THE INFLUENCE OF POTENTIAL RAW MATERIAL SHORTAGES ON THE MARKET PENETRATION OF ALTERNATIVE DRIVES

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Agenda

- Introduction
- Technology description
- Model description
- Simulation results
- Raw material consumption

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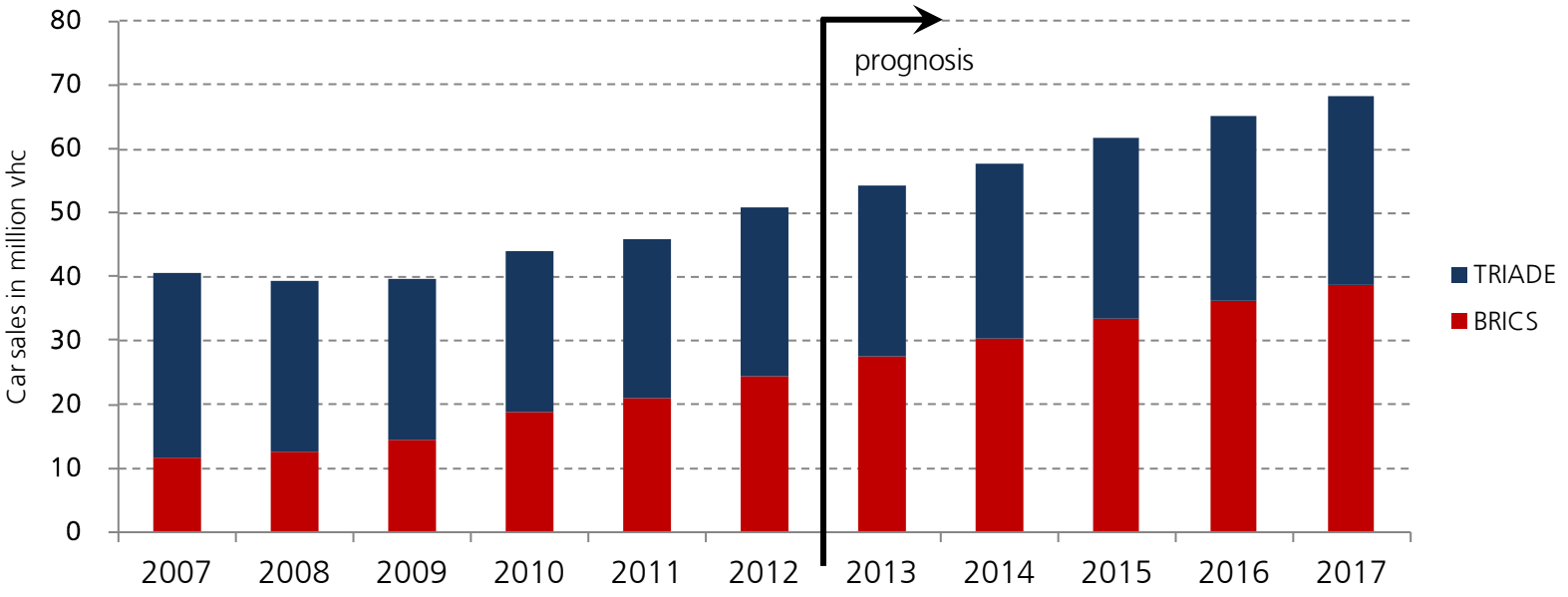
Introduction



Source: Frost & Sullivan

- **Worldwide car sales** will **grow** in future
- **BRICS-countries** will **dominate** the **car market** after 2015
- **Raw material consumption** will also be **driven by the growing number of car sales**

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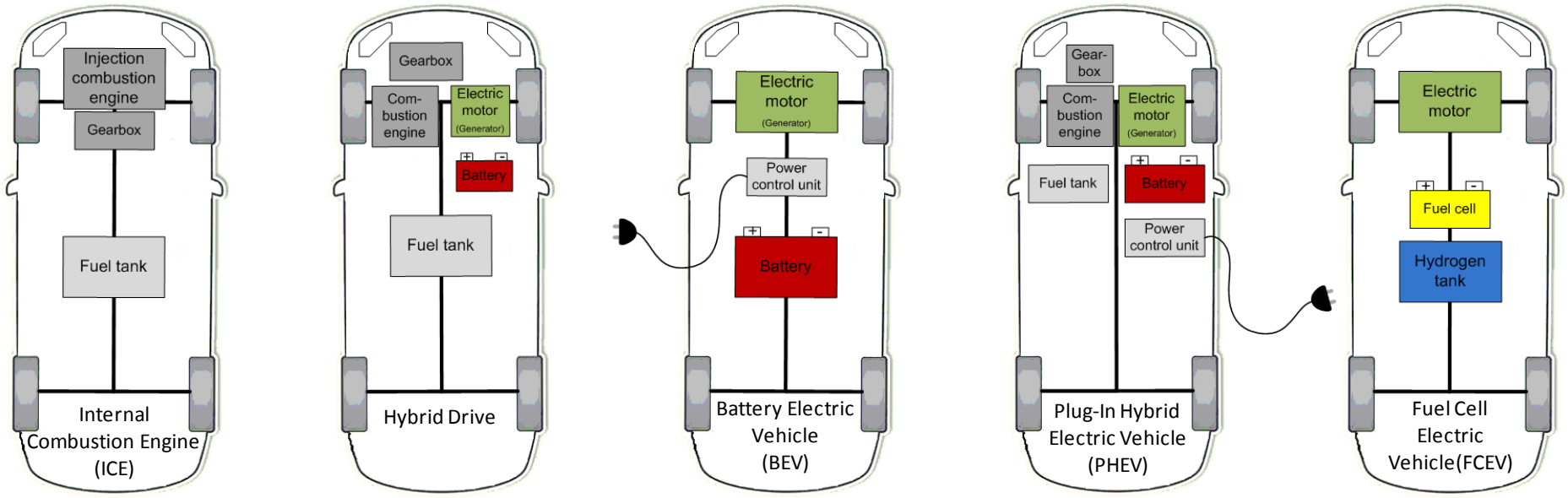
Drive Technologies in the Private Car Sector



