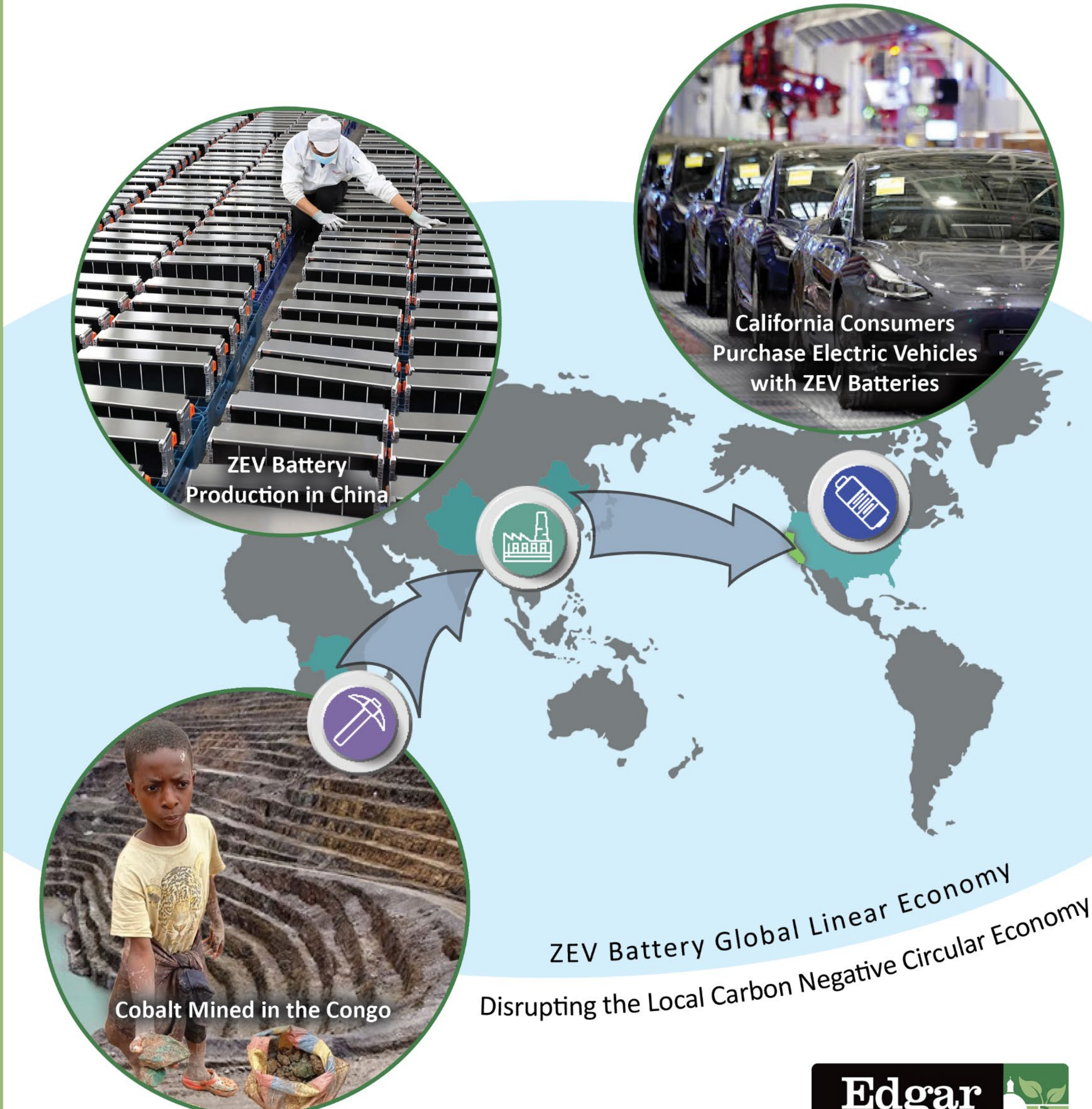
Life Cycle Greenhouse Gas Impacts of Electric Vehicle Battery Manufacturing

