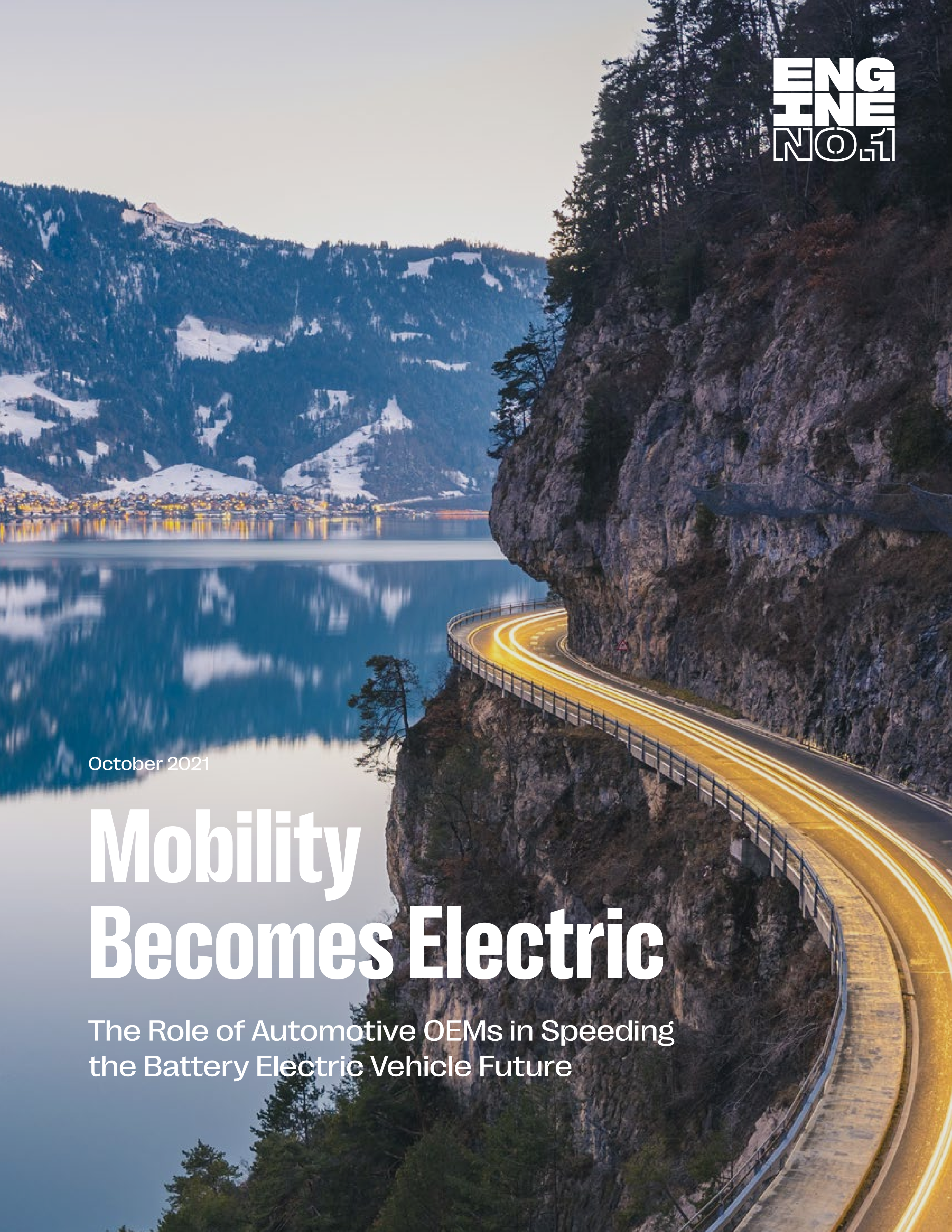

October 2021

Mobility Becomes Electric

The Role of Automotive OEMs in Speeding the Battery Electric Vehicle Future

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Introduction

For the first time in a century, the automotive industry is undergoing a transformation so fundamental that it could upend competition and remake entire markets. The battery electric vehicle (BEV) has the potential to become the new dominant design, representing the first major transition since internal combustion engine vehicles attained that status in the late 1920s.

Catalyzed by changes in public policy, innovation, and consumer demand, the shift to BEVs from internal combustion engine vehicles (ICEVs) has already seen new challengers to traditional auto companies emerge. This white paper makes the case that this is indeed the end of the ICEV era. But it won't be only pure-play BEV companies that succeed. Some incumbents—such as General Motors, as highlighted in this report—have now committed themselves toward an all-electric future, investing not just to survive the industry's transition, but to use it as an opportunity to grow stronger.

Previous waves of BEV adoption stalled due to several reasons: interrelated factors of supply and demand, corporate strategy, and consumer concerns, as well as policy pendulum swings—the last of which has yielded inertia and the persistence of the fossil-fuel regime. However, turning this into a virtuous cycle that reinforces rapid diffusion of BEVs is within reach.

For many, the transition to BEVs appears headed toward a replay of the transformations we've seen in other—primarily digital—industries. Tesla has achieved hard-won status as a leading transformative force and now thrives as a pure-play BEV start-up while other new similar firms quickly are following suit. Many believe that these new entrants will grow and take share from the traditional automakers, whose reliance on ICEVs dwarfs their small number of (possibly token) BEV models and whose agility is questionable. A quick decline in these large bureaucratic relics from a past century would follow as a natural course. The staggering valuation of Tesla, higher than most incumbent automakers combined, is consistent with this expected trajectory.

This perspective misses one central fact and one provable premise.

That central fact: the scale of the BEV transition challenge is beyond what Tesla and other new entrants can surmount in the time frame needed to bend the emissions curve. Consider that the global auto industry produces and sells nearly 100 million vehicles per year. By 2019, before the disruptions of COVID, the sales of BEVs reached 2 million, or 2 percent of that total. To be sure, Tesla is known for its ambitious goals and optimistic time frames for reaching them: At its 2020 shareholder meeting, the company set a 2030 target of 3 TWh battery cell production, split 50-50 between vehicles and energy.[1] Assuming 75 kWh/vehicle, this would be the equivalent of 20 million vehicles per year in the best case, which is roughly 20 percent of global automotive sales. This would make Tesla, in less than a decade, twice or three times the size of the world's largest automakers. Volkswagen, for instance, sold 10.8 million vehicles in 2019; Toyota, 10.7 million; Nissan-Renault-Mitsubishi, 10.1 million; General Motors, nearly 9 million; Hyundai/Kia, nearly 8 million; and Ford, nearly 6 million.

Even if Tesla succeeds in pulling off this improbable growth curve—and even if other BEV start-ups gain traction and scale—the total BEV volume from these pure-play firms would not be enough to bend the curve on transport-related carbon emissions to the extent demanded by policymakers and, increasingly, by the public. Furthermore, the durability of vehicles across all owners is currently exceeding 12 years. High longevity in the car parc—that is, among all vehicles in operation—means that the installed base of ICEVs, numbering roughly 250 million in the U.S., won't transform quickly despite an influx of new BEV models seeking buyers. It is undeniable that the incumbent ICEV firms will play a big role in the provision of personal mobility for decades to come.

All of which leads us to the provable premise: these incumbent automakers, or original equipment manufacturers (OEMs), are fully capable of becoming central players in the transition to BEVs and are also fully motivated to do so. They have, after all, amassed strong capabilities as system integrators of a complex multi-technology product and orchestrators of complex global supply chains. They also have a long track record of successfully absorbing new technologies, sometimes via internal "make" but more often through a contract-governed "buy" from sophisticated suppliers. Because OEMs need to "know more than they make"[2] in order to oversee product development and suppliers, they invest heavily in research and development (R&D) on new technologies, including battery chemistries and electric drive trains. This positions them well to influence the features of an eventual dominant BEV design. Finally, OEMs hold a long-established structural

[1] https://www.tesla.com/2020shareholdermeeting Battery Day presentation, slide 39

[2] Brusoni, Stefano, Prencipe, Andrea, and Pavitt, Keith. (2001). "Knowledge Specialization and the Boundaries of the Firm: Why Do Firms Know More Than They Make?" *Administrative Science Quarterly*, 46:597-621.

For the first time in a century, the automotive industry is undergoing a transformation so fundamental that it could upend competition and remake entire markets. The battery electric vehicle (BEV) has the potential to become the new dominant design, representing the first major transition since internal combustion engine vehicles attained that status in the late 1920s.

role as guarantors of vehicle quality and safety via their responsibility for meeting regulatory standards and their legal liability for product failures. That gives them yet another advantage: maintaining a high share of the value in the expanding mobility sector.

From this perspective, the crucial second act of the electrification transformation, now underway, will be ushered in by recent OEM commitments to a rapid scale-up of BEVs. These companies will, in other words, contribute to the quicker achievement of Tesla's mission "to accelerate the world's transition to sustainable energy." So the narrative of incumbents fading away, so typical in digital transformations, does not reflect the realities and imperatives of this sector's electrification.

The winner-take-all dynamics common to digital disruptions aren't likely in this transition, either. Incumbent OEMs already possess many of the capabilities and complementary assets needed to design, build, sell, and support BEVs. Many BEV components overlap with those in ICEVs and, even when vehicles are redesigned to support electrification (with lighter weight, less rolling resistance, less draw on the battery), these remain well within OEM capabilities, meaning less start-up advantage over incumbents. The global automotive sector has also proven to be stubbornly resistant to consolidation, despite persistent production overcapacity and comparatively low profit margins. This, coupled with economic and political forces, will keep multiple OEMs in the game.

Still, not all traditional OEMs will succeed in making the transition to the new era of electrified mobility. The challenge of managing a legacy business while investing in a new dominant design is indeed daunting, and policymakers, investors, and consumers will all be watching to see which firms emerge as leaders. Not all OEMs—or start-ups—will be able to attract sufficient financial or human capital, and if they fall behind in the race to design appealing BEVs, they will quickly fail or their assets will be acquired by others. After a period of ferment, a new set of dominant firms will emerge:

a mix of new BEV-only firms and former ICEV OEMs. This report examines several competitors trying to move toward BEV leadership, among them VW, Toyota, and Ford, and it highlights General Motors as a potential leader in this transition.

What's more difficult to predict is whether BEVs will in fact become the dominant technology for decarbonizing transportation. BEVs currently lead as most effective for the most rapid bending of the emissions curve, and that lead could grow if new battery chemistries, for example, solid-state, soon reach large-scale commercialization. Crucially, the interdependence of BEVs with charging makes it essential that investments into the expansion of charging infrastructure rise dramatically—and for charging access to be prioritized for public investment in difficult-to-serve locations. Ultimately making progress on emissions reductions is an all-hands-on-deck project that will involve many actors and many different technologies, including "last gasp" enhancements in internal combustion engines for higher efficiency; dual-drive-train hybrids, including plug-ins; and hydrogen-based fuel cells. Strategies that lean less on BEVs and more on these alternatives—including, notably, Toyota's current approach—can't be dismissed outright at this juncture.

To skeptics who doubt that incumbent firms can navigate a major technological transition when faced with start-ups and disruptive innovations, history provides ample examples of these firms' capabilities that proved valuable in both old and new technology regimes. There are also many examples of agility exhibited by such companies when they have been faced with upstart challengers. Of greater issue in the electrification of mobility is whether incumbents will actively support the other actors and policies as necessary to meet the aspirational goals that bend the emissions curve downward. Investors and consumers will do well to watch OEMs' direct actions, particularly those involving progress toward stated goals, as well as their political activities—for instance, a company potentially undermining those direct actions by paying obeisance to fossil-fuel interests.

This report builds the claim that virtuous cycles to accelerate the BEV transition are more feasible now than they have been at any other moment in history. BEV demand continues to exceed expectations. Newly announced BEVs can sell out within the first day of reservations. In many cases, the reason is clear: BEVs can simply be better for consumers. The driving experience can be faster, quieter, cleaner, and more fun. As vehicles, current and future BEV platform architectures provide innovation in safety, form, and function. For example, they can have more interior space, a larger front crumple zone, and a lower center of gravity, which lowers rollover risk. Through their batteries, BEVs could provide power to a worksite or replace generators that supply electricity to homes during a power outage.

Furthermore, BEVs could soon be less expensive to own than ICEVs. Though the average price of a BEV in the U.S. was still $6,600 higher than the industry average,[3] the cost of the battery pack (the most expensive component of a BEV) continues to decline as the supply chain increases scale and advances the chemistry and design of cell technology.[4] These innovations in the battery supply chain could take $5,000 out of the cost of manufacturing a BEV by 2024 and $7,000 by 2030.[5] BEVs also have a lower cost of operation and maintenance.[6]

This report opens with evidence that it is the "end of an era" for the internal combustion engine and that, yes, that "this time is different" when it comes to a BEV tipping point. Next are the intertwined arguments that "the Tesla is not enough" and that incumbent OEMs can and will play a crucial role in the BEV transition. On specific firms, the assessment of General Motors' potential to be a leader among OEMs is up first, followed by a comparative assessment of GM's competitors, an analysis of the overarching competitive dynamics, and an evaluation of scenarios of OEM disruption and consolidation. Then we will address the challenges of aligning BEV goals with domestic economic and political priorities at a time of cultural division. The penultimate section sets out what to watch for in GM's actions in order to evaluate its progress and commitment to the BEV transition. The report concludes with a call to action: that investors and consumers who act to fuel a virtuous cycle of change in the necessary electrification of mobility will gain an outsize share of the economic value generated.

