icct

www.theicct.org
communications@theicct.org
twitter @theicct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION
1500 K STREET NW | SUITE 650 | WASHINGTON DC 20005

Re: Comments on Proposed Advanced Clean Cars II (ACC II) Regulations

The International Council on Clean Transportation (ICCT) respectfully submits these comments on the California Air Resources Board's (CARB) proposed Advanced Clean Cars II Regulations.

The ICCT was established in 2001 as an independent source to provide unbiased research and technical and policy expertise for motor vehicle regulators working to improve the environmental performance and energy efficiency of road, marine, and air transportation, in order to benefit public health and mitigate climate change. Our work supports the development and implementation of advanced vehicle regulations in the world's largest markets. In the United States, the ICCT has been highly engaged with federal and state-level vehicle regulations, participating in expert working groups, submitting public comments on regulations' technical designs, and regularly publishing research on vehicle regulations and standards.

The ICCT commends the California Air Resources Board (CARB) on its continuing effort to reduce passenger vehicle emissions and to support the state's growing zero-emission vehicle (ZEV) market. We welcome the opportunity to provide comments on CARB's Proposed Advanced Clean Cars II (ACC II) regulation which sets increasingly stringent emissions standards for internal combustion engine (ICE) vehicles and requires an increasing number of ZEV sales to meet the state's goal of 100% ZEV sales by 2035. The comments below offer our support for the proposed regulation, provide international context for California's proposed ZEV sales targets relative to global developments, and include some technical observations on ZEV compliance costs for your consideration.

We would be glad to clarify or elaborate on any points made in the comments. CARB staff can feel free to contact ICCT staff Pete Slowik (peter.slowik@theicct.org), Logan Pierce (l.pierce@theicct.org), or Dr. Stephanie Searle (stephanie.searle@theicct.org) with any questions.

Stephanie Searle, PhD
Program Director, Fuels and United States
International Council on Clean Transportation

SUPPORT FOR THE PROPOSED ADVANCED CLEAN CARS II REGULATION

ICCT strongly supports the proposed Advanced Clean Cars II Regulation and recommends its adoption. This regulation is critical to achieving the pace and scale of needed transportation emission reductions in California. There is a clear and urgent need to rapidly transition the transportation sector to zero-emission vehicles. Continued and strengthened standards are important to protect public health and deliver on the state's air quality and climate change obligations. We support the Proposed Advanced Clean Cars II Regulation that puts the state on a path toward 68% of new vehicles sold being zero-emission or plug-in hybrid electric vehicles by 2030 and 100% by 2035.

As a member of the ZEV Transition Council and the International ZEV Alliance, California joins several of the world's major vehicle markets with the shared commitment to accelerate a global transition to ZEVs. This transition is crucial for decarbonizing road transport and meeting global climate goals. Specifically, ICCT's modeling shows that limiting global warming to below 2°C as targeted in the Paris Agreement will require that leading markets including California reach 100% zero-emission new light-duty vehicle sales no later than 2035.[1] Achieving the annual ZEV requirements outlined in the Proposed ACC II Regulation would put the state's light-duty vehicle fleet on track to deliver deep greenhouse gas emissions reductions in line with a below-2°C goal. Still, our analysis shows that to maintain a chance of limiting warming to 1.5°C, governments will need to consider even earlier transitions to 100% ZEV sales and complementary measures to halve global vehicle fleet emissions by 2030. Such actions could include accelerating replacement of the existing vehicle fleet with ZEVs, maximizing uptake of efficiency technologies for conventional vehicles and ZEVs, and large-scale avoid-and-shift measures.[2]

Adopting the proposed Clean Cars II regulation will bring profound benefits to the state and beyond. Many other jurisdictions follow California's leadership on automotive emissions regulations. As of May 13th, 2022, 17 U.S. states have adopted all or part of California's low-emission and zero-emission vehicle regulations, and 35% of national new light-duty vehicle sales meet California's emission standards.[3] The ACC program has proven to be effective at reducing emissions in the transportation sector in California and beyond. It is likely that many other states will continue to follow California's leadership and adopt the ACC II Program to replicate the air and climate pollutant emission reductions in their own states.

The ACC II Program also has implications outside of the United States. Canada has committed to align with "the most stringent performance standards in North America post-2025".[4] Although

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[1] Sen, A., and Miller, J. Emissions reduction benefits of a faster, global transition to zero-emission vehicles. *International Council on Clean Transportation.* https://theicct.org/publication/zevs-global-transition-benefits-mar22/

[2] Sen, A., and Miller, J. Emissions reduction benefits of a faster, global transition to zero-emission vehicles. *International Council on Clean Transportation.* https://theicct.org/publication/zevs-global-transition-benefits-mar22/

[3] States that have adopted California's vehicle standards under Section 177 of the Federal Clean Air Act. (May 13, 2022). *California Air Resources Board*. https://ww2.arb.ca.gov/sites/default/files/2022-05/%C2%A7177_states_05132022_NADA_sales_r2_ac.pdf

[4] ECCC, "Government launches consultations on commitment to require all new cars sold in Canada be zero emission by 2035," December 17, 2021, https://www.canada.ca/en/environment-climate-

the federal-level regulations are still being developed, California's rules are often more stringent than those set by EPA. Thus, it is likely that Canada's future standards are informed by California's ACC II. More broadly, California's ACC is an internationally recognized model program, and its design may be used to inform similar developments around the world in the future.[5]

INTERNATIONAL CONTEXT

California is not alone in its commitment to transition entirely to ZEVs. The number of national and subnational governments around the world committing to phase out the sale or registration of new internal combustion engine passenger vehicles continues to rise. Table 1 below highlights countries, provinces, and state governments that have announced an intention to phase out new sales of internal combustion vehicles (ICEs) by some future date.[6] It does not include announcements that signal an intent to phase out new gasoline and diesel cars but still permit the sale or registration of other new vehicles using fossil fuels, such as hybrid electric, compressed natural gas, or liquefied petroleum gas vehicles. Globally, there are 15 national and 3 subnational governments that have committed to phase out the sale or registration of new internal combustion engine passenger vehicles. The details of the targets vary; some phase-outs will only allow for battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) while others also allow for plug-in hybrid electric vehicles (PHEVs).

Table 1. Government targets to 100% phase out the sale or registration of new internal combustion engine light-duty vehicles (passenger cars and vans/light trucks) as of March 2022

Region	Jurisdiction	ICE phase-out year	Source
Africa	Cape Verde	2035	Electric Mobility Policy Charter
Asia-Pacific	Singapore	2030	Singapore Green Plan 2030
Europe	Austria	2030	Austria's 2030 Mobility Master Plan
Europe	Denmark	2030	Climate and Air Plan
Europe	France	2040	Mobility Guidance Law
Europe	Greece	2030	Draft Climate Law
Europe	Iceland	2030	Iceland's 2020 Climate Action Plan
Europe	Netherlands	2030	Looking out for each other, looking ahead to the future, 2021-2025 Coalition agreement
Europe	Norway	2025	National Transport Plan 2022-2033
Europe	Slovenia	2030	Market Development Strategy for the Establishment of Adequate Alternative Fuel Infrastructure in the Transport Sector in the Republic of Slovenia
Europe	Spain	2040	Law on Climate Change and Energy Transition
Europe	United Kingdom	2035	Transitioning to zero emission cars and vans: 2035 delivery plan
Central America	Costa Rica	2050	National Decarbonization Plan
North America	California	2035	Executive Order N-79-20
North America	Canada	2035	2030 Emission Reduction Plan
North America	New York	2035	Assembly Bill A4302

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change/news/2021/12/government-launches-consultations-on-commitment-to-require-all-new-cars-sold-in-canada-be-zero-emission-by-2035.html

[5] See for example Birkett (2020). How a California-style ZEV Mandate can deliver the phase-out of petrol and diesel cars. *Policy Exchange.* https://policyexchange.org.uk/wp-content/uploads/Route-%E2%80%9835.pdf

[6] Based on Wappelhorst (2021) with updates through March 2022. See https://theicct.org/publication/update-on-government-targets-for-phasing-out-new-sales-of-internal-combustion-engine-passenger-cars/ and https://zevtc.org/tracking-progress/light-duty-vehicle-map/

North America	Washington	2035	Senate Bill 5974
South America	Chile	2035	National Electromobility Strategy

As shown, 10 countries in Europe have announced ICE vehicle phase out targets. These phaseout timelines vary by jurisdiction and range from 2025 (Norway) to 2040 (France, Spain). In North America, Canada has a national ICE phaseout target for new sales by 2035. In the United States, three states have announced combustion vehicle phaseouts: California (2035), New York (2035), and Washington (2030). Compared to the other phaseout targets shown in Table 1 California's 2035 target lands in the middle of the pack in terms of the timing for phasing out combustion vehicles. There are 8 jurisdictions with phaseout targets from sooner than California (i.e., from 2025-2030, including Austria, Denmark, Greece, Iceland, Netherlands, Norway, Singapore, Slovenia, Washington), and 9 jurisdictions with phaseout targets by 2035 or later.

Based on our review of global phase-out developments, California's target for 100% of new vehicles sold being zero-emission or plug-in hybrid electric vehicles by 2030 appear to be well-aligned with those of other jurisdictions that have similarly high levels of climate and clean transportation leadership and ambition. More details about the various phaseout targets can be found in Wappelhorst (2021) and on the ZEV Transition Council phase-out tracker website.[7]

ZERO-EMISSION VEHICLE COSTS

CARB staff analysis shows clear and significant benefits associated with transitioning the state new passenger vehicle market to 100% ZEVs by 2035. We reviewed ARB's assumptions on battery costs and found that these are well aligned with the best available evidence and the scientific literature, and we present evidence on this point below. We also found that ARB's estimates of overall incremental battery electric vehicle (BEV) costs are conservative, and we recommend revising these assumptions downward based on available evidence. Specifically, we identified several elements of the ZEV Cost Workbook that we believe could be updated to better reflect the latest evidence and analysis, and we provide recommendations below for how ARB staff could improve the cost model. Updating the ZEV Cost Workbook based on the recommendations below would reduce the incremental ZEV costs and accelerate the expected timing for cost parity, which further strengthen the case for adopting the proposed ZEV targets of the ACC II program.

