The Impact of CO2 Emissions and Energy Consumption During Li-Ion Battery Manufacturing on the Environmental Balance Sheet of BEV

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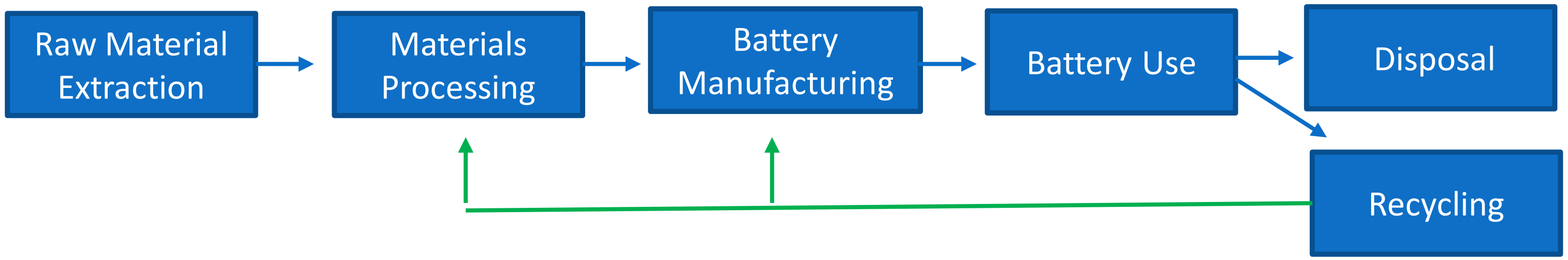
Overview

- Why is it important to pay attention to the impact of battery materials and manufacturing?
- Life Cycle Assessment: Energy use and CO_2 emissions during battery manufacturing
- The role of cathode and anode materials
- Opportunities to reduce the environmental impact
- Summary and conclusions

Life Cycle Assessment (LCA)

The LCA considers various impact categories from cradle to gate (up to product manufacturing), cradle to grave (up to disposal) or cradle to cradle (including recycling and reusing materials in the process)



Impact Category	**Description, Comments**
Use of Primary Energy	Primary energy in battery production (cradle-to-gate)
Global Warming Potential (GWP)	Measured in CO_2 equivalents
Acid Potential	Measured in SO_2 equivalents
Photochemical Oxidant Formation	Air pollution, smog
Ozone Depletion	Destruction of the ozone layer
Resource Depletion	Use of non-renewable resources like metals, fossil fuels

