GAIA
Advanced Lithium Battery Systems

Challenges for Large Scale Production of Lithium-Ion Batteries

3rd International congress on Battery Technology

June 22nd – 25th, Wiesbaden

LTC Lithium Technology Corporation

Overview

- GAIA Company Introduction
- Current Manufacturing Capacities and Estimated Demand
- Challenges of Material Sourcing
- Cooperating Along the Value Chain
- Future Developments
- Summary

GAIA
Advanced Lithium Battery Systems

Company Introduction

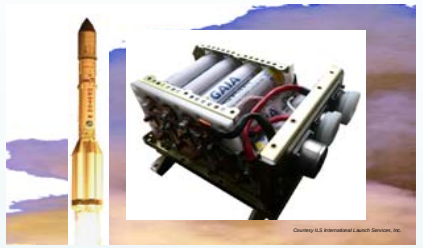
1996
GAIA was founded in Nordhausen, Thuringia, Germany

2003
Introduction of large cylindrical Li-Ion cells

2007
Prius with Li-ion as PHEV shown at the IAA

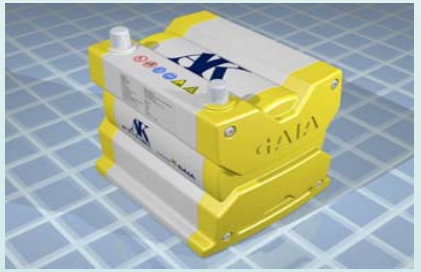
2008
Demonstration of full electric vehicles

2009
Qualification for space flight



Contract to supply 50kWh high power batteries to US bus manufacturer

Li-ion starter batteries for sports car, development of micro hybrid battery



2010
1.2 MWh battery for propulsion of solar boat

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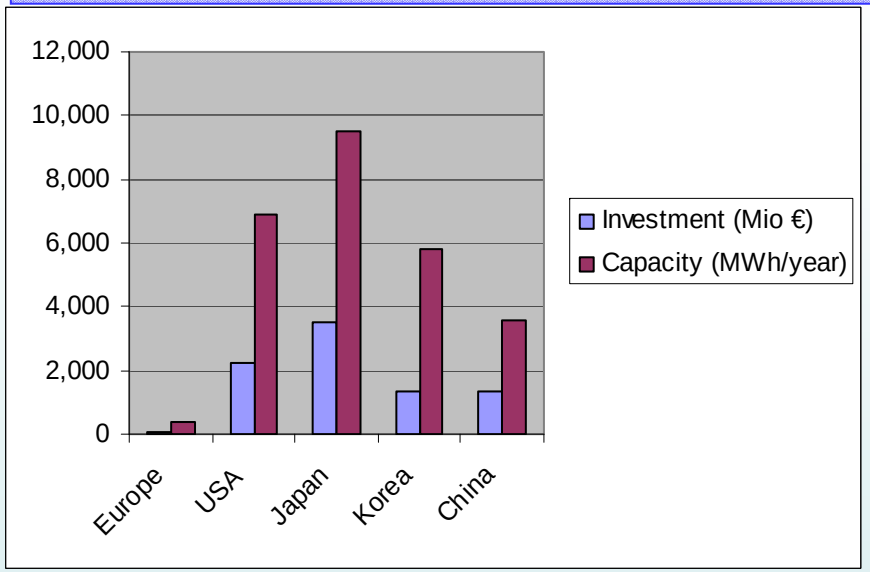
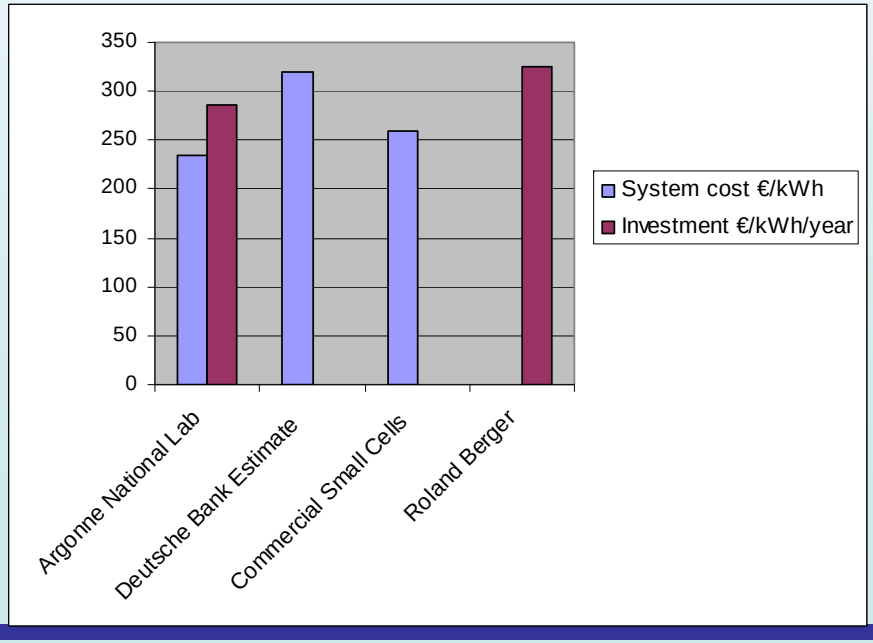
Current Manufacturing Capacities and Demand