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[7] See https://theicct.org/publication/update-on-government-targets-for-phasing-out-new-sales-of-internal-combustion-engine-passenger-cars/ and https://zevtc.org/tracking-progress/light-duty-vehicle-map/

Consider lower vehicle range battery electric vehicles (BEVs)

The BEVs considered in ARB's Cost Workbook are limited to 300- and 400-mile range BEVs. We believe there is evidence that many consumers, as they weigh the trade-offs between capital costs and range, may continue to prefer shorter-range BEVs through 2035, and this would have a significant impact on the assessed BEV costs. The minimum 300-mile range analyzed is longer than many popular BEVs on roads in California, the United States, and other markets with high electric vehicle uptake. Data on BEV travel behavior demonstrates that many BEVs with below 300 miles of range have been sufficient to meet consumer mobility needs, and that the technology can match or even exceed the average annual mileage driving patterns of combustion vehicles.

Automakers are taking different approaches to provide more options for differing consumer demands for lower cost and increased range.[8] Shorter-range lower-cost BEVs are more desirable for many cost-conscious consumers and households with multiple vehicles that do not need additional range or have widely available charging at home, work, and public locations. Longer-range higher-cost BEVs are more attractive to consumers with greater daily travel needs or those who are willing to pay a premium for more range. This is especially true for luxury vehicles; the early BEV market has been characterized by a disproportionately high share of high-income consumers and some popular BEV models have catered to that demographic with luxury features, including electric range over 300 miles. As charging speeds increase and home, workplace, and public charging infrastructure become widespread, and as BEV penetration increases among lower-income consumers, shorter-range BEVs can increasingly be attractive to a broader group of drivers.

Analysis of the Norwegian BEV market with the world's highest electric vehicle penetration provides context to the BEV fleet composition needed to achieve near 100% ZEV sales in the country. Figure 1 shows the estimated sales weighted BEV consumer label range (U.S., miles) for new sales (bars, left axis) and ZEV market share (line, right axis) in Norway from 2010 through September 2021.[9] The share of new ZEVs has increased from about 5% in 2013 to about 50% in 2018, 75% in 2020, and about 85% in January-September 2021. Over this same timeframe, the average range of new BEVs has remained about the same: in 2013, the sales weighted range of new BEV sales was about 220 miles compared to about 200 to 240 miles in 2018 and 2021. The significance of these findings is that acceptance of lower-range BEVs (200-250 miles) is not limited to first adopters; lower-range BEVs appear to satisfy well over half of the consumer market in Norway. This trend has persisted even as BEV technology has improved over the past decade and the number of longer-range BEV models available has increased.

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[8] For example, the 40 kWh and 62 kWh Nissan Leaf, the standard range and long-range Tesla Model 3, the standard and extended range Ford Mach-E, the standard range and long-range Hyundai Ioniq-5

[9] Based on data from EV-Volumes (EV Data Center, 2021), http://www.ev-volumes.com/datacenter. For models not certified in the U.S., the estimated U.S. consumer label range was based on WLTP certification data and corroborated with industry sources about their technical specifications.

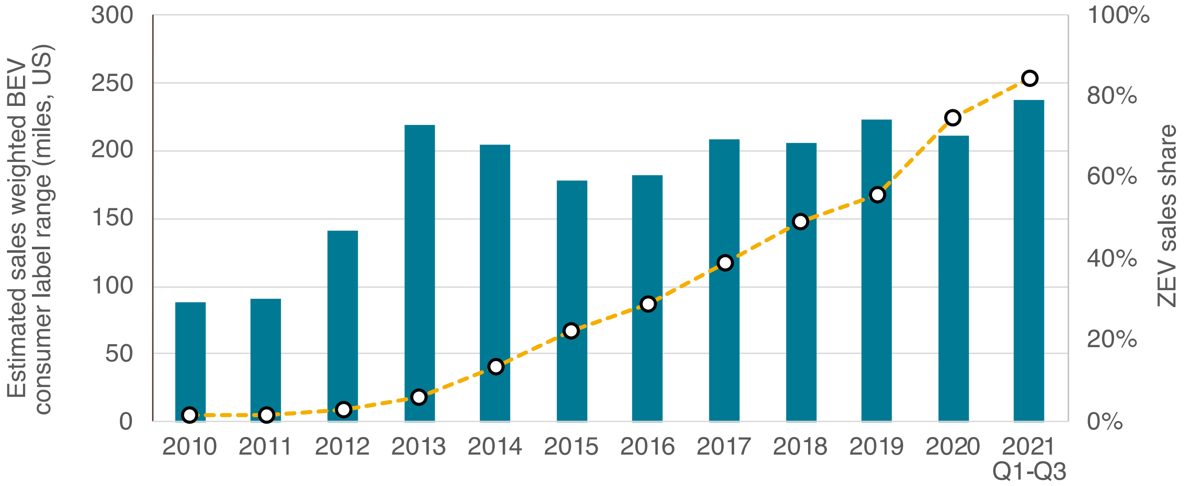

Figure 1. Average BEV range and ZEV sales share in Norway from 2010 thru September 2021

Figure 2 below illustrates the Norwegian BEV market composition in more detail. It shows the annual composition of BEV sales in Norway from 2016 through September 2021 by range, binned into 50-mile range increments. As shown, overall, from 2016 through September 2021, about 80% of BEV sales in Norway had an electric range less than 300 miles. About one-third of the BEV market had a range between 151-200 miles (red bars), followed by 21% with 201-250 miles (purple), 18% with 301-350 miles (orange), 16% with 101-150 miles (blue), 9% with 251-300 miles (green), and 4% with 351-400 miles (black). The 2021 data through September show a similar story: 77% of 2021 BEV sales in Norway had an electric range less than 300 miles. As shown by the black bars along the top of the figure, the share of 350- to 400-mile range BEVs diminished from 10% of the market in 2016 to less than 1% in 2020 and 2021. This data shows that the distribution of consumer preferences in Norway above and below a 300-mile range has not changed significantly over time, even as BEV penetration has reached most of the total passenger vehicle consumer market.

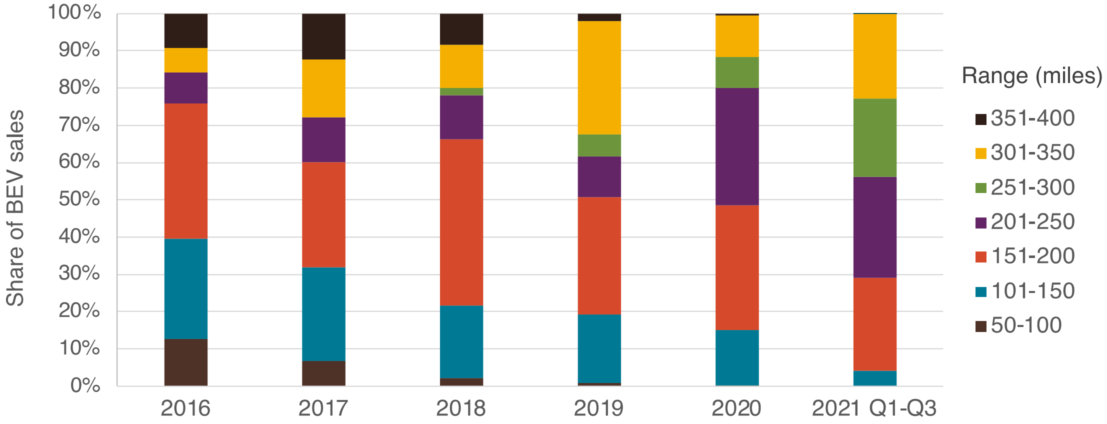

Figure 2. BEV sales by range in Norway from 2016 through September 2021

Further details about high-volume BEV sales in Norway and their all-electric range are summarized in Table 2. The table summarizes the 25-highest selling BEV models in Norway from 2020 through September 2021, including each model's share of BEV sales and their estimated range in miles. For BEV models that have multiple different versions and multiple ranges are listed (e.g., the "long-range" 353-mile Tesla Model 3 and the "standard-range" 263-

mile Tesla Model 3). The 25 models shown in Table 2 represent 90% of BEV sales in Norway over this timeframe. Overall, 21 of the 25 highest selling BEV models have an electric range that is less than 300 miles (colored in green), and four models come with options for either above or below 300 miles of range (Tesla Model 3, Tesla Model Y, Ford Mustang Mach-E, Hyundai Ioniq-5; in yellow). Again, while BEV penetration has expanded to reach most of the consumer market in Norway, most of the popular models have a lower range than what ARB is considering.