Depending on usage and technology price a wide range of different drives will be offered in future:

Especially battery-driven technologies and fuel cells depend on very specific raw materials

(**cobalt, lithium for batteries** – platinum for fuel cells – copper & rare earths for electric engines)

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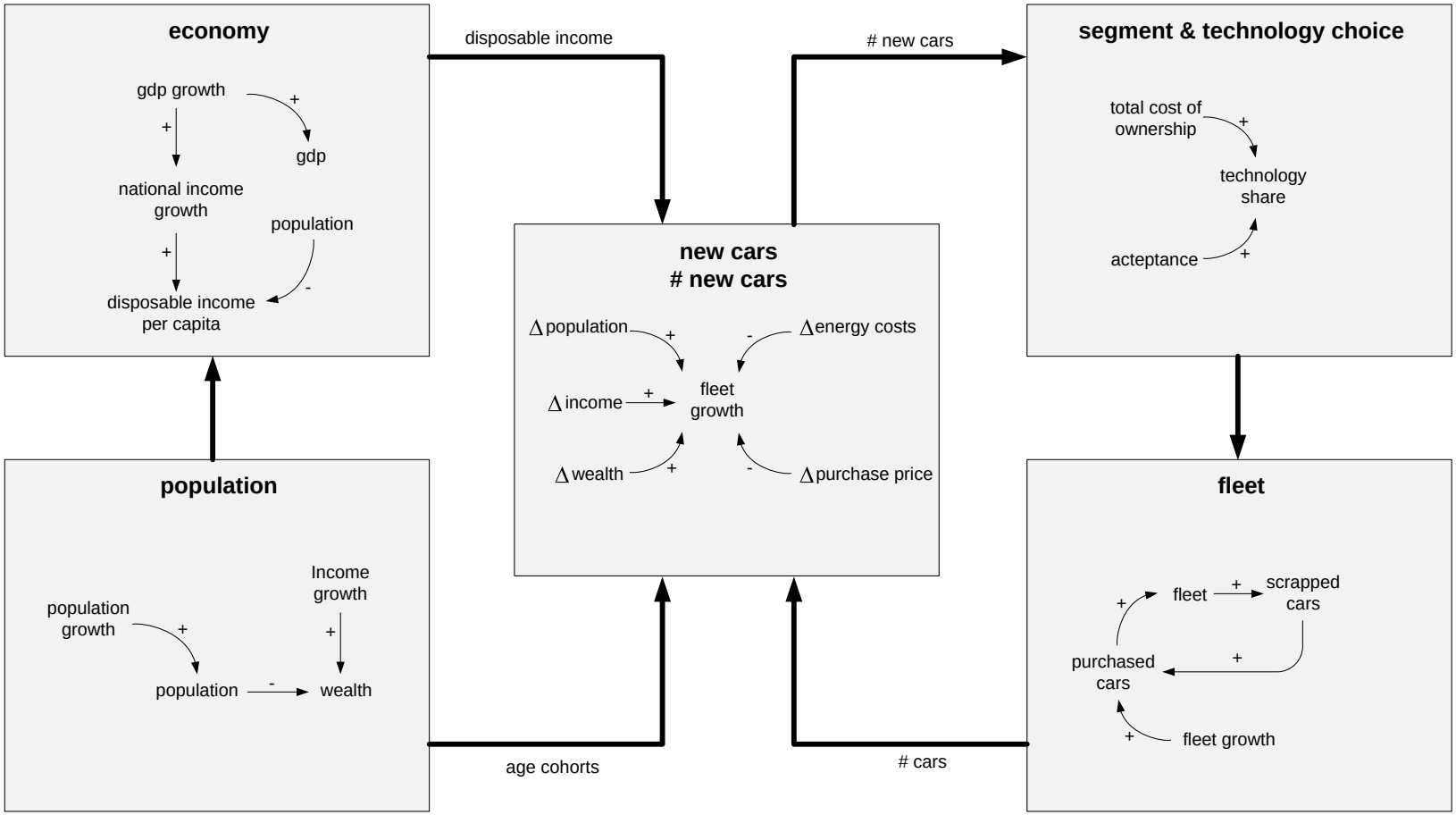
Overview of the Global Mobility Model **(GloMo)**