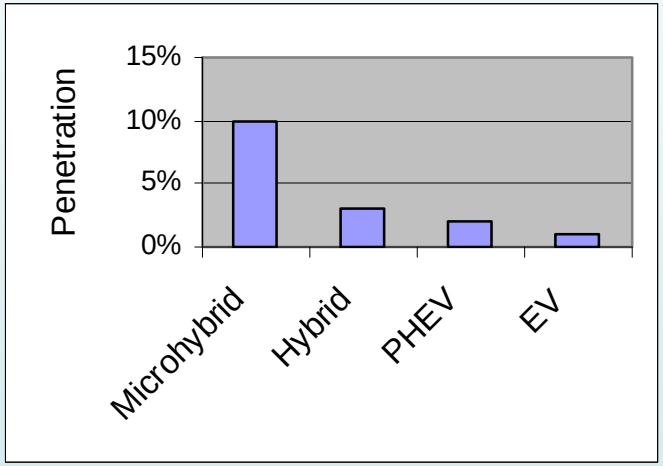
- Present production capacity of small cells (< 3Ah) is estimated at about 15,000 MWh/year
- Production of large cells (>10 Ah) and batteries is still in the pilot or low volume manufacturing state
- World wide, total investments of 8.5 billion € have been announced for a total capacity of 2.6 million PHEV/EV batteries per year (about 26,000 MWh/year)
- Asia and the US are dominating

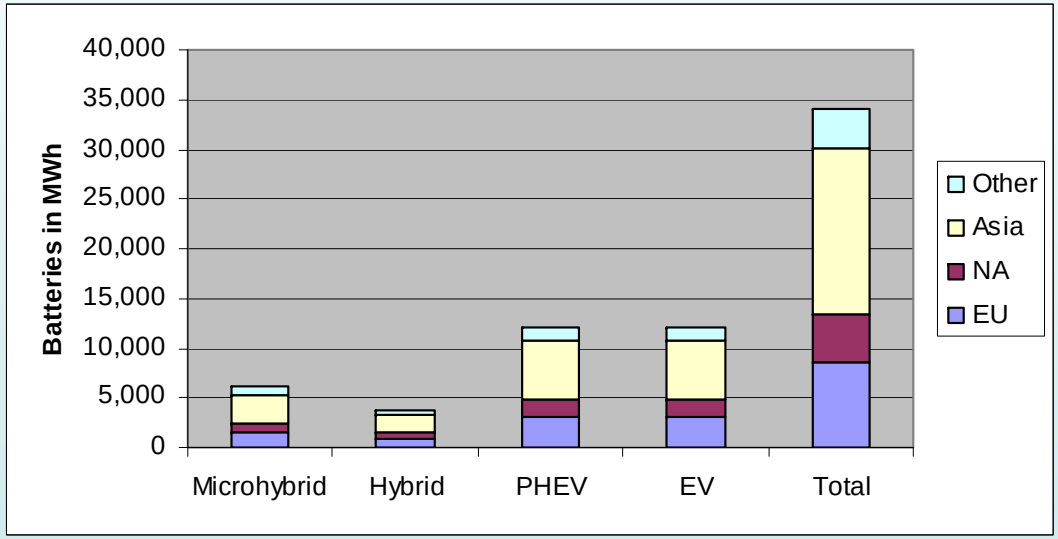


- Present cost of large batteries is too high for broad acceptance in the market
- Investments in large scale, highly automated manufacturing is necessary
- By 2015, the battery cost at system level is projected to drop to 300 €/kWh