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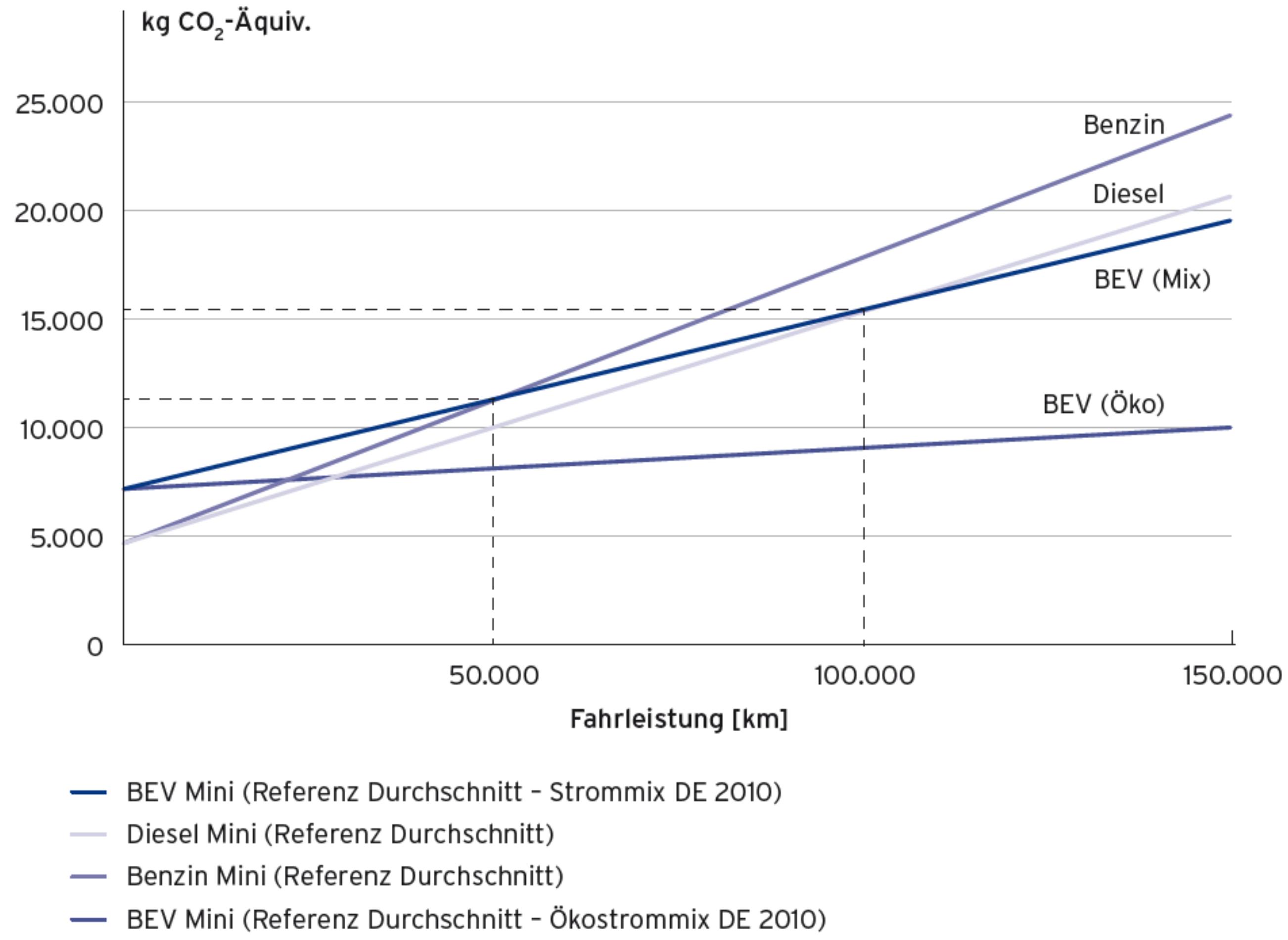
A Comparison of the Global Warming Potential (GWP) of Sub-Compact Passenger BEV with ICE-Cars

- The battery adds about 2,800 kg of CO2-equivalents or about 60% to the production of a BEV compared to a conventional vehicle
- Depending on the fuel used in the ICE-car, it takes up to 100,000 km of driving to compensate for this initial burden
- Cars with a larger range and therefore larger batteries have a larger GWP burden
- The source of electricity plays a large role in the life time GWP of an BEV



Eckert, S. Ökobilanz von E-Fahrzeugen, Elektromobilität vor Ort – Fachkonferenz des BMVI, Aachen 2016
Mix=Average GWP of German electricity mix
Öko=Generation by wind, water, solar and bio mass