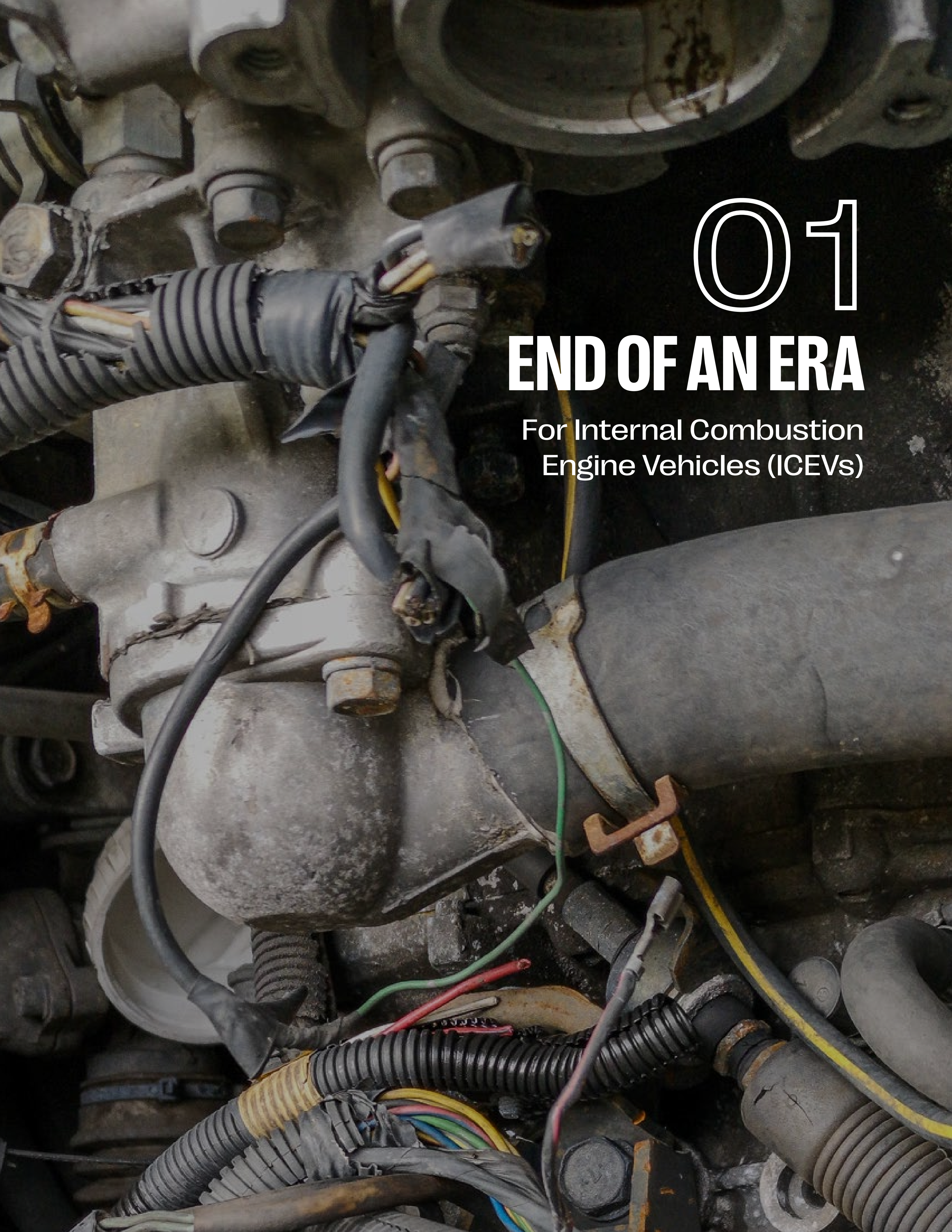
We are currently witnessing a gap in the quest to limit Earth's temperature increase—and an attendant opportunity has surfaced—as electricity generation has moved with surprising speed toward decarbonization via cleaner and renewable energy sources. Transportation is one of the largest emissions threats due to its stubborn resistance to electrification, even though it enjoys more electrification-technology options than do other emissions-intensive sectors, such as concrete and steel making. Accordingly, as policymakers around the world perceive an urgent need to address climate change, they are taking aim at the transportation sector and they have many levers to pull in their efforts to influence the key actors. Incumbent automakers and start-ups alike are scrambling to prevail in this energy-policy future. The only certainty is that the industry will undergo huge upheaval in the coming years, and those that navigate this transformation most effectively will thrive.

[3] As of August 2021. https://mediaroom.kbb.com/2021-09-14-New-Vehicle-Prices-Surge-to-Record-Highs-for-Fifth-Straight-Month,-According-to-Kelley-Blue-Book. Note that the federal income tax credit of $7,500 for BEVs only applies, under current law, to the first 200,000 vehicles sold by a given manufacturer; Tesla and GM have already hit this limit. Current proposed legislation would expand BEV tax credit thresholds, raise the dollar amount, and establish higher tax credits for BEVs built in the U.S. and (still higher) built by union workers.

[4] Starting from a pack cost of $157/kWh in 2019, Bloomberg New Energy Finance forecasts average battery pack prices dropping below $100/kWh by 2024 and reaching $58/kWh by 2030. See, e.g., https://www.washingtonpost.com/business/energy/why-an-electric-car-battery-is-so-expensive-for-now/2021/09/16/c210d566-16ab-11ec-a019-cb193b28aa73_story.html

[5] Assuming an average battery pack size of 75 kWh and BNEF's $92/kWh forecast for 2024.

[6] U.S. Office of Energy Efficiency and Renewable Energy estimates ICEV cost $0.101/mile vs. $0.061 for BEVs. https://www.energy.gov/eere/vehicles/articles/fotw-1190-june-14-2021-battery-electric-vehicles-have-lower-scheduled



01

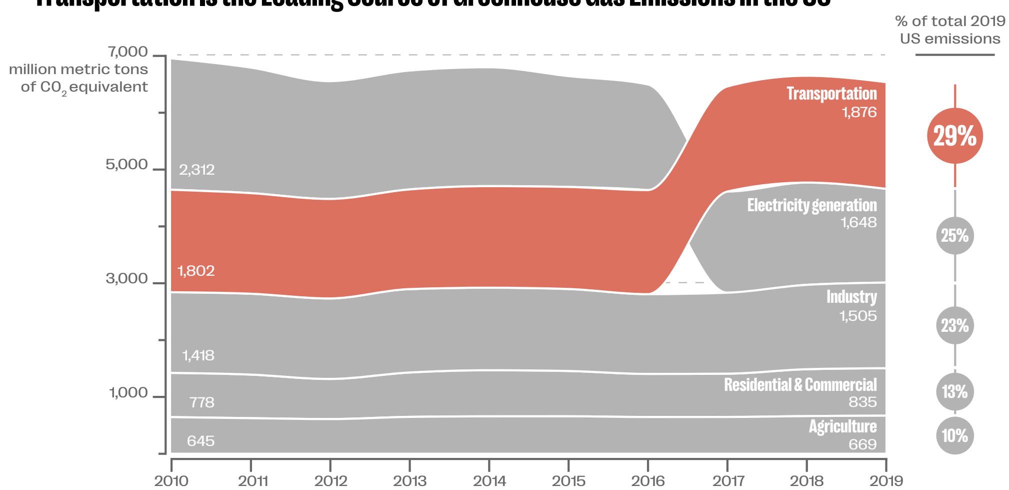
END OF AN ERA

For Internal Combustion Engine Vehicles (ICEVs)

Transportation now contributes the largest share of carbon emissions in the U.S., having recently surpassed electricity generation.[7] (See Figure 1-1.) Meanwhile, the electricity-generation sector has seen the greatest emissions decline due to shifts in energy source—first a move from coal toward gas, and now an increasing percentage of renewables. This switch in rank order is thus driven by three factors: growth in transportation emissions, reduction in electricity generation emissions, and transportation's slow pace of transition to electricity.[8] While electrification of transportation is picking up now, it has been slow due to limitations on both the supply and demand sides of the energy equation: battery cost and range and a low number of products on the supply end and minimal charging infrastructure along with consumer reluctance due to cost and range concerns on the demand side. Meanwhile, transport emissions have more than doubled over the past 50 years, with road-based vehicles contributing to nearly 80 percent of that increase.[9] Global growth in autos remains strong, particularly in emerging economies, and projections call for the current car parc

FIGURE 1.1

Transportation Is the Leading Source of Greenhouse Gas Emissions in the US



Source: EPA Greenhouse Gas Inventory Explorer

[7] Greenhouse gas (GHG) emissions from transportation account for about 29 percent of total U.S. greenhouse gas emissions, making the sector the largest contributor of U.S. GHG emissions. Between 1990 and 2019, GHG emissions in the transportation sector increased more in absolute terms than in any other sector. https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation

[8] https://www.eia.gov/todayinenergy/detail.php?id=38053

[9] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf

Policy goals at national, regional, and global levels are increasingly set with the intention of limiting the rise of global temperatures, and they are now driving industrial transformation at a faster pace than they have been at any other point in the past two decades. Firms and investors may ignore these developments at their own peril.

(i.e., all vehicles in operation) to nearly double by 2040.[10] As the impact of carbon emissions is not delimited by geography, these transport-driven increases threaten to overwhelm emissions-reduction progress elsewhere.[11]

So if current trends continue, transportation will be the sector most directly accelerating the pace of climate change and, specifically, of global warming. Policy goals at national, regional, and global levels are increasingly set with the intention of limiting the rise of global temperatures,[12] and they are now driving industrial transformation at a faster pace than they have been at any other point in the past two decades. Firms and investors may ignore these developments at their own peril. Instead they should position themselves well by reframing how best to pursue economic gains in this environment.

A recent report by David Victor,[13] issued in collaboration with Engine No. 1 in conjunction with its campaign to influence ExxonMobil's policies, made a strong case that we are reaching the end of the fossil-fuel era. To reiterate key points from Victor's report, days are numbered for the longtime consensus favoring continued growth in oil and gas demand. The market capitalization of key players reflects this fact: Since 2010, the top four oil and gas companies' market cap has shrunk by more than half and the largest green-energy supply companies—all electric—have tripled theirs. Estimates of projected demand for oil are more

[10] Nitch Smith, M., 2016, "The Number of Cars Worldwide Is Set to Double by 2040": https://www.weforum.org/agenda/2016/04/the-number-of-cars-worldwide-is-set-to-double-by-2040

[11] Note that many argue biofuels (e.g., 10 percent ethanol in gasoline) have not contributed to emissions reduction in any significant way to date, and next-generation biofuels are not as promising as a fuel source for passenger vehicles as electricity. See https://www.theatlantic.com/ideas/archive/2019/11/ethanol-has-forsaken-us/602191/

[12] The 2015 Paris Accords set a goal of limiting temperature increase to "below 2 degrees Celsius above pre-industrial levels." The 2018 report of Intergovernmental Panel on Climate Change (IPCC) argued that "below 1.5 degrees C" should be the new goal for action on climate change. (https://www.ipcc.ch/sr15/). The 2021 IPCC Assessment #6, summarizing all new scientific studies on climate since Assessment #5 in 2013, concludes that we will almost certainly exceed 1.5 C. temperature rise by 2040, regardless of what policies are enacted. This only heightens policymaker intentions to take action to bend the emissions curve steeply and quickly. Transportation becomes the most important target, given its current leading role in emitting emissions.

[13] https://reenergizexom.com/wp-content/uploads/2021/03/Energy-Transformations-Technology-Policy-Capital-and-the-Murky-Future-of-Oil-and-Gas-March-3-2021.pdf

wide-ranging than ever, with several credible forecasts looking for steep drops in that demand in the next decade, including in the 2020 BP and Shell forecasts. (See Figure 1-2.) The potential for demand implosion increases the risk of continued investment in new sources of oil and gas, and that could result in massive stranding of assets.

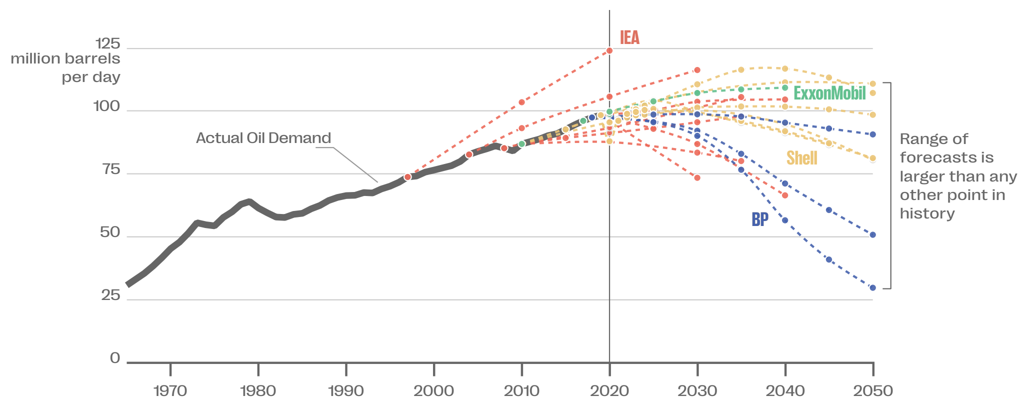
Climate change can't be remedied with any one technological fix. The solution lies not in the post-extraction, post-processing remedies of the past—for instance, scrubbers applied after coal-fired electricity generation—nor in the ambitious and as-yet-unproven technologies of the future, such as carbon sequestration. Carbon dioxide (CO_2) is a problem of accumulation, and its negative effects can only be fully addressed if we reduce future additions to the store of CO_2 already present in the atmosphere. Climate change is drawing more public and policy attention and concern now than ever before, and this is prompting a reframing for energy industries: that pursuing a future supply of fossil fuels is now less important than reducing excessive demand of oil and gas and switching to alternative low-emissions technologies.

This report starts with the trend away from fossil fuels, and a logical conclusion is drawn for the mobility sector: the internal combustion engine is also reaching the end

FIGURE 1.2

Rising Uncertainty Around the Future of Oil Demand

History of demand for oil and future projections from the International Energy Agency (IEA), BP, Shell, and ExxonMobil



Adapted from "Energy Transformations: Technology, Policy, Capital and the Murky Future of Oil and Gas," David Victor (2021)

The main figure shows the history of demand for oil (heavy black line) and projections (light-colored lines) for four organizations: the International Energy Agency (selected years, including 2020 scenarios), BP (2020 scenarios), Shell (selected years, including 2021 scenarios), and ExxonMobil (2019 Outlook for Energy). At no point in the history of oil demand forecasting has the range of possible futures been larger than today, and at no point has there been more attention to rapid declines in total demand. Source: International Energy Agency, BP, Shell, ExxonMobil. Data sources: Historical oil (liquids) data from BP Statistical Review; projections from Shell (2013 Mountains and Oceans scenarios plus 2018 Sky scenario and the 2021 Waves, Islands, and Sky 1.5 scenarios), BP (three scenarios released in 2020), the International Energy Agency (baseline projections since 2000 plus three scenarios in 2010 and three in 2020). And ExxonMobil sole Outlook for Energy scenario (2019). Online ExxonMobil has also "evaluated" the EMF27 two degree scenarios.

of its era. Historians of technology point to 1927 as the approximate point of the emergence of the dominant design for the mass-produced automobile.[14] By then, the familiar features of today's dominant form of transportation were in place: enclosed metal body, wheels and suspension, steering wheel and brakes, transmission determining the transfer of energy to the wheels, and an internal combustion engine providing power. By that time, ICEVs had essentially won a competition among contending power-train designs, beating out electric vehicles (notwithstanding the friendship between Henry Ford and Thomas Edison) due in large part to a dramatic drop in the price of gasoline and the invention of the electric starter.[15] With the establishment of a dominant design, investment soon flowed to the scaling of R&D, manufacturing, and supply chains around ICEVs, and the industry consolidated from hundreds of start-ups to an oligopoly of huge automakers.