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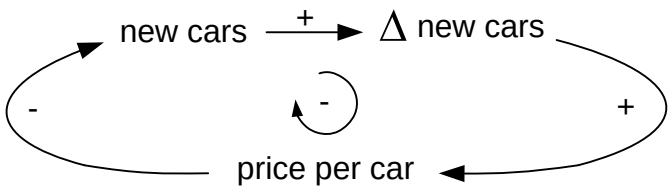
Feedback Loops within the Car Fleet Module

1



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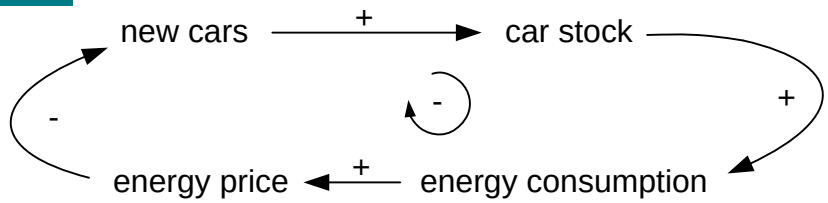

- **Feedback loops** as a **typical element** of **system dynamics** modelling
- Highly increasing number of **new cars** leads to higher prices due **production shortages**
- A **growing car stock** leads to higher energy consumption and **increasing fuel prices**

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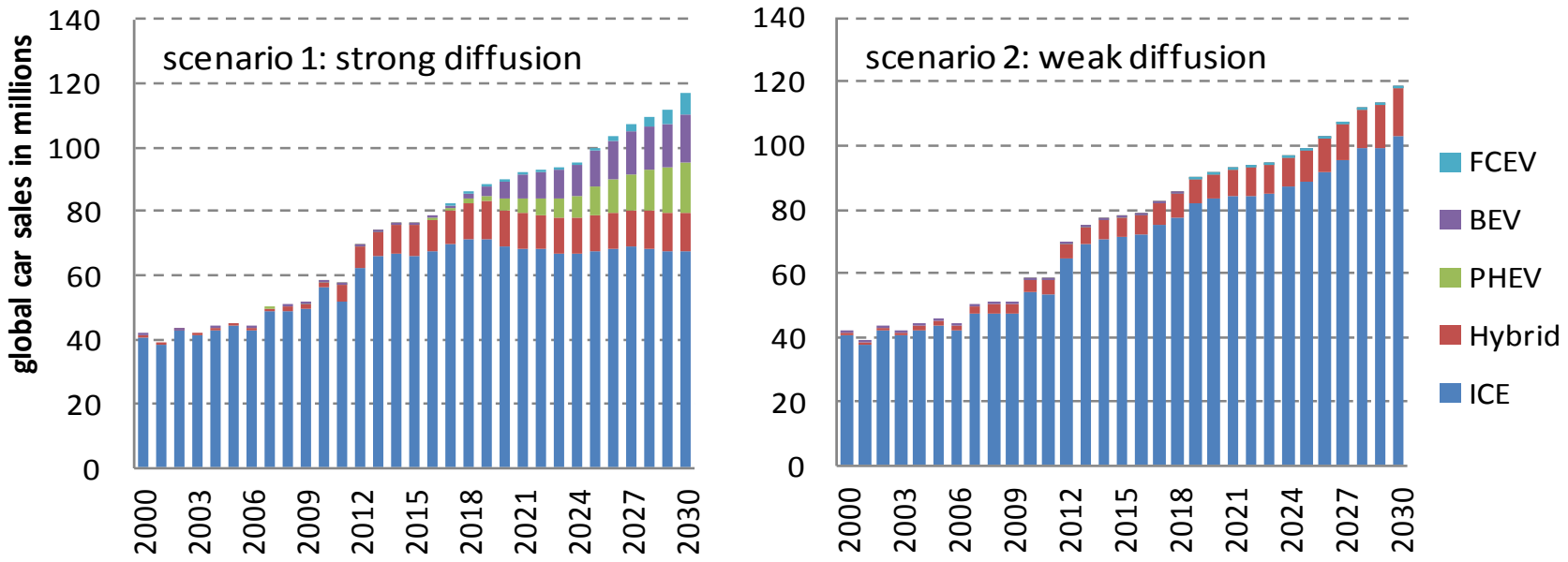
Scenarios of Alternative Drive Diffusion



