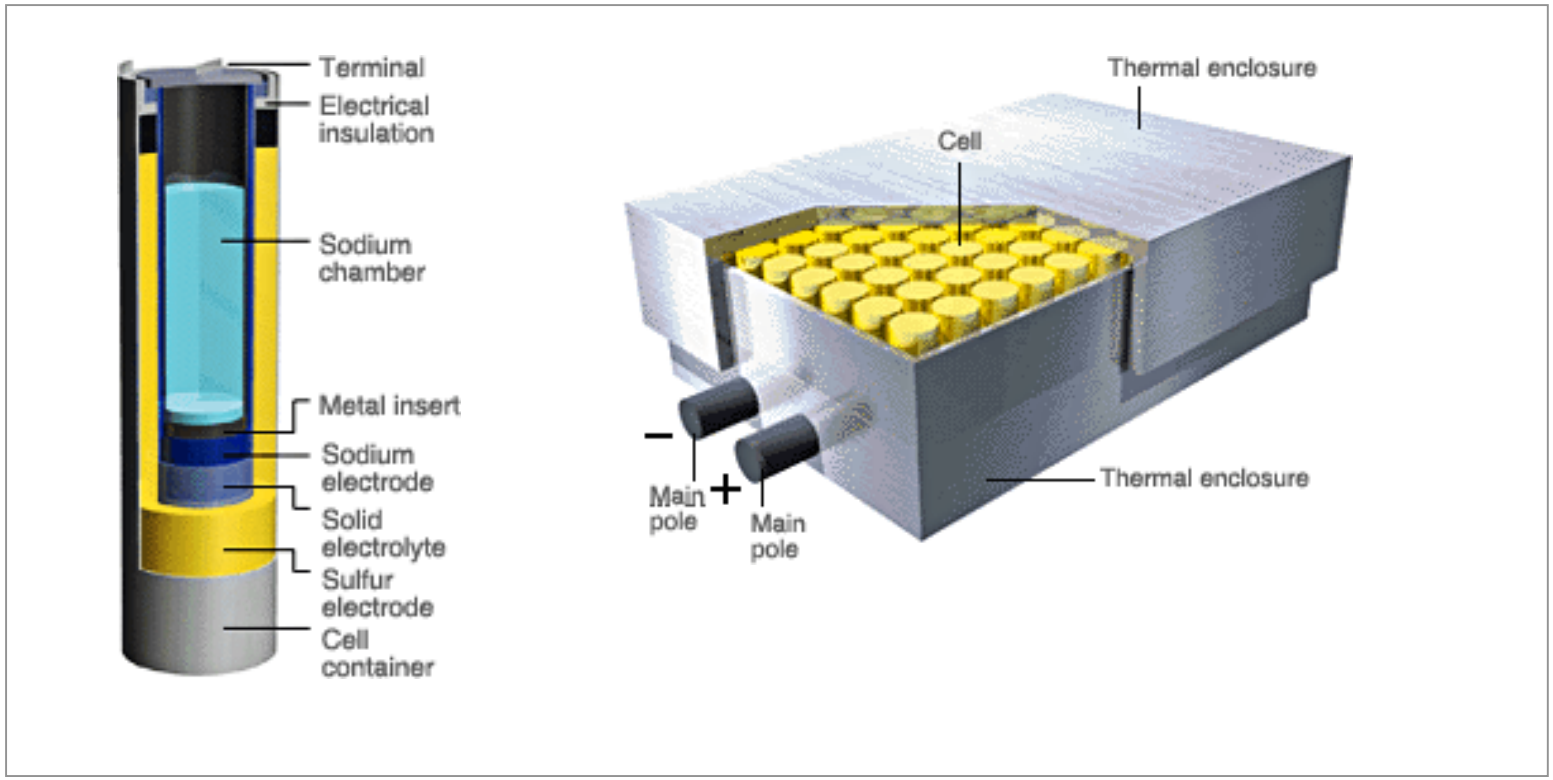
$2Na \; D \; 2Na^+ + 2e^-$

$2Na^+ + xS + 2e^- \; D \; Na_2S_x$

2.06 Volt
0.417 kg Na / kWh

Source: NGK Insulators Ltd.

Sodium-Sulfur Battery



High temperature battery:
2.1 V @ 300 °C, ~ 100 Wh/kg

Source: NGK

Scientific Network on Batteries

Joining forces with academia

Task academic partners in the network

- Fundamental evaluation of system and components
- Development of a mechanistic understanding of the interaction of components and materials
- Syntheses of materials
- Specific analytics for batteries

Task BASF in the network

- Coordination of all work-packages in the network
- Extending the network into BASF
- Benchmarking
- Adoption of respective materials to the system
- Extensive testing options for cells and components
- Scale-up

Scientific Network on Batteries

Partner

- Prof. Jürgen **Janek**, *University of Gießen, GER*
- Prof. Hubert **Gasteiger**, *Technical University of Munich, GER*
- Prof. Petr **Novák**, *PSI Villigen, CH*
- Prof. Doron **Aurbach**, *Bar-Ilan University, ISR*
- Prof. Brett **Lucht**, *University of Rhode Island, USA*

- Further partners
  about to be identified

Joint Lab BASF / KIT

Batteries and Electrochemistry Laboratory

- Ten scientists working jointly on the development of materials and components for next generation of batteries
- First projects related to ceramic ion conductors as electrolytes and protecting layers for advanced battery systems
- Scientific supervisors are Prof. J. Janek and Dr. A. Fischer
- The Joint Lab is having 361 m² lab and office space located at KIT Campus North
- All costs of about 12 million Euro over 5 years are shared equally by BASF and KIT
- The Joint Lab is part of the scientific network on batteries of BASF


BASF
The Chemical Company