March 23, 2022

Liane M. Randolph, Chair
California Air Resource Board
P.O. Box 2815
Sacramento, CA 95814

RE: 22-5-2: Public Meeting to Hear Draft Scenarios for Achieving Carbon Neutrality in the 2022 Scoping Plan Update

Dear Chair Randolph,

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

ZEVs are not zero greenhouse gas emission vehicles but have a carbon intensity of **62 to 90 (gCO_2e/MJ)** when combining the energy required to produce electricity to charge the battery and the manufacturing process of the battery. CARB's existing emissions factor, which accounts for the energy required to produce the electricity the charge the battery is **23.39 (gCO_2e/MJ)**. 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. **Meanwhile, CARB modeling keeps diesel viable for decades and has no mention of carbon- negative RNG.**

AB 32 Climate Change Scoping Plan Statutory Requirements is to Minimize Leakage

ZEV batteries that are manufactured out of state are increasing non-Californian emissions in other states and countries in the amount of **38.13 – 66.26 (gCO_2e/MJ)** depending on the type of ZEV battery. CARB is picking ZEV as the technology winner while leaking emission out of state.

Environmental Justice for All?
CARB Should Not Exacerbate Harm to Disproportionately Impacted Communities

Cobalt is mined by forced child labor in the Democratic Republic of the Congo. Think about the extraordinary volume of water and resources used to mine rare minerals for the car's Battery Electric Vehicle (BEV). Amnesty International has documented serious human rights violations linked to the extraction of the minerals used in lithium-ion batteries. Think about the environmental degradation the BEV car imposes on Mother Earth, outside of California on the people of Africa, China, South America, and first nations people of Canada. The Environmental Justice Advisory Committee should be briefed and provide input on this topic.

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In summary, the following comments are filed:

- CARB has a statutory requirement to minimize leakage when considering the AB 32 Climate Change Scoping Plan Update and needs to address the carbon intensity of BEV battery manufacturing (Slide 2 of Today's Presentation)

- CARB has a statutory requirement to support cost-effective and flexile compliance when considering the AB 32 Climate Change Scoping Plan Update, where heavy-duty ZEV provides neither. (Slide 2 of Today's Presentation)

- CARB should include BEV Battery Manufacturing Emissions into the LCFS since the core tenets of the LCFS are based on life-cycle analysis.

- When modeling for Transportation Demand for ZEVs and Energy Demand by Fuel Type, the carbon intensity of the BEV batteries should be based on an honest life-cycle analysis referencing the European Studies.

- Modeling the 4 scenarios does not even mention RNG, while keeping diesel use around for decades.

- CARB's Environmental Justice Advisory Committee should be briefed and provide input on the forced child labor in the Democratic Republic of the Congo and review Amnesty International documents on the serious human rights violations linked to the extraction of the minerals used in lithium-ion batteries. The EJAC should consider the extraordinary volume of water and resources used to mine rare minerals for the car's BEV, and the environmental degradation the BEV car imposes on people outside of California on the people of Africa, China, South America, and first nations people of Canada. CARB will be hosting the EJAC on March 30, 2022, where we plan to present this information in more details with references.