We are at a propitious moment when competition between power-train designs is alive again, leading to turbulence for the auto industry and the broader mobility sector. The BEV is widely acknowledged as having the potential to become the new dominant design[16] and representing the first major shift since ICEVs attained that status in the late 1920s. The competition now is not between a completely new technology and more traditional forms of personal mobility, as it was in that earlier period (when it was automobiles versus horses and carriages, trains, and streetcars). Instead, it is between a massive ecosystem of ICEV manufacturers, fossil-fuel providers, and a gasoline-based refueling infrastructure on one side, and an emergent ecosystem of BEVs that will in many ways resemble the autos of the past while incorporating a completely different drive-train design and power source that requires an entirely new fueling infrastructure on the other.

Inertia and opposition to change from the ICEV ecosystem, including from producers, policymakers, and consumers, is readily apparent[17] and casts a shadow over optimistic pronouncements about the potential for growth in BEV sales. Furthermore, the transition away from ICEVs will take longer because of the durability of the

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[14] On the role of dominant design in the evolution of industries, including sources on fixing the date for when the internal combustion engine achieved dominant design status for the U.S. auto industry, see Suárez, Fernando F., and James M. Utterback. "Dominant Designs and the Survival of Firms." *Strategic Management Journal*, vol. 16, no. 6, 1995, pp. 415–430.

[15] ICEVs also beat out steam engines, for different reasons. "Despite the simplicity of their engines, fast acceleration, low pollution, economy, and great power, the early steamers started up slowly and ran noisily, had unreliable controls and problems with freezing, and required extensive engineering knowledge to operate. . . . [they also] suffered from little infusion of capital into their production, some untimely accidents, and vigorous competition from mass-produced gas-powered cars." Martin V. Melosi, "Energy Use and the Internal Combustion Engine," The Automobile and the Environment in American History http://www.autolife.umd.umich.edu/Environment/E_Overview/E_Overview3.htm

[16] For a broad prediction in this direction, see Berkeley, J. The death of the internal combustion engine, *The Economist*, 12 August 2017, https://www.economist.com/leaders/2017/08/12/the-death-of-the-internal-combustion-engine For a representative technically oriented comparison between BEVs and ICEVs (albeit with data from the early 2010s), see "Battery Electric Vehicles vs. Internal Combustion Engine Vehicles," Arthur D. Little, 2016 http://www.adlittle.cn/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf

[17] This editorial in the J*ournal of Engine Research* argues strongly that continued innovation in ICEVs will make them a strong competitor to BEVs. https://journals.sagepub.com/doi/full/10.1177/1468087419877990 Indeed, a spurt of innovation is common for dominant designs challenged by a new technology, see Snow, Daniel C., "Extraordinary Efficiency Growth in Response to New Technology Entry: The Carburetor's 'Last Gasp'" (August 30, 2010). https://ssrn.com/abstract=1668643

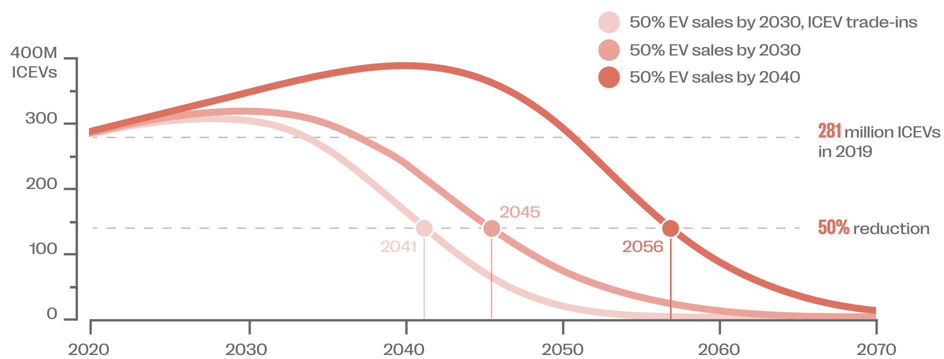
existing car parc (all vehicles in operation). Fast-tracking the transition will require a combination of rapid diffusion of BEVs and incentives to remove the oldest and heaviest polluting ICEVs from roadways[18], as shown in Figure 1-3.

But a few key ICEV players, or incumbent automakers, have the potential to become central in the BEV transition, and they will be necessary to achieve a pace of change in electrification fast enough to keep the rising temperatures below destructive levels.[19]

FIGURE 1.3

Internal Combustion Vehicles Will Remain On Roads for Decades

Projections of the number of ICEVs remaining in operation in the US under various EV adoption scenarios



Projections based on assumptions of 2% annual growth in total vehicles sold, and a 10-year interval between 50% EV sales and 95% EV sales. Average lifespan of new ICEVs held constant at 12.1 years (IHS Markit), except in the incentivized ICEV trade-in scenario (7.1 years).

[18] https://www.wharton.upenn.edu/story/research-spotlight-prof-arthur-van-benthem-on-new-cars-old-cars-and-air-pollution-today/

[19] The latest IPCC report (Sixth Assessment) declares that we have already lost this battle and that temperature rise above 1.5 °C. is inevitable—though it holds out hope that immediate and decisive action toward decarbonization could cause an eventual drop in temperature back below this threshold. https://www.ipcc.ch/assessment-report/ar6/

02

"THIS TIME IS DIFFERENT"

Why BEV Diffusion Will Accelerate Along a Steeper Slope

Sir John Templeton once said: "The investor who says, 'This time is different,' when in fact it's virtually a repeat of an earlier situation, has uttered among the four most costly words in the annals of investing."[20] And even when factors can be identified that indeed make a situation "different," the question becomes whether those factors will persist unmodified or uninterrupted. So, observers of past waves of interest in BEVs[21] might well be casting a skeptical eye on today's predictions of rapid diffusion. After all, such predictions are not new—this is the fourth wave we have witnessed in the past 30 years.

During the 1990s a first wave of enthusiasm, driven by new tough emissions standards in California, resulted in prototypes of electric vehicles but no commercially viable products. (Indeed, GM famously recalled all extant first-generation units of its pioneering EV1[22] and destroyed nearly all of them, as dramatized in the film *Who Killed the Electric Car?*) The second wave was marked by the rise of Tesla, which formed in 2003 to design an electric sports car and delivered the Roadster by 2008 and the Model S by 2012. Both vehicles were expensive niche cars marketed to the wealthy. The third wave, characterized by lower-cost, small BEVs marketed as "green," came with the 2010 launch of the Nissan Leaf. However, these very characteristics restricted this vehicle's appeal; the Leaf was purchased primarily by consumers who were willing to accept size and feature limitations for the sake of a cause-oriented purchase.

The latest fourth wave offers a wider variety of product types, from smaller sedans and midsize crossovers to huge SUVs and pickup trucks and even higher-performance sports cars, all based on better and cheaper battery technology that extends range and reduces purchase price. In this wave, BEVs are being marketed along multiple dimensions: performance (range, acceleration, quiet), enjoyment (acceleration!), and lower lifetime cost of ownership (less maintenance and savings on fuel) in addition to their contribution to emissions reduction.

Tesla's through line of progress and expanded product lineup spans waves two, three, and four. And its Model 3, launched in 2018, combines performance attributes at a lower price point—something investors had been waiting to see. Also spanning these three waves has been China's deliberate

[20] From his "16 Rules for Investment Success," published in 1933 in *Christian Science Monitor*. Templeton's quote was evoked as a peak moment in the 1980s bull market in "Why This Market Cycle Isn't Different" by Anise C. Wallace in *The New York Times* on October 11, 1987, one week before the global crash known as Black Monday. Wallace wrote, "At stock market tops and bottoms, investors invariably use this rationale to justify their emotion-driven decisions. Over the next year, many investors are likely to repeat these four words as they defend higher stock prices.... Even Mr. Templeton concedes that when people say things are different, 20 percent of the time they are right. But the danger lies in thinking that the different factor—like the recent investment in United States stocks by the Japanese—will be uninterrupted." https://www.nytimes.com/1987/10/11/business/investing-why-this-market-cycle-isnt-different.html

[21] A summary of alternatives to the internal combustion engine (and their acronyms) will be useful here. This report will refer to battery electric vehicles (BEVs), which are electric only. Fuel cell electric vehicles (FCEVs) are also all electric but use hydrogen-based fuel cells to generate the electricity. Hybrid electric vehicles (HEVs) are dual-drive trains combining a battery-powered electric motor and a gasoline-powered ICE; Toyota's Prius is the best-known example. Plug-in hybrid electric vehicles (PHEV) also have two drive trains; the electric motor's battery can be recharged by plugging in (as with any BEV), and the gasoline engine provides recharging when the battery level is low; GM's Chevrolet Volt is a PHEV while the newer Chevrolet Bolt is a BEV. China reports its national automotive sales using a category of New Energy Vehicles, which combines BEV, HEV, and PHEV.

[22] See https://www.latimes.com/archives/la-xpm-2000-mar-03-mn-5009-story.html; https://www.smithsonianmag.com/science-nature/the-death-of-the-ev-1-118595941/; https://en.wikipedia.org/wiki/Who_Killed_the_Electric_Car%3F

and coordinated campaign to build up BEVs both in supply, via subsidies to producers, and in demand, via incentives to consumers. By 2015 China had established the world's largest BEV market, per highest sales in absolute numbers, and had also claimed the dominant position in the supply chain for batteries, the associated raw materials, and electric-motor components. At present, China best demonstrates the potential of the fourth wave. It has generated IPOs for high-end BEV start-ups in Nio and Lucid, plus robust competition for the distinction of top-selling BEV across widely disparate product categories—for instance, between the Wuling Hongguang Mini (64 inches long, 1,500 pounds) and Tesla's Model 3 (185 inches, 4,000 pounds) and Model Y (187 inches, 4,400 pounds).[23]

Key "this time it's different" factors can be found in the twin growth narratives of Tesla sales and China's BEV market: more product variants; cheaper prices; better performance (battery range and features); more and better charging infrastructure; supporting services (e.g., over-the-air software updates and help finding charging stations); best-selling models with high buzz; and support from investors (Tesla) and government policies (China). Will these factors persist?

This report will say yes—but a larger question remains. Will these factors be sufficient to accelerate the adoption of low-emissions alternative technologies at the speed necessary to avert destructive global temperature increases? The answer to this question is no—unless we collectively shift our mind-sets. This report aims to convince investors, and all readers, that the incumbent automakers have a vital role to play in achieving a speedy transition to BEVs and that they have been heretofore undervalued.[24]

[23] The Wuling Mini won in June 2021, with more than 29,000 in sales compared with Tesla at just over 28,000 vehicles (16,515 Model 3s and 11,623 Model Ys). https://insideevs.com/news/521728/china-wuling-ev-sales-june2021/

[24] Howard Marks, reflecting on Templeton's edict, notes: "Companies that do have better technology, better earnings prospects and the ability to be disrupters rather than disrupted still aren't worth infinity. Thus it's possible for them to become overpriced ... even as they succeed as businesses ... [Eventually], after the modern winners have been lauded [and bid up] to excess, there will come a time when companies lacking the same advantages will be so relatively cheap that they can represent better investments." https://www.advisorperspectives.com/commentaries/2019/06/13/this-time-its-different

03

THE TESLA IS NOT ENOUGH

Why Incumbent Automakers Are Needed for the BEV Transition

Recent market enthusiasm for Tesla and other BEV start-ups suggests that investors are betting on BEV innovators as most likely to lead this transition—and to overcome these barriers. But this bet may be revealed as magical thinking based on a misinterpretation of the scale of the challenge.[29] Instead, from a system-level perspective on the transition from ICEVs to BEVs, the most important priority now is encouraging full-on engagement of incumbent automakers in speeding the electrification of mobility.

As noted above, this report argues that the transition to electrification of mobility cannot happen quickly enough to meet the increasingly urgent emissions-reduction goals of policymakers without the active participation of the current ICEV ecosystem. For mobility to become electric at the pace the world needs, Tesla and emerging start-ups in the new BEV ecosystem, such as Lucid, Nio, and Rivian, will not be enough.

To understand this claim, it will help to establish the context of the global automotive industry as we enter the 2020s. Setting aside distortions in sales from the COVID-19 pandemic,[25] the global auto market comprises roughly 85 to 90 million light commercial vehicles sold per year (sedans, sport utility vehicles, pickup trucks).[26] The industry is quite concentrated after nearly a century of a stable dominant design, with a handful of global OEMs, operating in multiple countries and making nearly all available products. For example, in 2019 three OEMs achieved unit sales of more than 10 million: Volkswagen at 10.8 million; Toyota at 10.7 million; and the Nissan-Renault-Mitsubishi alliance (10.1 million). And three other automakers were not far behind: GM sold nearly 9 million units; Hyundai/Kia sold nearly 8 million; and Ford nearly 6 million. China is the world's largest

[25] The automotive sector offers a distinctive window on the unpredictable dynamics of the pandemic. Sales first plummeted due to both supply shortages and precipitous demand drops during lockdown, then rose as personal mobility via cars became an appealingly safe option based on increased risks of virus exposure on public transit and ride-sharing. Then sales were slow due to semiconductor chip shortages, which led to production delays.

[26] This report focuses only on the light commercial vehicle (LCV) category. The same move away from the internal combustion engine will occur for medium-duty (e.g., box trucks, school buses) and heavy-duty (e.g., tractor trailer trucks; construction) vehicles. To date, fuel cells are proving to be better suited to heavy-duty applications than to BEVs. https://www.ornl.gov/news/heavy-duty-vehicles-ideal-entry-hydrogen-fuel-cell-use

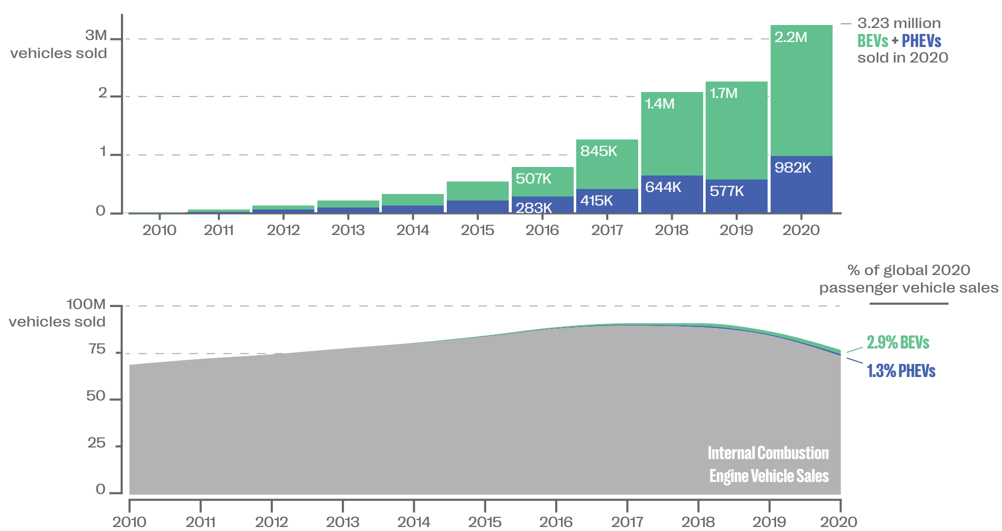
automotive market at more than 21 million in sales, the U.S. is second at roughly 17 million, and the EU is third at nearly 16 million (all 2019 figures).