- Strong technology progress
- Low technology prices
- High oil price

- Weak technology progress
- High technology prices
- Medium oil price

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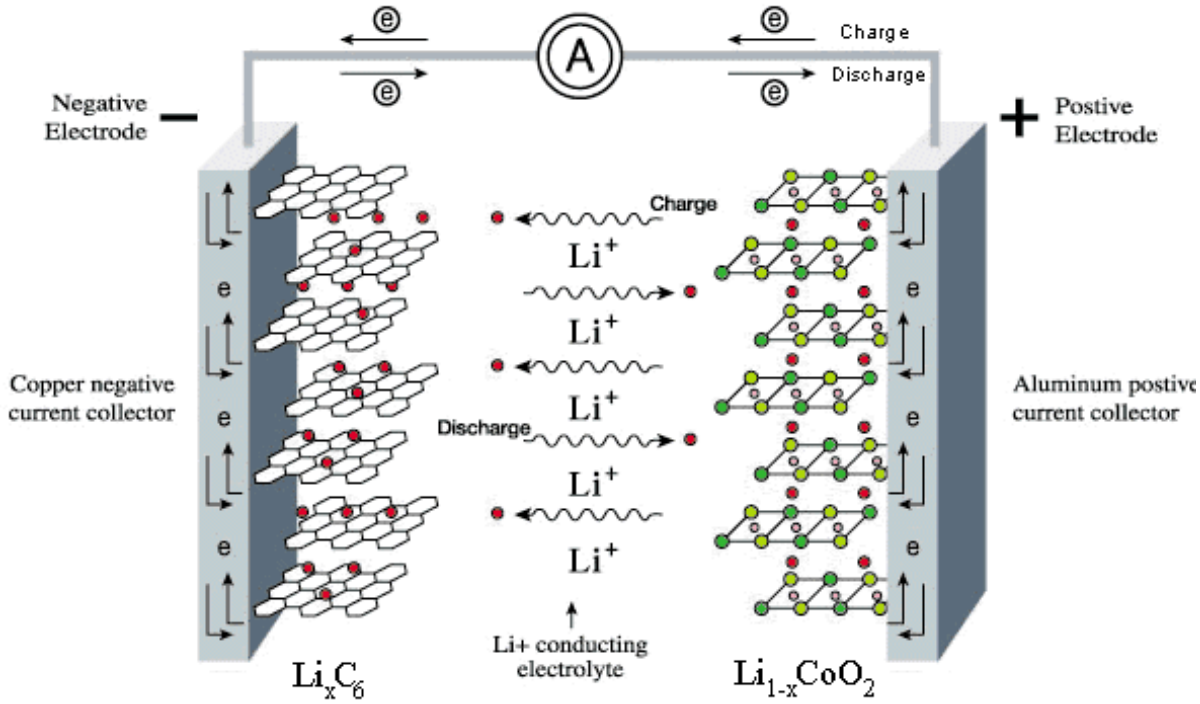
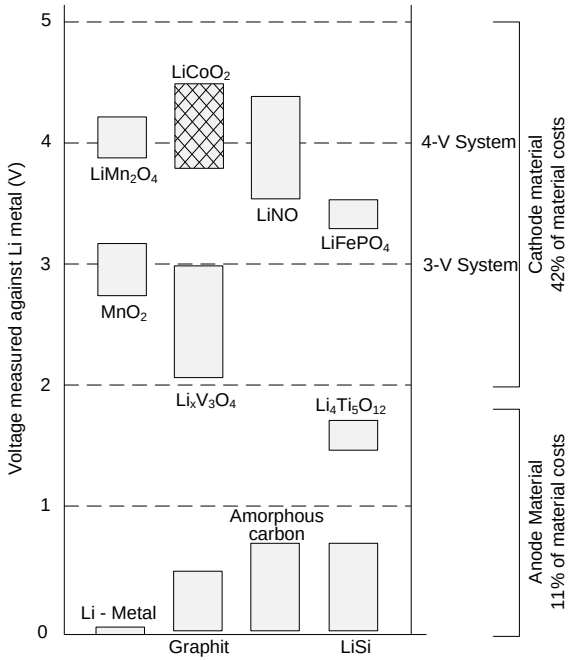
Basic Raw Materials for Lithium Ion Batteries: Lithium & Cobalt





Potential cathode materials for large scale batteries for electric vehicles:

$LiCoO_2$ (lithium cobalt oxide), $LiMnO_2$ (lithium manganese oxide),
LiNiO (lithium nickel oxide), $LiFePO_4$ (lithium iron phosphate)

➡ **mixed oxides such as $Li(Ni_{0,85}Co_{0,1}Al_{0,05})O_2$ or $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$**

Sources: Fraunhofer ICT (TÜBKE 2011)
KIT (KETTERER 2009)