Edgar & Associates Inc. | March 23, 2022



Edgar & Associates

Life Cycle Greenhouse Gas Impacts of Electric Vehicle Battery Manufacturing

Edgar & Associates Inc. March 23, 2022

Edgar & Associates, Inc. is an environmental engineering company and lobbying firm based in Sacramento and specializing in all aspects of solid waste management, recycling, composting, renewable energy, clean fleets, low carbon fuel, greenhouse gas reductions strategies, and calculating verifiable carbon footprints. Edgar & Associates, Inc. acts as technical adviser and consultant to companies involved with materials management services including collection, hauling, processing, recycling, composting, bioenergy, and anaerobic digestion. Edgar & Associates, Inc. assists in the deployment of technologies and in obtaining grant funding to commercialize low carbon systems. Since its inception, we have assisted companies' greater levels of waste diversion and the lowest carbon footprint possible. Edgar & Associates has technical staff of engineers and environmental scientists competent in all aspects of life cycle analysis for low carbon fuel programs, Net-Zero greenhouse gas analysis, and preparing certified carbon footprints with The Climate Registry.

ZEVs are not Zero Emissions but have a Carbon Intensity of 62 to 90 (gCO_2e/MJ)

ZEVs are not zero emissions but have a carbon intensity of **62 to 90 (gCO_2e/MJ)** when combining the energy required to produce electricity within the battery and the manufacturing of the battery. CARB's existing emissions factor[1] accounts for the energy required to produce the electricity within the battery is **23.39 (gCO_2e/MJ)** when adjusting the energy economy ratio (EER) by a factor of 3.4. The range of emissions from the battery manufacturing alone, assuming a 100,000-mile lifespan, have a carbon intensity of **38.13 – 66.26 (gCO_2e/MJ)**, depending on the type of ZEV battery. Combining the carbon intensity of the electricity from the California grid with the upstream emissions from manufacturing the ZEV batteries, the carbon intensity becomes **62.52 – 90.64 (gCO_2e/MJ)**.

Electric Vehicle Batteries differ from lead-acid batteries found in typical internal combustion engines in important ways. The manufacture, composition, and materials required of the two batteries are substantially dissimilar. Most internal combustion engine passenger vehicles rely on lead-acid battery that typically weigh 18.6 kilograms, whereas electric car batteries weigh approximately 500 kilograms. Lead-acid batteries are comprised of lead and other relatively common inputs, whereas electric vehicle battery rely on more exotic materials such as cobalt, nickel, and lithium. A crucial difference is that lead-acid batteries are not part of the fueling system of vehicles, whereas for an electric vehicle the battery and its contents *are* the fuel.

There has been a series of European Studies that have prepared specific lifecycle analysis on ZEV batteries that are referenced in the report and listed below:

- Lithium-Ion Vehicle Battery Production 2019, IVL in cooperation with Swedish Energy Agency. The Summary of that Report is on the next page.
- Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhous Gas Emissions, 2018, The International Council on Clean Transportation

[1] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf

- Report C 444 - Lithium-Ion Vehicle Battery Production – Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling

Summary

This report is an update of the previous report from 2017 by IVL: Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries (C243). It has been financed by the Swedish Energy Agency.

A literature study on Life Cycle Assessments (LCAs) of lithium-ion batteries used in light-duty vehicles was done. The main question presented was, what are the greenhouse gas (GHG) emissions from the production of the lithium-ion batteries for vehicles. A search for standardization of LCA methodology and new information regarding recycling, and information on the supply risks for important lithium-ion battery materials was also included in the literature study.

The data is presented as GHG emissions expressed as CO_2-equivalents, in relation to the batteries' storage capacity, expressed as kWh storage capacity. Based on the new and transparent data, an estimate of 61-106kg CO_2-eq/kWh battery capacity was calculated for the most common type, the NMC chemistry. The difference in the range depends mainly on varying the electricity mix for cell production. If less transparent data are included the maximum value is 146kg CO_2-eq/kWh. The calculated range is substantially lower than the earlier 150-200kg CO_2-eq/kWh battery in the 2017 report. One important reason is that this report includes battery manufacturing with close to 100 percent fossil free electricity in the range, which is not common yet, but likely will be in the future. The decrease in the higher end of the range is mainly due to new production data for cell production, including more realistic measurements of dry-room process energies for commercial-scale factories, and solvent-slurry evaporation estimates that are more in line with actual production. The former range also included emissions from recycling which was about 15kg CO_2-eq/kWh battery, which is not included in the new range.