Compare these numbers with recent electric-vehicle sales. Globally, in 2019, BEV sales were 1.7 million, or roughly 2 percent of total sales, bringing the total global stock to 7.2 million vehicles. (See Figure 3.1.) China was the largest BEV market, with nearly 1 million, or 57 percent of global sales, in 2019—roughly 2.5 times the 23 percent market share of BEVs in Europe and 4 times higher than the 14 percent market share in the U.S. In 2020, despite a slowdown in auto sales due to COVID, sales of BEVs were up to more than 4 percent of global sales, pushing the global stock to over 10 million. In 2020, EU sales surpassed those in China for the first time due to tightening emissions standards and boosts in sales incentives.[27] (See Figure 3.2.)

Analysts offer various interpretations of the growth rates of BEV sales. Year-on-year percentage growth figures can seem impressive but may be less so when we recognize that for many years the denominator of annual sales alternated between shrinking and growing. That said, no one disputes that the relative level of BEV sales remains very low when compared with those of ICEVs. Plus, despite the influx of new BEV models seeking buyers, high longevity in

FIGURE 3.1

Global EV Sales Are Rising But Still Vastly Outnumbered by Internal Combustion Vehicles



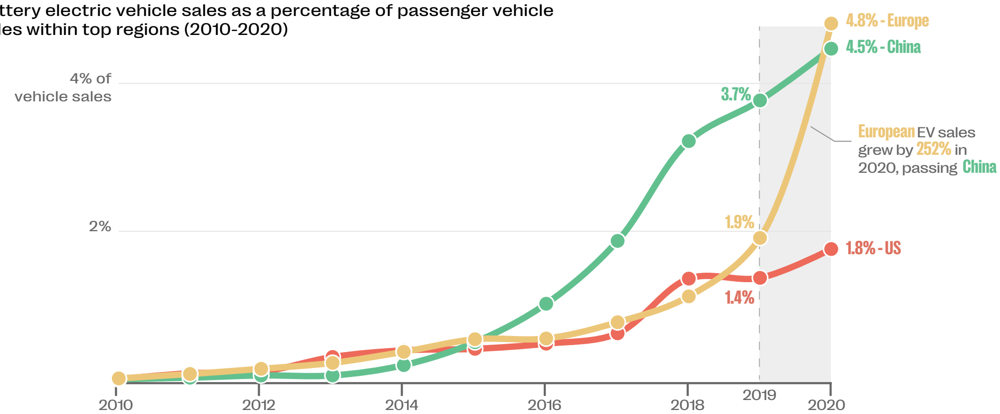
Source: EV-Volumes, IEA data from the IEA (2020) Global car sales by key markets, 2005-2020, www.iea.org/data-and-statistics. All rights reserved.

[27] https://www.ev-volumes.com/

FIGURE 3.2

Battery Electric Vehicle Sales Rise in China and Europe with US Lagging Behind

Battery electric vehicle sales as a percentage of passenger vehicle sales within top regions (2010-2020)



Source: EV-Volumes
BEV sales worldwide increased by 34% in 2020, despite total vehicle sales being down 14%

the car parc means that the current supply of ICEVs (roughly 250 million in the U.S.) won't shift quickly, considering the durability of vehicles and a lifespan that exceeds 12 years.

Several studies emphasize the huge disparity in current BEV and ICEV sales, and via various forecasting methods they examine the diffusion pattern needed to achieve significant market growth—and hence emissions reduction—in the next several decades. A recent simulation-based report concludes that "multiple barriers to [BEV] diffusion exist, including low consumer acceptance, high vehicle costs, and a lack of refueling infrastructure, meaning that sophisticated strategies and policies will be needed to achieve a [BEV] market transition that is both ecologically and economically sustainable."[28] Recent market enthusiasm for Tesla and other BEV start-ups suggests that investors are betting on BEV innovators as most likely to lead this transition—and to overcome these barriers. But this bet may be revealed as magical thinking based on a misinterpretation of the scale of the challenge.[29] Instead, from a system-level perspective on the transition from ICEVs to BEVs, the most important priority now is encouraging full-on engagement of incumbent automakers in speeding the electrification of mobility.

Tesla has achieved a great deal, winning over skeptics en route to staggering valuations—higher than most traditional OEMs' market caps combined. Yet Tesla alone won't (based on current projections) be the predominant

[28] David R. Keith, Jeroen J.R. Struben & Sergey Naumov (2020). "The Diffusion of Alternative Fuel Vehicles: A Generalised Model and Future Research Agenda," Journal of Simulation, 14:4, 260-277, DOI: 10.1080/17477778.2019.1708219. Available open-access at: https://dspace.mit.edu/handle/1721.1/130155

[29] David Hart (2016) "Rescuing the Low-Carbon Energy Transition From Magical Thinking," Information Technology & Innovation Foundation, https://itif.org/publications/2016/10/27/rescuing-low-carbon-energy-transition-magical-thinking

supplier of BEVs to the world. Tesla certainly doesn't project anything like a monopoly position. At its 2020 shareholder meeting, Tesla set a 2030 target of 3 TWh battery cell production, split 50–50 between vehicles and energy.[30] At 75 kWh per vehicle, this is the equivalent of 20 million vehicles per year in the best case, which is roughly 20 percent of global automotive sales. This would make Tesla two or three times larger than the world's largest automakers in less than a decade, which is not impossible but it is unlikely. (See Figure 3–3.)

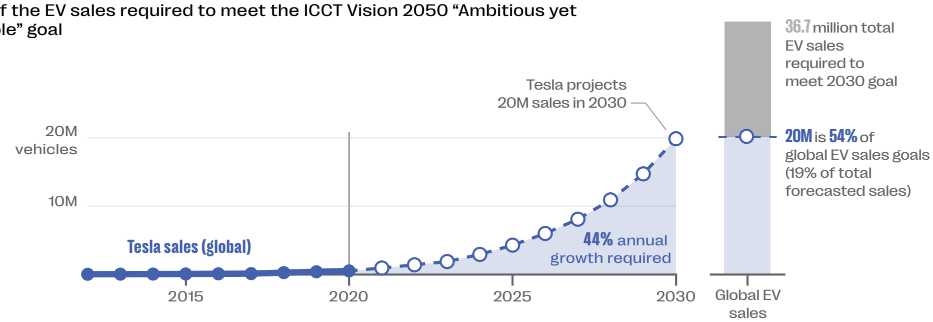
Elon Musk's goal of electrifying mobility would more likely be achieved if Tesla's competitors are simultaneously expanding BEV supply and demand. As he stated in 2014: "It's the goal of Tesla to accelerate the advent of sustainable transport, and I'd rather the other manufacturers would go fully electric as soon as possible."[31] Many of Tesla's supporters, be they owners, investors, or simply fans, perceive the company's mission in this way. See this comment on a *Financial Times* report on Tesla's July 26, 2021, earnings announcement: "[Furthermore] the enterprise's mission is not to take away everyone's market share, but to spur the adoption of sustainable transport and energy production, which is only possible with many active and successful market participants."[32] It's likely that some consumers, varying in preferences, and when offered a wide range of alternatives, will bypass Tesla and choose BEV models offered by traditional OEMs.

The good news is that existing automotive OEMs are fully capable of being central actors in the diffusion of BEVs—and they are finally taking steps to assume that role. OEMs are uniquely capable of being system integrators. They have broad and

FIGURE 3.3

Tesla's Optimistic Sales Projections Fall Short of Global EV Goals

Tesla's projection of 20 million deliveries per year by 2030 would account for 54% of the EV sales required to meet the ICCT Vision 2050 "Ambitious yet feasible" goal



Source: Tesla; ICCT Vision 2050; IHS Light Vehicles, Aug 2021 forecast
36.7 million EV sales by 2030 goal based on IHS total sales projections and ICCT Vision 2050 goal of 35% EV sales by 2030. Required growth rate calculated assuming compound annual growth.

[30] Anthony French-Constant, "Elon Musk Talks Tesla," *GQ UK*, 2014

[31] https://www.gq-magazine.co.uk/article/elon-musk-interview-tesla-p85d-mars

[32] https://www.ft.com/content/cbf718d8-3205-427d-b6bf-006cefff165e

deep knowledge of the many different technologies and vast numbers of parts in a modern vehicle that are necessary for a staggeringly complex product that must appeal to consumers in both practical and emotional ways.[33] These capabilities exist across many domains of functional expertise: R&D, product development, supply-chain management, manufacturing, sales and distribution, marketing and brand management, post-sales services (financing, insurance, maintenance), and use-based services (GPS, internet connectivity, concierge services).

Even though 50 to 75 percent of the value of a vehicle is outsourced to suppliers, OEMs have retained the dominant share of value in the automotive sector because they "know more than they make."[34] There is more value in OEMs' system-integration capabilities, which are difficult to imitate, and their sustainable source of competitive advantage, than there is in any of the individual components in the vehicle.[35] This share of value also persists because OEMs have so much experience as the guarantors of safety and quality in their role of meeting regulatory requirements and being responsible for product liability.[36]

One of Tesla's less-heralded achievements—though one that has been crucial to its current high valuations—has been learning to master all the capabilities of a traditional automaker. Notably, after starting by outsourcing key tasks, Tesla reversed course and achieved its mastery as an OEM through increased vertical integration—that is, by doing increasing numbers of things internally.[37]

Investors are often skeptical about traditional OEMs' transition to BEVs—based on the belief that these companies' past sources of competitive advantage will obsolesce due to a shift in the dominant design. But these system-integrator capabilities are just as valuable for BEVs as they are for ICEVs, perhaps even more so.

Many believe that BEVs have fewer parts and hence are less complex than ICEVs in that regard, and that this can potentially affect both supply chains and aftermarket service requirements. Often overlooked, however, is that interdependencies among functional subsystems are even higher for BEVs than for ICEVs, and that plays to traditional-OEM strengths.[38] These companies have also proven that they can accommodate BEV production with relative ease in mixed-model assembly plants along with ICEVs.

[33] MacDuffie, John Paul and Takahiro Fujimoto (2010). "Get Ready for the Complexity Revolution: Why Automakers Will Keep Ruling the Auto Industry," *Harvard Business Review* (June), pp. 23-25.

[34] Brusoni et al, ibid.

[35] Jacobides, Michael G. and John Paul MacDuffie (2013). "How to Drive Value Your Way," *Harvard Business Review* (July–August), pp. 46-56.

[36] Jacobides, Michael, John Paul MacDuffie, and C. Jennifer Tae (2016). "Agency, Structure, and the Dominance of OEMs: Change and Stability in the Automotive Sector," Strategic Management Journal, 37(9): 1942–1967.

[37] MacDuffie, John Paul (2018). "What Is and Isn't Unique about Tesla," in "Forum on Tesla and the Future of the Global Auto Industry," Management and Organization Review, Vol. 14, No. 3, pp. 481-489.

[38] Personal communication. This research is not yet available publicly.

For most manufacturing steps, both vehicle types pass through the same workstations.[39]

Traditional OEMs are masters of scale, and this capability will become increasingly important as the BEV market grows. Indeed, as noted above, the only conceivable path to achieving 2030 emissions goals, either globally or in the U.S., depends on successful scaling from both Tesla (and other BEV pure-play start-ups) and the automakers who dominated the ICEV era. (See Figure 3-4)

Recall that in the 20th century's post-dominant design period (the 1930s to the 1950s), auto-industry structure shifted from entrepreneurial ferment to oligopolistic competition among giant companies whose very size was a barrier to entry. History and economics both suggest that a similar evolution in industry architecture will accompany a rapidly growing BEV market.

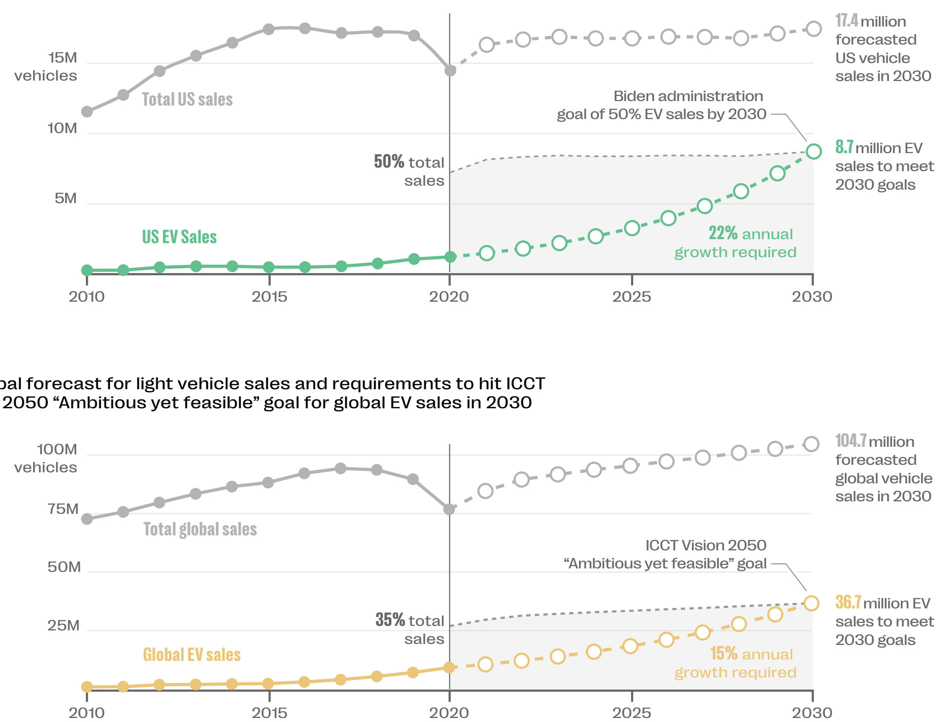
In addition, the early stages of industry consolidation are often characterized by the vertical integration of such crucial resources as raw materials, key technologies,

FIGURE 3.4

Aggressive Growth in EV Sales Is Required to Meet 2030 Goals

A) US forecast for light vehicle sales and requirements to hit Biden Administration goal of 50% EV sales by 2030

B) Global forecast for light vehicle sales and requirements to hit ICCT Vision 2050 "Ambitious yet feasible" goal for global EV sales in 2030



Source: EV-Volumes; IHS Light Vehicle Sales, Aug 2021 forecast; US Bureau of Economic Analysis; ICCT Vision 2050
Required growth rate calculated assuming compound annual growth.