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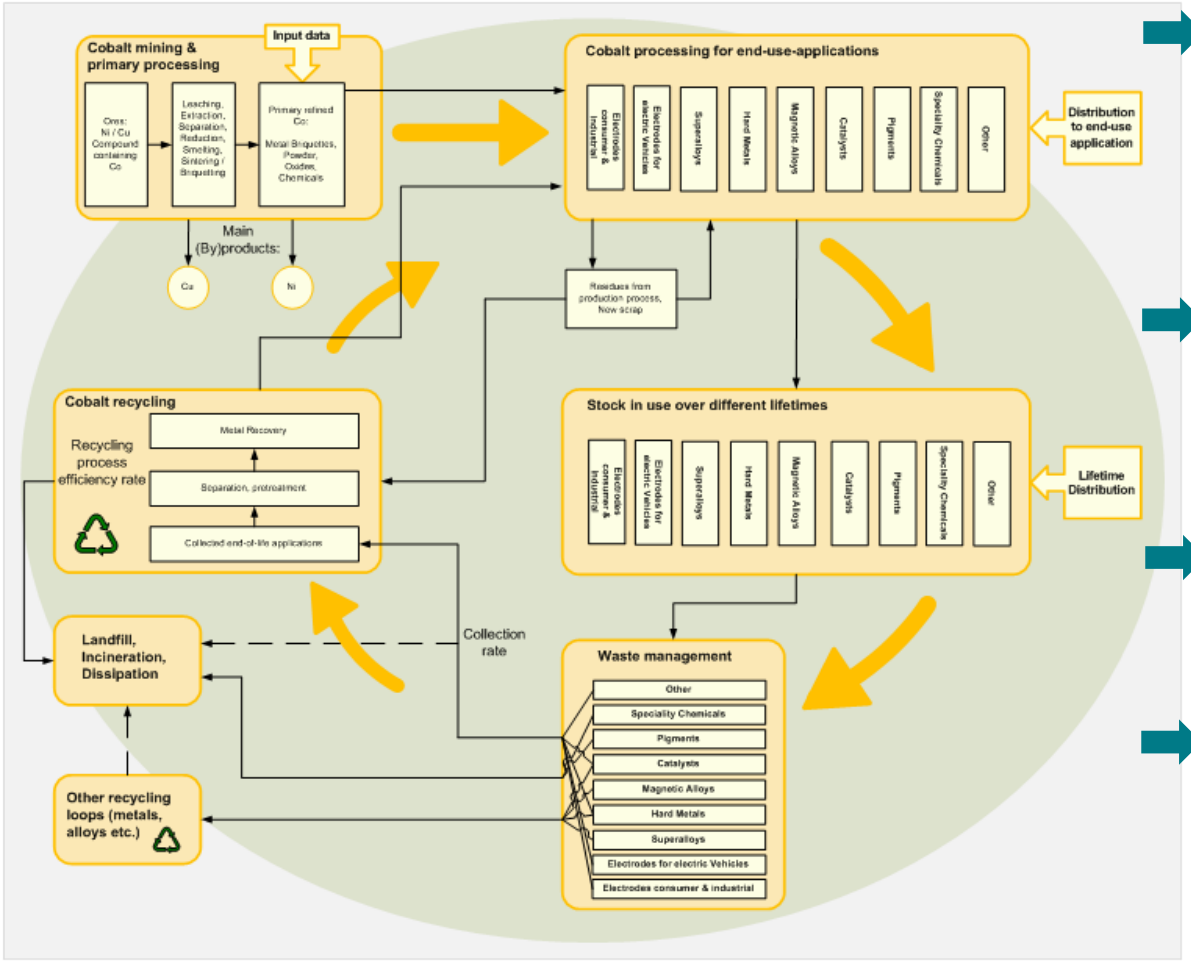
The Life Cycle of Cobalt within a System Dynamics Model



- Simulation of global material flows from mining over production and fabrication to end-use applications
- Stock in use over the porduct lifetime (lifetime distributions)
- Simulation of waste management and recycling
- Identification of cobalt demand by sector regarding primary (from mining) and secondary (from recycling) production

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Development of Market Shares in During the Previous Decade

Cobalt:

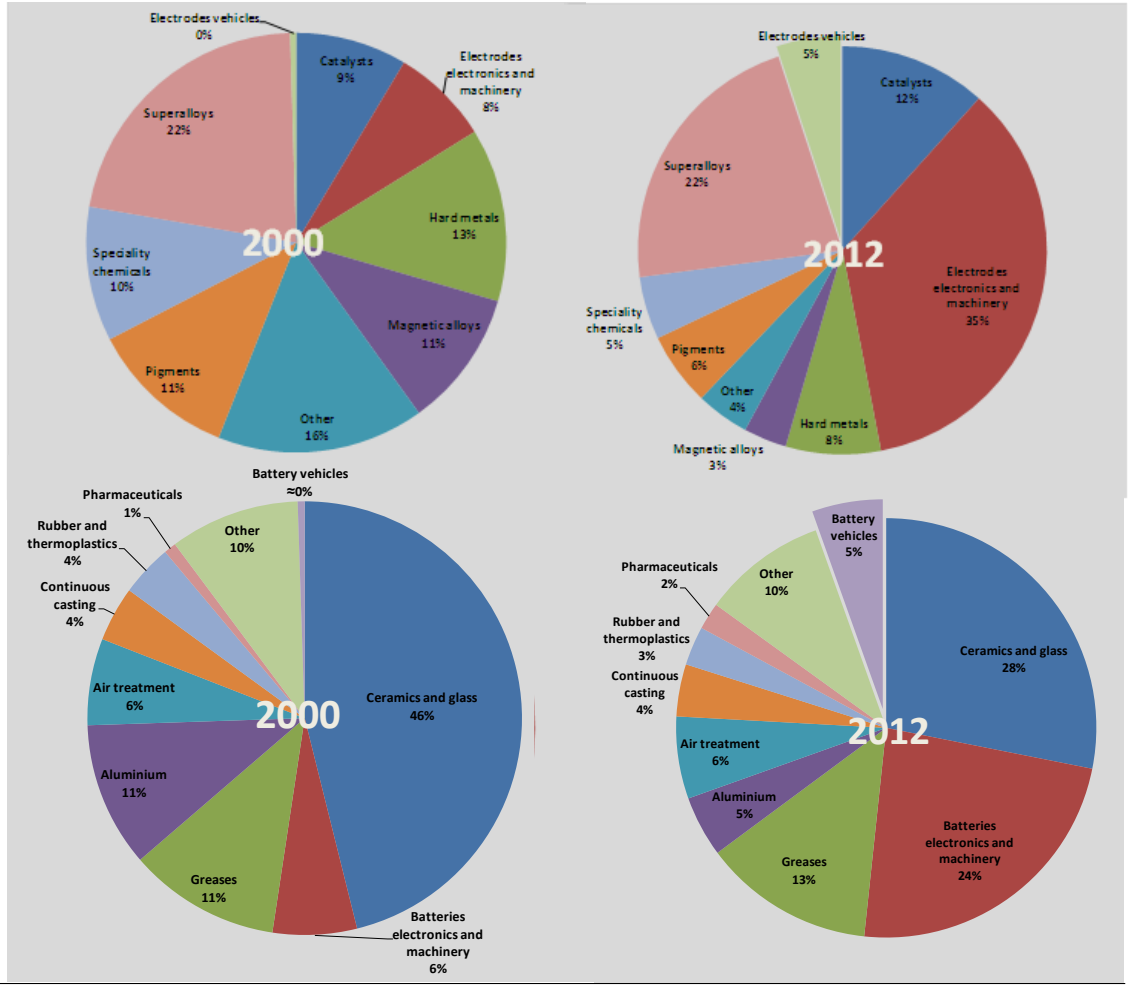
Rapid increase of demand for Electrodes during the last decade – particularly due to lithium-ion cells in electronic products

Current share of vehicle batteries around 5%

Lithium:

Rapid increase of demand for Lithium-ion cells during the last decade – particularly due to batteries in electronic products

Current share of vehicle batteries around 5%



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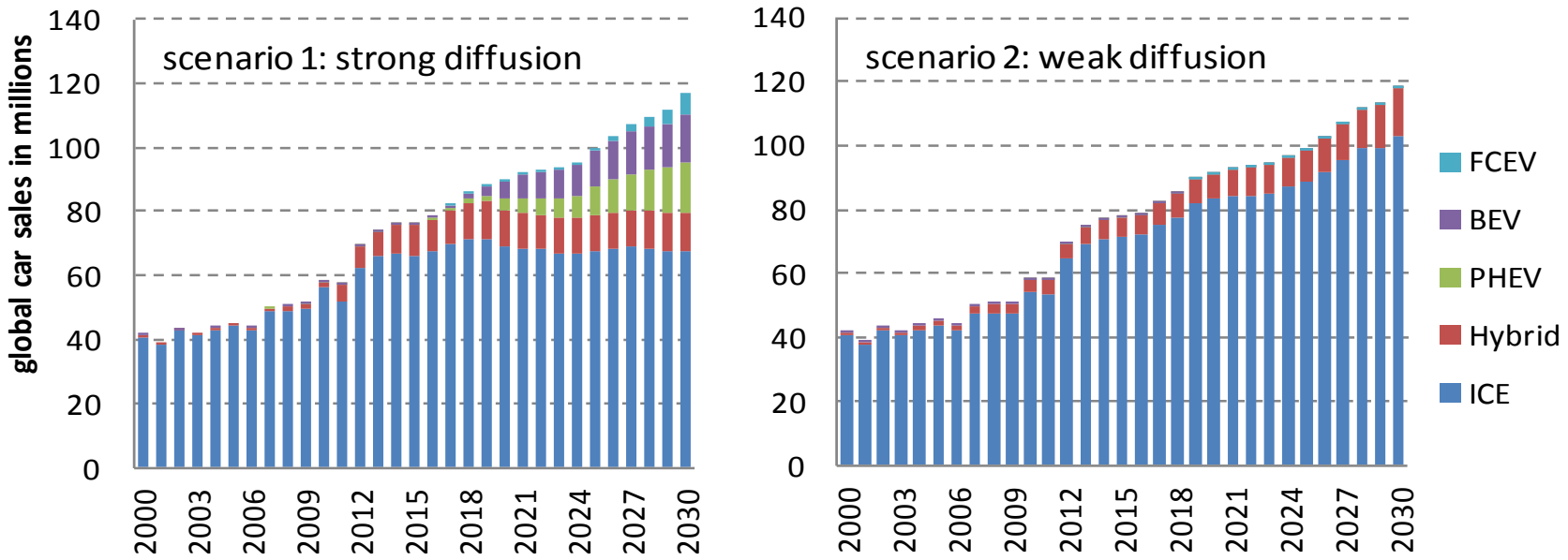
Scenarios of Alternative Drive Diffusion



