ZEMO LCA WEBINAR SERIES: INSIGHTS INTO EV BATTERY LIFE CYCLE ANALYSIS
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LITHIUM BATTERY LIFE CYCLE ANALYSIS

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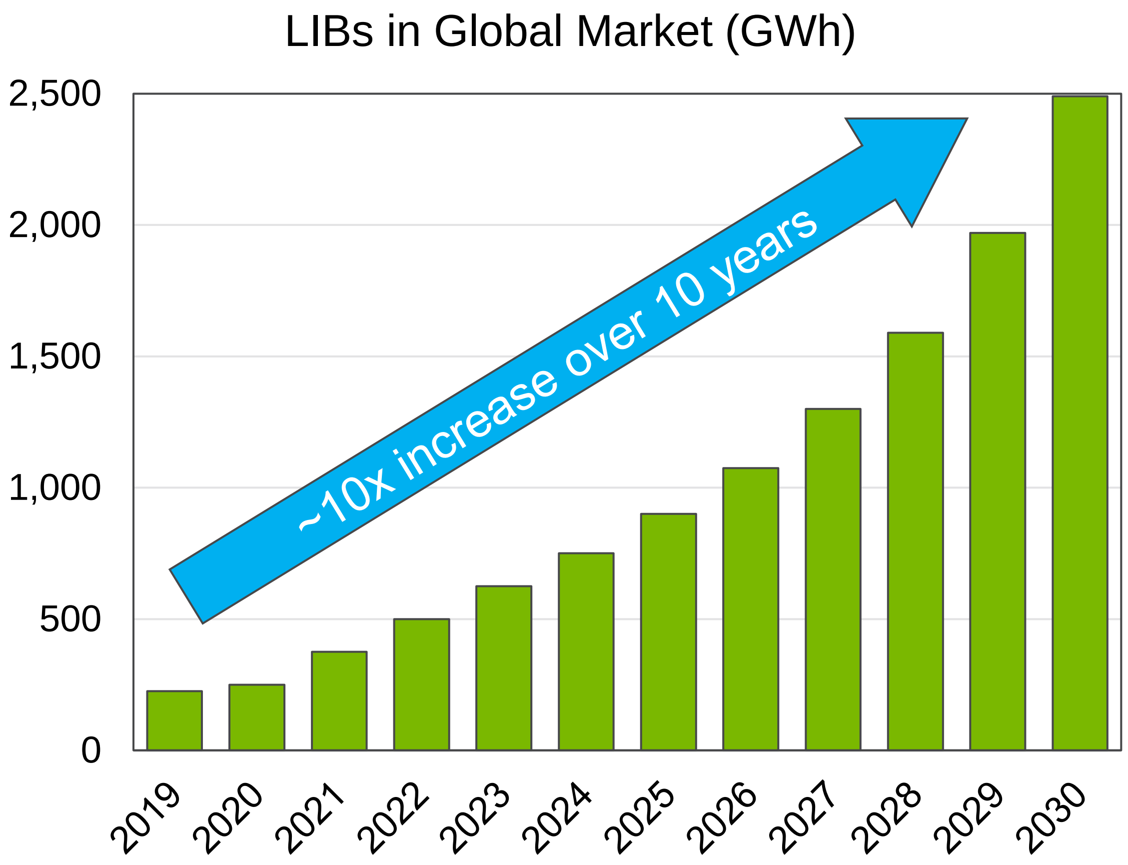
SCALE OF LITHIUM ION BATTERY DEMAND

Multi-sectoral demand for LIB now and in the future

- LIB demand includes:
  - Consumer electronics
  - Personal transport (scooters, bikes, etc.)
  - Light duty vehicles
  - Medium/Heavy duty vehicles
  - Stationary battery storage
- Global goals to reduce fossil fuel usage
  - Batteries for mobile energy storage
  - Stationary batteries to accommodate renewable electricity supply fluctuations and misalignment with demand



Developed based on data from Hans Eric Melin, Circular Energy Storage

OUTLINE

- Life cycle analysis (LCA) using Argonne's GREET® model
- Development of lithium-ion battery (LIB) LCA
- Lithium from brine and ore
- Effects of location on battery LCA

