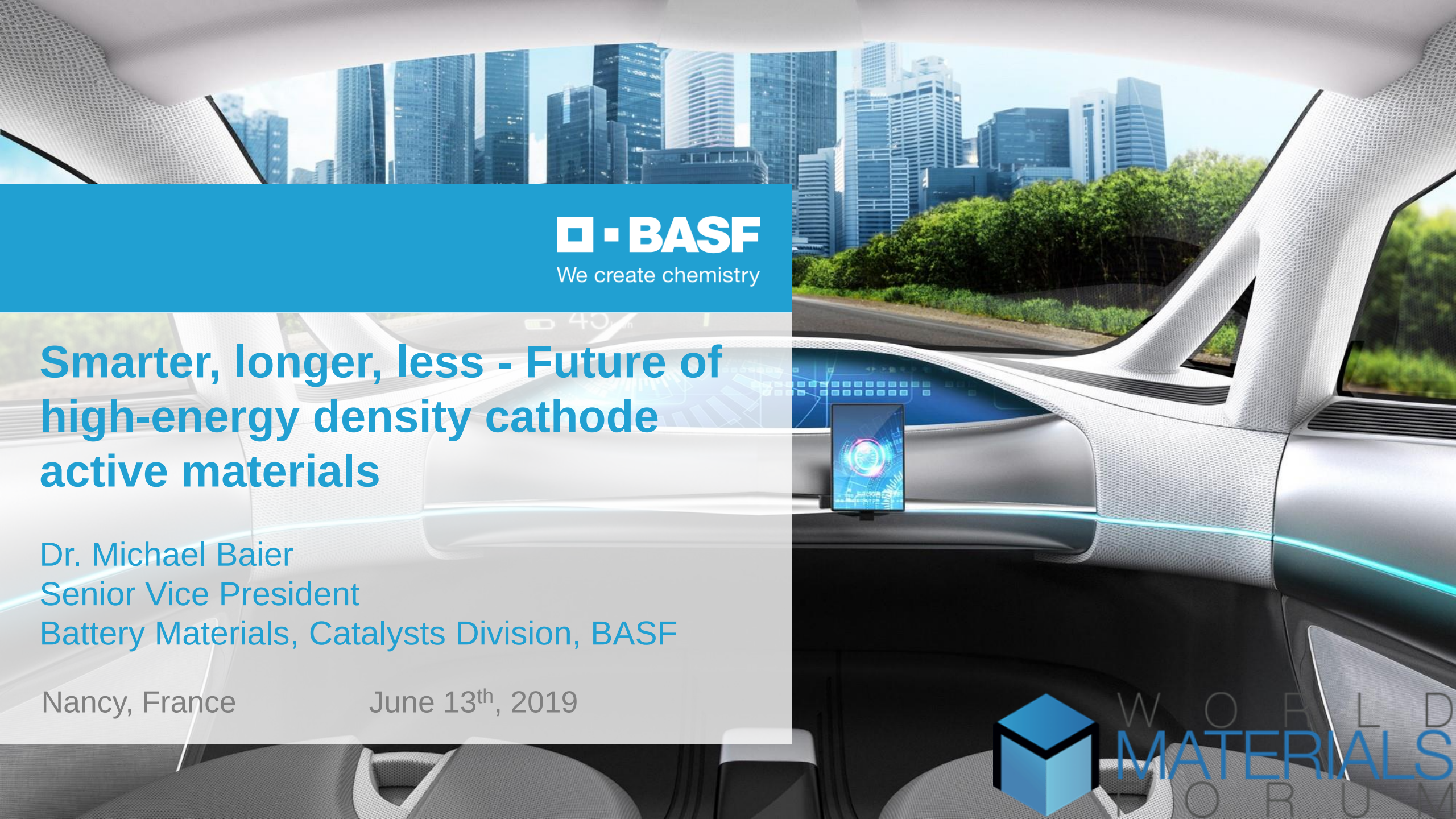


BASF
We create chemistry

Smarter, longer, less - Future of high-energy density cathode active materials

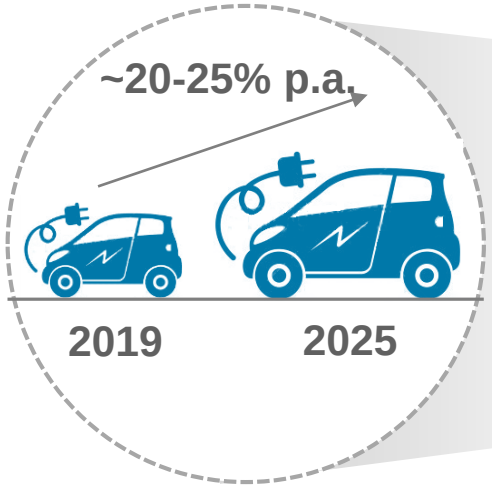
Dr. Michael Baier
Senior Vice President
Battery Materials, Catalysts Division, BASF

