

Article

Eco-Efficiency of a Lithium-ion Battery for Electric Vehicles: Influence of Manufacturing Country and Commodity Prices on GHG Emissions and Costs

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Life cycle Inventory

This life cycle inventory uses Ecoinvent 3.4 background data.

Pack manufacturing

A 20-kWh pack is modeled (Table S1). The inventory of Ellingsen et al. [1] is used for module packaging, battery retention, battery tray, battery management system, and cooling system. These components are scaled linearly to the pack energy capacity.

Table S1. Inventory for the manufacturing of a pack manufactured in Korea. BMS: battery management system.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Module packaging	35.7		kg
Battery retention	6.66		kg
Battery tray	18.2		kg
BMS	7.00		kg
Cooling system	7.76		kg
Cell, NCA-G, 21700, (KR)	78.3		kg
Precious metal refinery {RoW} construction APOS, U	2.93×10^{-6}		p
Electricity, medium voltage {KR} market for APOS, U	0.0616		kWh
Heat, waste		0.0616	kWh
Battery pack		154	kg

The cell inventory originates from the dismantling activity. The manufacturing yields found in the BatPac model [2] were used to calculate the waste amount (Table S2). In the cell, the cathode substrate is an aluminum sheet, and the anode substrate is a copper sheet. The electrolyte is assumed to be a solution of LiPF₆ in ethylene carbonate/ dimethyl carbonate 50/50 (v/v).

Table S2. Inventory for the manufacturing of cells in Korea.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Paste, cathode, NCA (nickel cobalt aluminium)	0.429		kg
Paste, anode, graphite	0.267		kg
Substrate, cathode	0.023		kg
Substrate, anode	0.03		kg
Electrolyte	0.08		kg

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Separator	0.104		kg
Cell container 21700	0.186		kg
Water, decarbonized, at user {GLO} market for APOS, U	380		kg
Transport, freight, sea, transoceanic ship {GLO} market for APOS, U	20		tkm
Transport, freight, lorry, unspecified {RER} market for APOS, U	0.13		tkm
Electricity, medium voltage {KR} market for APOS, U	16.7		kWh
Water		380	kg
Heat, waste		16.7	kWh
Cell, NCA-G, 21700, (KR)		1	kg
Market for used Li-ion battery		0.12	kg

X-Ray Diffraction (XRD) analysis and energy dispersed X-ray spectroscopy (EDX) are used to determine the cathode paste nature and chemical composition (**Error! Not a valid bookmark self-reference.**).

Table S3. Inventory for the manufacturing of the cathode paste.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Active material, cathode, $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$	0.94		kg
Carbon black {GLO} market for APOS, U	0.02		kg
Polyvinylfluoride {GLO} market for APOS, U	0.04		kg
N-methyl-2-pyrrolidone {GLO} market for APOS, U	0.01		kg
Transport, freight train {GLO} market group for APOS, U	0.309		tkm
Transport, freight, lorry, unspecified {GLO} market for APOS, U	0.209		tkm
Transport, freight, sea, transoceanic ship {GLO} market for APOS, U	0.599		tkm
Chemical factory, organics {GLO} market for APOS, U	4×10^{-10}		p
1-Methyl-2-pyrrolidinone		0.01	kg
Paste, cathode, NCA		1	kg

The cathode active material (Table S4) and precursor (Table S5) is modelled based on [3].

Table S4. Inventory for the manufacturing of the cathode active material.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
$\text{Ni}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}(\text{OH})_2$	0.95		kg
Lithium hydroxide {GLO} market for APOS, U	0.25		kg
Oxygen, liquid {RER} market for APOS, U	0.04		kg
Water, decarbonized, at user {GLO} market for APOS, U	0.188		kg
Electricity, medium voltage {GLO} market group for APOS, U	0.443		kWh
Water		0.422	kg
Hydrogen		0.005	kg
Aluminum		3.80×10^{-4}	kg
Nickel		6.49×10^{-4}	kg
Cobalt		1.22×10^{-4}	kg
Lithium		2.19×10^{-4}	kg
Active material, cathode, $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$		1	kg

Cobalt sulfate is modeled according to [4] and nickel sulfate is modeled according to [5].

Table S5. Inventory for the manufacturing of NCA precursor.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Aluminium sulfate, powder {GLO} market for APOS, U	0.094		kg
Cobalt sulfate CoSO_4 (CN)	0.26		kg
Nickel sulfate (CN) NiSO_4	1.36		kg
Sodium hydroxide, without water, in 50% solution state {GLO} market for APOS, U	0.88		kg

Ammonia, liquid {RER} market for APOS, U	0.37	kg
Electricity, medium voltage {GLO} market group for APOS, U	0.012	kWh
Heat, central or small-scale, natural gas {GLO} market group for APOS, U	0.0352	kWh
Ammonia	0.370	kg
Water	1.42×10^{-17}	kg
Nickel	0.00071	kg
Cobalt	0.00188	kg
Sulfate	0.0306	kg
Sodium sulfate	1.56	kg
Sodium hydroxide	0.00247	kg
$\text{Ni}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}(\text{OH})_2$	1	kg

The anode paste is graphite doped with silicon (Table S6). The Ecoinvent data for metallurgical grade is used to model silicon [6].

Table S6. Inventory for the manufacturing of the anode paste.

Materials/Fuels/Electricity/Heat/Emissions	Input	Output	Unit
Graphite, battery grade {GLO} market for APOS, U	0.94		kg
Silicon, metallurgical grade {GLO} market for APOS, U	0.02		kg
Styrene-acrylonitrile copolymer {GLO} market for APOS, U	0.04		kg
Chemical plant	4×10^{-10}		P
Water		0.96	kg

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