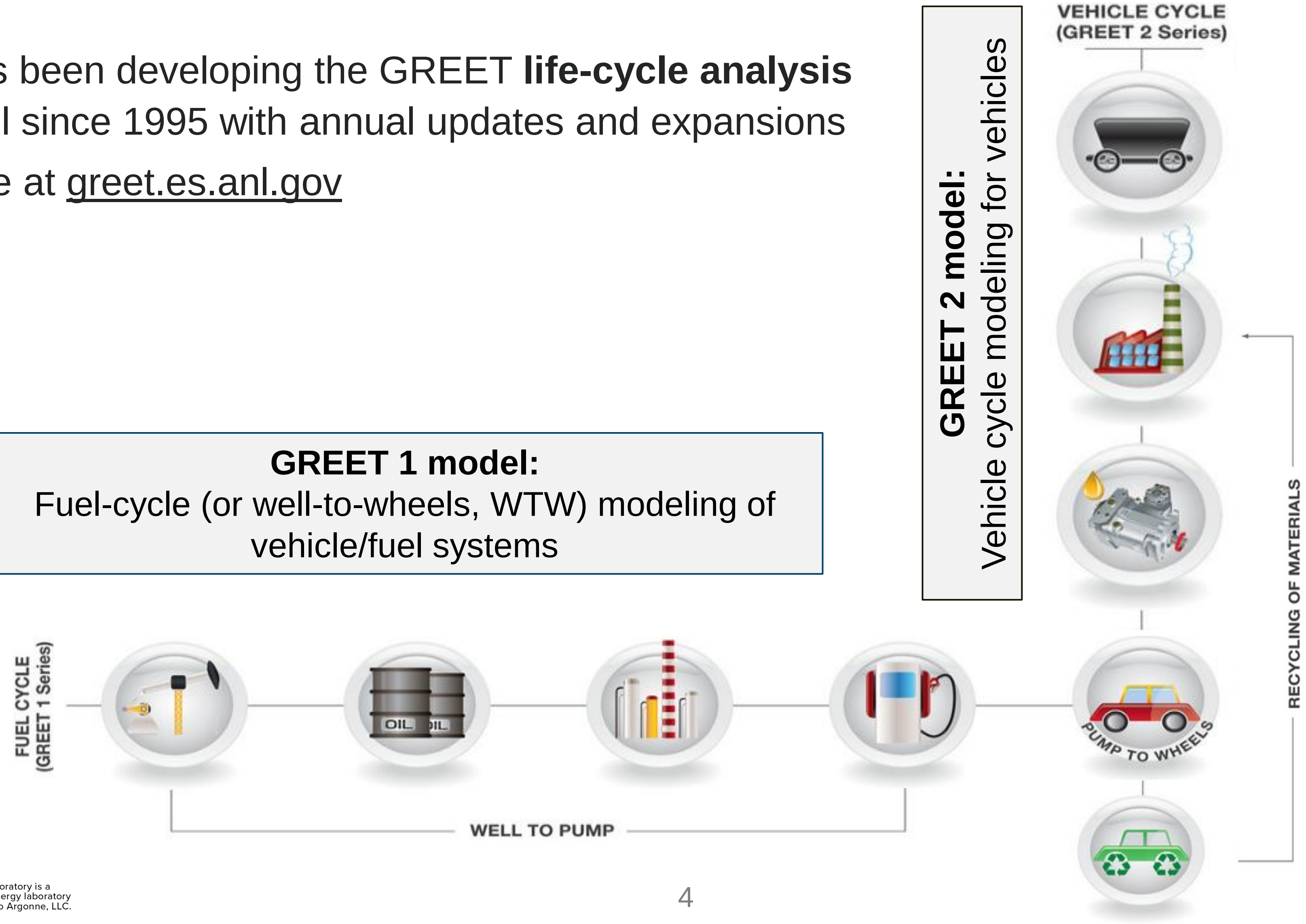
THE GREET® MODEL

(Greenhouse gases, Regulated Emissions, and Energy use in Technology)

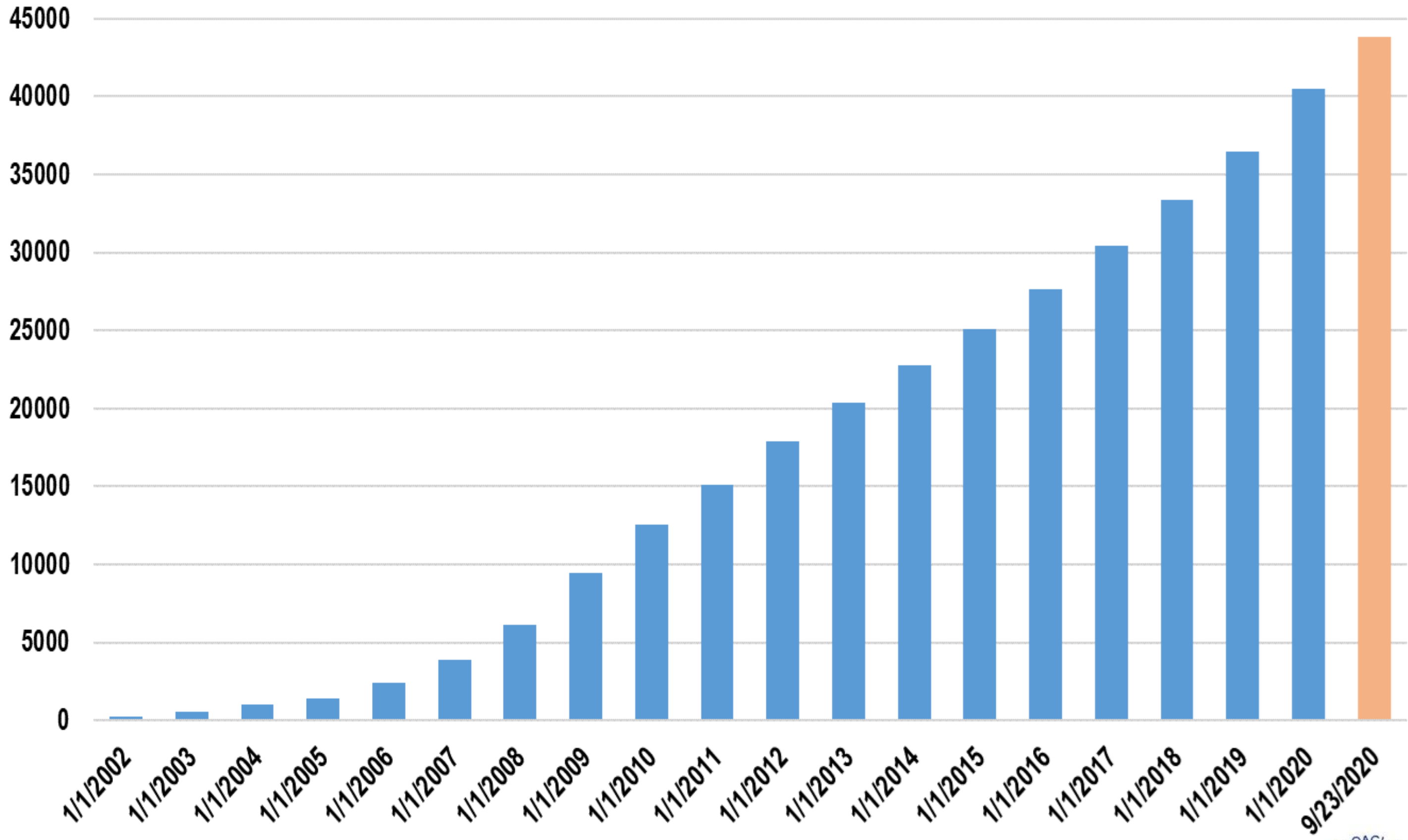
- Argonne has been developing the GREET **life-cycle analysis (LCA)** model since 1995 with annual updates and expansions
- It is available at greet.es.anl.gov