Current Manufacturing Capacities and Demand (continued)

- Even modest assumptions of electrification of the drive train lead to a total demand of 34,000 MWh of required annual battery production capacity
- This exceeds the announced installation of capacity
- Other battery technologies will continue to compete with micro hybrid and hybrid applications, however, it is expected that LiIon will also dominate these applications when cost is at acceptable levels





Assumptions:
Car production at 2009 levels (60 million vehicles)
No difference in geographic distribution of electrification

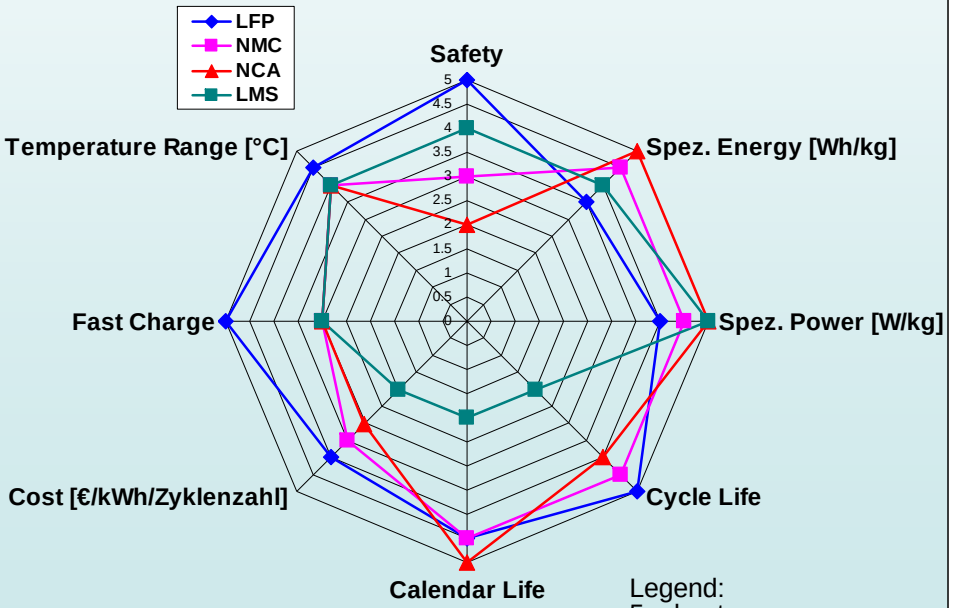
Assumptions:

Microhybrid	1 kWh	Hybrid	2 kWh
PHEV	10 kWh	EV	20 kWh

Challenges of Materials Sourcing: Battery Chemistry

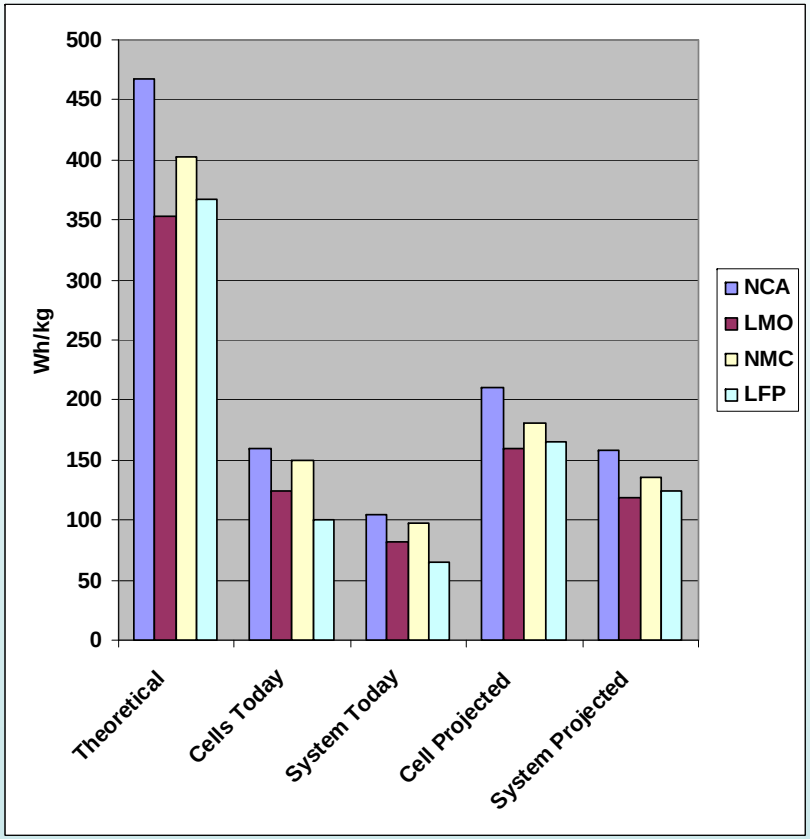
Choice of Active Materials

- Li-ion batteries are being developed with different active materials
- Most systems at present use anode carbon materials
- Four different cathode materials are being considered for automotive batteries
- There is no clear winner at this point in time



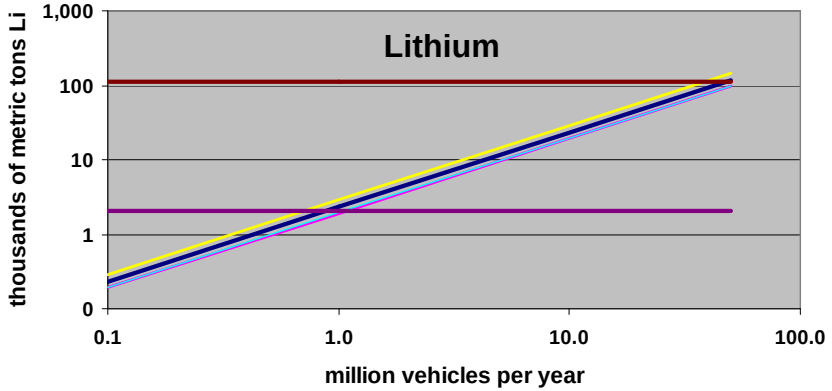
Legend:
5 = best
1 = worst

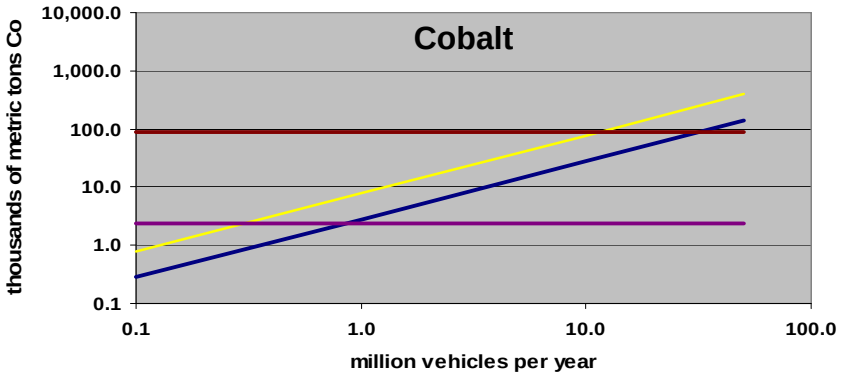
LFP=Lithium Iron Phosphate
NMC=Nickel-Manganese-Cobalt Oxide
NCA=Nickel-Cobalt-Aluminum Oxide
LMS=Lithium-Manganese Spinel