[39] Alochet, Marc, John Paul MacDuffie, and Christophe Midler (2021). "Mirroring in Production? Early Evidence from the Scale-up of Electric Vehicles," working paper.

manufacturing capacity, and top talent. The move of today's OEMs into full vertical integration of battery design and manufacturing, or quasi-integration via alliances, fits this pattern as well. Start-ups, Tesla notwithstanding, have less power to compel such alliances, less previous technical knowledge (or "absorptive capacity"[40]), less ability to participate as technical coequals, and are less capable of managing the integration of batteries into the rest of the vehicle.

It is daunting for incumbents to manage legacy businesses based on a near end-of-life technology while investing in a new technology and competing with new firms that have the benefit of focusing only on the future technology. The history of digital technologies provides many examples of incumbents that failed to make this transition, and indeed were often blind to the risk to their existing business model.[41]

What is different about the transition from ICEVs to BEVs? We emphasize three big differences, consistent with the above account, and illustrate with examples in the next section:

1. Traditional OEMs have been performing R&D on BEVs for years and hold considerable intellectual property (IP) in both patents and trade secrets, consistent with their "know more than they make" system-integrator role.
2. Such OEMs have the capacity to learn about new components and technologies, even without prior expertise, and to integrate that new knowledge as they have already done with so many new components based on new technologies in the past. Examples include airbags; software controls for mechanical systems, or "drive by wire"; and aluminum and magnesium body parts.
3. ICEVs and BEVs will overlap in most vehicle subsystems, notwithstanding the fundamental changes in drive train components, i.e., power source, motor, transmission. BEVs do affect how many vehicle subsystems are designed—for instance, tires need less rolling resistance and HVAC must draw less electricity—but these are evolutionary changes that are fully tractable for traditional OEMs to master within their usual system-integrator role.

In short, traditional OEMs provide access to BEV-scaling opportunities that investors would be wise to pursue. A worthwhile starting point is backing an OEM that has taken a leadership role in the electrification of mobility and that has strong capabilities to support that role—in past R&D, in a "know more than they make" strategy, and in scaling capabilities.

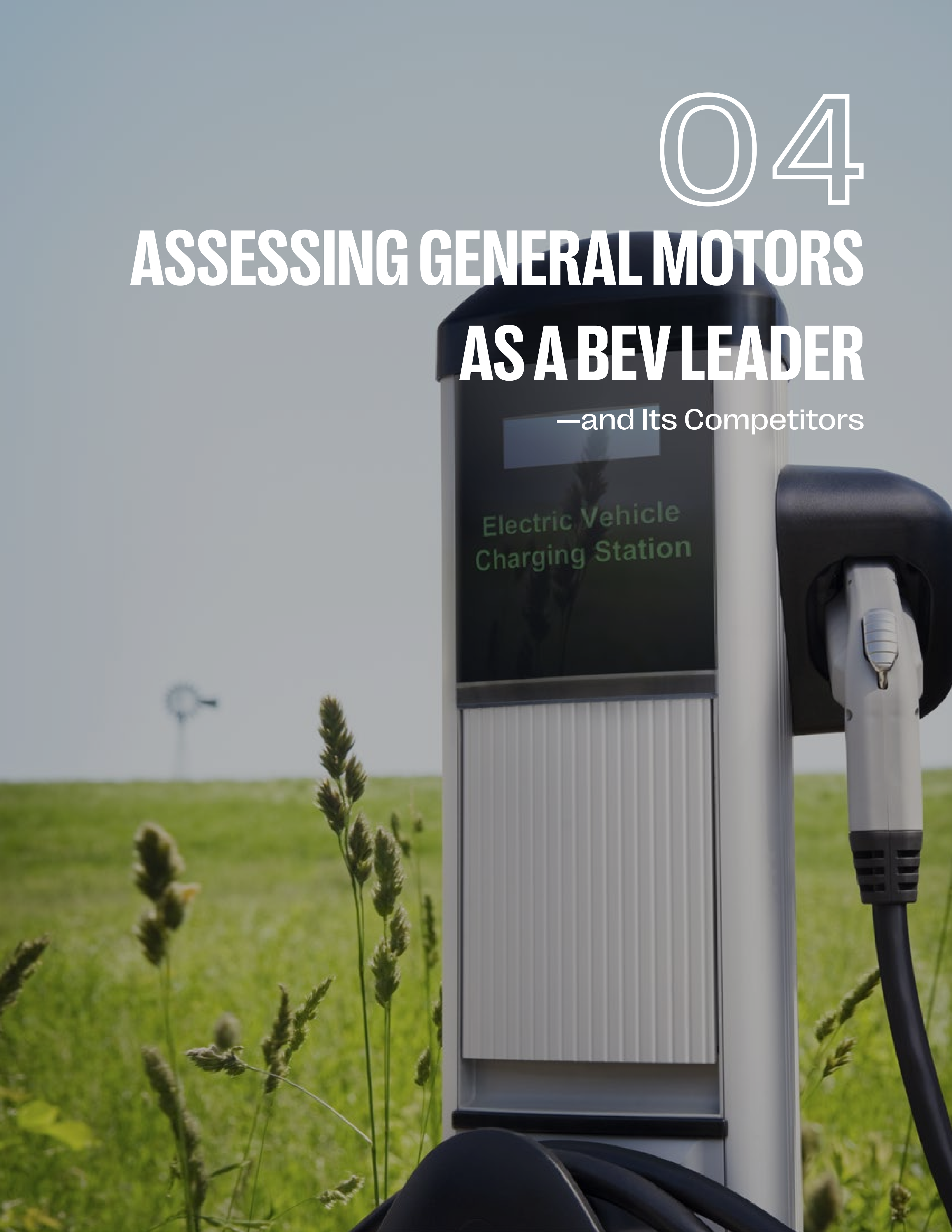
[40] "Absorptive capacity," as defined by Cohen and Levinthal (1990), is a firm's ability "to recognize the value of new, external information, assimilate it, and apply it to commercial ends," Administrative Science Quarterly 35(1): 128.

[41] Kodak and Polaroid (photography) and Nokia (smartphones) are notable technology company examples; Borders (books), Tower Records (recorded music), and Blockbuster Video (VHS and DVD rentals) are notable media examples.

04

ASSESSING GENERAL MOTORS AS A BEV LEADER

—and Its Competitors



Among traditional automotive OEMs, GM appears to be the current BEV front-runner in the U.S., and possibly worldwide, as it remains in close competition with Volkswagen (VW) for the latter designation. GM has a long track record of designing and bringing specific BEVs to market—from the infamous and prematurely killed EV1 to the Volt, Bolt, and forthcoming Cadillac Lyriq, GMC Hummer, and Silverado BEV. GM's R&D group holds many patents related to BEVs, and from the 1990s onward its product-development teams pioneered several key technologies central to all current BEV designs, from low-rolling-resistance tires and regenerative braking to a heat pump for HVAC and low-friction bearings, seals, and lubricants.[42] GM's longtime involvement in China via multiple joint ventures (JVs) has provided deep exposure to and experience in all aspects of design, production, sales, and service in the world's largest and fastest-growing BEV market. Indeed, the Wuling Hongguang Mini, made by JV GM-SAIC-Wuling, is now the best-selling BEV in China, surpassing Tesla Model 3 and Model Y sales. These capabilities arguably position GM ahead of competitors; see below for an explicit comparison of GM with VW, Toyota, and Ford.

In the realm of future commitments, GM gained substantial attention when pledged in January 2021 that it would make only BEVs by 2035, and that it would achieve carbon-neutral emissions in global products and operations by 2040. Supporting the headline targets were details on the company's broad product-portfolio plans, its greatly expanded R&D investments, a reimagined brand and "Everybody In" marketing campaign, its alliances with battery partner LG Chem and seven major charging providers (including EVgo), and its timeline for reducing Scope 1, 2, and 3 emissions.

Starting with technology, recall that the automotive sector is reliably among the top three in percentage of total global R&D spending: 16 percent in 2018, exceeded only by healthcare (at 21.7 percent) and computing/electronics (at 22.5 percent).[43] In addition, the auto sector is the third biggest in patenting activity, behind only computing and telecoms.[44] In the past decade, Toyota's cumulative filing of patents related to electric vehicles (EVs) exceeded 125,000, with Ford and Hyundai in a distant second and third place at 50,000 to 60,000 EV patents filed.[45] Patent counts, moreover,

[42] https://www.caranddriver.com/news/a36887553/gm-ev1-electric-car-technology/
[43] https://www.statista.com/statistics/270233/percentage-of-global-rundd-spending-by-industry/#statisticContainer
[44] https://www.autodealertodaymagazine.com/364033/the-worlds-top-10-car-manufacturers-submitting-the-most-patents
[45] https://www.bristolstreet.co.uk/news/revealed-the-car-brands-driving-automotive-innovation/

Battery innovations that reduce cost and improve performance are crucial preconditions for realizing the anticipated surge in BEV demand... GM, by virtue of its large strategic bet on BEVs, has perhaps the strongest foundation, starting with past R&D investments, substantial patenting, and now its proactive moves to secure future battery supply.

provide an incomplete picture of technology innovation in the auto sector, which has often preferred instead to use trade-secret law to protect its IP in the U.S., particularly for process innovations.[46]

GM is particularly active in battery-related patents. The company was issued 661 U.S. patents on battery technology between 2010 and 2015, trailing only Toyota's 762 battery patents among global automakers.[47] GM and its recent partner, Honda, are also leaders in fuel-cell patents.[48] And all of this past work has set the stage for GM's recent announcement of its Ultium battery platform, developed with LG Chem. Ultium's features are a good example of how a traditional OEM can innovate in BEVs to support a business strategy of scaling a broad portfolio of product types and customer requirements.

Ultium was announced with fanfare at the Consumer Electronics Show (CES) in 2020, but GM had been developing it for four or five years with LG Chem, one of the leading battery makers in the world and a leader in filing patents on battery innovation. The two companies began working together in 2009. The relationship intensified during development of the Chevrolet Bolt, and in 2019 GM and LG Chem (through its subsidiary LG Energy Solution) launched a joint venture to mass produce battery cells that GM would then configure into modules and packs for specific vehicles.

Cost reduction and expanded range are the primary metrics by which EV battery advances have been evaluated, but Ultium warrants application of a broader set of criteria. Perhaps the most distinctive feature

[46] Kenneth Simons, "Process Innovation Patenting: Frequency and Predictors," 2021. Rensselaer Polytechnic Institute working paper.

[47] http://fingfx.thomsonreuters.com/gfx/rngs/GM-ELECTRIC/0100609P0NF/index.html

[48] "GM and Honda are acknowledged leaders in fuel cell technology with more than 2,220 patents between them, according to the Clean Energy Patent Growth Index. GM and Honda rank No. 1 and No. 3, respectively, in total fuel cell patents filed in 2002 through 2015." https://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2017/jan/0130-tunein.html

of Ultium is its flexibility of configuration. Tesla's cylindrical cells (think AA batteries) are packaged together in large numbers, first in modules and then in battery packs, encompassing thousands of cells per pack.[49] Ultium, on the other hand, uses a pouch-and-prismatic design—picture low-height horizontal boxes—that allows for different size cells and deployment in either vertical or horizontal orientation. Tesla's cylindrical cells, by contrast, are always vertical.

Ultium's pack designs can vary by vehicle size and weight, as well as by profile (height and aerodynamic characteristics) and center of gravity. This means they can be optimized for all products in a wide portfolio, for instance low-profile sports cars, tall SUVs, and heavy pickup trucks. The packs will have net capacities of between 50 and 200 kilowatt-hours (144 to 576 cells), put out between 235 and 1,000 horsepower, and provide up to 450 miles of range; the top-end capacity is double what the current largest Tesla battery, the P100D, can hold.[50]

Three further innovations enhance Ultium's versatility and advantage over competing designs: 1) being able to switch from parallel to series connections to take advantage of 800-watt fast chargers; 2) a wireless battery-management system that saves lots of weight in wires; and 3) a battery chemistry that uses more nickel, which is relatively inexpensive and in plentiful supply, and 70 percent less cobalt.[51] Cobalt is more expensive, is facing supply constraints, and entails human-rights concerns about mining in the Democratic Republic of the Congo (DRC), currently the source of 60 to 70 percent of cobalt production.[52]

Battery innovations that reduce cost and improve performance are crucial preconditions for realizing the anticipated surge in BEV demand—yet that surge, if attained, could create supply chain bottlenecks. OEMs understand how critical it is for them to guarantee a future supply of batteries via investments in three areas: 1) production capacity; 2) advance contracting for raw materials; and 3) plans for end-of-life recycling. Events that trumpet battery plans (including Tesla's "Battery Day" and VW's "Power Day") are increasingly common—but OEMs are not starting from the same place. GM, by virtue of its large strategic bet on BEVs, has perhaps the strongest foundation, starting with past R&D investments, substantial patenting, and now its proactive moves to secure future battery supply.

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[49] Tesla's "85" kWh pack consists of 16 modules of 444 cells for 7,104 total cells. Tesla's "60" kWh pack consists of 14 modules of 384 cells for 5,376 total cells. https://electrek.co/2016/02/03/tesla-battery-tear-down-85-kwh/

[50] https://www.engadget.com/gm-is-placing-all-of-its-ev-eggs-in-the-ultum-battery-basket-163038784.html; https://www.caranddriver.com/features/a36877532/general-motors-ev-ultium-battery-electric-future/

[51] The 70 percent reduction in cobalt is as compared to its Bolt electric vehicle.