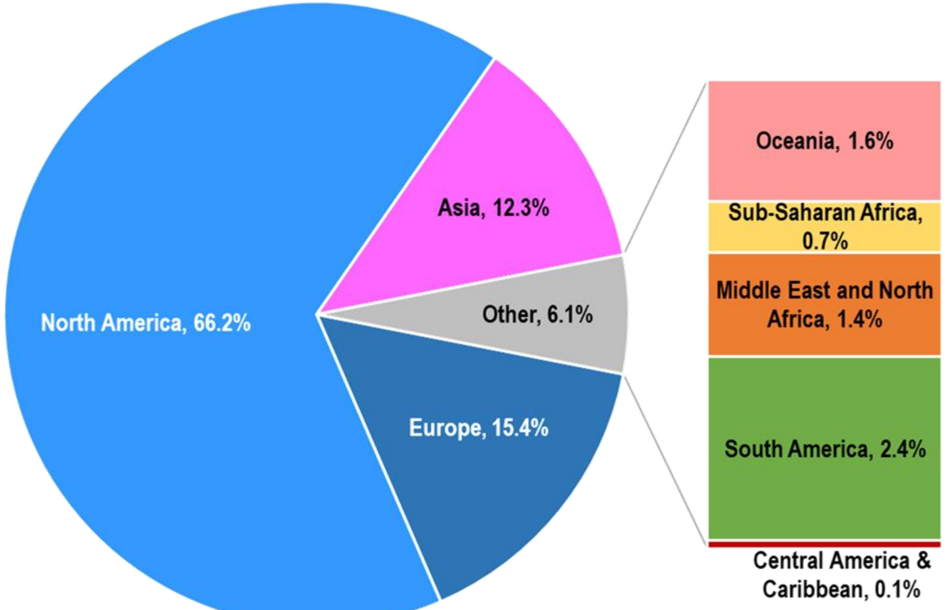
GREET 2 model:
Vehicle cycle modeling for vehicles

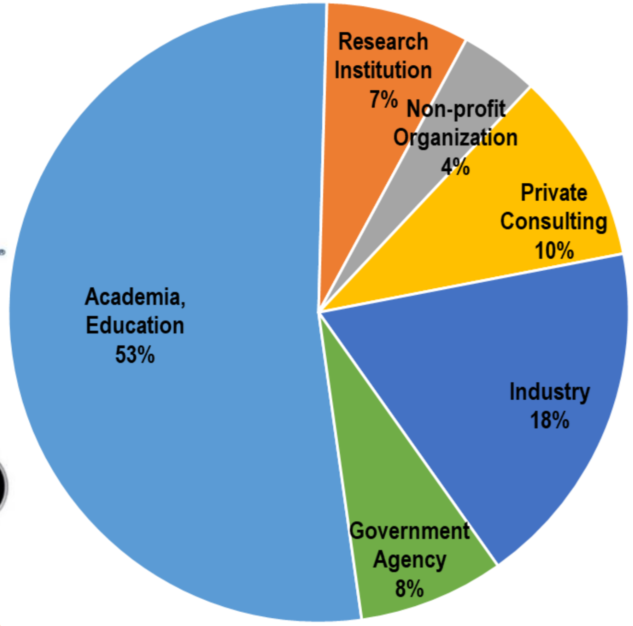
GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems



~ 44,000 Registered GREET Users Globally

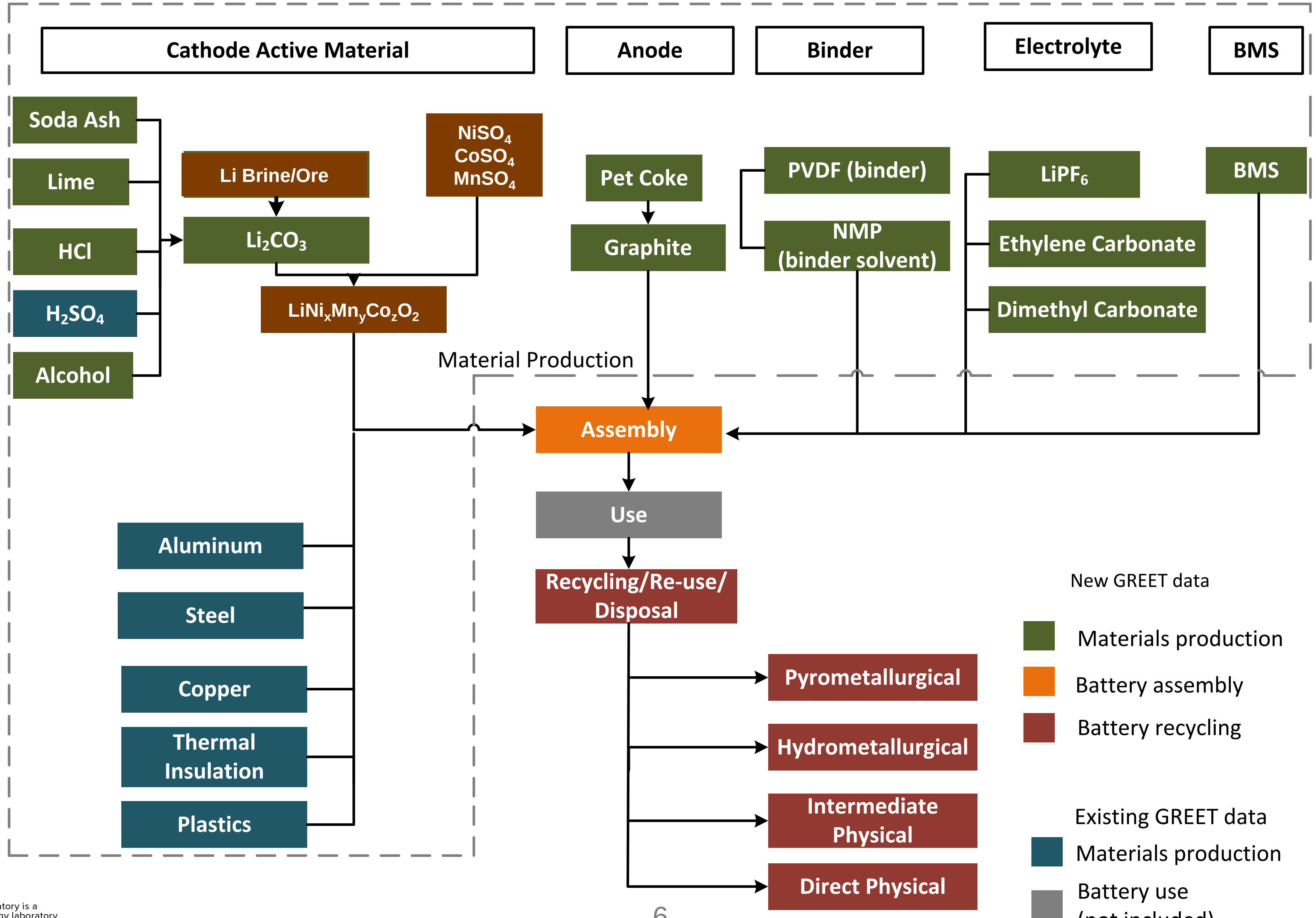






GREET BATTERY LCA MODULE

For LIBs, contains detailed component and material breakdowns



CELL PRODUCTION

A significant energy consumer, does not scale linearly with production

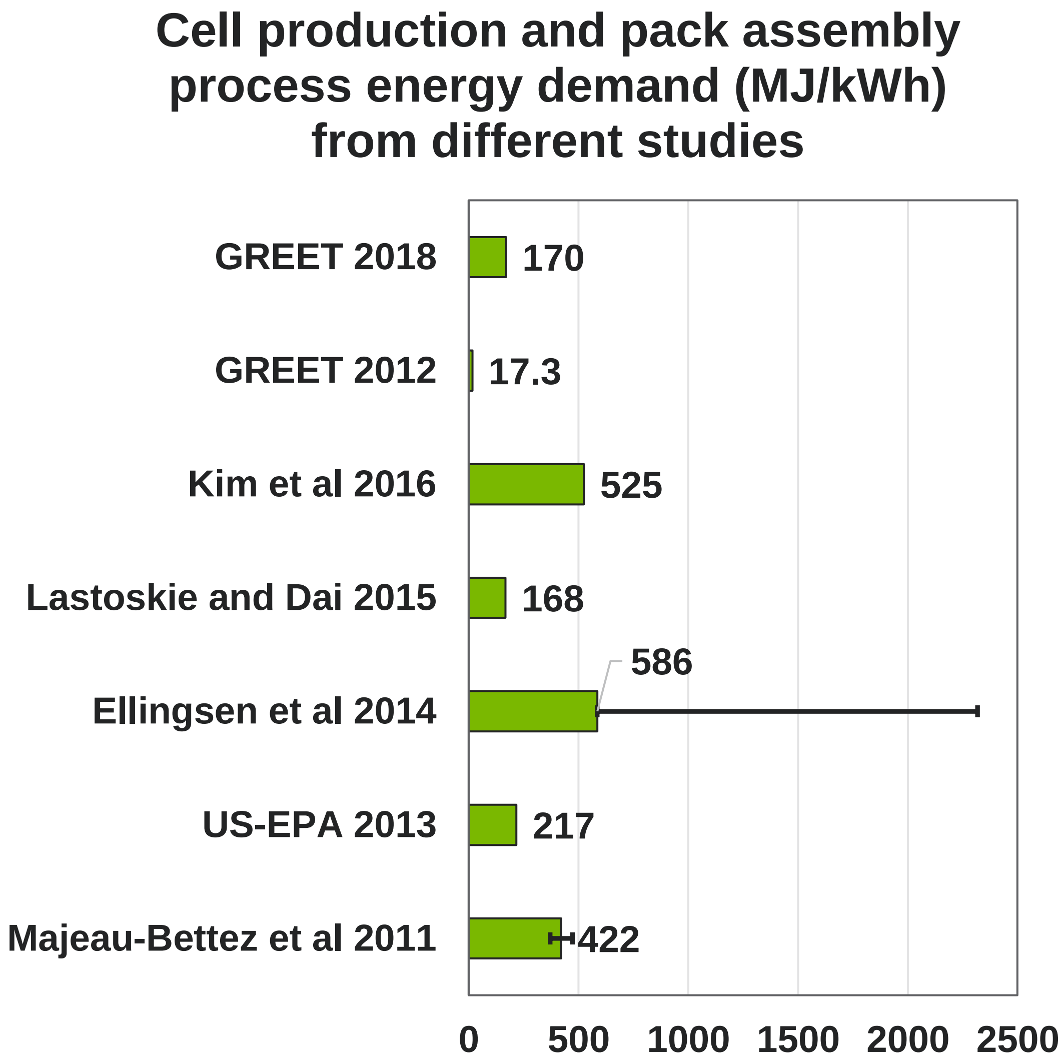
- Consists of electrode production, cell stacking, current collector welding, cell encasement, electrolyte filling, and cell closure (Dai *et al.* 2017)
- All steps occur in dry room
  - Prevent the electrolyte salt, $LiPF_6$, from reacting with water (Ahmed *et al.* 2016)
  - Moisture content of the air <100 ppmv
- Dry room conditions must be maintained regardless of total throughput
  - Energy consumption is essentially the same regardless of total production within limits of that particular dry room