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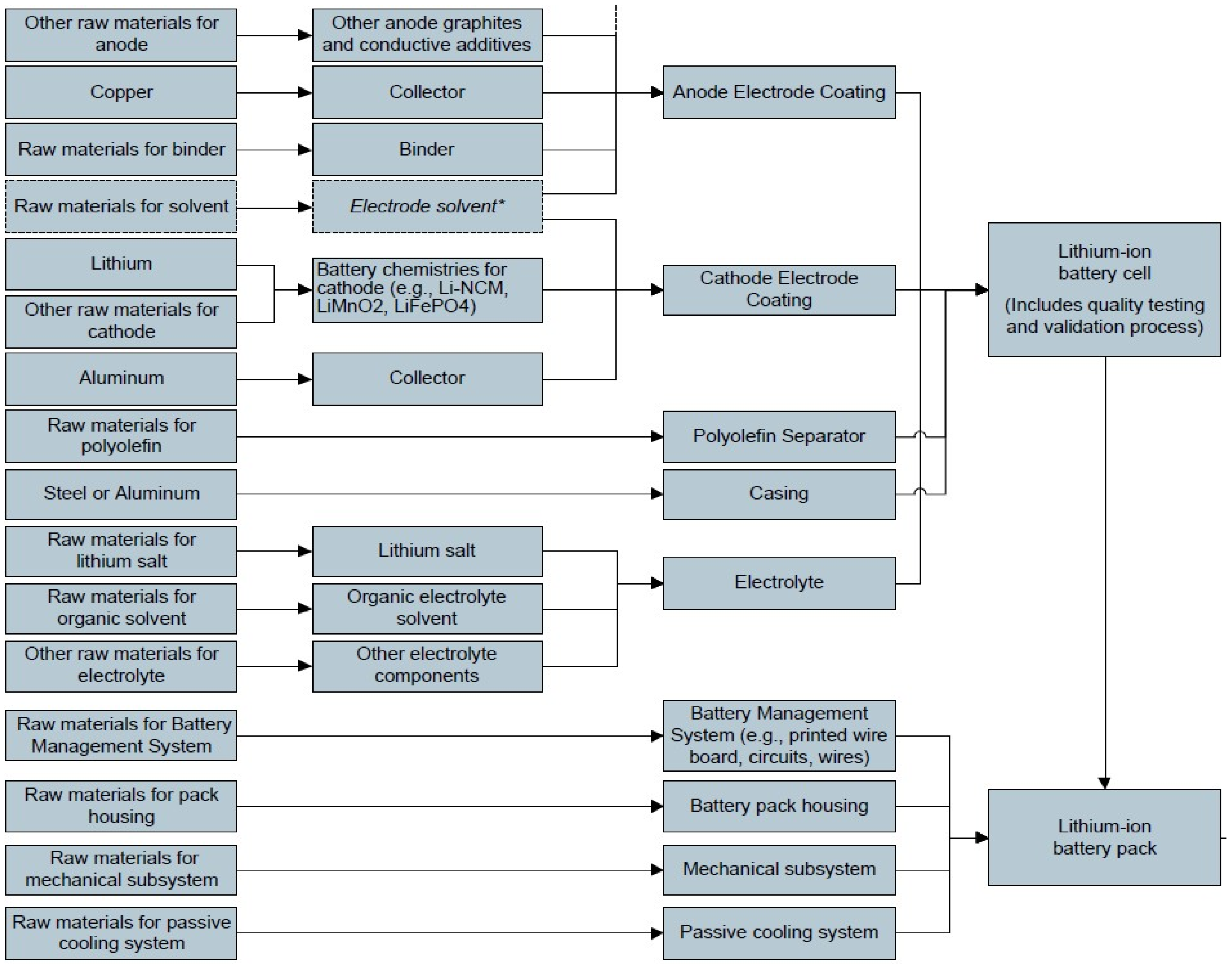
Flow Diagram Li-Ion Battery Manufacturing



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Cradle-to-Gate Energy Use and GWP: Literature Search

The primary energy used to produce a battery is about 400 times the amount of energy a battery can store

Literature	CO_2 equiv. emission (kg/kWh)	Primary Energy Use (kWh Production/kWh Battery Storage Capacity)
1	90 – 145*	190 – 290*
2	170	
3	170**	590**
4	112	490
5	220	
6		210 – 310**
Durchschnitt	**158**	**400**

*50% added for the pack
**Assuming a battery pack with 100 Wh/kg

1. McManus, M.C. (2012) Environmental consequences of the use of batteries in low carbon systems: The impact of battery production. Applied Energy. 93: 288-295
2. Graf, R. et al. (2015) Bewertung der Praxistauglichkeit und Umweltwirkungen von Elektrofahrzeugen – Zwischenbericht. Herausgeber BMVI
3. Aguirre, K. et al. (2012) Lifecycle Analysis of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. Report to the California Air Resources Board
4. Amarakoon, S. et al. (2013) Application of Life-Cycle Assessment to Nanaoscale Technology: Lithium Ion Batteries for Electric Vehicles. EPA 744-R-12-001
5. Majeau-Bettez, G. et al. (2011) Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. Environmental Science & Technology 45(10): 4548–4554
6. Dunn, JB et al. (2015) The significance in Li-Ion batteries in electric vehicle life cycle energy and emissions and recycling's role in its reduction. Energy and Environmental Science 8, 158-168