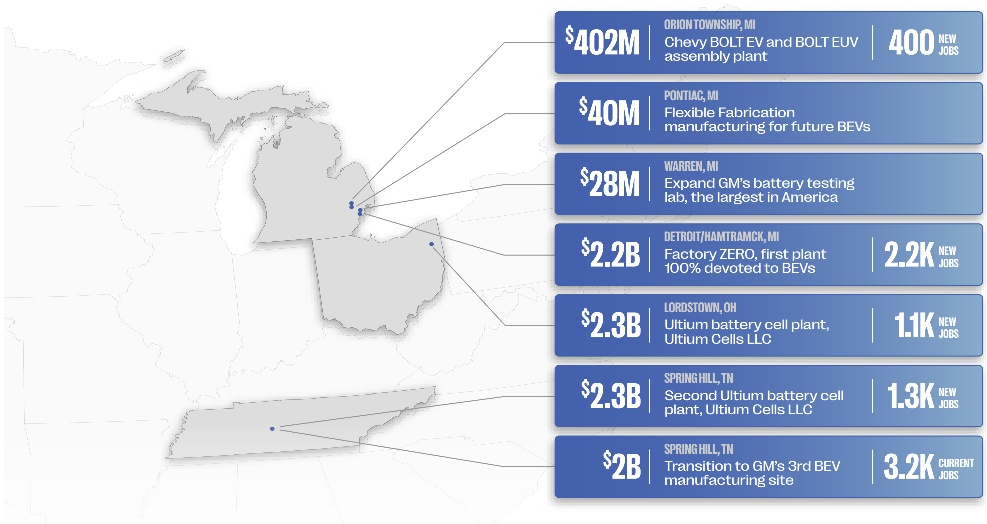
[52] https://driving.ca/features/feature-story/the-creator-of-gms-ultium-battery-tech-talks-towing-cold-and-the-future; https://www.cfr.org/blog/why-cobalt-mining-drc-needs-urgent-attention

First and foremost, GM is planning four U.S. Ultium battery factories for a total production likely exceeding 140 GwH. (See Figure 4-1.) Because these will provide new jobs, the United Automotive Workers (UAW) actively supports this initiative even though the switch from ICEVs to BEVs will eliminate an as-yet-unknown number of ICEV-related jobs.[53] The first plant, currently under construction and expected to be complete in 2022, is a JV with LG Chem located near the site of the former GM assembly plant in Lordstown, Ohio. The second plant, also with LG Chem, is slated to open on the site of the former Saturn assembly plant in Spring Hill, Tennessee, in 2023. Once fully operational, the two factories will be able to produce more than 70 gigawatt hours, twice that of Tesla's Nevada gigafactory, which it operates in partnership with Panasonic.[54]

Details about the other two factories have not yet been announced but GM hints that it may not only work with LG Chem for future battery capacity. In one sense, this is not surprising in terms of GM's supply chain strategy, since automotive OEMs prefer to avoid single sourcing for key components so they can have more secure supply and more bargaining leverage for setting prices and addressing contractual issues that arise.[55] On the other hand, GM and LG Chem have

GM Invests More Than $6.5 Billion Toward US BEV Production and Research

GM's investments will promote BEV manufacturing in the US, and support approximately 8,200 jobs across Michigan, Ohio, and Tennessee.



Source: GM https://www.gm.com/electric-vehicles.html#investments

[53] For a white paper by the UAW on the EV future, see https://uaw.org/wp-content/uploads/2019/07/190416-EV-White-Paper-REVISED-January-2020-Final.pdf

[54] https://techcrunch.com/2021/04/16/gms-second-2-3b-battery-plant-with-lg-chem-to-open-in-late-2023/

[55] GM attributes the current recall of batteries for all GM Bolts ever sold (not yet Ultium batteries) to manufacturing errors by LG Chem. This is surely a strain on the relationship as GM insists that LG Chem must fund the estimated $1.8 billion in recall and replacement costs. https://insideevs.com/news/532661/gm-lg-bolt-battery-recall/

worked together on the Ultium battery platform for many years, surely with both parties anticipating future returns from their R&D and manufacturing investment as production scale increased. Alternately, GM could be planning vertical integration of more steps in battery production, making cells themselves rather than through a supplier partner, something that other OEMs are likely considering. Such a move would give GM more ownership of the Ultium platform, currently a major competitive advantage, and more control over future battery supply.

Second, GM is also prioritizing domestic sourcing for battery raw materials, via a strategic alliance with Australian firm Controlled Thermal Resources, to extract lithium from geothermally superheated waters in California's Salton Sea. The California Energy Commission estimates that the 600,000 tons of lithium available at the site exceeds current global demand for the metal across all sectors, i.e., phones and other electronics, not just BEVs.[56] Also, Ultium's battery design substitutes nickel for cobalt—and nickel is plentiful in the U.S. and Canada.

Considering potential shortages of many raw materials, GM is focusing on recycling as the third area when it comes to controlling its battery supply chain. So far, Chinese and Korean firms are the primary battery manufacturers, and those countries have a head start in recycling lithium, cobalt, and nickel from existing BEVs for reuse in new batteries. The EU is drafting legislation to mandate regional BEV battery recycling from 2023 forward.[57] GM's response is to work with Toronto-based Li-Cycle to recycle material scrap from battery cell manufacturing in Lordstown.[58] Li-Cycle can extract for recycling 95 percent of the cobalt, nickel, lithium, graphite, copper, manganese and aluminum from old batteries and use them in the production of new batteries or for adjacent industries. Li-Cycle currently operates two spoke plants that extract metals—in Kingston, New York, and Ontario, Canada—and is building a third in Alabama. The hub plant that manufactures the materials for input to new batteries from the spoke inputs is being built in Rochester.

In addition to batteries, GM is sending out other signals of its commitment to being a leader in BEVs. First, in June 2021, GM

[56] https://fortune.com/2021/07/02/gm-california-lithium-project-hells-kitchen-ctr-electric-vehicle-batteries/

[57] Davide Castelvecchi, "Electric Cars and Batteries: How Will the World Produce Enough?" Nature, August 17, 2021; https://www.nature.com/articles/d41586-021-02222-1

[58] https://www.recyclingtoday.com/article/li-cycle-recycling-gm-lg-ultium-ev-battery-scrap/; https://plants.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2021/may/0511-ultium.html

announced that it will boost global spending on electric and autonomous vehicles to $35 billion through 2025, a 30 percent jump over its November 2020 forecast.[59] Second, GM has made major changes in its marketing and branding support of e-mobility innovations. According to GM's CMO Deborah Wahl, the "Everybody In" campaign is "a call to action meant to reflect a movement that's inclusive and accessible" to enable a world with "zero crashes, zero emissions and zero congestion." This language is accompanied by a new logo featuring a lowercase "gm" with an "M" that resembles an electrical plug, and the campaign kicked off with a Super Bowl ad, all of which suggests that GM understands the importance of changing "hearts and minds" via the creation of cultural buzz and momentum around BEVs.[60] Finally, a less visible but crucial component demonstrates GM's overall commitment to tackling climate change: its stated goals and timeline for Scope 1, Scope 2, and Scope 3 emissions reduction in its overall business operations in order to meet its commitment of being "carbon neutral" in global products and operations by 2040.[61]

CEO Mary Barra, her leadership team, and the company's board have been deft at coordinating these interrelated commitments and campaigns to win investor attention and confidence—and the stock price has responded in kind. GM enjoyed a 22 percent jump within days of the January 28, 2021, announcement of its ambitious 2035 "no more ICEV" and 2040 "carbon-neutral" goals.[62]

More recently, GM has announced the additional goal of being No. 1 in BEV market share in the U.S. by 2025.[63] To achieve this, the company will produce more than 30 mass-market models, two thirds of which will be targeted at the U.S. market. This reflects GM's commitment to investing heavily now in developing new BEV models and building manufacturing and battery capacity, which will pay off when the anticipated surge in EV demand occurs in a few years. As noted below, GM has no plans to add hybrid drive-train products to its ICEV lineup as a transitional technology, unlike many of its competitors. BEV production will result in a near-term drop in margins for GM, one it believes it can easily navigate due to higher-than-normal margins on its ICEV lineup due to COVID-related shortages and new revenue opportunities from software-based services. Assuming the demand for BEVs continues to soar, GM believes it will avoid facing supply constraints due to its

[59] https://www.reuters.com/business/autos-transportation/exclusive-gm-boost-spending-electric-vehicles-30-add-two-new-battery-plants-2021-06-15/

[60] https://chargedevs.com/newswire/gms-everybody-in-campaign-evokes-an-inclusive-electric-future/

[61] See Engine No. 1's report on GM's strategy to reduce Scope 3 emissions in the attached addendum

[62] https://www.nytimes.com/2021/01/28/business/gm-zero-emission-vehicles.html

[63] https://gmauthority.com/blog/2021/08/gm-committed-to-achieving-1-electric-vehicle-market-share-in-north-america/

current investments and therefore will rise quickly to a dominant competitive position and market-share leadership.[64]

GM executives have also been quite clear in stating that these goals are "aspirational" and can't be achieved without supportive public policies and the embrace of BEVs by consumers. Investors should also take this broader perspective. To reiterate a central argument from above, investors will benefit from traditional automotive OEMs becoming leaders in BEVs as a means of achieving more rapid scaling of mobility electrification. Investors also benefit when these OEMs offer proactive support to complementary private sector and government moves rather than having a compliance-only attitude. Time will tell whether GM—and other contending OEMs—will lean into this proactive role.[65]

GM is not alone in seeking to capitalize on the current momentum toward the electrification of mobility. What are the competitive dynamics around BEVs and what are the prospects for GM's leading competitors?

Observers of the digital transformation of various industries—including academics, investors, or the media—have come to anticipate a winner-take-all competitive dynamic that favors firms that combine early entry and rapid scaling to achieve a dominant position in a relatively short period. Venture capitalists (VCs) and other investors—with abundant capital and patience (in a relative sense)—are willing to support new firms with potential to be the disruptive winner during a prolonged period of losses.

Winner-take-all dynamics are typically fueled by network effects and platform strategies.[66] Common examples include tech companies such as Google, eBay, Amazon, or Etsy, along with platforms as Facebook, LinkedIn, Instagram, or Twitter. Will one BEV firm be the winner that takes all? It depends on how dependent the diffusion of BEVs will be on network effects—and whether BEVs will turn out to be a platform business. Charging infrastructure, as a necessary complement to BEVs, certainly has platform characteristics as more BEV owners create more benefits for providers of charging, which in turn benefits and attracts

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[64] See Barra's comments during GM's Q2 2021 earnings call. Transcript available at https://seekingalpha.com/article/4444995-general-motors-co-gm-ceo-mary-barra-on-q2-2021-results-earnings-call-transcript

[65] Skeptics will note that in 2019, GM joined with Toyota and Fiat Chrysler in supporting the Trump administration's rollback of emissions standards for automotive fleets established under the Obama administration. Reversing this position in late November 2020, after the election of President-elect Biden, suggests political expedience as at least one motivator for GM's stance on federal and state emissions rules. https://www.reuters.com/article/us-autos-emissions-gm/gm-hits-reverse-on-trump-effort-to-bar-california-emissions-rules-idUSKBN2832HF

[66] The literature on these phenomena is vast. For "winner-take-all," as exemplified by big tech's GAFA (Google, Apple, Facebook, Amazon), see Digital Dominance: The Power of Google, Amazon, Facebook and Apple, M. Moore, D. Tambini, eds., 2018 (Oxford University Press). For platform strategies, see Platform Revolution: How Networked Markets are Transforming the Economy, and How to Make Them Work for You, G. Parker, M. Van Alstyne, S. Choudary, 2016 (WW Norton) and The Business of Platforms: Strategy in the Age of Digital Competition, Innovation, and Power, A. Gawer, D. Yoffie, M. Cusumano, 2019 (Harper Business). Some question whether platforms are automatically—or even commonly—characterized by "winner-take-all" competition; see D. Evans and R. Schmalensee, https://hbr.org/2016/05/why-winner-takes-all-thinking-doesnt-apply-to-silicon-valley and D. McIntryre, https://sloanreview.mit.edu/article/beyond-a-winner-takes-all-strategy-for-platforms/

[67] Of course, ICEVs also have this attribute vis-à-vis gasoline stations, though this mature and semi-regulated market is relatively stable, and indeed the number of gas stations has been shrinking in the U.S. even as automotive sales have been increasing. See https://www.marketwatch.com/story/how-many-gas-stations-are-in-us-how-many-will-there-be-in-10-years-2020-02-16

more BEV owners, and so forth.[67]

The answer matters because, as argued above, a rapid pace of electrification of mobility is needed to avoid a global temperature increase that will lead to many negative environmental, economic, and social consequences. Investors have lately treated Tesla as the putative winner of the BEV race and are showing a willingness to back Tesla-like start-ups with great enthusiasm, even as valuations of traditional automotive OEMs have stayed flat or fallen. But remember that "the Tesla is not enough" to electrify mobility as fast as we need—and Musk has understood this and sought rapid conversion to electrification by auto OEMs from early in Tesla's history.[68]

Table 4-1

Comparison of GM, VW, Toyota, and Ford's Electric Vehicle Strategies

	General Motors	Volkswagen	Toyota	Ford
Stated strategy and goals	"No more ICEVs after 2035; carbon neutral by 2040; 30 EV mass-market models planned, 2/3 for U.S. market; expects to be #1 in EV market share in NA and sell over 1M EVs globally by 2025; big U.S. investment"	Half of sales are EVs by 2030; leading EV producer by 2025; stop selling ICEs in Europe in 2035, soon after that in China and U.S.	2 million BEVs+FCEVs by 2030. 8 million if you include HEVs+PHEVs. 15 new BEVs by 2025 out of 75 total models including HEV, PHEV, FCEV); touts 17 million "electrified" vehicles since Prius launch in 1997; net-zero by 2050	BEVs as 40-50% of global sales by 2030; two EV architectures (trucks/SUVs and crossover/cars), two battery architectures (retail and fleet); focus on services for fleets; recent big U.S. investment in BEV production and batteries
Stated battery plans	Ultium Cells, JV of GM & LG Chem; two U.S. plants (Lordstown, OH; Spring Hill, TN); two more planned in U.S., locations TBD, may move to full vertical integration; total capacity of 140 GWh per year by 2025. Recycling alliance with Li-Cycle. Sourcing lithium in U.S. via alliance w/ Controlled Thermal Resources	Goal of 6 factories in Europe by 2030, e.g., Sweden (w/NorthVolt) (2022); Germany (2024); Spain (TBD); JV w/ China's Gotion High-Tech (2025)—total capacity of 240 GWh	Targeting 200 GWh by 2030 through Panasonic JV and other external suppliers. New JV w/ Panasonic (past JV for Prius); JV with BYD in China; adding 80K capacity in Himegi, Japan. Big push on solid-state, prototype launch is delayed	Three U.S. plants as JV w/ SK Innovation, two in KY, one in TN, aiming for total U.S. capacity of 141 GWh (2.2M EVs), 240 GWh by 2030 worldwide (in 10 plants)
Stated R&D commitment	$35B for EV and AV through 2025, 75% boost from early 2021 announcement	$41.7B by 2025 out of total of $86.3B; new e-R&D centers in Wolfsburg & China	$13.6B by 2030 in battery production and R&D. $9.9B for 2021; no specific breakdown of R&D on EVs vs. other technologies	$30B by 2025; up from earlier commitment of $20B
Ability to scale	High ability to scale; 3rd largest OEM; four assembly plants (Factory Zero, former Detroit Hamtramck; Orion, MI; Spring Hill, TN; Ingersoll, Ontario (BrightDrop vans)	High ability to scale; #1 or #2 volume OEM worldwide; highest EV volume potential due to MEB (EV platform) and product range plus investments in R&D and battery capacity	High ability to scale; #1 or #2 volume OEM; new e-TNGA platform shared w/ Subaru; strong in mixed-model production, can change mix quickly; moves slowly for strategic commitments, fast for implementation	Middle range of OEM volume; knows how to scale; overall smaller after eliminating many sedans, pulling back globally
Products drawing attention	Cadillac Lyriq; Chevrolet Silverado; GMC Hummer; Cruise Origin (AV+EV); BrightDrop van; 2023 Lyriq First Edition sells out quickly	ID.3 (Europe only); ID.4 (US and China too); ID.5 (sporty); ID.6 X/Cross (SUV for China); Audi Q4 e-tron and Skoda Enyaq. Stumbled at rollout of ID.3 re: software updates	bZ4X SUV in 2022; 15 BEVs planned by 2025, 7 in bZ sub brand; all on e-TNBA platform, including first Subaru EV (Solterra), on bZ4X platform, also launching in 2022	e-Mach Mustang; Ford F-150 Lightning; Ford E-Transit van. All have high number of pre-orders
Capabilities for EV transition	High (see text)	Slow with electrification focus before 2015; now very motivated due to Dieselgate; strong EV platform strategy	Has the most electrification-related patents (by 2X); technicians w/ HEV experience prepared to service EVs; will partner with its dealers to install necessary charging infrastructure	Early commitment to HEVs from Bill Ford; recent announcement of $11.4B investment in multiple U.S. BEV battery and assembly plants; longtime patenting in HEVs, BEVs, AVs, mobility
International exposure	High for EVs due to big presence in China; pulled back in Europe, India, Australia, LATAM (though recently introduced new vehicles in LATAM)	Big and early presence in China; taking bigger stakes in Chinese JVs; very strong in Europe; relatively weak in U.S.	High due to big presence in China and North America; also prominent in Europe and SE Asia; closed plant in Australia	Relatively small in China; pulled back in Europe, Australia, LATAM, and India; much less global than in the past; U.S. is key to its success; dependent on a few key products
Alliances of note (beyond batteries)	Honda on AVs and EVs; EVgo on charging; Cruise in Avs; SolidEnergy Systems on solid-state batteries (leveraging GM's own IP on lithium-metal batteries)	Ford on AVs and commercial vehicles; Electrify America on charging (channel for U.S. spending out of Dieselgate settlement); increasing investment in QuantumScape (solid-state batteries)	Mazda and Subaru for EVs; solo initiatives through Woven Planet subsidiary; acquired Lyft's AV operations, investor in Aurora, which acquired Uber's AV operations	Argo for AV; VW for AVs and commercial vehicles. Solid Power on solid-state batteries. Recycling with Redwood Materials