ANL CAMP Facility

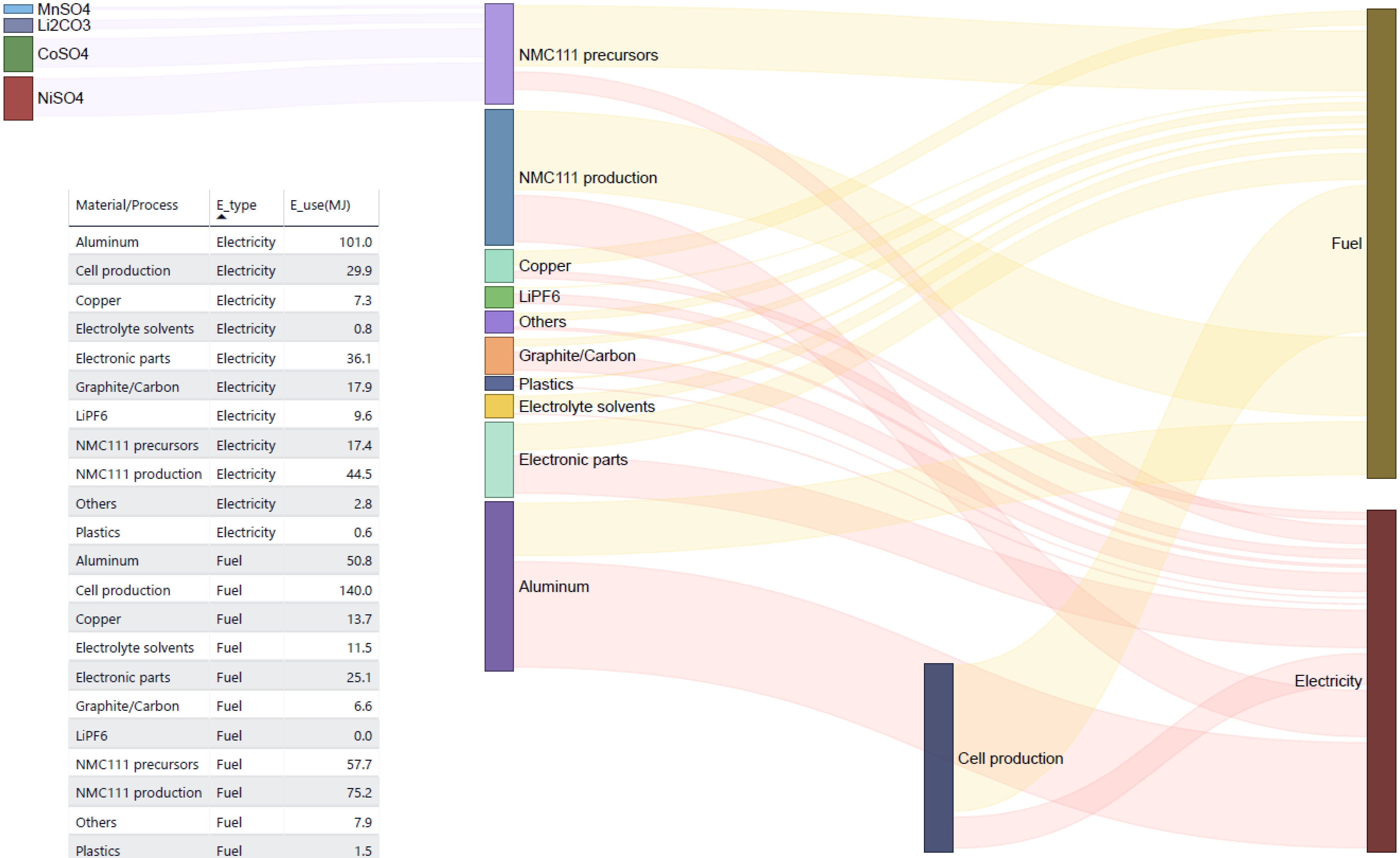
https://www.anl.gov/cse/cell-analysis-modeling-and-prototyping-camp-facility

CELL PRODUCTION AND PACK ASSEMBLY

- The energy demand for cell production and pack assembly in GREET was updated in 2017, based on primary data for a 2 GWh/yr battery production line operating at 75% capacity.
- Dry room operation and electrode drying are the two most energy-intensive processes for LIB production.
- The energy consumption of a dry room is largely determined by its volume. With the same dry room, higher production throughput leads to lower energy use per kWh LIB produced.



PROCESS ENERGY FOR 1KWH NMC111 BATTERY



Material/Process	E_type	E_use(MJ)
Aluminum	Electricity	101.0
Cell production	Electricity	29.9
Copper	Electricity	7.3
Electrolyte solvents	Electricity	0.8
Electronic parts	Electricity	36.1
Graphite/Carbon	Electricity	17.9
LiPF6	Electricity	9.6
NMC111 precursors	Electricity	17.4
NMC111 production	Electricity	44.5
Others	Electricity	2.8
Plastics	Electricity	0.6
Aluminum	Fuel	50.8
Cell production	Fuel	140.0
Copper	Fuel	13.7
Electrolyte solvents	Fuel	11.5
Electronic parts	Fuel	25.1
Graphite/Carbon	Fuel	6.6
LiPF6	Fuel	0.0
NMC111 precursors	Fuel	57.7
NMC111 production	Fuel	75.2
Others	Fuel	7.9
Plastics	Fuel	1.5

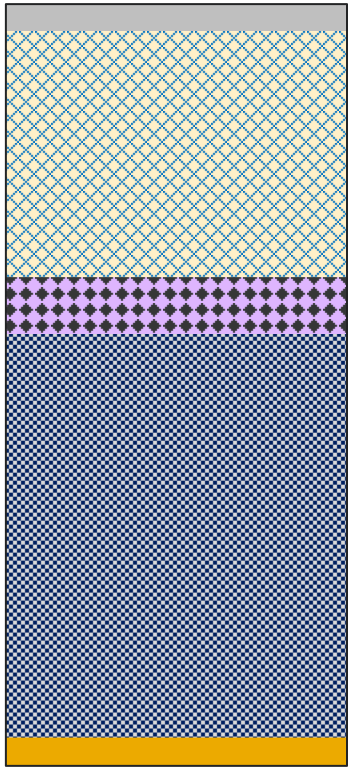
“Others” include PVDF, steel, insulation, and coolant.

Source: Dai *et al.*, **Batteries** 2019, 5, 48.