Table 2. Summary of 25-highest selling BEVs in Norway from 2020 through September 2021

Automaker	Model	Share of sales from 2020 through Q3 2021	Estimated consumer label range (US, miles)
Tesla	3	11%	353, 263
Audi	e-tron Quattro	9%	218, 165
Volkswagen	ID 3	7%	250, 200
Nissan	Leaf	6%	226, 150
Hyundai	Kona	5%	258
Mercedes	EQC	5%	220
Volkswagen	ID 4	4%	260, 240
SAIC	MG EZS	4%	250, 185
Polestar	2	4%	233
Volvo	XC40	3%	223, 208
Ford	Mustang Mach-E	3%	305, 270, 230
Tesla	Model Y	3%	326, 303, 244
Volkswagen	e-Golf	3%	125
Peugeot	2008	3%	190
Skoda	Enyaq	3%	290, 260, 215
Kia	Niro	2%	243, 155
Peugeot	e-208	2%	195
Hyundai	Ioniq	2%	170
Renault	Zoe	2%	230
Kia	Soul	2%	243, 150
Skoda	Citigo-e	2%	150
Mazda	MX-30	2%	100
BMW	I3	1%	153
Hyundai	Ioniq-5	1%	303, 220
Volkswagen	e-Up!	1%	143

We believe Norway provides a useful comparison to California because drivers show similar patterns. Average commute distance would be useful for comparison, but in the absence of these data we look at average annual vehicle miles traveled (VMT); this metric is comparable between the two regions. Annual VMT is about 10,250 miles in Norway,[10] compared to about 12,850 miles in California[11] and 11,900 miles in the United States.[12] The data suggest that annual VMT in Norway is about 86% that of the U.S. and 80% that of California. Furthermore, the Norway data indicate that the annual VMT of BEV drivers is about 6.5% greater than the

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[10] Based on Erik Figenbaum & Susanne Nordbakke, Institute of Transport Economics Norwegian Center for Transport Research (2019) data on average annual driving distance of BEV and ICE households in 2018, https://www.toi.no/getfile.php?mmfileid=50956

[11] Estimated based figures 5.1-1. and 5.2-1. in the California EMFAC2021 Volume III Technical Document (April, 2021) https://ww2.arb.ca.gov/sites/default/files/2021-08/emfac2021_technical_documentation_april2021.pdf and corroborated with data from the California Department of Motor Vehicle registered autos data (CA DMV, 2019), https://www.dmv.ca.gov/portal/uploads/2020/06/2019-Estimated-Vehicles-Registered-by-County-1.pdf

[12] Based on the Oak Ridge National Laboratory (ORNL) Transportation Energy Data Book (2021) data tables 3.14 and 3.15 for Annual Mileage for Cars and Light Trucks by Vehicle Age, Survival Rates for Cars and Light Trucks by Vehicle Age, https://tedb.ornl.gov/data/ and the share of cars and light trucks from the 2021 EPA Automotive Trends Report, https://www.epa.gov/automotive-trends

annual VMT of ICE drivers in Norway, indicating that electric vehicle range has not limited annual miles traveled. The large majority of Norwegian passenger vehicle consumers are choosing BEVs with ranges lower than 300 miles, and on average these consumers drive relatively similar daily distances as U.S. and Californian drivers. We believe these data suggest that Californian drivers would in general be satisfied with similar BEV ranges as chosen by Norwegian consumers.

We understand that ARB, in its Cost Workbook, must make projections about how both vehicle technology and consumer preferences will change over time and as BEV penetration reaches first a majority and then 100% of passenger vehicle consumers. We believe the Norwegian data shows that even as penetration increases across the entire market, there is a strong market for ranges less than 300 miles. This acceptance of a lower range vehicle suggests that people will buy the range that they can afford rather than waiting for longer range vehicles that they may like marginally better. As current US BEV sales are dominated by luxury vehicles, it would be appropriate to assume that as the market expands into mainstream customers, many of these new consumers would be satisfied with the same BEV ranges as are being purchased today, if not lower range. This BEV market evolution from primarily luxury vehicles through 2021 to a mainstream market is reflected in automaker electric vehicle investments and announcements for dramatically expanded electric vehicle model offerings, sales, and sales shares.[13] Those who think they need 300 or 400 miles would enter the market later as those ranges reach cost parity.

Due to all the above reasons, ICCT suggests that ARB staff explicitly include 200- and 250-mile range BEVs in its analysis of ZEV incremental costs and consider a lower "average" BEV range of 250 miles in 2025 to analyze compliance costs. Doing so would reduce the estimated incremental costs of BEVs by about $2,800 in 2025.[14]

Update combustion vehicle removal costs

Internal Combustion Engine (ICE) and transmission removal costs applied in ARB's ZEV Cost Modeling Workbook are based on 2018 National Highway Traffic Safety Administration (NHTSA) Corporate Average Fuel Economy (CAFE) Model technology input costs and Environmental Protection Agency (EPA) staff work.

While ARB's analysis considers cases where BEVs have additional all-wheel drive and towing costs, the analysis of removal costs does not appear to include the additional deletion costs for combustion towing vehicles and combustion vehicles with all-wheel drive (AWD). For example, the cost of adding a Heavy Duty Trailer Tow Package to the 2021 Ford Expedition is $795.[15] For all-wheel drive costs, the Toyota Prius LE is priced at $1,400 greater than the standard Toyota Prius LE.[16] Including technology costs for towing and all-wheel drive components in the analysis would more comprehensively reflect combustion vehicle removal costs. If indeed ARB's analysis adds in the full cost of towing and all-wheel drive for applicable BEVs without subtracting the

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[13] See Table 1 in Anh Bui, Peter Slowik, and Nic Lutsey (2021), *Power Play: Evaluating the U.S. position in the global electric vehicle transition*. https://theicct.org/publications/us-position-global-ev-jun2021

[14] Calculated using updated efficiency and power assumptions to reflect the needs of shorter range BEVs

[15] See Ford (2021), 2021 Expedition, Choose Your Path, https://shop.ford.com/build/expedition/#/chooseyourpath/

[16] Toyota (2021). Your build: 2022 Prius LE. https://www.toyota.com/configurator/build/step/model/year/2022/series/prius/model/1223/modal/2/

ICE delete costs for these components, we would recommend ARB subtract these delete costs to ensure towing and all-wheel drive costs are not double counted for BEVs.

We understand that ARB's Cost Workbook incorporates additional combustion vehicle costs in 2025 for compliance with the state LEV3 criteria pollutant, current GHG, ACC II criteria pollutant, and ACC II GHG regulations that apply to new vehicles through model year 2025. Beyond 2025, ARB's ZEV Cost Modeling Workbook applies the same ICE and transmission removal costs, LEV3 criteria emissions costs, current GHG compliance costs, and ACC II criteria pollutant and GHG compliance costs through 2035. Yet over this same timeframe, state and federal emissions and efficiency standards that get progressively more stringent would result in modest, gradual vehicle price increases for ICE vehicles. Although state and federal regulations for post MY2025 have yet to be finalized, California and the United States are very likely to continue to adopt increasingly stringent criteria pollutant and GHG regulations. Previous analysis of light-duty vehicle efficiency technology and costs found that the cost of adding technologies to the baseline vehicles increases the combustion vehicle engine and transmission costs by about 0.35% per year.[17] If ARB is using BEV incremental costs to project the cost impacts that consumers would bear in purchasing a BEV compared to an ICE in future years, then it would be appropriate to account for these projected increases in ICE costs by applying gradual and modest vehicle price increases to combustion vehicles to more accurately reflect combustion vehicle removal costs beyond 2025.

We thus recommend that ARB incorporate an annual ICE and transmission cost increase of, for example, 0.35%, for all years after 2025.

Re-examine 2025-2035 BEV technical specifications for DC efficiency and motor power

ARB's analysis of incremental ZEV costs relies on several inputs related to BEV technical specifications. CARB staff made adjustments to the BEV efficiency and motor power assumptions in the updated March 2022 ZEV Cost Workbook compared to the original October 2021 ZEV Cost Workbook. Specifically, CARB appeared to increase BEV DC efficiency by about 8% and reduce BEV motor power by about 2%. While these changes bring ARB's analysis more in line with recent evidence on vehicle specifications, ICCT believes that the updated assumptions for BEV motor power and efficiency do not appear to fully reflect the extent of technological progress to date or expectations for continued advancements based on recent research. This affects the cost analysis because cost increases with motor power and the worse the efficiency, the larger and more expensive the battery becomes for the vehicle. Refining these inputs based on the most up to date data and technical analysis would more accurately reflect BEV technology and its incremental costs.

ARB's efficiency assumptions are improved compared to average BEVs on the market today but do not fully account for expected technological improvements. Overall efficiency improvements will stem from two types of technological development: a) vehicle curb weight reduction and b) direct efficiency improvements independent of weight. To illustrate, we present the efficiency compared to curb weight of nearly every BEV model available on the U.S. market from 2019-2022 in Figure 3, omitting a few models we were unable to categorize. The full list of these

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[17] Nic Lutsey, Dan Meszler, Aaron Isenstadt, John German, and Josh Miller. *Efficiency technology and cost assessment for U.S. 2025-2030 light-duty vehicles*. (Washington, DC: ICCT, 2017), https://theicct.org/publications/US-2030-technology-cost-assessment

models and their specifications is provided in the Appendix. We see that, especially for the vehicle types for which we have many data points (medium cars and medium SUVs), there is an evident and logical increase in energy consumption with curb weight. Thus, efficiency is heavily dependent on vehicle weight. We also see a large degree of variation in efficiency between models of similar curb weight. This latter finding strongly suggests that there is technological potential to improve efficiency that is independent of curb weight.

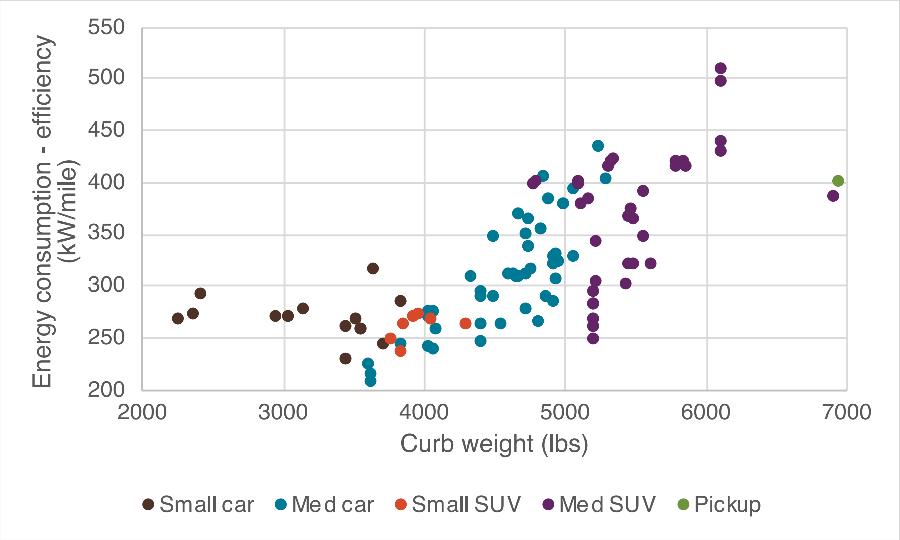

Figure 3. Efficiency versus curb weight for real-world 2019-2022 BEV models

Argonne National Laboratory's "Autonomie" model presents an option for considering how technology can be expected to improve over time, and ARB could consider using the projected inputs in this model in their ZEV Cost Workbook. Autonomie is an advanced simulation tool for vehicle energy consumption and performance analysis co-developed with industry.[18] This tool provides projections of vehicle weight and specifications in 2025, 2030, and 2035. However, as we show in a comparison between the Autonomie inputs and real-world BEV data below, even the Autonomie model does not adequately capture expected improvements in vehicle efficiency. At the conclusion of our analysis, we present a correction factor ARB could combine with the Autonomie inputs to account for expected improvements in both vehicle weight and efficiency improvements unrelated to weight.