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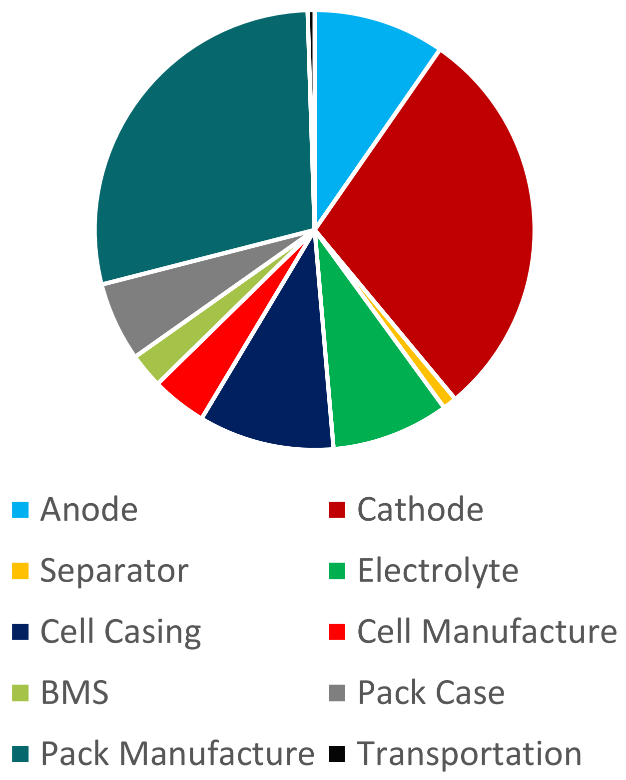
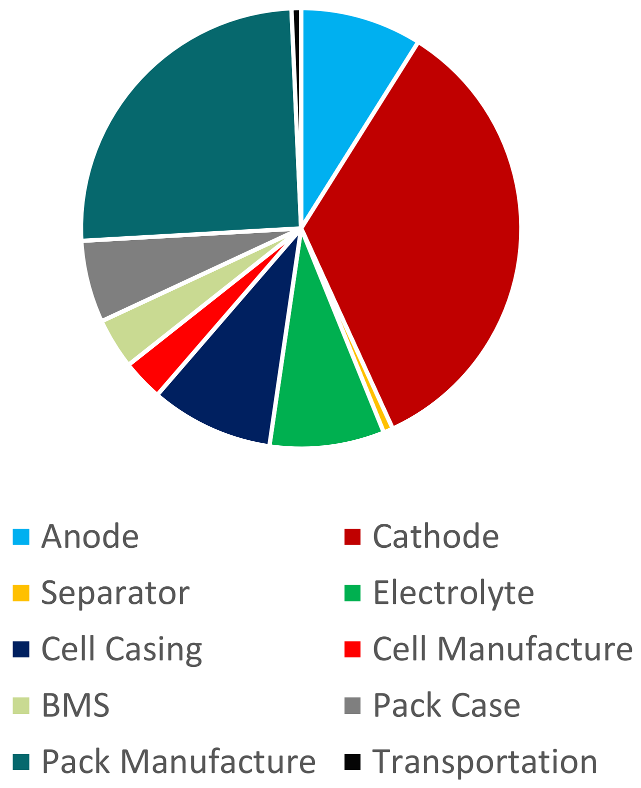
Contributions of Battery Components and Manufacturing

Largest contributor to Primary Energy Use and GWP is the cathode

Primary Energy Use (Total 490 kWh/kWh)



GWP
(Total 112 kg of CO2 equiv./kWh)