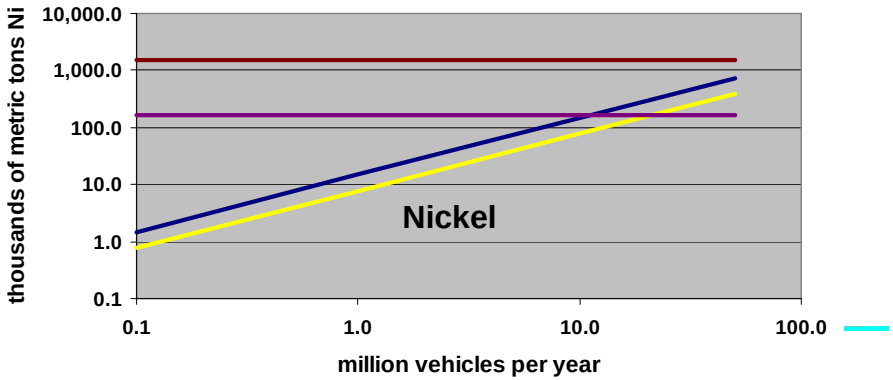


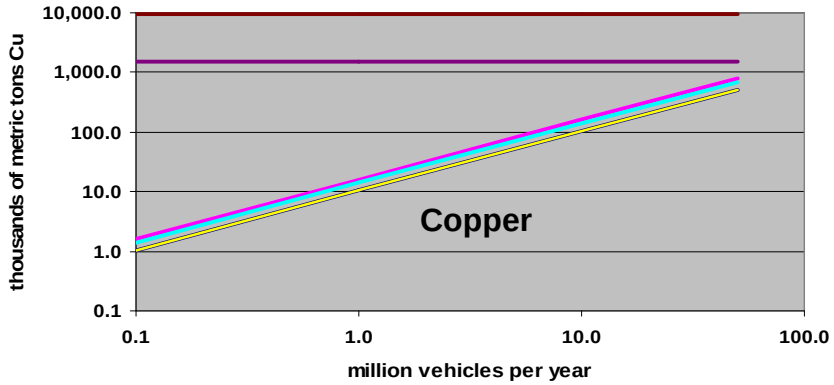
Challenges of Materials Sourcing: Supply of Critical Metals

- Cobalt free systems will not experience a shortage of raw materials until late in the game
- Recycling will play a key role in the long run