RECENT EFFORTS IN LIB LCA

Argonne continues to improve understanding of battery materials

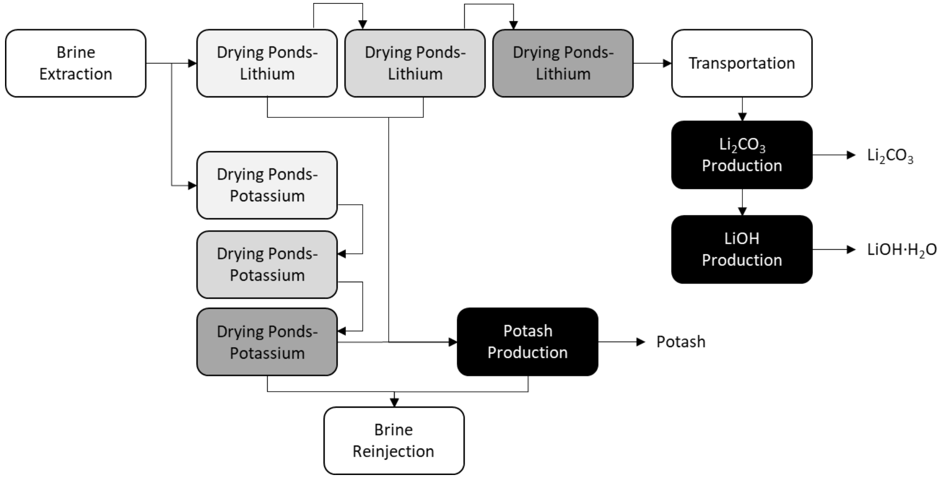
- Lithium
  - Updated and expanded background life cycle inventory (LCI) data
  - Consider production from brine (Chile) and ore (Australia, with processing in China)
  - Based on primary and modeling data
- Regionality
  - Improved coverage and variability to allow defined locationality of certain material and process provenance
  - Li, Al, Ni, cathode material, battery assembly, etc.
- Refine battery energy and composition based on latest BatPac model

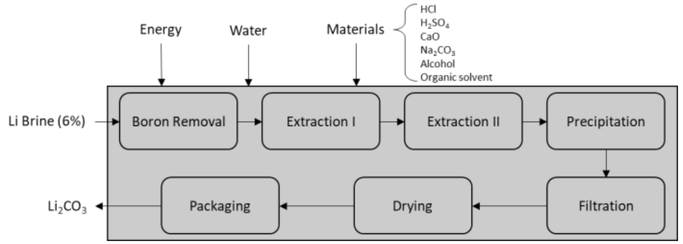


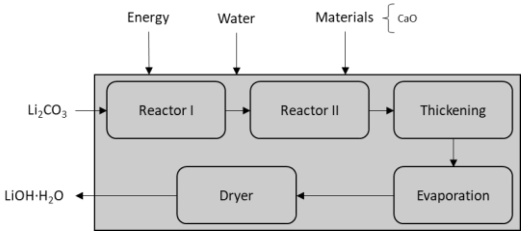
Adapted from Albertus et al. (2018) *Nature Energy* (https://doi.org/10.1038/s41560-017-0047-2)

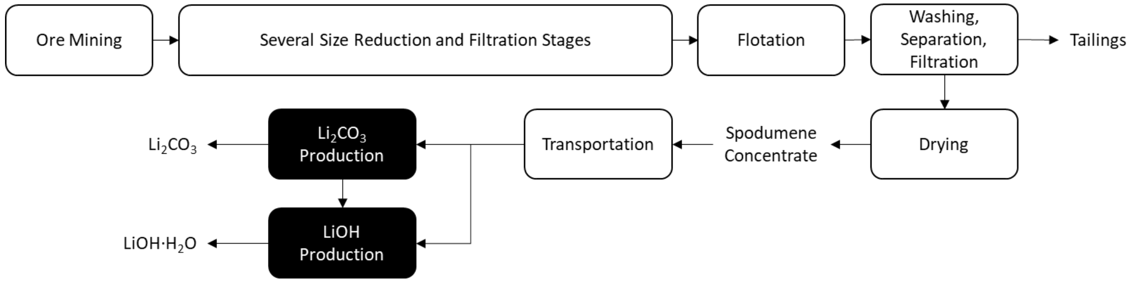
LITHIUM LCA UPDATES

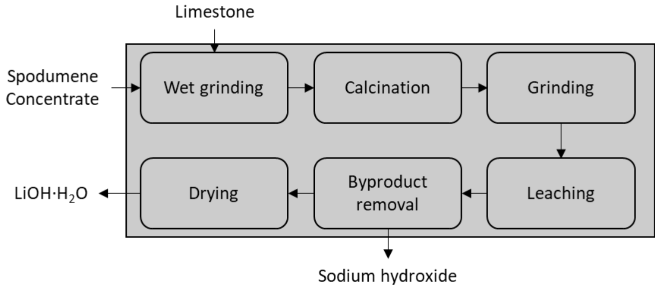
Pathways for brine- and ore-based production