Autonomie's efficiency assumptions for 2025 are worse than best-in-class BEV models available today. The Autonomie model provides 3 technology cases: low-technology, high-technology without lightweighting, and high-technology. With respect to efficiency, the main difference between the 3 technology cases is vehicle weight; we find no discernible or consistent difference in the ratio of efficiency to vehicle weight between the cases, nor between projected years. Thus, while Autonomie accounts for significant weight reductions over time, it does not seem to fully capture improvements in efficiency that are independent of weight. In fact, we find that Autonomie's assumptions for energy consumption per unit vehicle weight are higher (i.e., worse) than for the best-in-class BEV models available today. In Figure 4 we show the estimated relationships between efficiency and vehicle weight for each vehicle class for 2025 in Autonomie, in the colored lines. We derive these by performing a linear regression between efficiency and weight inputs in the model for each vehicle class; within each vehicle

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[18] ANL (2021). *Autonomie vehicle system simulation tool.* https://www.anl.gov/es/autonomie-vehicle-system-simulation-tool

class we combine inputs for all vehicle ranges, for base and performance models, and for all technology cases. In the same figure we also show the efficiency compared to curb weight for the best-in-class BEV models available today, in dots. We define “best-in-class” as the top third for each vehicle category in terms of efficiency:weight out of the models listed in the Appendix. We can see that in almost all cases, the best-in-class BEVs available in 2019-2022 have lower energy consumption (i.e., better efficiency) than Autonomie would predict for their weights. Using a linear estimation for these trends is a conservative approach and efficiency improvement for today’s best-in-class is likely greater than what we show. **We calculate that, on average, the efficiencies of best-in-class BEV models available in 2019-2022 are 11% better (i.e., the energy consumption is 11% lower) than predicted by the Autonomie model for the same vehicle weight.**

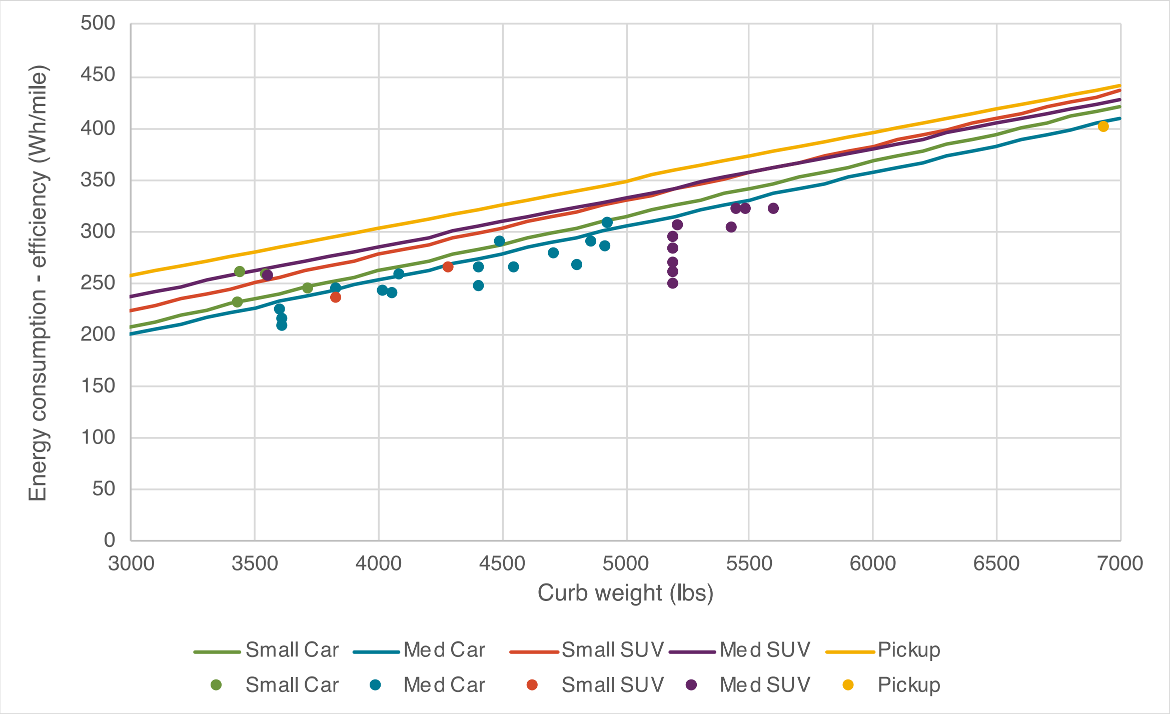

Figure 4. Best in class real-world vehicle efficiency and curb weight (in dots) compared to 2025 assumptions in Autonomie (lines) for each vehicle class

The best-in-class BEV models available today can be considered an indicator of where the market is going, because we expect the advancements from the most technological advanced vehicles today to permeate the industry. We thus suggest viewing the best-in-class in 2019-2022 as the likely industry average in 2025 in various BEV specifications, including the efficiency:weight ratio. To be clear, today’s BEV models have higher energy consumption (i.e., worse efficiencies) than predicted in the Autonomie model for any particular vehicle class and range, but this is entirely due to weight. Even in Autonomie’s low-technology case, the vehicle weights for each class and range are significantly lower than in today’s BEV models. For example, the average weight of medium car models available in 2019-2022 with a range of around 250 miles is 4,637 pounds. Autonomie’s low-technology case predicts a weight of 3,232 pounds for a base model medium car with the same range in 2025, declining to 2,993 pounds in 2030 and 2,983 pounds in 2035. In Autonomie’s high-technology and high-technology without lightweighting cases, the weight reductions are greater over time for all vehicle classes and ranges.

There is emerging evidence that BEV weight will decline over time with technology improvements. These reductions can come from many sources, but a large source is expected to be the batteries themselves. The cells are becoming more energy dense reducing battery weight. There are several companies today trialing alternative battery anodes such as lithium metal and high-content silicon. Reported gravimetric energy densities for today's batteries along with announcements for lithium metal and high-content silicon are shown in Table 3.

Table 3. Recent announcements for improved energy density in batteries

Company	Technology	Energy density (Wh/kg)	Source
Existing	Lithium-ion (various)	100-260	Yang, Gene et al. (2020) Advances in Materials Design for All-Solid-state Batteries: From Bulk to Thin Films. Journal of Applied Sciences. https://www.researchgate.net/publication/342821920_Advances_in_Materials_Design_for_All-Solid-state_Batteries_From_Bulk_to_Thin_Films
SES	Lithium metal	417	BusinessWire (2021) SES Unveils World's First 100 Plus Ah Li-Metal Battery, Announces New Gigafactory at First SES Battery World https://www.businesswire.com/news/home/20211103005931/en/SES-Unveils-World%E2%80%99s-First-100-Plus-Ah-Li-Metal-Battery-Announces-New-Gigafactory-at-First-SES-Battery-World
Solid power	Lithium metal	440	Solid Power. https://solidpowerbattery.com/ Accessed December 21, 2021
Solid power	High content silicon	390	Solid Power. https://solidpowerbattery.com/ Accessed December 21, 2021
Quantumscape	Lithium metal	380-500	Quantumscape. https://www.quantumscape.com/ Accessed December 21, 2021

General Motors and VW are also pursuing the commercialization of lithium metal chemistry.[19] Although these technologies are not yet at scale, battery advancements are likely to be in the market over the next 5-10 years.

The car body, exclusive of the battery may also be a source of weight reduction. The Autonomie model reflects these trends citing material substitution, improved packaging, and unit body construction.[20] Telsa announced plans for using "structural batteries" in their vehicles which are battery packs integrated into the structure of the car, saving weight over modular battery packs. They claim that weight reductions from the structural battery along with body casting improvements will reduce curb weight by 10%.[21] Ford recently substituted steel in their F150

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[19] The Mobilist (2020) "GM Claims It's On the Verge of Commercializing the Most Exotic Battery Chemistry of All" https://themobilist.medium.com/gm-claims-its-on-the-verge-of-commercializing-the-most-exotic-battery-chemistry-of-all-a310254fd1e2

[20] Argonne National Labs (2016) Assessment of vehicle sizing, energy consumption, and cost through large-scale simulation of advanced vehicle technologies. ANL/ESD-15/28. Available from https://publications.anl.gov/anlpubs/2016/04/126422.pdf

[21] Tesla (2020) 2020 Annual Meeting of Stockholders and Battery Day Tuesday, September 22, https://www.tesla.com/2020shareholdermeeting

trucks with aluminum. Along with other improvements, the weight of the truck was reduced by about 700 pounds.[22]

To illustrate how weight reductions similar to that in the Autonomie low-technology case are possible and what the effects are, a Telsa Model 3 Long-range AWD (see specifications in the Appendix) was modeled to incorporate future improvements. Batteries are 400 Wh/kg (as opposed to 260 Wh/kg today), and Tesla's stated 10% body mass reduction target is incorporated (Table 4). The "existing car" shown represents the exact specifications of the current Tesla. The "future car" represents the calculated weight reduction and resulting efficiency improvement from that weight reduction. We use the magnitude of efficiency improvement from weight shown in the medium car case in the Autonomie model and apply it to the existing Tesla efficiency. The overall weight reduction is 639 pounds and is in line with the low-technology case in Autonomie.