Regarding standardization of LCA, Product Category Rules (PCRs) are published for their Product Environmental Footprint developed by the European Commission.

The average nickel-content is expected to increase and cobalt-content to decrease in newer batteries as the batteries that are produced are expected to move towards higher energy density and away from cobalt, which is at supply risk. The supply of nickel may in future also become at risk.

The PEF benchmark reports that twelve percent of the total GHG emissions for batteries is in the end-of-life stage in Europe.

There is still a need for more data, especially since the different production steps can be performed in different ways with different efficiencies. Also, better data for electronics production still needs to become available. A standardized way for data collection is recommended, for example by using the Product Environmental Footprint Category Rules (PEFCR). Furthermore, more information on the metals supply chains is needed, as well as better traceability, so that sustainable production can be achieved and guaranteed.

Manufacturing Emissions of Batteries

When considering the life cycle impacts of both vehicle types, the manufacturing emissions of the two different batteries must be considered for an honest representation of the greenhouse gas implications of both vehicles. While both types of vehicles *require* a battery, the emissions created in the production of the two batteries varies greatly. As this report shows, the emissions from the manufacture of an electric vehicle battery for a passenger vehicle is between **80 and 100 times** greater than that of a lead-acid battery.

Although both battery types are essential to the car, the electric vehicle batteries have embedded manufacturing emissions that are at least **4,552 kg/100,000 miles** greater than those of conventional lead-acid batteries. This calculation conservatively assumes that lead-acid batteries have a lifespan of 30,000 miles versus a 100,000-mile lifespan for an electric vehicle battery.

Emissions per average passenger vehicle battery manufactured				
	Li-Ion Battery (high-end estimate) (IVL 2019)	**Li-Ion Battery** (Argonne 2010)	**Li-Ion Battery (low-end estimate)** (IVL 2019)	**Lead-Acid Battery (**Argonne 2010)
kg CO_2e/battery	8,253	5,954	4,749	59
kg CO_2e/ 100,000 miles	8,253	5,954	4,749	197
		Minimum Difference		4,552

Calculation of Manufacturing Emissions of Batteries

For the purposes of this report, the calculation of life cycle emissions for electric vehicle battery manufacture is based on IVL's 2019 report "Lithium-Ion Vehicle Battery Production – Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling". Based on this report as shown in Table 10 on the next page, emissions estimate of **61-106 kg CO_2e/kWh** battery capacity was calculated for the most common type of electric vehicle battery[2].

Attachment 1 extrapolates from this calculation to convert these emissions into the units utilized by the Low Carbon Fuel Standard's emission factors. These emissions factors are grams of carbon dioxide equivalent per megajoule of energy used (g CO_2e/MJ). The range of emissions from the battery manufacture alone, assuming a 100,000-mile lifespan, is **38.13 – 66.26 (gCO_2e/MJ).**

CARB's existing emissions factors for the energy required to produce the electricity within the battery relates to a carbon intensity of **23.39 (gCO_2e/MJ)** [3], which includes an adjustment of 3.4 for the Engine Economy Ratio (EER). When added with the manufacturing emissions, the carbon intensity for ZEV

[2] Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling. IVL in cooperation with Swedish Energy Agency. Authors: Erik Emission, Lisbeth Dahllöf. https://www.ivl.se/download/18.694ca0617a1de98f473464/1628416191286/FULLTEXT01.pdf
[3] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf

battery use becomes **62.52 – 90.64 (gCO_2e/MJ)**, depending on the ZEV battery type as explain in the IVL Study.

Table 10. Total GWPs comparison between value range obtained from calculations in this report with data from Dai et al. (see Section 4.4) and other sources.