[68] Given the focus of this report, we won't attempt to assess the many BEV start-ups now on the scene, from Nio and Lucid and Fisker (high-end luxury models) to Rivian (pickup trucks), nor the autonomous vehicle (AV) start-ups that will almost certainly be BEVs as well (e.g., Google's Waymo, Amazon's Zoox, Aurora, Baidu). In general, these firms are covered by the "Tesla is not enough" argument. In addition, entrants from the purely digital realm may well need to partner with automotive OEMs in order to succeed with any or all of the connected autonomous sharing electric (CASE) mobility innovations given the need to master both physical and digital phenomena. See https://www.forbes.com/sites/johnpaulmacduffie/2021/03/09/whos-shaping-who-tech--automotive-in-the-2020s/?sh=701a5ee92dc4

While GM has the potential to be a leader in the BEV transition, there's no basis to proclaim GM as the automatic winner. In that spirit, consider GM in relation to VW, Toyota, and Ford—three prominent OEM competitors in the BEV transition. Table 4-1 provides capsule summaries of these four firms in multiple categories: stated strategy and goals; stated battery plans; stated R&D commitment; ability to scale; products drawing attention; capabilities for EV transition; international exposure; and alliances of note (beyond batteries).

In summary, in comparison to GM:

- VOLKSWAGEN is the leader in Europe and the most similar OEM to GM in overall BEV strategy, ambition, and capabilities. While its emphasis on BEVs is comparatively recent, VW is highly motivated by the embarrassment of "Dieselgate," which imperiled its brand by pushing fraudulent claims about the emissions-reducing ability of internal combustion engine (ICE) technology. In response, VW has exceeded virtually all other OEMs in the breadth and detail of its BEV-product plans (which include a sophisticated platform strategy); the scale of its battery capacity investments; and its alliances for new technologies and charging infrastructure. While not strong in North America, VW has had the longest and deepest involvement with the Chinese market versus these other OEMs, and it should have advantages in marketing its BEVs there.
- TOYOTA possesses best-in-world capabilities in flexibility and resilience in production, supply chain, and product development. It should be able to shift its product portfolio in response to consumer demand should it choose to do so. But Toyota has also been a notable skeptic about BEVs: It has committed to hybrid dual-drive-train vehicles as the current transitional technology and to hydrogen fuel cells as the long-term electrification bet. This skepticism of BEVs could hurt the company's public image, which it honed as a "green" pioneer through its development of the Prius nearly 25 years ago.
- FORD is behind GM, but it has a substantial track record in patenting on electrification. It recently announced a very large investment in U.S. BEV-related production—$11.4 B, the largest in its history. It is partnering with SK Innovation for batteries and announced a new assembly plant for next-gen F-150 Lightning, emphasizing good jobs and training for employees. It has strong capabilities in scaling up production volumes in response to consumer demand, but it still needs to overcome persistent quality problems. Its recent partnership with VW could prove advantageous to both firms. Ford has generated considerable buzz on the strength of its planned electrification of iconic products such as the Mustang Mach-E (now available)

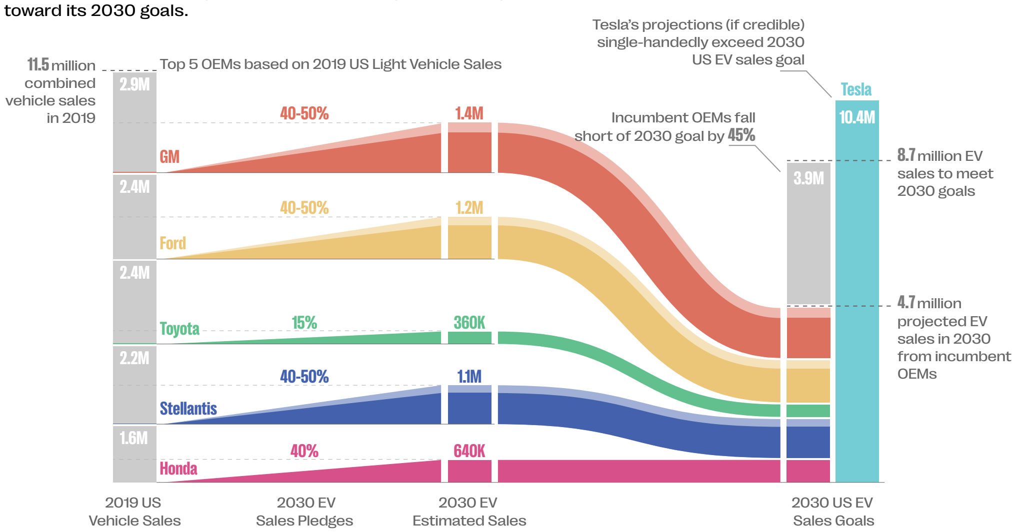
and F-150 Lightning (planned for 2022). Reservations sold out quickly. Ford's reduced international footprint means it has fewer opportunities to learn about foreign BEV markets—and this is a particular disadvantage in China.

Based on these evaluations of GM in relation to VW, Toyota, and Ford—and remembering that Tesla, despite its successes, won't be able to maintain dominance over BEV sales in a scenario of rapid growth—this report takes the position that BEVs will not be a winner-take-all market. Designing, building, and marketing BEVs successfully is well within the capability set of traditional OEMs. Now that strategic commitments and capital allocations are aligning with external forces requiring emissions reductions, these companies should be able to grab a substantial, and perhaps dominant, share of this growing market despite Tesla's prominence and several other start-ups arriving in the market. (See Figure 4-2.) No single OEM has a sufficient early-mover lead to achieve market share so high as to pose a barrier to entry, or scale, that would keep other OEMs out of the BEV market. That said, these companies won't all have the same outcomes; market-share levels will surely shift, as this is a turbulent era not just for automobiles but for the entire mobility sector.

FIGURE 4.2

Pledges by Incumbent OEMs Achieve 55% of 2030 Goals

The Biden Administration's 2030 EV sales goal is feasible if incumbent OEMs stick to their pledges and Tesla makes significant progress toward its 2030 goals.



Source: 2019 Vehicle sales, IHS Markit Inc; IHS Light Vehicle Sales, Aug 2021 forecast
Estimated 2030 EV sales from each OEM are based on 2019 light vehicle sales and publicly announced pledges of EV sales target percentages. Estimated goal of 8.7 EV sales by 2030 based on total vehicle sales projections (IHS) and the Biden administration's goal of 50% EV sales by 2030. Tesla's estimated 2030 US sales (10.4M) based on their goal of 20M global sales and a historic average of ~52% of sales from the US.

05

PERSPECTIVES ON INCUMBENTS

What Likelihood of Disruption? Consolidation?

For decades, analysts taking a primarily financial perspective on the global automotive industry have observed two salient facts and reached one strongly held conclusion. The facts: First, overall production capacity across all global automakers is larger than total global sales, usually by 10 to 15 percent, and higher in some times and in some countries;[69] second, profit margins under these conditions of intense global competition and overcapacity are kept comparatively low. The conclusion: the industry must and will undergo drastic consolidation to a small number of very high-volume OEMs.

With the transition to BEVs underway and given skepticism about the ability of incumbent OEMs to escape their ICEV legacy (reflected in their low valuations relative to Tesla), new expectations of disruption and consolidation abound. When the automotive sector moved to a dominant design based on an ICE drive train in the early 20th century, we saw consolidation from hundreds of firms to just a few. Will that happen now or soon? And what are the chances that the legacy OEMs will be among the survivors?

Addressing these questions requires answering two others: 1) Is it inevitable that new entrant start-ups will disrupt and displace incumbents during a major technological transition? and 2) What factors have caused the sector to resist drastic consolidation in the past—and will they persist through the BEV transition?

As noted, many investors already see BEVs as a disruptive innovation that will cast a harsh light on traditional OEMs and reveal the irrelevance or obsolescence of their legacy capabilities. This line of thinking presumes that start-ups like Tesla will prevail because traditional OEMs won't be able to shift capital, technical expertise, or managerial attention away from their core ICEV business in order to create BEV designs as attractive as start-up offerings. Nor, goes the argument, will they be able to overcome mixed incentives for dealers that will find it more natural to sell legacy products than to persuade consumers to make the move to a new technology that may be difficult to understand or anxiety-producing to own. Born-as-BEV firms won't face this conflict, and they can more easily provide consumers with a positive experience, cleanly differentiated from their past ICEV ownership.

This point of view would consider the argument delineated above to be absurd: that is, the notion that automotive OEMs are undervalued as the transition from ICEVs to BEVs accelerates. When have incumbents ever been able to avoid failing in the face of technological innovations that are difficult for them to absorb, but are as natural as breathing for a start-up?

[69] In 2019, some estimates placed overcapacity in China at over 30 percent. https://www.forbes.com/sites/willyshih/2019/01/23/excess-capacity-in-chinas-auto-industry-is-not-likely-to-have-a-happy-ending/?sh=4c2e9da627d5

Here, history can be a guide. Examples of incumbents whose capabilities and complementary assets enabled persistent value capture during or after a major technological transition include:

- Fujifilm, a traditional analog film manufacturer that succeeded in digital photography[70]
- Olivetti, a pioneer in traditional typewriters that successfully made the transition first to electric typewriters and then to word processors and computers[71]
- Typesetters, whose font libraries retained value across multiple technology transitions: mechanical "hot type" (1886), which faced challenges from analog photo-typesetting (1949), digital CRT photo-typesetting (1965), and laser image setting (1976).[72]
- Unlike Fujifilm, Kodak failed to survive the transition to digital photography in the modern era; but founder George Eastman pioneered film photography after a successful period as a manufacturer of glass plates, a radical innovation.[73]
- In aircraft, two engine incumbents—Pratt & Whitney and Rolls-Royce—were successful in making the shift from piston engines to jet propulsion. Similarly, two airframe incumbents, Boeing in the U.S. and Vickers in the UK (folded into Airbus), were successful in the transition from the propeller-drive to the jet-propulsion era.[74]

Being a large established firm is also not necessarily a barrier to establishing a prominent market position with a new technology. Two quotes provide valuable perspective on this issue. First, from famed business historian Albert Chandler, observing the early 20th century:

"The major challengers in the capital-intensive industries of the 20th century were not smaller firms that took advantage of changes in technologies and markets … far more often the successful challengers were long-established companies, usually first movers, from other countries or from other industries in the same country … Here the established enterprise became Schumpeter's entrepreneur."[75]

This second quote is from Clayton Christensen, a business strategist well known for highlighting how "competence-destroying technology" could give "disruptive innovators" the opportunity to overturn

[70] Nishizaki, Kei, "Fujifilm: Transformation from a Photographic Film Maker, 2016. https://digital.hbs.edu/platform-rctom/submission/fujifilm-transformation-from-a-photographic-film-maker/

[71] Danneels, Erwin et al. "Overcoming the Inertia of Organizational Competence: Olivetti's Transition from Mechanical to Electronic Technology," Industrial & Corporate Change 27(3): 595–618, 2018.

[72] Tripsas, Mary. "Unraveling the Process of Creative Destruction: Complementary Assets and Incumbent Survival in the Typesetter Industry," Strategic Management Journal, Summer 1997 Special Issue, 119-142.

[73] Chandy, R.K. and Tellis, G.J. "The Incumbent's Curse? Incumbency, Size, and Radical Product Innovation," Journal of Marketing, 64(3): 1-17, 2000.

[74] Gibbert, Michael and Scranton, Philip. "Constraints as Sources of Radical Innovation? Insights from Jet Propulsion Development," Management and Organization History, 4(4): 385-399.

[75] Chandler, Albert. *Scale and Scope: Dynamics of Industrial Capitalism*, Harvard/Belknap Press, 1990, pp. 601-602.

incumbents. Here Christensen discusses the conditions under which large firms navigate technologically turbulent times successfully:

"When significant customers demand it … large, bureaucratic firms can embark upon and successfully execute technologically difficult innovations—even those that require very different competencies than they initially possessed … We observe that established firms, though often at great cost, have led their industries in developing critical competence-destroying technologies, when the new technology was needed to meet existing customers' demands."[76]

In summary, there are ample examples of incumbent firms becoming leaders during technological transitions. Large bureaucratic firms can succeed in mastering even "competence-destroying" technologies when change is demanded by significant customers and other stakeholders: policymakers and regulators; employees and their representatives; and communities seeking investment and employment. While batteries and electric drive trains are arguably "competence-destroying" for the legacy OEMs, most components for BEVs overlap with those required for ICEVs. As a result, most value-adding tasks required for BEVs are "competence-sustaining" rather than "competence-destroying," which shifts advantage to legacy OEMs who don't face a start-up's challenge of mastering all of those components and value-adding tasks for the first time.