Table 4. Weight reduction scenario for Tesla Model 3

Tesla Model 3 Long Range AWD potential weight reduction								
	Curb weight (lbs)	**Battery cell energy density (Wh/kg)**	**Battery capacity (kWh)**	**Battery weight (lbs)**	**Non-battery weight reduction %**	**Non-battery weight (lbs)**	**Efficiency (Wh/mi)**	**Range (mi)**
Existing car	4065	260	79	668	0%	3397	238	331
Future car	3426	400	67	368	10%	3057	202	331

The battery weight is 300 pounds lighter not only because of the increased energy density, but also because higher efficiency from weight reduction results in fewer kWh overall needed to propel the vehicle for a given range. If energy density climbs even higher, further reduction in kWh needed for the same range will result. Similarly, any non-battery weight reduction in the vehicle increases efficiency and reduces the battery energy needed.

Importantly, ARB's weight assumptions for BEVs in the Cost Workbook are not clear; we do not know how they compare to the weight assumptions in the Autonomie model but suspect that assuming higher vehicle weights could help explain the relatively poor efficiencies assumed in ARB's Workbook.

In summary, we make the case that we can expect efficiency improvements over time due to both a) vehicle weight reduction and b) efficiency improvements unrelated to weight. The Autonomie model provides a useful basis to make assumptions about vehicle weight reduction over time. However, it does not adequately account for expected improvements in efficiency unrelated to weight. **We thus suggest that ARB follow the inputs in the Autonomie model for vehicle weight in future years, but apply the 11% correction factor we calculated above to account for the non-weight related efficiency improvements we expect based on real-world evidence.**

We present these recommended values, compared to ARB's assumptions for vehicle efficiency, in Table 5. We conservatively show the Autonomie model's low-technology case with moderate weight reduction over time, using our 11% correction factor. Efficiency improvements could be more rapid over time if one followed the more ambitious weight reduction assumptions in

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[22] Ford (2014) Ford uses high-strength steel plus high-strength aluminum alloys on toughest F-150 ever https://media.ford.com/content/fordmedia/fna/us/en/news/2014/01/13/ford-uses-high-strength-steel-plus-high-strength--aluminum-alloy.html

Autonomie's high-technology case, or even its high-technology without lightweighting case. **We find that, on average, our recommendation for efficiencies for the vehicle classes are 10% better (i.e., energy consumption is 10% lower) than ARB's assumptions for 2025.** The implication of this finding is that BEVs could be produced with smaller batteries and thus at lower cost than ARB has assumed.

Table 5. DC Energy - CD AER Efficiency (Wh/mi) in ARB and ANL analysis

	Vehicle class	Tech type	DC Energy - CD AER Efficiency (Wh/mi)										
			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
ARB (March 2022)	SmallCar	BEV300	209	208	207	205	204	203	202	201	200	199	198
	SmallCar	BEV400	232	231	229	228	227	226	225	224	223	222	220
	MedCar	BEV300	215	214	213	212	211	210	209	208	207	206	205
	MedCar	BEV400	240	238	237	236	235	234	232	231	230	229	228
	SmallSUV	BEV300	225	223	222	221	220	219	218	217	216	215	214
	SmallSUV	BEV400	249	248	247	245	244	243	242	241	239	238	237
	MedSUV	BEV300	272	270	269	268	266	265	264	262	261	260	258
	MedSUV	BEV400	301	299	298	296	295	293	292	290	289	288	286
	Pickup	BEV300	347	345	343	342	340	338	337	335	333	331	330
	Pickup	BEV400	384	382	380	378	376	375	373	371	369	367	365
ANL low technology case with efficiency correction	Vehicle class	Tech type	DC Energy - CD AER Efficiency (Wh/mi)										
			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	SmallCar	BEV300	186	185	183	182	181	180	178	177	176	175	174
	SmallCar	BEV400	207	205	203	201	199	197	196	195	194	193	192
	MedCar	BEV300	192	190	189	188	186	185	183	182	182	181	180
	MedCar	BEV400	213	211	209	207	205	203	202	201	201	200	199
	SmallSUV	BEV300	235	234	232	230	228	226	223	221	219	217	215
	SmallSUV	BEV400	261	259	256	253	251	248	246	243	241	239	236
	MedSUV	BEV300	255	253	251	250	248	246	243	240	237	234	231
	MedSUV	BEV400	282	280	277	275	273	271	267	264	261	258	255
	Pickup	BEV300	309	307	304	302	300	298	293	290	287	284	280
	Pickup	BEV400	342	339	336	333	329	326	323	319	316	312	309

We similarly compare ARB's assumptions for motor power with the outputs from the low-technology case in the Autonomie model in Table 6. The only difference in motor power between the 3 Autonomie technology cases is directly related to assumed vehicle weight. Overall, the 2025-2035 specifications for BEV motor power in the low-technology Autonomie model are an average of 9% lower than ARB's assumptions. We do not have enough information to understand how ARB derived its motor power assumptions; however, we note that the early BEV market may not be a good indicator of future motor power. The early BEV market has been characterized by a disproportionately high share of high-income consumers and some popular BEV models have catered to that demographic with luxury features, including high motor power. This is best evidenced by the Tesla Model 3 and Tesla Model S, which have motor power ranging from 211 kW to 580 kW. As BEVs become mainstream, a greater share of consumers are likely to choose lower cost over high performance, and hence we expect average motor power for any given vehicle size and weight to decline.[23] The lower motor power assumptions in Autonomie are based on benchmarked acceleration typical to that available in current gasoline vehicles and benchmarking on premium vehicles could explain the difference between ARB's motor power assumptions and those in Autonomie. We recommend ARB consider aligning its assumptions on motor power with those in the Autonomie model.

Table 6. Comparison of eMotor Power (kW) in ARB and ANL analysis

	Vehicle class	Tech type	eMotor Power (kW)										
			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
ARB (March 2022)	SmallCar	BEV300	109	109	108	107	107	106	106	105	105	104	104
	SmallCar	BEV400	123	122	121	121	120	120	119	118	118	117	117
	MedCar	BEV300	123	123	122	121	121	120	120	119	118	118	117
	MedCar	BEV400	137	137	136	135	135	134	133	133	132	131	131
	SmallSUV	BEV300	138	138	137	136	136	135	134	134	133	132	132
	SmallSUV	BEV400	156	155	155	154	153	152	151	151	150	149	148
	MedSUV	BEV300	149	149	148	147	147	146	145	144	144	143	142
	MedSUV	BEV400	168	167	167	166	165	164	163	162	162	161	160
	Pickup	BEV300	225	224	223	222	221	220	219	217	216	215	214
	Pickup	BEV400	251	250	248	247	246	245	243	242	241	240	239
ANL low technology case	Vehicle class	Tech type	eMotor Power (kW)										
			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	SmallCar	BEV300	98	98	97	96	95	91	94	94	94	94	90
	SmallCar	BEV400	108	102	101	99	98	98	97	96	96	96	96
	MedCar	BEV300	117	118	117	115	114	108	113	112	112	112	109
	MedCar	BEV400	129	123	121	120	118	117	116	116	116	116	115
	SmallSUV	BEV300	140	140	138	136	135	129	132	131	130	129	125
	SmallSUV	BEV400	155	146	144	142	139	140	136	135	134	133	133
	MedSUV	BEV300	154	154	152	150	148	141	145	144	143	142	137
	MedSUV	BEV400	171	160	158	155	153	154	150	148	147	146	146
	Pickup	BEV300	203	205	202	200	197	189	193	192	190	188	184
	Pickup	BEV400	230	214	211	208	204	205	200	199	197	196	196

Battery costs

The battery cost curves ($/kWh) applied in CARB's March 2022 ZEV Cost Workbook appear to accurately reflect the latest evidence, based on industry developments, automaker announcements, and technical research literature.

Projections of future battery cost reductions rely on continued lithium-ion battery technology and manufacturing-level improvements. Improvements include battery chemistry innovation (e.g.,

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[23] This BEV market evolution from primarily luxury vehicles through 2021 to a mainstream market is reflected in automaker electric vehicle investments and announcements for dramatically expanded electric vehicle model offerings, sales, and sales shares. See Table 1 in Anh Bui, Peter Slowik, and Nic Lutsey (2021), *Power Play: Evaluating the U.S. position in the global electric vehicle transition*. https://theicct.org/publications/us-position-global-ev-jun2021

higher nickel content cathodes, lower cobalt use, shifts to silicon-graphite anode mix, greater specific density), and a general increase in production volume from about 50,000 to 100,000 electric vehicle battery packs annually in 2020 to about 500,000 and greater from 2025 on.

We review various projections of electric vehicle battery pack costs and this is summarized below. Figure 5 illustrates the recent estimates of electric vehicle battery pack costs, based on expert sources, the best available research literature projections, and automaker announcements. The blue hashed line in the figure represents CARB's battery cost projections that are applied in its ZEV Cost Workbook, which is compared here with other sources. The figure also shows expert projections by BNEF (2020), UBS (2021) and technical research studies, including Nykvist et al. (2019), Penisa et al. (2020), Hsieh et al. (2018), Berckmans et al. (2017).[24] The automaker announcements include General Motors and Volkswagen for $125 to $135 per kilowatt-hour in 2021-2022, Tesla for $55/kWh in 2025, and Renault and Ford for $80/kWh in 2030.[25] As shown, CARB's battery cost projections land in the middle of the pack amongst the analyses shown, with some studies projecting much lower future battery costs sooner, and others projecting somewhat higher costs, through 2030.