For further calculation concerning raw material consumption of electric vehicles, the following battery sizes are used:

- **Hybrid: 1.5 kWh**
- **PHEV: 15 kWh**
- **BEV: 25 kWh**
- **490 g/kWh Cobalt**
- **160 g/kWh Lithium**

decreasing over time due to higher raw material efficiency and substitution of cobalt by $LiFePO_4$

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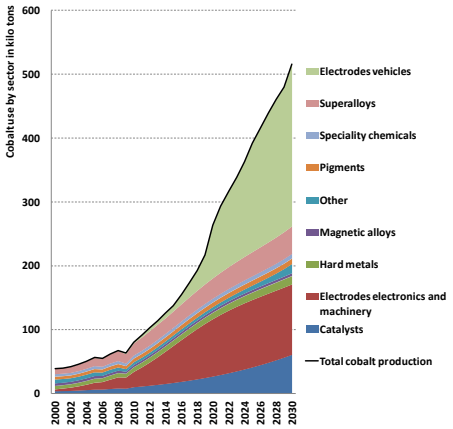
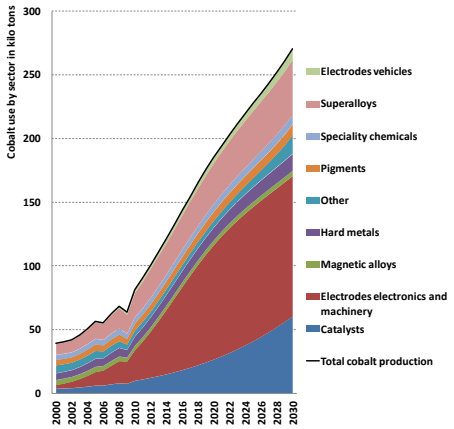
Effect of the Two Scenarios on the Global Cobalt Market

Cobalt market effects:

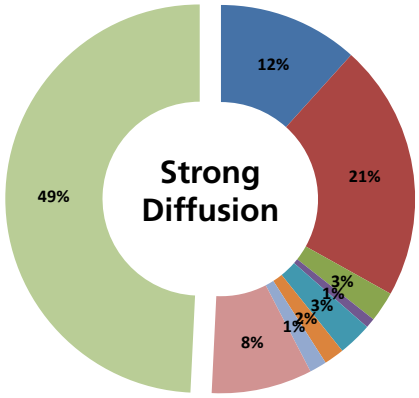
Severe effect of the strong diffusion scenario:
≈50% of demand caused by automobile industry, 70% by total electrode production

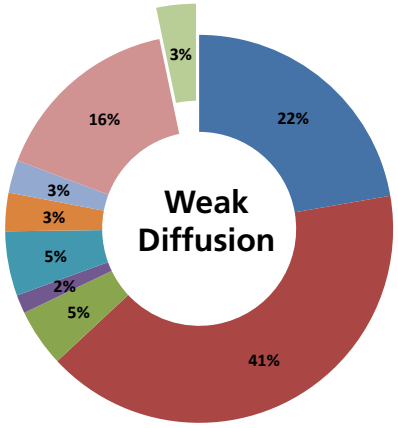
Negligible share of automobile industry in the weak diffusion scenario





- High uncertainty of market development
- High dependence of future demand on automobile industry
- High risk for investments in mining and production facilities





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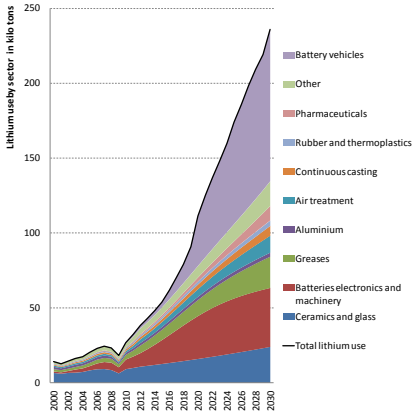
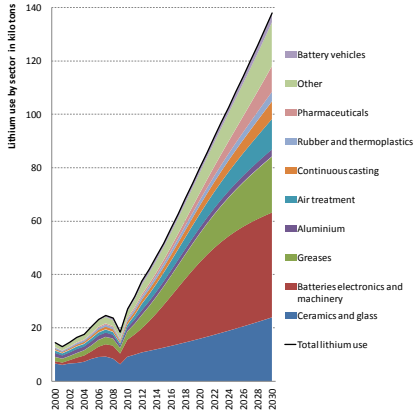
Effect of the Two Scenarios on the Global Lithium Market

Lithium market effects:

Severe effect of the strong diffusion scenario:
≈40% of demand caused by automobile industry, 60% by total electrode production