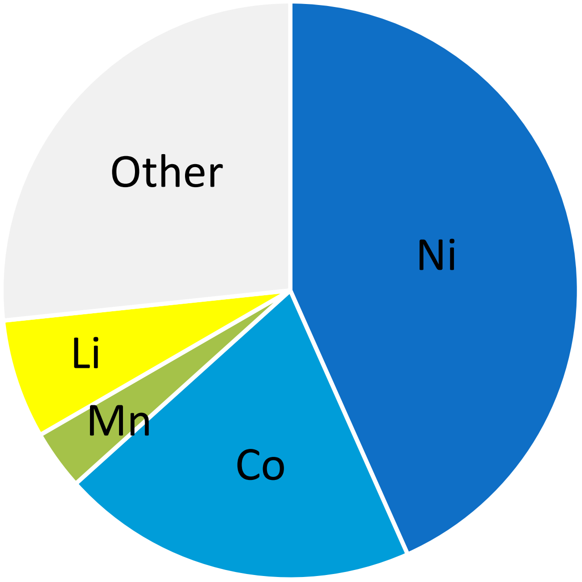


Amarakoon, S. et al. (2013) Application of Life-Cycle Assessment to Nanaoscale Technology: Lithium Ion Batteries for Electric Vehicles. EPA 744-R-12-001

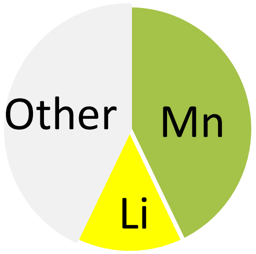
Dependence on Cathode Type

- NMC has by far the largest use of primary energy in its manufacturing
- The largest contributions are due to the use of Ni and Co
- The complex manufacturing process plays also a role

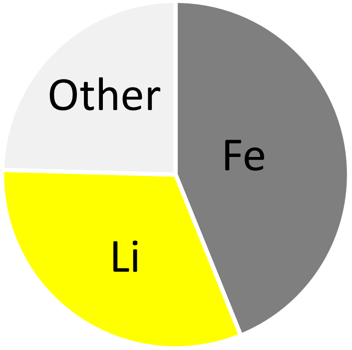
NMC, 155 MJ per kg
or 70 kWh per kWh battery capacity



LMO, 35 MJ per kg
or 20 kWh per kWh



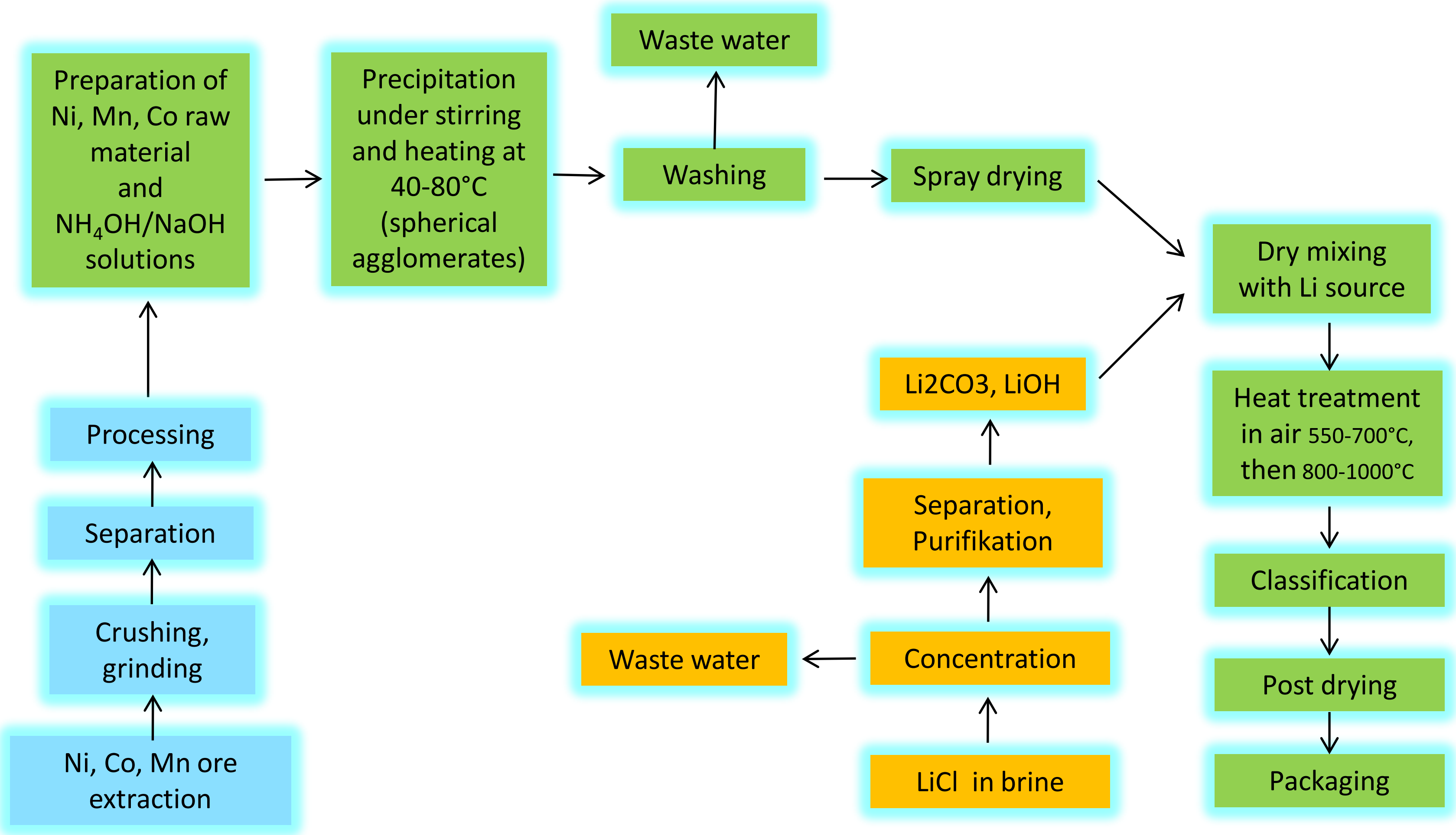
LFP, 55 MJ per kg (Hydrothermal process)
or 30 kWh per kWh capacity