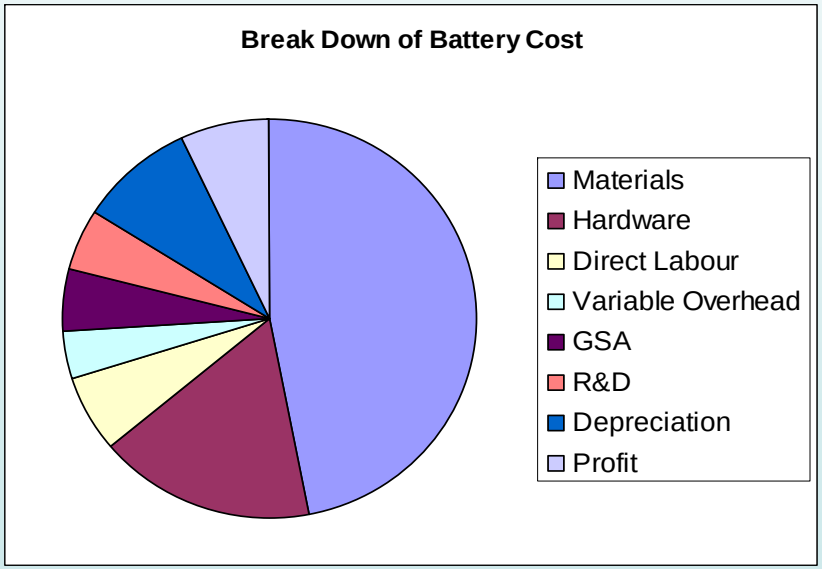


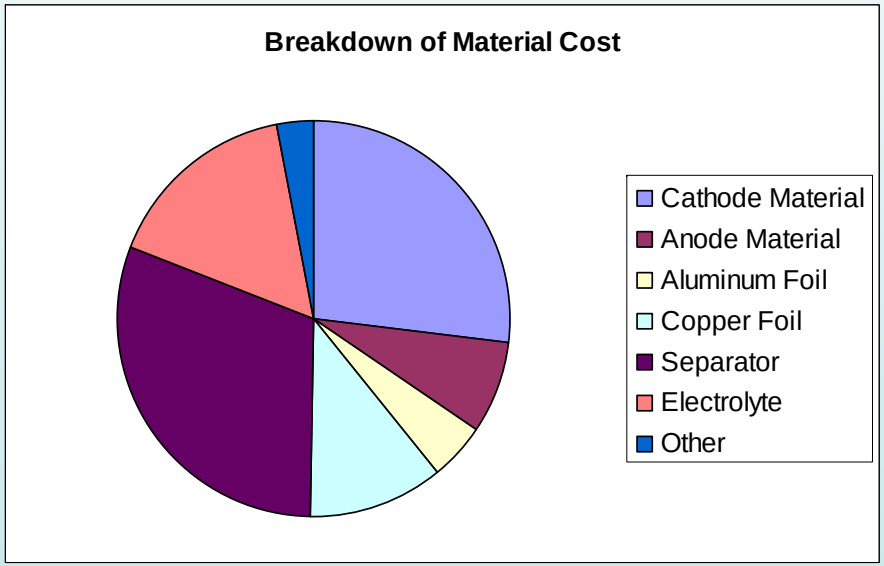
Assumption. Vehicles with 10kWh battery on board

Sources: US Geological Survey, Deutsche Bank

Challenges of Materials Sourcing: Advanced Materials

- Materials Cost makes up nearly half of the battery cost with active materials, separator, copper foil and electrolyte as the biggest contributors
- High power designs have a large cost contribution from the foils
- Key components can only be sourced out of Asia
- Patents restrict the freedom to operate for some of the materials
- Some of the materials are still in the early stage of industrialization



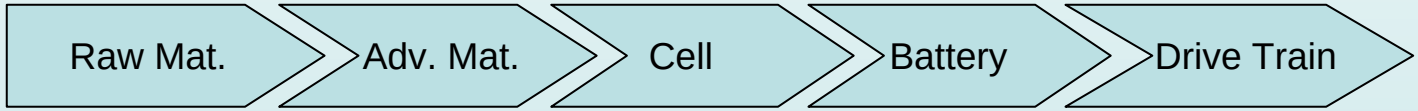


Assumption: iron phosphate/graphite chemistry, high power cell design

Cooperation Along the Value Chain

- Growth of vehicle application is expected to be rapid starting in the next two years
- Ramp-up of volume will probably exceed production levels of small lithium ion batteries within 5 years
- Cooperation along the value chain is required to enable supply of materials, cells and batteries to support the market growth
- Market growth will depend on battery cost, especially for PHEV and EV. This will re quire cost reduction along the complete value chain
- Transportation of cells and batteries is regulated. Local supply is favored.
- Performance and other battery attributes depend on continued development along the value chain