Negligible share of automobile industry in the weak diffusion scenario





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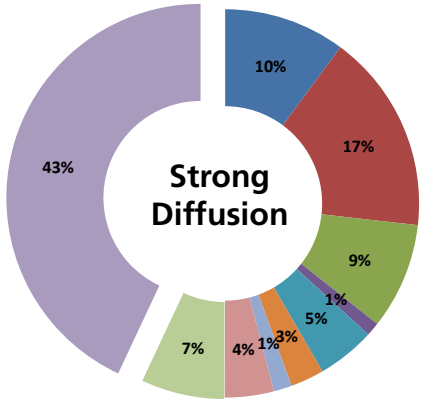

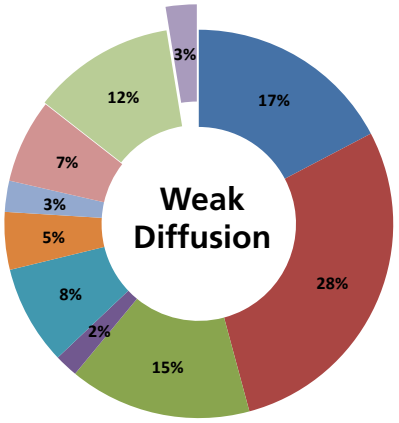

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Future Work and Improvements of the Model

GloMo:

Improved statistical correspondances

Raw Material Market Model:

Higher detail in modeling other raw material demendent sectors in order to get a better understanding of potentials of substitution in cases of raw material scarcity and high pricing

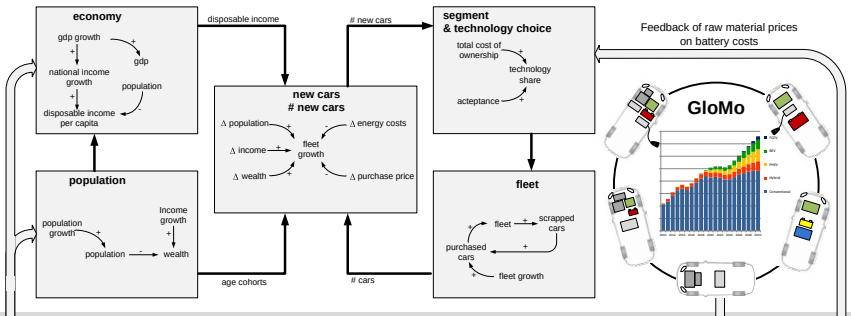
More detail in modeling future future battery technology development

Linkage of the models:

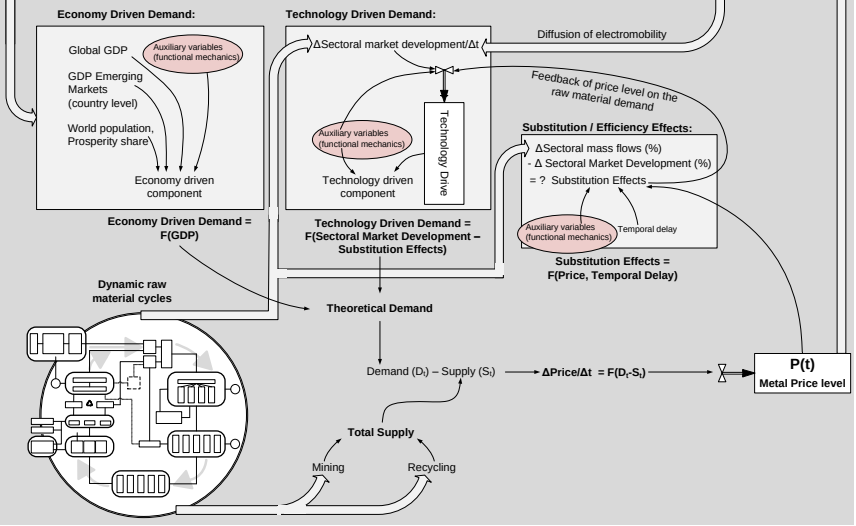
Joint exogenous variables such as economic development

Improved feedback mechanism of high pricing on technological development

Global Mobility Model [GloMo]:
Combined Structural Equation and System Dynamics Model with a Logit-Desicion-Model for discrete technology choice on the micro level



Raw Material Market Model [RaMa] (individual model for each metal):
Combined Structural Equation and System Dynamics Model



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Conclusions

- **Forecast** of worldwide **cars sales per drivetrain technologies** is **volatile** and strongly depends on the development of framework conditions (technology availability, oil price,…)
- Uncertainty in forecasting battery technology: **Raw materials, particularly cobalt are likely to be substituted in the long term**
- **High planning uncertainties** and market risks both mining companies and battery or car producers are confronted with
- **Market penetration of BEV and PEV depends on supply with lithium and cobalt** which both have high geological reserves, thus the potential depletion of the materials is not relevant
- **High lead times and planning periods** of mining projects (5-10 years):

  Are today's investments in mining and production facilities able to meet future demand?

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