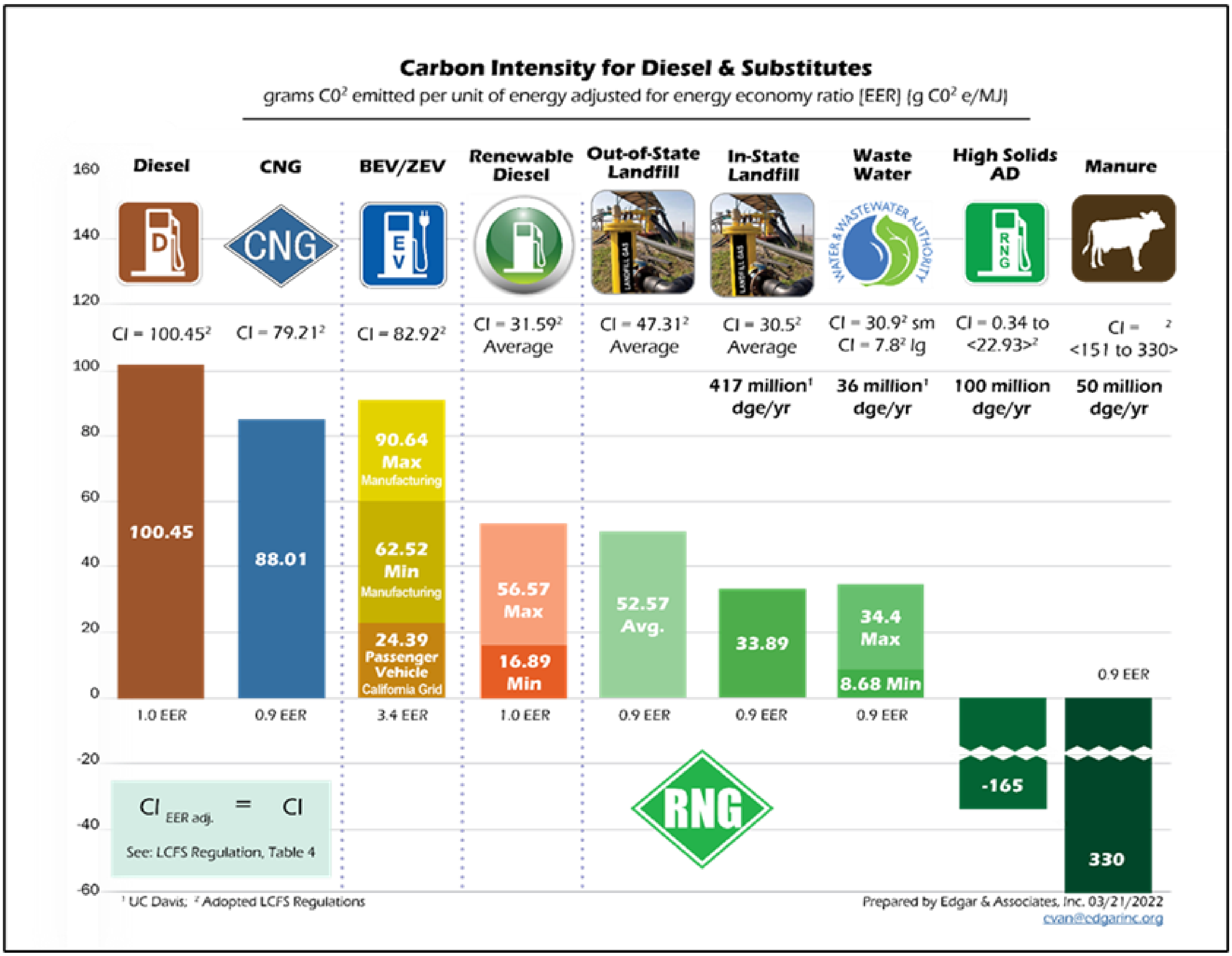
Edgar & Associates submits our comments and the attached White Paper based upon European studies regarding the carbon intensity of ZEV batteries. On behalf of our fifty public and private sector clients that operate permitted waste facilities involved in the collection, hauling, processing, and composting of green and food waste materials throughout California, we base our decisions on defensible science and lifecycle carbon accounting. Our clients collect organic waste at the curb in heavy-duty vehicles that have been transitioning from diesel to near-zero NOx trucks. Many are using in-state, carbon-negative, renewable natural gas (RNG), that many of our clients produce. After processing organics which are diverted from the landfill to achieve SB 1383 mandates that reduce short-lived climate pollutants, our clients haul the compost, digestate, and wood chips in heavy-duty transfer vehicles.

Our clients are in the wheelhouse of the circular economy mitigating methane where the work so far on the Scoping Plan 2022 Update fails to place short-lived climate pollutant as a priority in the near-term, and instead picks BEVs as a winner by 2045. Our industry produces and uses carbon negative RNG and there will be enough RNG to fuel the entire refuse industry, the same industry that collects the organics waste and diverts it from landfills to implement SB 1383.