Dunn, JB et al. (2015) The significance in Li-Ion batteries in electric vehicle life cycle energy and emissions and recycling‘s role in its reduction. Energy and Environmental Science 8, 158-168

Synthesis of NMC through Co-Precipitation

Complex and energy intensive processes from the ore to the finished cathode material



Impact of Metals Used in Batteries

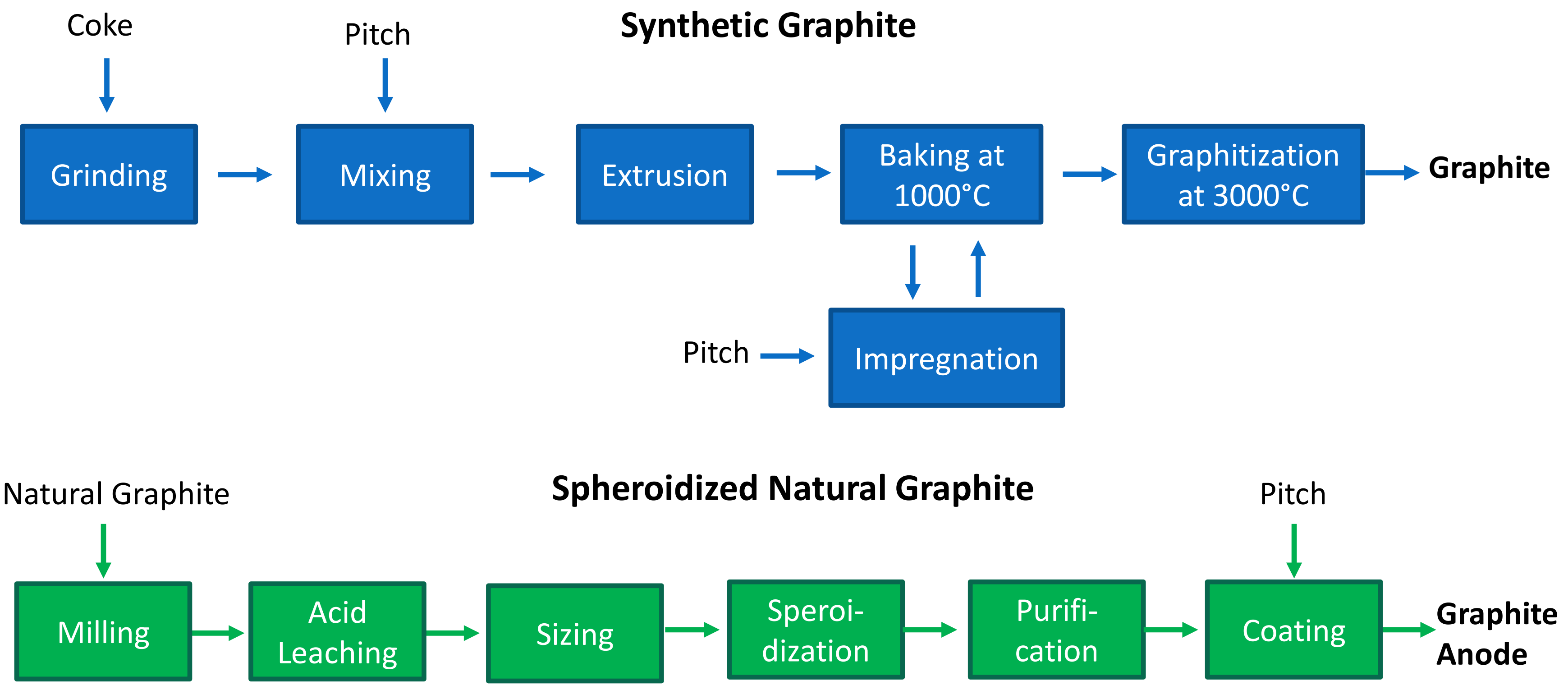
- Next to Ni and Co, the impact on energy use and GWP is also high for Al
- Ni, Co and Cu are responsible for significant SO_2 emission