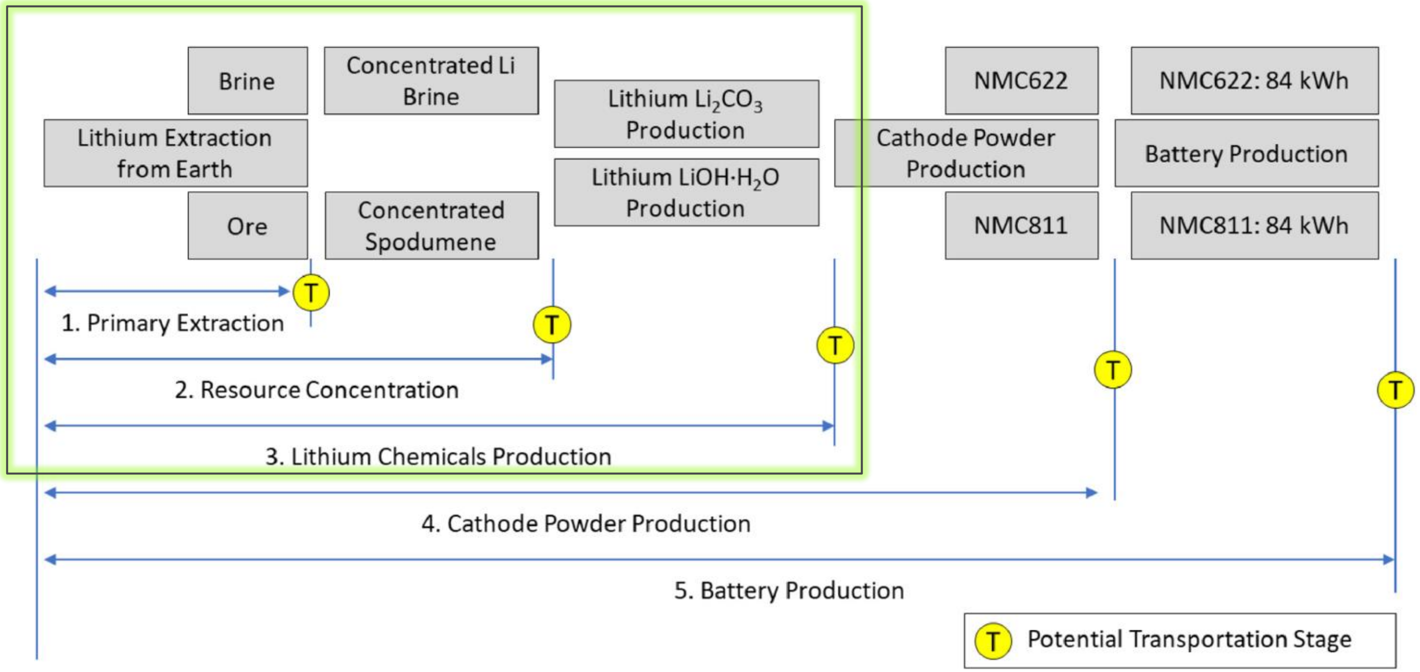


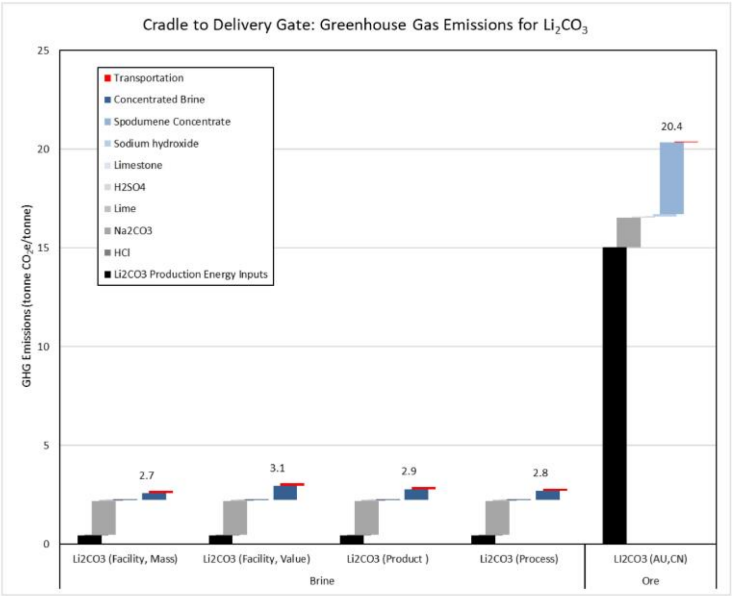


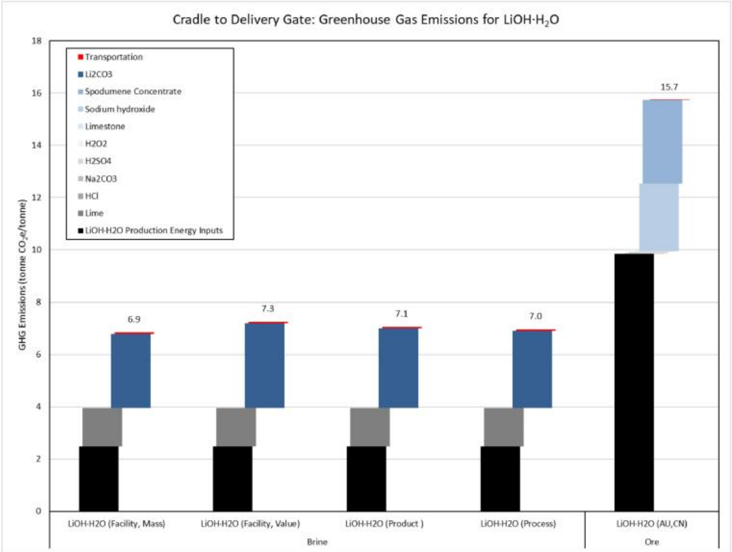
Kelly, Jarod C., et al. "Energy, greenhouse gas, and water life cycle analysis of lithium carbonate …." *Resources, Conservation and Recycling* 174 (2021): 105762. https://doi.org/10.1016/j.resconrec.2021.105762