Carbon Intensity

CARB determines the alternative fuel's carbon intensity (CI) value by dividing its Energy Economy Ratio (EER) in order to obtain the EER-adjusted CI value, representing the emissions that occur from the use of alternative fuel per MJ of conventional fuel displaced.

CARB determines ranges of CI for each type of fuel compared to the two baseline fuels (gasoline and diesel). Each marker represents an individual certified fuel pathway CI, adjusted by the EER. There is a range of carbon intensity that may be achieved by a fuel pathway. The wide range of



carbon intensities is due to the life cycle emissions methodology of the LCFS, variations in feedstock types, origin, raw material production processing efficiencies, and transportation, all of which contribute to an individual producer's fuel pathway CI. All valid CI values shown are certified including legacy, Tier 1, Tier 2, and Lookup Table pathways, and presented in the graph above.

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. CARB needs to determine the CI for the LCFS program by using a bottom-up approach for battery manufacturing and provide a range of CI values such for other alternative fuels on top of the energy required to produce the electricity within the battery which is **23.39 (gCO_2e/MJ)** as shown on the graph on the next page. ZEVs are not zero greenhouse gas emission vehicles but have a carbon intensity of **62.53 to 90.64 (gCO_2e/MJ**.) as shown on the graphic above.

Methane is a short-lived climate pollutant that is 84 times stronger than CO_2 over a 20-year period. NASA flew over California landfills and published an inventory showing them as super emitters of methane. When the Governor announced his goal for carbon neutrality by 2035, it was the distinguished Dr. Ram Ramanathan that presented that methane mitigation was the only tool left to bend the climate curve before irreversible damage is done to this earth, since methane has short-lived impacts over 20 years. President Biden unveiled a U.S. Methane Emissions Reduction Action Plan that redoubles efforts to reduce methane . With a Code Red for Humanity announced by the IPPC, action is needed in the near-term. At the United Nations COP26 meetings in Glasgow more than 100 countries joined a U.S. and E.U.-led coalition to cut 30% of methane emissions by 2030.

AB 32 Climate Change Scoping Plan Statutory Requirements is to support cost-effective and flexile regulations and policies

Our clients have been transitioning from diesel to near-zero low NOx trucks, using their own RNG or in-state RNG. At this time and for the near-term, heavy-duty BEVs neither have the duty cycle, charging infrastructure or grid reliability plus lack the cost-effectiveness as BEV trucks cost almost twice as much, needing 2:1 replacement compared to low NOx RNG trucks. AB 32 Climate Change Scoping Plan Statutory Requirements is to support cost-effective and flexile compliance, where heavy-duty ZEV provides neither.

Edgar & Associates has technical staff of engineers and environmental scientists competent in all aspects of life-cycle analysis (LCA) for low carbon fuel programs. Edgar and Associates regularly prepares Net-Zero greenhouse gas analysis, verified carbon footprints for The Climate Registry, material mass balances, and transportation emission calculations. Science supported LCAs should be used in all cases of carbon accounting and be an integral part of the Low Carbon Fuel Standard (LCFS). Edgar and Associates is technology neutral and carbon neutral now with the lowest carbon emission at the most cost-effective price and should be endorsed by CARB. All fuels options, including BEV vehicles, should determine their carbon intensity based upon an honest LCA.

Diesel for Decades and RNG for None
Slide 20 of the E3 modeling slides of 4 scenarios for the Heavy-Duty Vehicles (HDV) models has diesel use for decades, does not even mention RNG use (This is from the March 15, 2022, slides, but is not shown on the March 24, 2022, slide desk today). There is adequate RNG supply for the refuse fleet to utilize in-state RNG in 2025 with current in-state RNG production that is underway. RNG should be modeled with its life-cycle analysis of being carbon negative, where in the near-term carbon goals can be met with the co-benefit of reducing NOx to near-zero for the fleet that will be using the in-state RNG.