Metal	**Source**	**Process**	**Use in Batteries**	**Impact**		
				Energy	GWP	Other
Nickel	Sulphide ore (2.3% Ni)	Smelting, refining	Cathode	high	high	SO_2
Cobalt	Sulphide ore	By-product Ni, Cu mining	Cathode	high	high	Resource depletion, SO_2
Manganese	Oxide ore (35%)	Smelting, electrolytic	Cathode	low	low	
Iron	Iron ore (64% Fe)	Blast furnace	Cathode	low	low	
Copper	Sulphide ore	Smelting, electro refining	Anode	medium	medium	SO_2
Aluminum	Bauxite ore (17% Al)	Electrorefining, smelting	Cathode, cell case	high	high	
Lithium	Brine	Concentrating, purifying	Cathode	low	low	Long term resource depletion

Norgate, T.E. (2007) Assessing the environmental impact of metal production processes, Journal Cleaner Production, 15, 838–848
Gaines, L. (2016) Lifecycle Analysis of Li-Ion Batteries and End of Life Issues, Presentation ENV-Vision, Washington DC

Graphite Anode Materials

- Synthetic graphite and spheroidized natural graphite are most commonly used
- The energy used in the synthesis of graphite anode material corresponds to 10 kWh per kWh of battery storage
- The copper foil used for the anode has a similar contribution (7 kWh/kWh)



Dunn, J.B. et al. (2015) Material and Energy Flows in the Production of Cathode and Anode Materials for Lithium Ion Batteries, Report ANL/ESD-14/10 Rev.