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[24] Bloomberg New Energy Finance. (2020). Battery pack prices cited below $100/kWh for the first time in 2020, while market average sits at $137/kWh. Retrieved from https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/; UBS. (2020, October 27). Tearing down the heart of an electric car: can batteries provide an edge, and who wins. PowerPoint Presentation; Nykvist, B., Sprei, F., and Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. *Energy Policy.* https://doi.org/10.1016/j.enpol.2018.09.035; Penisa, X., Castro, M., Pascasio, J., Esparcia, E., Schmidt, O., and Ocon, J. (2020). Projecting the price of lithium-ion NMC battery packs using a multifactor learning curve model. *Energies.* Retrieved from https://www.mdpi.com/1996-1073/13/20/5276; Hsieh, I-Yun L., Pan, M. S., Chiang, Y-M., and Green, W. (2018). Learning only buys you so much: practical limits on battery price reduction. *ScienceDirect.* Retrieved from *https://www.sciencedirect.com/science/article/abs/pii/S0306261919301606*; Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., & Van Mierlo, J. (2017). Cost projection of state of the art lithium-ion batteries for electric vehicles up to 2030. *Energies 2017,* 10(9), 1314. Retrieved from http://www.mdpi.com/1996-1073/10/9/1314

[25] Lienert, P, & White, J. (2017). GM races to build a formula for profitable electric cars. Retrieved from https://www.reuters.com/article/us-gm-electric-insight/gm-races-to-build-a-formula-for-profitable-electric-cars-idUSKBN1EY0GG; Davies, C., (2017). VW I.D. EV boast: We'll hugely undercut Tesla's Model 3 says exec. Retrieved from https://www.slashgear.com/vw-i-d-ev-boast-well-hugely-undercut-teslas-model-3-says-exec-17491688/; Tesla (2020). Tesla battery day. Retrieved from https://www.youtube.com/watch?v=l6T9xIeZTds; Ford (2021). Delivering Ford+. *Ford Motor Company Investor Relations.* https://s23.q4cdn.com/799033206/files/doc_presentations/2021/06/Ford-_CMD-Presentation_May-26-2021.pdf; Renault: https://europe.autonews.com/automakers/renault-raises-ev-targets-pledges-lower-battery-costs

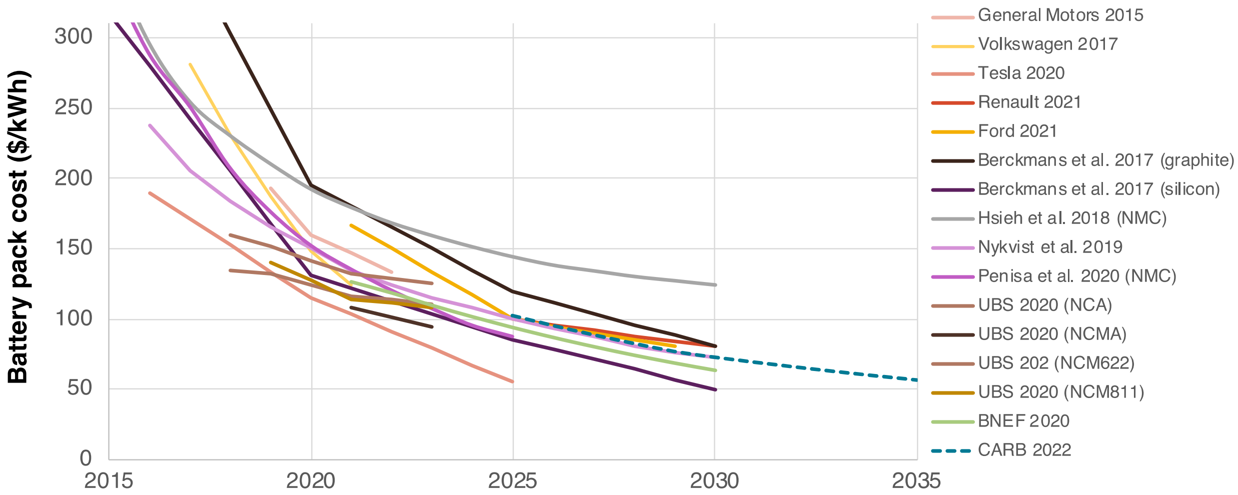

Figure 5. Electric vehicle battery pack costs from technical studies and automaker statements

The differences between projections in Figure 5 rely on various assumptions about raw material costs and learning rates. The grey Hsieh et al. (2018) line showing battery costs of $124/kWh in 2030 underscores the key linkage between raw material prices and battery pack costs by applying especially high cobalt prices in 2030. The projections are based on a 2-stage learning curve model that incorporates raw material price projections and learning in battery manufacturing. The finding of $124/kWh in 2030 for NMC battery packs is based on an assumed annual cobalt price increase of $13.3/kg, from $25.36/kg in 2016 to about $211/kg in 2030 that the authors call “probably an overestimate”. For context, that is about 2.3 times greater than prices during the recent cobalt price peak in March 2018, six times greater than the average prices in 2017 and 2019, and 2.9 times greater than prices in May 2022.[26] Nickel and Lithium are also assumed to increase by $1.3/kg and $1.9/kg annually, from $9/kg and $40/kg in 2016 to $27/kg and $67/kg in 2030, respectively. Hsieh et al. (2018) also analyze an alternative scenario where material prices remain constant and find a battery price of $93/kWh in 2030.

Other studies have found that increasing raw material costs would have a marginal impact on total battery manufacturing costs. Penisa et al. (2020) find that learning and innovation have greater influence on battery costs than raw material price increases and show that doubling the price of lithium and cobalt increase battery pack prices by 5% to 10%. Similarly, older BNEF research found that doubling lithium prices could increase battery prices by 8%, based on 2017 prices.[27] However as battery pack prices continue to fall, raw material prices represent a growing share of the total costs, and changes in raw material prices would have a greater relative effect on total costs. Mauler et al. (2022) apply future material price expectations and cost reductions based on innovation and find cell-level costs of $70/kWh in 2030 based on 2021 raw material prices.[28] When the researchers apply raw material price increases, the cell-level cost reductions are decreased; under the “most pessimistic” raw material price expectations, the

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[26] Wentker, M., Greenwood, M., and Leker, J. (2019). A bottom-up approach to lithium-ion battery cost modeling with a focus on cathode active materials. *Energies.* https://www.mdpi.com/1996-1073/12/3/504 and Trading Economics. (2022). Cobalt. Accessed May 1, 2022. https://tradingeconomics.com/commodity/cobalt

[27] Bloomberg New Energy Finance. (2017). Lithium price spike has moderate effect on batteries. Retrieved from https://about.bnef.com/blog/lithium-price-spike-has-moderate-effect-on-batteries/

[28] Mauler, L., Lou, X., Duffner, F., and Leker, J. (2022). Technological innovation vs. tightening raw material markets: falling battery cost put at risk. *Energy Advanced.* Retrieved from https://pubs.rsc.org/en/content/articlelanding/2022/ya/d1ya00052g

cost reductions from innovation are fully offset. This is based on an annual price increase of 5.5% for lithium, 9% for nickel, and 12% for cobalt. These projections are about the same annual increase applied in Hsieh et a. (2018), (4% for lithium, 8% for nickel, and 16% for cobalt).

Despite these risks, a 2021 battery cost review finds that many expert studies have long-term confidence and optimism in stable battery market growth, and expect a continued decline in battery costs regardless of raw material price developments.[29] Experts at Roush Industries argue that projecting battery cell costs based on raw material prices is not a reliable indicator of future cell costs, based on technological improvements in the battery cell, pack, and vehicle integration that allow for greater energy density and reduced raw materials per kilowatt-hour.[30] Furthermore, automakers and battery suppliers typically enter long-term battery and raw material contracts and thus are less vulnerable to price volatility of raw materials, as evidenced by recent supply deals by Ford, General Motors, and Tesla.[31]

Based on the above analysis, we believe that CARB's battery cost projections are appropriate.

Re-examine non-battery powertrain component costs

The total non-battery powertrain component costs applied in CARB's March 2022 ZEV Cost Workbook appear to be greater than the non-battery powertrain costs quantified in recent electric vehicle teardown analyses. Table 7 summarizes the BEV non-battery powertrain components and their costs for a representative 150 kW Chevrolet Bolt. As shown, the total costs for 2025 are $2,562. As context, the total non-battery costs for a 300-mile range "SmallCar" – the vehicle class of the Chevrolet Bolt – in CARB's March 2022 ZEV Cost Workbook is $3,317, which is about $750 greater than the component costs found in the component-level cost analysis by UBS (2017) and the National Academies of Sciences, Engineering, and Medicine (2021).[32] We thus recommend that CARB re-examine non-battery powertrain component costs based on the latest evidence. Doing so would reduce BEV incremental costs by several hundred dollars and accelerate the expected timing for cost parity.