Source of data	This report	Argonne National Laboratory (Dai,et al., 2019)	Argonne National Laboratory (Kelly,et al., 2019)	PEFCR (recalculated) (RECHARGE, 2018)
Total production and materials GWP [kg CO_2-eq/kWh battery capacity]	61-106	73	65 (European supply chain), 100 (Chinese supply chain)	77

Attachment 1 – Calculation of Emissions Factor

Electric Vehicle Battery Production Emissions (Low End)			
	Value	**Unit**	**Source**
Low End Emission Factor	61	kg CO_2e/kWh of capacity	Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling. Lithium-Ion Vehicle Battery Production **IVL with Swedish Department of Energy** - **November 2019**
Average EV Car Battery	78	kWh of capacity	Survey of 7 advertised car battery capacities: **Tesla, VW, Hyundai, Chevy, Audi, Volvo, Ford**
Average Battery Production Emissions	4,749	kg CO_2e/battery produced	(Low End Emissions Factor) X (Average EV Car Battery)
Average Expected Lifespan of EV Battery	100,000	miles/battery	https://www.autotrader.com/car-tips/how-long-do-electric-car-batteries-last
Battery Emissions per mile	0.0475	kg CO_2e/mile	(Average Emissions per Battery) / (Battery Life's Expectancy)
Electricity Driving Economy	0.346	kWh/mile	https://ecocostsavings.com/average-electric-car-kwh-per-mile/
Electricity to Energy Conversion	3.6	MJ/kWh	https://www.unitjuggler.com/convert-energy-from-kWh-to-MJ.html
Energy Used per Mile	1.2456	MJ/mile	(3.6 MJ/kwh) X (0.346 kWh/mile)
Miles per MJ	0.803	Miles/MJ	1 / (1.2456 miles/MJ)
Emission Factor	**38.13**	**g CO_2e/MJ**	**(0.803 miles/MJ) X (0.0475 kg CO_2e/mile) X (1,000 grams/kilogram)**

Battery Production Emissions (High End)			
	Value	**Unit**	**Source**
Low End Emission Factor	106	kg CO_2e/kWh of capacity	Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling. Lithium-Ion Vehicle Battery Production **IVL with Swedish Department of Energy** - **November 2019**
Average EV Car Battery	78	kWh of capacity	Survey of 7 advertised car battery capacities: **Tesla, VW, Hyundai, Chevy, Audi, Volvo, Ford**
Average Battery Production Emissions	8,253	kg CO_2e/battery produced	(Upper End Emissions Factor) X (Average EV Car Battery)
Average Expected Lifespan of EV Battery	100,000	miles/battery	https://www.autotrader.com/car-tips/how-long-do-electric-car-batteries-last
Battery Emissions per mile	0.0825	kg CO_2e/mile	(Average Emissions per Battery) / (Battery Life's Expectancy)
Electricity Driving Economy	0.346	kWh/mile	https://ecocostsavings.com/average-electric-car-kwh-per-mile/
Electricity to Energy Conversion	3.6	MJ/kWh	https://www.unitjuggler.com/convert-energy-from-kWh-to-MJ.html
Energy Used per Mile	1.2456	MJ/mile	(3.6 MJ/kwh) X (0.346 kWh/mile)
Miles per MJ	0.803	Miles/MJ	1 / (1.2456 miles/MJ)
Emission Factor	**66.26**	**g CO_2e/MJ**	**(0.803 miles/MJ) X (0.0825 kg CO_2e/mile) X (1,000 grams/kilogram)**

Electric Charging Emissions (Low End)			
	Value	**Unit**	**Source**
Emission Factor for Grid Electricity	82.92	g CO_2e/MJ	https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/elec_update.pdf
EER Factor for Electricity vs Gasoline	3.40	EER Ratio	https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf
EER Adjusted Emission Factor	24.39	EER adjusted g CO_2e/MJ	https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf

Total LCA Emissions Low End	**62.52**	**g CO_2e/MJ**	**California Grid Emissions + Battery Production Life Cycle Analysis (Conservative)**
Total LCA Emissions High End	**90.64**	**g CO_2e/MJ**	**California Grid Emissions + Battery Production Life Cycle Analysis (Upper Bound)**
Total LCA Emissions Average	**76.58**	**g CO_2e/MJ**	**California Grid Emissions + Battery Production Life Cycle Analysis (Average)**