Nancy, France June 13th, 2019

WORLD MATERIALS FORUM

Capture the fast growth of battery materials market

Electromobility (E-Mobility) drives battery materials growth



Market projections for 2025*:

10-15 million electric vehicles built per year

700-1,000 kt of CAM in E-Mobility

€25-30 billion CAM market size

Chemistry of cathode active materials (CAM) is key to address E-mobility challenges

Recent reports & OEM announcements indicate even stronger growth

- Electric vehicles (EV): BEV and PHEV; numbers capture various growth scenarios and BEV vs PHEV rations
- Plug-in hybrids: PHEVs
- Pure battery EVs: BEVs
- * Source: consolidated market views from LMCA, Bloomberg, BMO, Bernstein

WORLD MATERIALS FORUM

BASF
We create chemistry

Battery cell value chain

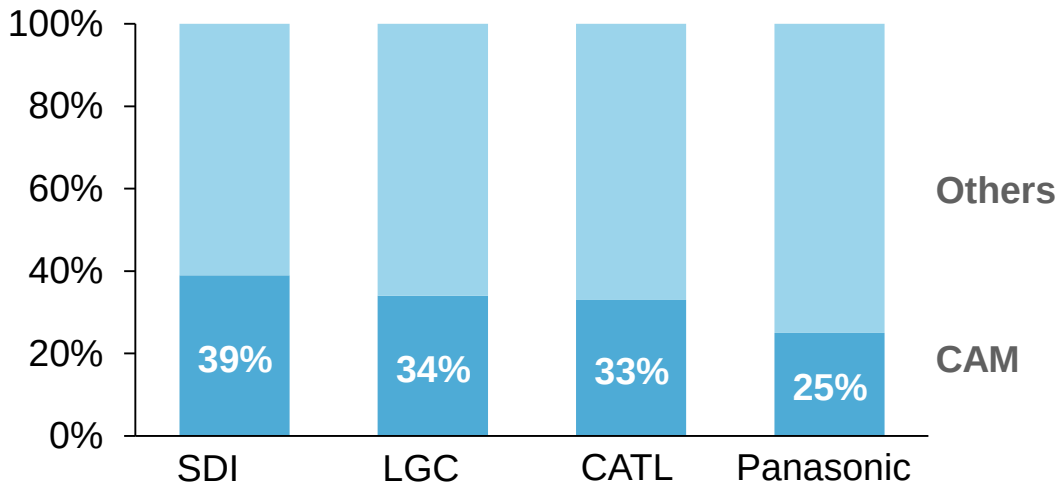
CAM is the major cost driver with around 1/3 of total cell cost in the EV industry

Mining → Metal refinery → Battery materials → Battery cell and pack → Applications





Cell cost breakdown of major market players



Source: UBS Evidence Lab

WORLD MATERIALS FORUM

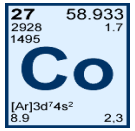
BASF
We create chemistry

Metals are the main driver for CAM's performance and cost

Lithium

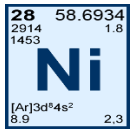
- Sourcing via brining or mineral route
- Sustainability challenges to be addressed

Cobalt



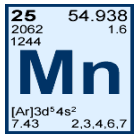
- Expensive only as Ni or Cu mining by-product (high dependency on DRC)
- Sustainability challenges to be addressed

Nickel

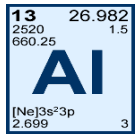


- Driver of energy density and key to lower cost
- Too high content drives stability issues and gassing

Manganese



Aluminium



- Sustainability subject to regular assessments
- Materials readily available in the correct grades and product form

Sustainability and availability need to be addressed by the industry

CAM technology roadmap: past, present & future

Trend to use less Cobalt followed by less Cobalt & Nickel

Cost €/kWh*

Phase I: less Cobalt

Phase II: less Cobalt and less Nickel

Next-generation lithium-ion batteries

NCM-111 (Ni, Co, Mn)

NCM-622 (Ni, Co, Mn)

NCA (Ni, Co, Al)

NCM-811 (Ni, Co, Mn)

Advanced NCA (Ni, Al)

Mn-rich (Ni, Mn)

Materials for Lithium-anode and all-solid-state-batteries

Ni
Co
Mn
Al

2014 // 2017 2019 // 2024 > 2025-2030 Market launch

WORLD MATERIALS FORUM

BASF We create chemistry

Smart new CAM with higher energy density

Key enabler for less material consumption and longer driving range

CAM	Co-content (mol-%)	Spec. energy density (Wh/kg)	Kilogram CAM per kWh	Ni+Co+Mn costs per kg (av. 2018*)	Ni+Co+Mn costs per kWh (av. 2018*)
NCM-111	33				
NCM-622	15-20				
NCM-85%	5-10	+66%	-40%	-66%	-79%
NCA-91%	3-5				
Mn-Rich	0				