CARB needs to Include ZEV Battery Manufacturing Emissions into the LCFS
Electric Vehicle Battery manufacture emissions must be included in the life cycle analysis of electric vehicle emissions. Unlike the tires, steering wheel, or frame of a car, the battery production emissions must be considered when comparing to other vehicles. These batteries, in addition to being 25 times heavier than the lead-acid batteries found in conventional vehicles also produce over 80 times the emissions during manufacture than lead-acid batteries. As BEV batteries must be replaced after a certain amount of use and contain the locomotive energy of the vehicle, they constitute fuel

According to the Study, 'Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhous Gas Emissions, 2018' by the International Council on Clean Transportation, the following is quoted regarding including LCAs:

"The methodology used for a life-cycle assessment (LCA) can greatly influence its conclusions about the carbon intensity of batteries. An LCA can evaluate the environmental impacts of a system using either a bottom-up or top-down approach. A bottom-up approach incorporates the activity data for each stage of each component of a battery and aggregates these different components. In contrast, a top-down analysis first determines the total emissions from a plant and attributes these emissions to different processes. Top-down inventories tend to include more auxiliary energy uses, but they may double-count certain processes and emissions. In this context, top-down inventories typically find higher emissions, often by a factor of two or more."

In 2009, the Global Trade Analysis Project (GTAP) model was adopted with the original LCFS adoption. In 2011, CARB directed staff to continue working with interested stakeholders to update the indirect land use change (ILUC) carbon intensity values for various biofuels. Staff has been collaborating with stakeholders, and as part of the 2015 LCFS re-adoption, the GTAP model was updated, and the AEZ-EF model was created to supplement GTAP's estimates of greenhouse gas emissions from various types of land conversions. Mining of minerals for BEV batteries is an indirect land use change and CARB should develop models used for the land use change assessment with supporting documentation and BEC battery manufacturing.

Table H-5 from CARB's Methodology for Detailed Analysis for Indirect Land Use Change (ILUC) summarizes the iLUC values for all the 6 biofuels analyzed for the LCFS regulation. The values are the average of 30 scenario runs for each biofuel. Complete details for each of the biofuels are also provided in this methodology.

Biofuel	**iLUC (gCO_2/MJ)**
Corn Ethanol	19.8
Sugarcane Ethanol	11.8
Soy Biodiesel	29.1
Canola Biodiesel	19.4
Sorghum Ethanol	14.5
Palm Biodiesel	71.4

CARB Should Not Exacerbate Harm to Disproportionately Impacted Communities
Cobalt is mined by forced child labor in the Democratic Republic of the Congo. Think about the extraordinary volume of water and resources used to mine rare minerals for the car's Battery Electric Vehicle (BEV). Amnesty International has documented serious human rights violations linked to the extraction of the minerals used in lithium-ion batteries. Think about the environmental degradation the BEV car imposes on Mother Earth, outside of California on the people of Africa, China, South America, and first nations people of Canada. The Environmental Justice Advisory Committee should be briefed and provide input on this topic.

CARB will be hosting a virtual public meeting for the Assembly Bill (AB) 32 Environmental Justice Advisory Committee (EJAC) on March 30, 2022, from 1 pm to 5 pm. The virtual meeting is open to the public and includes a public comment period, in which we plan to present this information in more detail with references.

There is no time to waste for a prefect ZEV tomorrow in 2045 that may be carbon neutral where there are proven carbon negative programs today that can bend the climate curve by mitigating methane now and actualize a circular economy.

Sincerely,

Evan WR Edgar
Regulatory Affairs Engineer

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], which 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)** r 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

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 was 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 CO2-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 CO2-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 CO2eq/kWh. The calculated range is substantially lower than the earlier 150-200kg CO2-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 CO2- 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, data for electronics production still needs to become better. 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 produced 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, CO2 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, CO2 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, CO2 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 CO2e/kWh of capacity	Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use, CO2 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, CO_2 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 CO2-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 CO2-eq/kWh for smaller PHEV batteries.

The new GWP range is substantially lower than the earlier reported 150-200kg CO2-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 CO2-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 CO2/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.