Value Chain and Key Elements



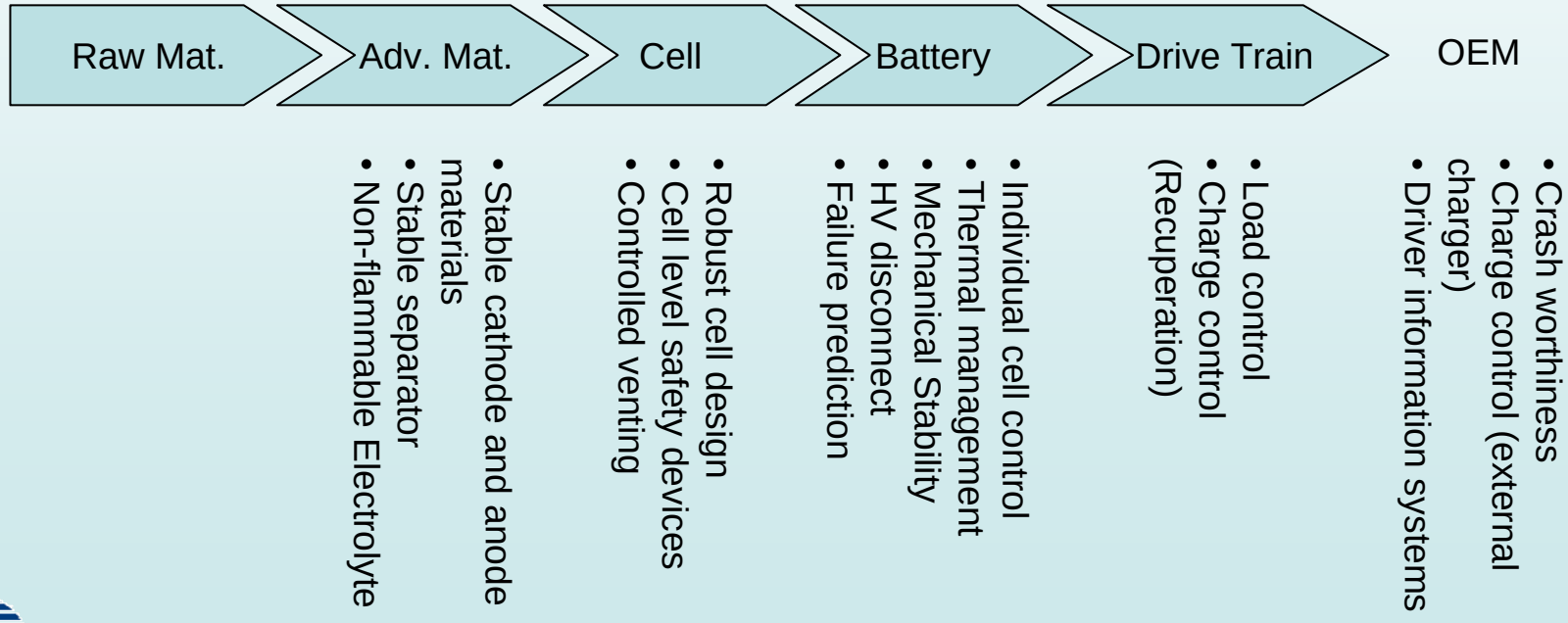
•Lithium •Cobalt •Nickel •Copper	•Cathode •Anode •Separator •Electrolyte	•Electrodes •Cells	•Battery Management •Cooling •Mechanical Stability	•Interface with battery	•Vehicle Energy Management

Cooperation Along the Value Chain: Safety Concepts

Li-ion cells have a high energy content and low heat capacity. Uncontrolled release of the stored energy can lead to high temperatures

- Both anode and cathode materials can undergo exothermic reactions with the electrolyte at elevated temperatures
- The electrolyte is flammable and has components with high vapor pressure

Contributions to Safety Along the Value Chain



Future Developments

Automotive applications require a further increase in specific energy and a reduction of cost

- **Specific energy**
  - Today's Li-ion chemistries will not exceed 150 Wh/kg (system level)
  - New anode materials such as silicon or tin inter-metallic compounds as anode materials could raise the specific energy by about 20%. High-volt cathode materials could bring further improvements.
  - The author believes that 200 Wh/kg (system level) will be the limit
- **Cost**
  - High volume, automated production will reduce cost at the system level to below 400 €/kWh
  - Further cost reduction is possible with new materials and manufacturing processes

To overcome the limitations of Li-ion chemistry, new electrochemical Systems are being researched

- **Lithium Metal Systems**
  - Lithium-Air has a theoretical specific energy of 12,000 Wh/kg or about the same as liquid fuels. These are early stage research projects
  - Lithium-Sulfur has a theoretical specific energy of 2.500 Wh/kg. Prototypes suffer from low power and short life times

Summary

Lithium Ion Batteries are expected to be part of electrified drive trains from micro hybrids to battery powered electric vehicles

- Present manufacturing capacities of large cells and batteries are small
- A total investment of 8.5 billion € has been announced into large scale manufacturing to enable the production of over 20,000 MWh per year
- Demand could outgrow the installed capacity based on an expected low price of 300 €/kWh
- Sourcing of raw materials will not be an issue for Co-free chemistries
- Planned battery manufacturing capacity will quickly outgrow the production capacity for battery materials
- Cooperation along the value chain will be required to assure material supply and safe vehicles with acceptable cost
- New materials and processes will further improve performance and reduce cost
- Lithium Ion will not be replaced with a new chemistry within 10 years

Thank you for your attention!

Dr. Klaus Brandt

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