LITHIUM CHEMICALS LCA

Comparison of Li_2CO_3 and $LiOH.H_2O$ from brine or ore







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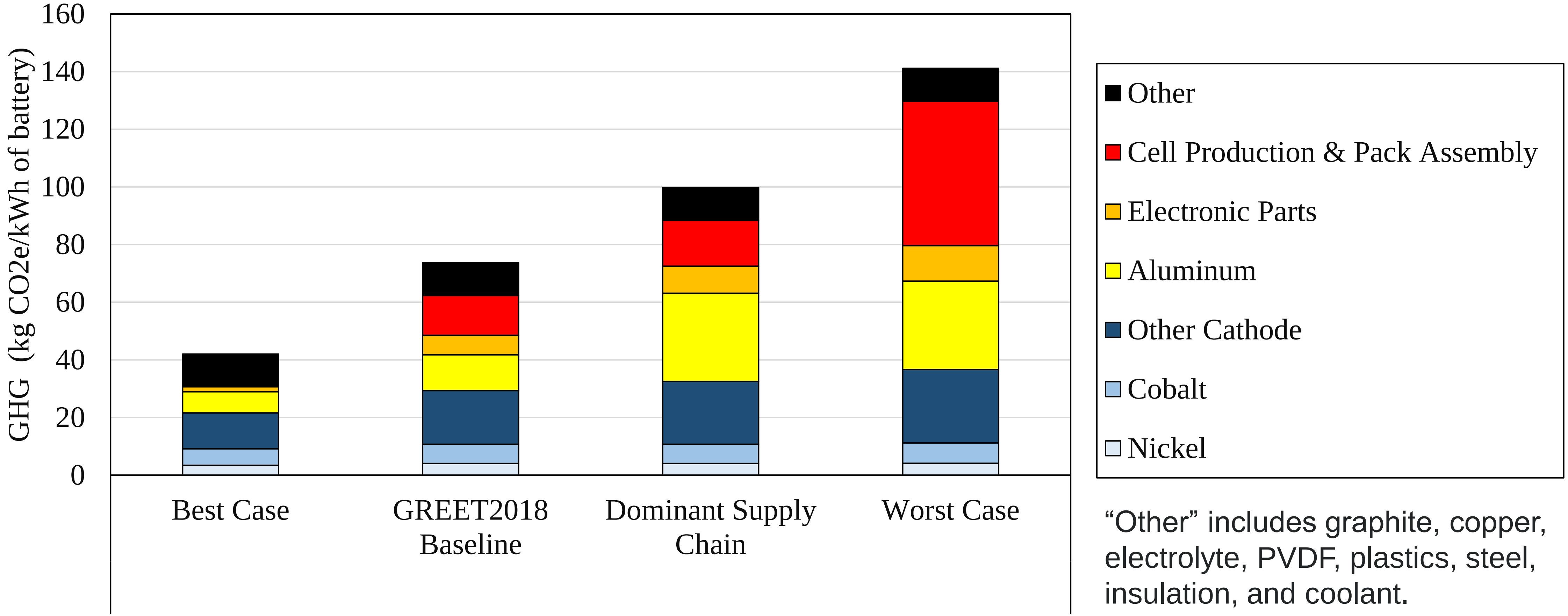
LIB LCA GHG RESULTS

Best, worst, and notable supply chains

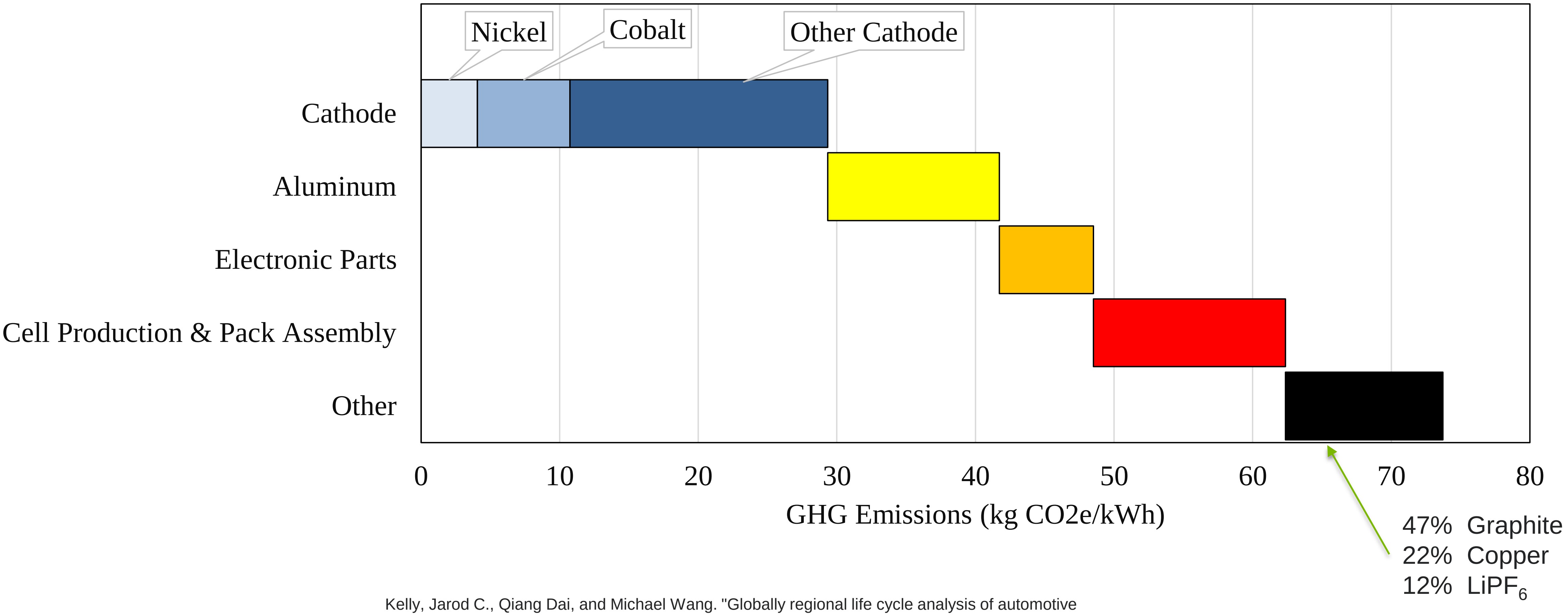


“Other” includes graphite, copper, electrolyte, PVDF, plastics, steel, insulation, and coolant.
“Other Cathode” includes process energy use and non-Ni/Co reagents.

Kelly, Jarod C., Qiang Dai, and Michael Wang. "Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries." *Mitigation and Adaptation Strategies for Global Change* 25.3 (2020): 371-396. https://doi.org/10.1007/s11027-019-09869-2

WHAT 'MATTERS MOST' FOR AN NMC111 LIB

GHG Emissions per kWh



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SUMMARY

- Lithium and other material's supply chains are critical in determining the LCA performance of batteries
- Continued understanding of material sources and processing technologies are necessary for appropriate LCA
- The lithium-ion battery market is dynamic and continued advancement means that results of today's LCA may not match those of tomorrow's
  - Increased energy density
  - Change in cathode, anode, electrolyte, etc.

THANK YOU
(AND DOE/VTO)

Questions?


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