Attachment 2 – Supporting Tables

Table 3 – LCA

Life Cycle Emissions of Specific Electric Vehicle Batteries				
Make	Model	kWh capacity	Lower End kg CO_2e/ kWh	Upper End kg CO_2e/ kWh
			61	106
Ford	2022 F-150	131	7,991	13,886
Volvo	2022 XC40	78	4,758	8,268
Audi	2020 E-tron	95	5,795	10,070
Chevy	2020 Bolt	66	4,026	6,996
Hyundai	2020 Kona	64	3,904	6,784
VW	2019 e-Golf	36	2,196	3,816
Tesla	2019 Model 3	75	4,575	7,950
Average		78	4,749	8,253

Table 4 – Lead-Acid Battery Production Emissions

Lead-Acid Battery Production Emissions			
	Value	**Unit**	**Source**
Average Battery Weight	41	pounds/battery	https://batteryglobe.com/how-much-does-a-car-battery-weigh/
Metric Conversion	0.45	kg/pound	Conversion
Average Battery Weight	18.60	kilograms/battery	(0.45 pounds/kg) x (41 pounds per battery)
Emissions of Battery Production	3.18	kg CO_2e/kg battery	https://publications.anl.gov/anlpubs/2010/11/68455.pdf
Total Battery Production Emissions	59	kg CO_2e/battery	(18.60 kg/battery) x (3.18 kg CO_2e/kg)

These Conclusions are from the Report noted below.

- Report C 444 - Lithium-Ion Vehicle Battery Production – Status 2019 on Energy Use, CO2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling

Conclusions

Based on the new data, filtered by the reporting transparency, an estimate of 61-106kg CO_2-eq/kWh battery capacity was calculated for NMC batteries in light-duty vehicles. The interval mainly depends on the electricity mix and the energy source of heating required in cell production. If data with less transparency are included the maximum value is 146kg CO_2-eq/kWh for smaller PHEV batteries.

The new GWP range is substantially lower than the earlier reported 150-200kg CO_2-eq/kWh battery. One important reason is that this report includes battery manufacturing with nearly 100 percent fossil free electricity in the range, which is not common yet, but may be more common in the future. The decrease in the higher end of the range is mainly due to new and more accurate production data for cell production, including dry-room process energies. The new data is also for commercial-scale factories instead of pilot-scale factories, which lowered the emissions per unit produced due to higher production efficiencies. Also, the use of water instead of NMP in the anode slurry evaporation step in the LCA modelling lowered the calculated GWP. Lastly, the former range also included emissions from battery recycling which was about 15 CO_2-eq/kWh battery capacity.

Regarding standardization of LCA, Product Category Rules (PCRs) are published for their Product Environmental Footprint developed by the European Commission. It standardizes the method of calculating energy use and emissions, which may be different from the methods used by other authors. The calculated emissions were within our estimated range at 77kg CO_2/kWh battery capacity. Both the PEFCR and our new estimate were calculated for the NMC 111-graphite chemistry. However, our calculations also show that there is potentially a 7 percent lower energy consumption and 14% lower GWP for NMC 811 batteries per kWh battery capacity compared to NMC 111.

Average nickel content is expected to increase and cobalt content to decrease in newer batteries as the batteries that are produced are expected to move towards higher energy density and away from cobalt, which is at supply risk, but nickel may therefore become at risk too.

Regarding GHG emissions in the recycling step the PEF benchmark reports that 12 percent of the total is in the end-of-life stage in Europe.

It is motivating to see that the estimated GHG values for battery production have decreased, but it is also important to continue research and development into resource-risks and handling of battery materials. Recycling will become more important in the future as the batteries produced today will all eventually reach their end-of-life. When they do, it will become a higher priority to take responsibility from their resource flows.

There is still a need for more accurate and detailed data, especially since the different production steps can be performed in different ways with different efficiencies. Also, data for electronics production still needs to become better. More information on the supply risks of different metals is also needed, as well as traceability of the metals, so that sustainable production can eventually be achieved and guaranteed.