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[29] Mauler, L., Duffner, F., Zeier, W., and Leker, J. (2021). Battery cost forecasting: a review of methods and results with an outlook to 2050. *Energy & Environmental Science.* Retrieved from https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee01530c

[30] Rogers, G., Nair, V., Pillai, S. (2021a). Technical Review of 48V and Battery Electric Vehicles costs for Revised 2023 and Later Model Year Light – Duty Vehicle Greenhouse Gas Emission Standards: Final Report. *Roush Industries, Inc.*, prepared for CAELP. Retrieved from https://downloads.regulations.gov/EPA-HQ-OAR-2021-0208-0210/attachment_3.pdf

[31] Scheyder, E. (2022, April 11). Ford inks Argentina lithium supply deal with Lake Resources. *Reuters.* Retrieved from https://www.reuters.com/business/autos-transportation/ford-inks-argentina-lithium-supply-deal-with-lake-resources-2022-04-11/; McLain, S., and Rogers, C. (2022, April 12). GM strikes deal to secure cobalt for electric-car batteries. *The Wall Street Journal.* Retrieved from https://www.wsj.com/articles/gm-strikes-deal-to-secure-cobalt-for-electric-car-batteries-11649775349; Hull, D., and Stringer, D. (2022, March 30). Tesla dodges nickel crisis with secret deal to get supplies. *Bloomberg.* Retrieved from https://www.bloomberg.com/news/articles/2022-03-30/tesla-dodges-nickel-crisis-with-secret-deal-locking-in-supplies

[32] UBS. (2017). UBS evidence lab electric car teardown: Disruption ahead? [Q-Series newsletter]. Retrieved from https://neo.ubs.com/shared/d1ZTxnvF2k/ and National Academies of Sciences, Engineering, and Medicine. 2021. Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy—2025-2035. Washington, DC: The National Academies Press. https://doi.org/10.17226/26092

Table 7. BEV non-battery powertrain component costs for a 150 kW Chevrolet Bolt, based on from recent studies

Component	Cost			Source
	2017	2020	2025	
Thermal management	$250	--	$225	UBS (2017)
Power distribution module	$250	--	$295	UBS (2017)
Inverter	--	$700	$412	NASEM (2021)
Electric drive module	--	$895	$724	NASEM (2021)
DC converter	$150	--	$134	UBS (2017)
Controller	$51	--	$46	UBS (2017)
Control module	$93	--	$84	UBS (2017)
High voltage cables	$335	--	$302	UBS (2017)
On-board charger	$273	--	$205	UBS (2017)
Charging cord	$150	--	$135	UBS (2017)
Total	--	--	$2,562	--

Consider recent evidence for continued ZEV assembly cost reductions

CARB's ZEV Cost Workbook applies a constant $1,600 reduction to ZEV assembly costs relative to conventional vehicles over the 2025 to 2035 analytical timeframe. While it is well established that BEV assembly costs are already much lower than conventional vehicle assembly costs, there is evidence to suggest that the assembly cost gap between BEVs and conventional vehicles will continue to grow.

BEV non-powertrain components and assembly costs are projected to further decline in the future for several reasons. As automakers expand their BEV model offerings and increase production volumes, there is a shift toward dedicated BEV platforms which enable new areas of cost reductions due to increased economies of scale, cross-segment parts sharing, partnerships among other automakers and suppliers, modified price points on the same vehicle, and better design-to-cost strategies that conventional vehicles have benefitted from for decades.[33]

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[33] Rogers, G., Nair, V., and Pillai, S. (2021b). Technical review of gasoline engine technologies for revised 2023 and later model year light- duty vehicle greenhouse gas emission standards. *Roush Industries Inc.* Retrieved from https://downloads.regulations.gov/EPA-HQ-OAR-2021-0208-0210/attachment_2.pdf; Transport and Environment (2021). Hitting the EV inflection point. Retrieved from https://www.transportenvironment.org/discover/hitting-the-ev-inflection-point/; Baik, Y., Hensley, R., Hertzke, P., and Knupfer, S. (2019). Making electric vehicles profitable. *McKinsey and Company.* Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/making-electric-vehicles-profitable; Chatelain, A., Erriquez, M., Moulière, P-Y., and Schäfer, P. (2018). What a teardown of the latest electric vehicles reveals about the future of mass-market EVs. *McKinsey and Company.* Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/what-a-teardown-of-the-latest-electric-vehicles-reveals-about-the-future-of-mass-market-evs; Erriquez, M., Morel, T., Moulière, P-Y., and Schäfer, P. (2017). Trends in electric-vehicle design. *McKinsey and Company*. Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/trends-in-electric-vehicle-design

This continued BEV cost reduction potential does not appear to be considered in CARB's most recent March 2022 ZEV Cost Workbook. It is thus recommended that CARB consider the most recent evidence regarding the potential for ZEV assembly cost reductions in the agency's analysis of incremental ZEV costs.

Quantify consumer cost competitiveness and ownership benefits

CARB's ZEV Cost Workbook assesses upfront incremental costs and finds that initial cost parity is expected in the next 8-13 years for long-range BEVs in most vehicle segments. Although the benefits at the time of vehicle purchase are clear, the consumer benefits on a vehicle ownership basis are significantly greater due to electric vehicles' lower fueling and maintenance costs. A 2019 ICCT analysis of U.S. electric vehicle costs found that cost-competitiveness for consumers approaches even faster than initial cost parity based on their lower operating costs. Specifically, the first-owner 5-year ownership cost analysis found that consumer ownership parity for electric vehicles is 1-2 years sooner than initial cost parity.[34] A 2022 Energy Innovation study found that in the total monthly costs of owning and financing new electric vehicles are lower than their gasoline counterparts from day one in California and several other states.[35]

If CARB staff considered the consumer benefits for first owners and for the entire vehicle lifetime, the expected benefits from transitioning to ZEVs would be substantially greater and cost parity would be achieved earlier than currently quantified.

Appendix

Table 6 presents the data and results for real-world 2019-2022 BEV models used in the analysis of vehicle efficiency above. For models where EPA certification presented DC efficiency, we used it directly (for 49 models). For all other models we performed a conversion from reported AC efficiency (for 66 remaining models). AC efficiency incorporates charger losses, but DC efficiency must be used to estimate battery size and is a more consistent basis for comparison. We derived this conversion factor by comparing the AC and DC efficiency of all models for which we have both reported values, finding a range of 0.79-0.95. We select a value of 0.9 for the conversion of AC to DC efficiency for the 66 models for which EPA certification lacked this specification. This is a conservative assumption; for most cases, it will overestimate energy consumption.

Table 6. Data and analysis of real-world 2019-2022 BEV models

OEM	Model	Model year	Vehicle class	Combined Adjusted AC Efficiency (Wh/mile)	Curb Weight (lbs)	Real-world Range (Miles)	EPA Cert DC Efficiency (Wh/mile)	DC Efficiency Assumption For This Analysis (Wh/mile)	Autonomie Predicted Efficiency By Weight (Wh/mile)	Percent Difference Autonomie-Real Efficiency
Tesla	Tesla Model 3 Long Range AWD Performance	MY2019	MedCar	291	4099	310	257	257	263	2%

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[34] Nic Lutsey and Michael Nicholas (2019), Update on electric vehicles costs in the United States through 2030. *International Council on Clean Transportation.* https://theicct.org/publication/update-on-electric-vehicle-costs-in-the-united-states-through-2030/

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Tesla	Tesla Model 3 Mid Range (RWD)	MY2019	MedCar	275	3837	264	242	242	244	1%
Tesla	Tesla Model S AWD - 100D	MY2019	MedCar	358	4957	335		322	344	6%
Tesla	Tesla Model S AWD - 75D	MY2019	MedCar	344	4723	259		309	319	3%
Tesla	Tesla Model S AWD - P100D	MY2019	MedCar	364	5062	315		328	355	8%
Tesla	Tesla Model S AWD Long Range	MY2019	MedCar	323	4873	370	288	288	334	14%
Tesla	Tesla Model 3 Long Range AWD P18	MY2020	MedCar	272	4033	322	241	241	258	7%
Tesla	Tesla Model 3 Long Range AWD P19	MY2020	MedCar	303	4033	304	269	269	258	-4%
Tesla	Tesla Model 3 Long Range AWD P20	MY2020	MedCar	309	4036	299	274	274	258	-6%
Tesla	Tesla Model 3 Standard Range	MY2020	MedCar	257	3624	220	207	207	231	11%
Tesla	Tesla Model 3 Standard Range Plus	MY2020	MedCar	242	3624	250	213	213	231	8%
Tesla	Tesla Model S Long Range Plus	MY2020	MedCar	307	4815	402	265	265	328	19%
Tesla	Tesla Model S P19	MY2020	MedCar	350	4939	348	306	306	342	10%
Tesla	Tesla Model S P21	MY2020	MedCar	375	4939	326	329	329	342	4%
Tesla	Tesla Model S Standard Range	MY2020	MedCar	329	4723	287	277	277	319	13%
Tesla	Tesla Model Y Performance AWD (21" Wheels)	MY2020	MedCar	326	4416	291	289	289	289	0%
Ford Motor Company	Ford Mustang Mach-E AWD	MY2021	MedCar	363	4508	211	346	346	298	-16%
Ford Motor Company	Ford Mustang Mach-E AWD Extended	MY2021	MedCar	373	4838	270	355	355	331	-7%
Ford Motor Company	Ford Mustang Mach-E California Route 1 (RWD)	MY2021	MedCar	333	4602	305	309	309	307	-1%
Ford Motor Company	Ford Mustang Mach-E GT	MY2021	MedCar	402	4988	270	379	379	347	-9%
Ford Motor Company	Ford Mustang Mach-E GT Performance Edition	MY2021	MedCar	412	4989	260	379	379	347	-9%
Ford Motor Company	Ford Mustang Mach-E RWD	MY2021	MedCar	338	4338	230	308	308	282	-9%
Ford Motor Company	Ford Mustang Mach-E RWD Extended	MY2021	MedCar	346	4647	300	309	309	311	1%
Tesla	Tesla Model 3 Long Range AWD	MY2021	MedCar	268	4065	353	238	238	261	9%
Tesla	Tesla Model 3 Performance AWD	MY2021	MedCar	320	4065	315	274	274	261	-5%
Tesla	Tesla Model 3 Standard Range Plus RWD	MY2021	MedCar	253	3616	263	222	222	231	4%
Tesla	Tesla Model S Long Range	MY2021	MedCar	305	4560	405	263	263	303	13%