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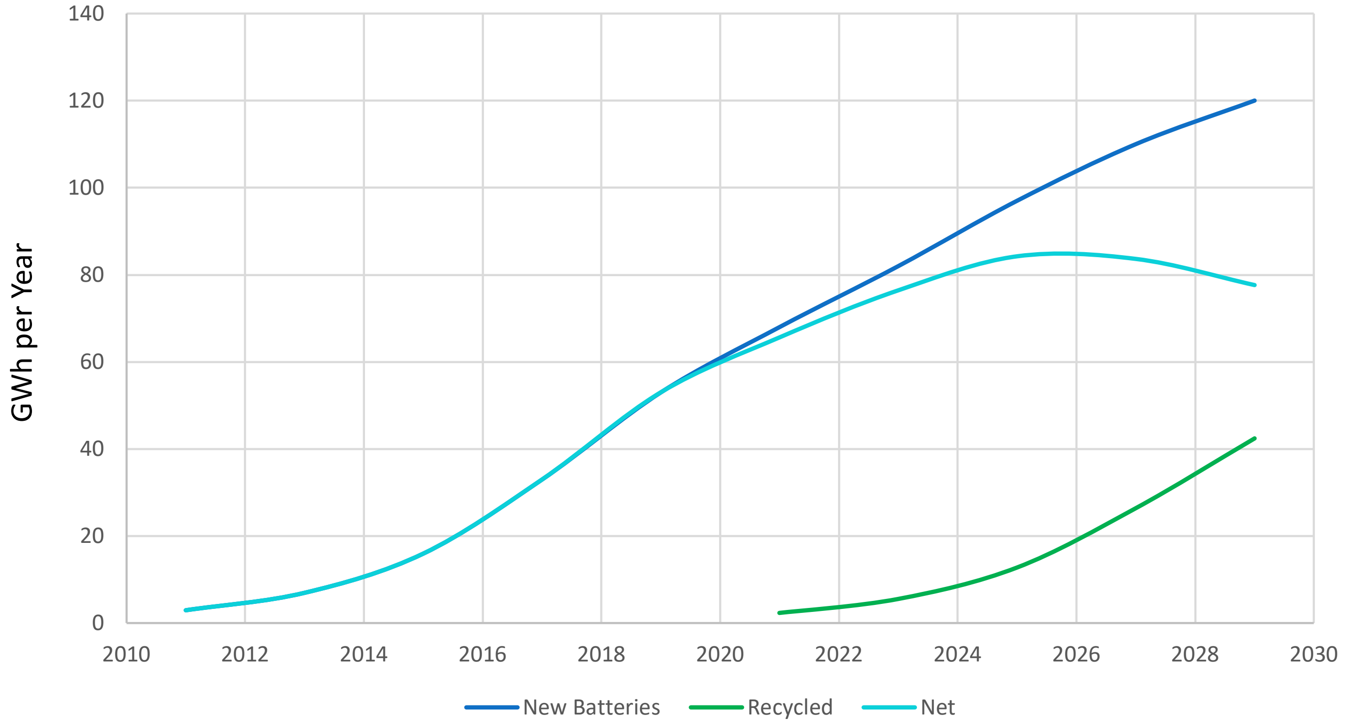
Re-Use and Recycling

- Re-Use (second life), for example for stationary storage, will spread the energy and resource use over a longer time period and reduce the requirement for new battery production
- Recycling will reduce the resource requirements only in the longer term
  - The long life and the fast rise of the market will lead to a peak demand of resources
  - The size and timing of the peak use of new materials will depend on market development



Market development adopted from Pillot, C (2015) The Rechargeable Battery Market and Main Trends 2014-2025, AABC Europe 2015
Assumptions: 10 year battery life, 80% of materials recovered by recycling

Additional Opportunities to Reduce the Environmental Impact

- Increase in energy density will also reduce the amount of materials required per kWh battery energy storage capacity
  - Reduction of non-active components (e.g. Cu and Al-foil)
  - Higher capacities of cathode materials per transition metal
  - High capacity Li-alloys as anodes to replace graphite
- Improved cycle and calendar life will allow for extended second use
- Recycling technologies that recover not only base metals but allow the re-use of cell components such as active materials
- From an environmental point of view, critical elements such as Ni and Co should be reduced or replaced
- The impact of cell manufacturing can be reduced for example by replacing organic solvents in electrode fabrication
- Renewable energy should be used in cell and battery manufacturing (see Tesla Giga Fab)
- Fast charging capability and sufficient charging opportunity to eliminate requirement for large (e.g. 100kWh) batteries to overcome range issue of BEV

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Summary and Conclusions

- Compared to conventional vehicles, the battery of a BEV adds a large additional environmental burden
- For example, the energy required to manufacture the battery is 400 times the energy storage capacity
- Depending on many factors like the size of the battery, the GWP of the electricity source and the fuel of the conventional vehicle, it can take 100,000 km of car mileage to have a positive impact of the BEV
- The largest contributor to the energy requirement and GWP is the cathode
  - Nickel and cobalt are by far the largest contributors
- Other elements that have a big impact are aluminum, copper and graphite
- Recycling and reuse are necessary to reduce the impact significantly
  - They will however have a delayed effect due to the fast growth of the market und the long battery life
- The trend towards higher energy densities is generally beneficial
- Fast charging and sufficient charging opportunities have a lower impact than large batteries with a longer range

Thank you for your attention!

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