* Average metals costs (Co, Ni, Mn) in CY 2018

- **Increasing energy density in CAM through innovations**
  - Smart combination of CAM technology and battery design: smaller batteries with improved performance
  - Longer driving range or less materials to achieve certain range
  - Less use of metals and thus less cost per kWh

CAM production trend: Lower cost, less environmental impact, less energy consumption, improved sustainability

Sustainability

- Less CO_2 footprint
- Use of recycled materials
- Increased use of renewable energy

Efficiency

- Big-volume manufacturing, high throughput
- High consistency of quality
- Lower energy consumption
- Automation and Industry 4.0

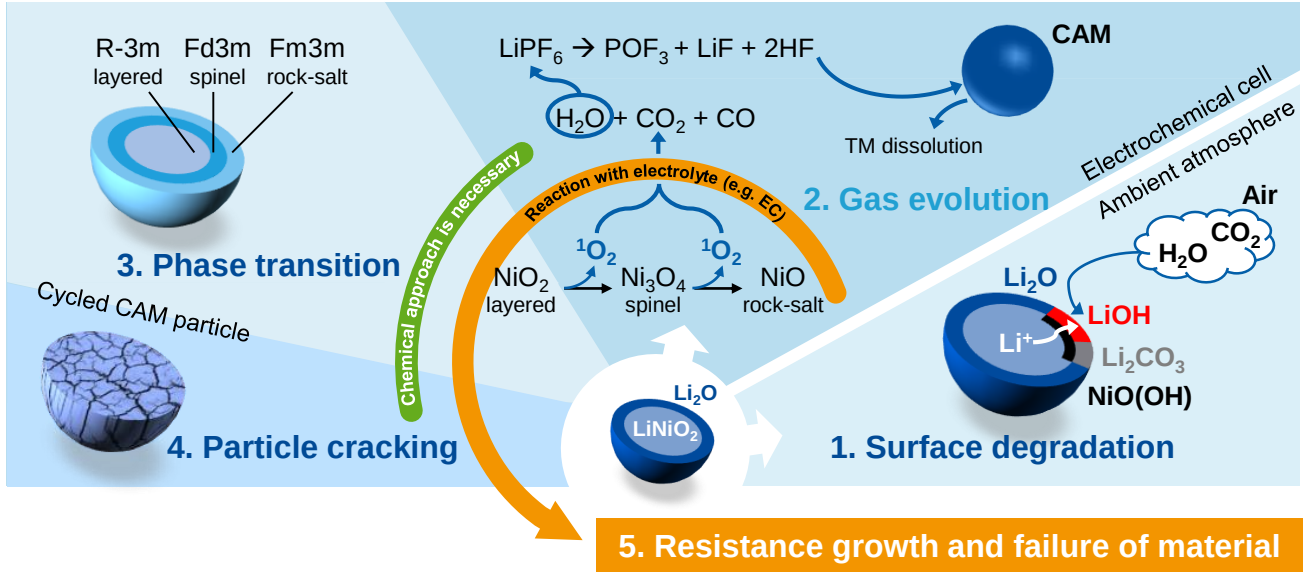
Continuous process optimization to ensure highly efficient and sustainable production of CAM

Smarter solutions to tackle the challenges in Nickel-rich CAM development

Overcome the intrinsic instability of Ni-rich CAM by Doping / Washing / Coating

Challenge

- Surface reactions of CAMs in the cell and at ambient conditions
- Phase transition by cation migration and oxygen release



Solution

- Bulk stabilization and surface treatment
- Eliminate the reaction of H_2O with CAM

- **Improve bulk stability**
  - Tailoring morphology and structure
  - Element doping/element substitution
- **Surface stabilization**
  - Reactive coating: Li incorporation by formation of non-reactive compounds on surface
  - Reduce the amount of water extractable lithium

- **Deactivation mechanism of Ni-rich CAM is understood**
- **Doping, Surface washing and Coating as countermeasures**

WORLD MATERIALS FORUM

BASF
We create chemistry

Smarter, longer, less – CAM innovations for a better and more sustainable E-Mobility

Short and reliable supply chain

Sustainable raw materials sourcing

CO_2 footprint

High local content

Future drivers

- Smart innovations in product development and production to improve performance while using less materials (metals)
- Higher energy and recycled materials for improved sustainability of E-mobility
- Less resources used in production and in final product

WORLD MATERIALS FORUM

BASF
We create chemistry

We create chemistry