Tesla	Tesla Model S Performance (19" Wheels)	MY2021	MedCar	323	4929	387	284	284	340	16%
Tesla	Tesla Model S Performance (21" Wheels)	MY2021	MedCar	373	4929	334	328	328	340	4%
Tesla	Tesla Model S Plaid (21" Wheels)	MY2021	MedCar	368	4765	348	314	314	323	3%
Tesla	Tesla Model Y Long Range AWD	MY2021	MedCar	297	4416	326	262	262	289	9%
Tesla	Tesla Model Y Performance AWD	MY2021	MedCar	335	4416	303	294	294	289	-2%
Tesla	Tesla Model Y Standard Range Plus RWD	MY2021	MedCar	273	4416	244		245	289	15%
Volkswagen Group	Volkswagen ID.4 1st	MY2021	MedCar	343	4683	250		309	315	2%
Volkswagen Group	Volkswagen ID.4 Pro S	MY2021	MedCar	343	4683	250		309	315	2%
Volvo	Volvo Polestar 2	MY2021	MedCar	367	4746	233	338	338	321	-5%
Volvo	Volvo XC40 AWD BEV	MY2021	MedCar	428	4746	208	338	338	321	-5%
Hyundai	Hyundai Ioniq 5 AWD (Long Range)	MY2022	MedCar	343	4663	256		309	313	1%
Porsche	Porsche Taycan 4S Perf Battery	MY2022	MedCar	424	4899	199		382	337	-13%
Porsche	Porsche Taycan 4S Perf Battery Plus	MY2022	MedCar	435	5075	227		392	357	-10%
Porsche	Porsche Taycan Perf Battery	MY2022	MedCar	409	4680	200		368	314	-17%
Porsche	Porsche Taycan Perf Battery Plus	MY2022	MedCar	449	4857	225		404	333	-22%
Porsche	Porsche Taycan Turbo	MY2022	MedCar	446	5297	212		402	384	-5%
Porsche	Porsche Taycan Turbo S	MY2022	MedCar	481	5251	201		433	378	-15%
Volkswagen Group	Audi Q4 e-tron quattro	MY2022	MedCar	356	4927	241		321	340	6%
Volkswagen Group	Audi Q4 e-tron Sportback quattro	MY2022	MedCar	356	4927	241		321	340	6%
Volvo	Polestar 1 Single Motor	MY2022	MedCar	319	4498	270		287	297	3%
Volvo	Polestar 2 Dual Motor	MY2022	MedCar	389	4737	249		350	320	-9%
Volvo	Volvo XC40 Recharge twin	MY2022	MedCar	403	4749	223		363	321	-13%
Jaguar Land Rover	Jaguar I-Pace (BEV)	MY2019	MedSUV	443	4782	234		398	325	-23%
Tesla	Tesla Model X AWD - 100D	MY2019	MedSUV	405	5450	295		365	371	2%
Tesla	Tesla Model X AWD - 75D	MY2019	MedSUV	380	5223	238		342	354	3%
Tesla	Tesla Model X AWD - P100D	MY2019	MedSUV	415	5481	289		373	373	0%
BYD Motors Inc.	BYD e6	MY2020	MedSUV	466	5335	187		420	362	-16%
Tesla	Tesla Model X Long Range	MY2020	MedSUV	374	5461	328	319	319	372	14%
Tesla	Tesla Model X P20	MY2020	MedSUV	400	5571	305	346	346	381	9%
Tesla	Tesla Model X P22	MY2020	MedSUV	456	5571	272	391	391	381	-3%

Tesla	Tesla Model X Standard Range	MY2020	MedSUV	355	5225	258	303	303	354	14%
Jaguar Land Rover	Jaguar I-PACE EV400	MY2021	MedSUV	443	4805	234		399	326	-22%
Tesla	Tesla Model X Long Range Plus	MY2021	MedSUV	344	5437	371	301	301	370	19%
Tesla	Tesla Model X Performance (20" Wheels)	MY2021	MedSUV	368	5498	341	321	321	375	14%
Tesla	Tesla Model X Performance (22" Wheels)	MY2021	MedSUV	417	5498	300	365	365	375	3%
Volkswagen Group	Audi e-tron	MY2021	MedSUV	459	5798	222		413	400	-3%
Volkswagen Group	Audi e-tron Sportback	MY2021	MedSUV	465	5787	218		418	399	-5%
Lucid USA, Inc	Lucid Air Dream P AWD w/19" wheels	MY2022	MedSUV	312	5203	471		281	353	20%
Lucid USA, Inc	Lucid Air Dream P AWD w/21" wheels	MY2022	MedSUV	326	5203	451		294	353	17%
Lucid USA, Inc	Lucid Air Dream R AWD w/19" wheels	MY2022	MedSUV	288	5203	520		259	353	27%
Lucid USA, Inc	Lucid Air Dream R AWD w/21" wheels	MY2022	MedSUV	312	5203	481		281	353	20%
Lucid USA, Inc	Lucid Air Grand Touring AWD w/19" wheels	MY2022	MedSUV	275	5203	516		248	353	30%
Lucid USA, Inc	Lucid Air Grand Touring AWD w/21" wheels	MY2022	MedSUV	298	5203	469		268	353	24%
Mercedes-Benz	Mercedes EQS 450+	MY2022	MedSUV	349	5613	350	319	319	384	17%
Porsche	Porsche Taycan 4 Cross Turismo	MY2022	MedSUV	441	5106	215		397	346	-15%
Porsche	Porsche Taycan 4S Cross Turismo	MY2022	MedSUV	445	5106	215		400	346	-16%
Porsche	Porsche Taycan Turbo Cross Turismo	MY2022	MedSUV	469	5348	204		422	363	-16%
Porsche	Porsche Taycan Turbo S Cross Turismo	MY2022	MedSUV	460	5318	202		414	361	-15%
Rivian Automotive	Rivian R1S (SUV)	MY2022	MedSUV	486	6916	316	385	385	513	25%
Volkswagen Group	Audi e-tron GT	MY2022	MedSUV	420	5115	238		378	346	-9%
Volkswagen Group	Audi e-tron quattro	MY2022	MedSUV	459	5864	222		413	405	-2%
Volkswagen Group	Audi e-tron S (20" wheels)	MY2022	MedSUV	486	6107	208		437	428	-2%
Volkswagen Group	Audi e-tron S (21" or 22" wheels)	MY2022	MedSUV	564	6107	181		508	428	-19%
Volkswagen Group	Audi e-tron S Sportback (20" wheels)	MY2022	MedSUV	475	6107	212		428	428	0%
Volkswagen Group	Audi e-tron S Sportback(21/22" wheel)	MY2022	MedSUV	551	6107	185		496	428	-16%
Volkswagen Group	Audi e-tron Sportback quattro	MY2022	MedSUV	465	5853	218		418	404	-3%
Volkswagen Group	Audi RS e-tron GT	MY2022	MedSUV	425	5170	232		382	350	-9%
Rivian	Rivian R1T (Pickup Truck)	MY2022	Pickup	495	6949	314	399	399	465	14%

FCA US LLC	Fiat 500e	MY2019	SmallCar	300	2957	84		270	206	-31%
Mercedes-Benz	Mercedes Smart EQ Fortwo Electric Drive Convertible	MY2019	SmallCar	323	2427	57		291	189	-53%
Mercedes-Benz	Mercedes Smart EQ Fortwo Electric Drive Coupe	MY2019	SmallCar	302	2377	58		272	188	-44%
Volkswagen Group	Volkswagen e-Golf	MY2019	SmallCar	288	3455	125		259	231	-12%
Tesla	Tesla Model 3 Mid Range	MY2020	SmallCar	275	3724	264	242	242	248	2%
BMW	BMW I3 BEV (120 Amp-hour battery)	MY2021	SmallCar	298	3040	153		268	209	-28%
BMW	BMW I3s BEV (120 Amp-hour battery)	MY2021	SmallCar	298	3040	153		268	209	-28%
Hyundai	Hyundai Ioniq Electric	MY2021	SmallCar	254	3446	170		229	230	1%
SC Auto Sports, LLC	Kandi K27	MY2021	SmallCar	295	2270	59		266	187	-42%
BMW	Mini Cooper SE Hardtop 2 Door	MY2022	SmallCar	307	3144	114		276	214	-29%
General Motors	Chevy Bolt EUV (BEV)	MY2022	SmallCar	294	3559	247	257	257	237	-8%
General Motors	Chevy Bolt EV (BEV)	MY2022	SmallCar	281	3559	259	257	257	237	-8%
MAZDA	Mazda MX-30	MY2022	SmallCar	367	3655	100	315	315	244	-29%
Nissan	Nissan Leaf (40 kW-hr battery pack)	MY2022	SmallCar	304	3524	149	268	268	235	-14%
Nissan	Nissan Leaf (62 kW-hr battery pack)	MY2022	SmallCar	313	3843	226	284	284	257	-11%
Nissan	Nissan Leaf SV/SL (62 kW-hr battery pack)	MY2022	SmallCar	323	3843	215	284	284	257	-11%
Honda	Honda Clarity (Battery Electric Vehicle)	MY2019	SmallSUV	295	4050	89		266	278	4%
Kia	Kia Soul Electric	MY2020	SmallSUV	292	3854	243		263	268	2%
Tesla	Tesla Model 3 Long Range	MY2020	SmallSUV	259	3837	330	235	235	267	12%
Hyundai	Hyundai Ioniq 5 RWD (Long Range)	MY2022	SmallSUV	292	4297	303		263	293	10%
Hyundai	Hyundai Ioniq 5 RWD (Standard Range)	MY2022	SmallSUV	303	3968	220		272	273	0%
Hyundai	Hyundai Kona Electric	MY2022	SmallSUV	275	3770	258		247	264	6%
Kia	Kia Niro Electric	MY2022	SmallSUV	300	3937	239		270	272	1%
Volkswagen Group	Volkswagen ID.4 AWD Pro	MY2021	Unidentified	349		249		314		
Volkswagen Group	Volkswagen ID.4 AWD Pro S	MY2021	Unidentified	363		240		326		
Volkswagen Group	Volkswagen ID.4 Pro	MY2021	Unidentified	335		260		301		
Kia	Kia EV6 AWD (Long Range)	MY2022	Unidentified	317		274		285		
Kia	Kia EV6 RWD (Long Range)	MY2022	Unidentified	280		310		252		
Kia	Kia EV6 RWD (Standard Range)	MY2022	Unidentified	283		232		255		

Volvo	Volvo C40 Recharge twin	MY2022	Unidentified	393		226		354		