Even if we don't see widespread displacement of incumbents by disruptive challengers, what about consolidation? As noted, those who have anticipated consolidation in the past now expect the transition to electrified mobility to accelerate selection pressures, resulting in a new cast of key actors and a new distribution of value generation and value capture.

A leading pre-BEV proponent of sector consolidation was Sergio Marchionne, the late CEO of Fiat Chrysler Automobiles (FCA), who passed away in 2018. After a career in finance at General Electric, he entered the automotive industry with a bold prediction that no more than 10 automakers would survive beyond 2020. Marchionne also argued tirelessly that the auto industry wasted capital by having too many firms doing duplicative R&D and product development, given high demands from regulators for emissions reduction, consumers for product variety, and the necessity of investing in new and disruptive technologies. His thesis was consistent with the financial critique of a sector marked by overcapacity and persistently low profitability.

But his prediction was clearly wrong. The 2020 EPA Automotive Trends report identifies 13 large manufacturers producing

[76] Christensen, Clayton and Bower, Joseph. "Customer Power, Strategic Investment, and the Failure of Leading Firms," Strategic Management Journal, 17(3), 1996, p. 199.

the vast majority of vehicles sold in the U.S. Five are Japanese (Toyota, Nissan, Honda, Mazda, Subaru); three are American (GM, Ford, Tesla); four are European (FCA, VW, Mercedes, BMW); and one is Korean (Hyundai/Kia, which is treated as one firm).[77] Volvo, Jaguar Land Rover, and Chinese OEMs such as SAIC, Chery, Geely, and BYD should be added to this list. That adds up to around 20 OEMs with a history of global sales, with Tesla in as the newest member of the club. And this number could grow given the new set of promising BEV start-ups on the horizon with high potential for scale, such as Rivian and Nio.

There has certainly been some consolidation in the global auto industry. FCA did follow the path predicted by Marchionne, as it has combined with PSA and the former Opel to form Stellantis. Volvo was purchased by Geely; Jaguar Land Rover is now under Indian ownership. And the high cost of R&D on new technologies certainly creates financial pressure for OEMs and start-ups alike. But alliances among OEMs have been a much more common way of sharing these costs; recent examples include Nissan-Renault-Mitsubishi; GM-Honda; Ford-VW; Toyota with Mazda and Subaru. Furthermore, OEMs initiate collaborative relationships with suppliers from both inside and outside the sector as part of their "know more than they make" strategy. Interorganizational ties, rather than consolidated ownership of assets, have often been the chosen path for OEMs to develop capabilities in new technologies.

Other factors militate against extensive consolidation in the automotive sector. Automakers have brands with long histories and, more importantly, long association with nations and national pride. Opening new production capacity is politically popular and subsidies are often made available, while closing production capacity is unpopular and often resisted by governments and unions. Trade and economic policies for industries can be and are used to protect national champions and, particularly for developing countries, to give a fledging automaker time to develop its capabilities for global competition. The rapid growth of China's automotive market is not coincidentally linked to the rapid growth in JVs between foreign OEMs and Chinese entities. JVs became a price of entry to the Chinese market, and they infused a great deal of know-how into Chinese OEMs—both the formerly state-owned enterprises and newer entrants such as BYD and Geely. The goal of achieving regional independence in important supply chains, such as batteries, is driving regulatory policy and government investments. All of these are reasons that the global automotive sector has not been structured according to a strict financial logic of scale and efficiency, and why this feature is likely to persist.

[77] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf, page 3.

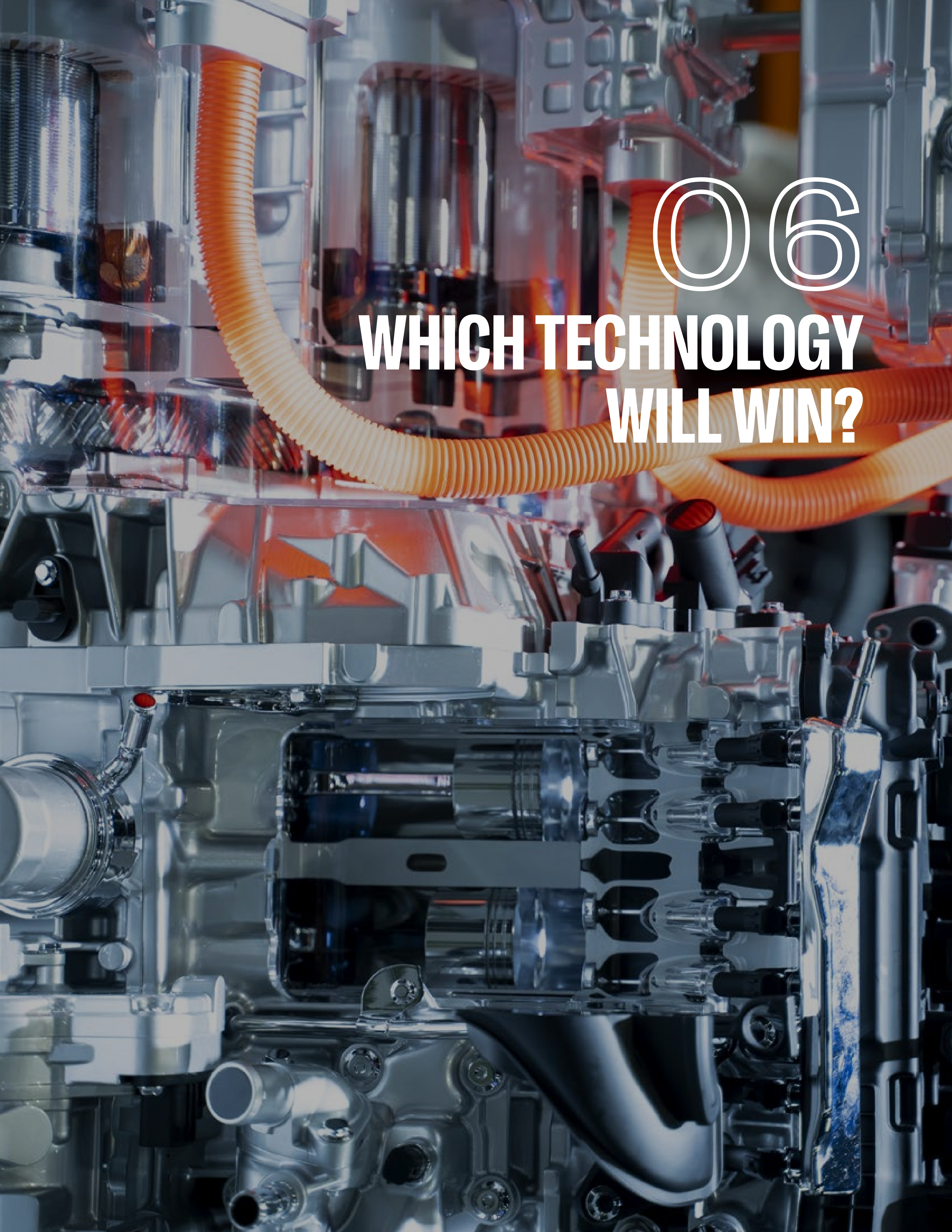
The analogy for legacy automotive OEMs is that high previous investment in electrification-related R&D may prove to be the differentiator that separates those that survive and thrive in the BEV era from those that fail quickly.

So far, the impact of the upsurge in BEV interest has been quite the opposite of consolidation. Rather, it is a time of ferment, of new technological and market possibilities bubbling up, of entrepreneurs and VCs aiming to seize those opportunities. Perhaps the best analogy is the early history of the mass-production automobile industry in the U.S. (taking the 1903 founding of Ford Motor Company as a starting point) when hundreds of firms competed before a dominant design was reached nearly a quarter century later.

As noted, consolidation around oligopolistic competition among large-scale manufacturers did occur once ICEVs won the technology race. And recall that the transition from ICEVs to BEVs will be prolonged by the long life of the car parc, slowing the pressures for consolidation. But even if consolidation doesn't happen immediately, might it materialize—and quickly—once a BEV dominant design exists? The answer is likely yes. Not all currently active firms will survive. Some legacy OEMs will fail or be absorbed; many more start-ups will fail or be acquired; and market share will shift, perhaps dramatically, among the main players. Firm failure could occur surprisingly quickly, correlated as it will be with the pace of BEV diffusion.

In the historical examples of incumbents who successfully navigated a major technological transition and became leaders going forward, the predominant pattern is survival of one to two legacy firms—and failure of a larger number—combined with one to two successful new entrants, as well as many failed start-ups. For example, with aircraft engines, Pratt & Whitney and Rolls-Royce made the transition successfully to jet propulsion but most other propeller-era firms failed. Meanwhile, GE joined the leaders in jet propulsion as a new entrant based on strong capabilities in the related technology of steam turbines. The analogy for legacy automotive OEMs is that high previous investment in electrification-related R&D may prove to be the differentiator that separates those that survive and thrive in the BEV era from those that fail quickly.

Ultimately, given the persistence of forces that resist consolidation in this sector, concentration will stay diffuse. But it's unlikely that there will be as many as 20 active BEV OEMs once the ICEV era fully ends.



06 WHICH TECHNOLOGY WILL WIN?

Even if no single firm wins the transition to electrification, will BEVs be the winner-take-all technology out of a set of low-to-zero-emissions alternatives for mobility? This is more difficult to forecast. BEVs won't necessarily be dictated by massive shifts to electrify everything and to decarbonize the electricity grid. In technology terms, BEVs do have a certain first-mover advantage. Scaling up BEV volumes can bring lower per-unit production costs, particularly for batteries, and more profits to plow into further performance improvements. On the other hand, from an options perspective, one might argue that investors should continue to make bets on BEV alternatives. There are, for instance, plug-in hybrids with a small internal combustion engine for recharging only (PHEVs) and fuel cells powered by hydrogen as the source of electricity (FCEVs). Given these different predictions, what are the likely forces for convergence on BEV as the winning technology? What are the caveats regarding pace and direction?

Forces for Convergence to BEVs:

- Contemporary BEV designs are stabilizing around common characteristics—a forward indicator of a potential dominant design. For instance, there are lithium-ion batteries, albeit of slightly varying chemistries; complementary innovations that reduce rolling friction, utilize regenerative braking, reduce electrical drawdown for HVAC and other functions; and software for power management in both utilization and recharging.
- For these BEV designs, performance is increasing, particularly when it comes to battery range; cost is decreasing, especially for batteries; and total cost of ownership is increasingly close to parity with ICEV designs. Many expect BEVs will soon have clear advantages in cost of ownership over ICEVs, independent of subsidies that could reduce purchase price.
- Even though less than 20 percent of the electrical grid is based on renewable sources, meaning that some 80 percent of electricity generation is contributing to higher emissions, BEVs are cleaner than alternative technologies. The 2021 report from the International Council on Clean Transportation (ICCT) finds this to be true even in the countries with the most coal-fired electricity generation, e.g., India and China.[78]
- This same ICCT report finds that hybrid electric vehicles (HEVs) generate only 20 percent less in emissions than do ICEVs. It also concludes that PHEVs are not very different from HEVs given that most use cases require active charging of their battery by the onboard ICE.[79]

[78] https://theicct.org/publications/global-LCA-passenger-cars-jul2021
[79] Ibid.

- Sales of FCEVs are still miniscule: Total sales of Toyota's Mirai in the U.S. and Canada are still less than 10,000 in the six years since the model's 2015 launch.[80] And hydrogen-refilling infrastructure is rare to nonexistent in most countries and most U.S. states. FCEVs may have applications in certain transportation niches, such as delivery vehicle fleets, heavy trucking, or buses, but they are unlikely to be a mass-market path to rapid emissions reduction.
- Competition in BEVs is driving massive capital investments by traditional OEMs, as well as venture investments in BEV start-ups. No comparable level of capital flows is going toward any other emissions-reducing technologies currently.
- Tightening emissions standards in developed economies can only be met by rapid diffusion of BEVs, even though contributions are also needed from improved ICEV performance, plus HEV/PHEV usage and FCEV innovations.

Caveats on Pace and Direction:

- Current investments and corporate commitments point to a huge increase in the supply of BEVs. This doesn't guarantee a match in demand. Consumer attitudes, such as concern about purchase price, range anxiety, and concern about lack of charging infrastructure—even if these are less rational than in the past—still affect purchase decisions and can serve as a barrier to BEV adoption.
- The U.S. has not yet established policies and regulations to incentivize faster adoption of BEVs, and political volatility may prevent their implementation anytime soon. This same volatility could deter the public-private joint action needed to boost charging-infrastructure availability.
- The promise of solid-state batteries comes with caveats as well. Indeed, these would mark a substantial technical advantage over today's lithium-ion cells given less recharging time, less susceptibility to catching fire, and lower dependence on cobalt and other raw materials that are either in short supply, controlled by only a few suppliers or countries, or obtained under objectionable working conditions. But solid-state batteries are not yet commercially available and will be much more expensive than li-ion batteries for many years to come.[81] These technical advantages will thus cut against the price and cost reductions, fueling faster adoption of BEVs with li-ion. And if BEV demand won't spike until solid-state batteries are available, the pace of change—while directionally the same—could be much slower.

[80] https://www.goodcarbadcar.net/toyota-mirai-sales-figures-usa-canada-monthly-yearly/
[81] https://www.dnv.com/to2030/technology/are-solid-state-batteries-the-holy-grail-for-2030.html

Contemporary BEV designs are stabilizing around common characteristics—a forward indicator of a potential dominant design... [C]ost is decreasing, especially for batteries; and total cost of ownership is increasingly close to parity with ICEV designs. Many expect BEVs will soon have clear advantages in cost of ownership over ICEVs, independent of subsidies that could reduce purchase price.

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- Until a new dominant design emerges, policies precluding or disincentivizing continued investment and R&D in alternate transport-related technologies (such as fuel cells) are counterproductive. Eventually multiple types of drive trains could find a place in the overall quest to decarbonize transportation.

In summary, BEVs do have substantial momentum and cost-plus-technical advantages over low-emissions alternatives at present. But eventually multiple drive trains are likely to find a place in the quest to decarbonize transportation: e.g., FCEVs and new battery chemistries.

Based on its announced product portfolio and related market analysis, GM could be the OEM with the largest percentage of new models as BEVs, while other OEMs have made larger commitments to hybrids or are lagging in the transition to electrification. If GM is correct about future BEV demand, the company will be in the best position to be market-share leader because of its large BEV product portfolio. Profits could also benefit from GM's concentration on the higher-priced, higher-margin segments of luxury vehicles, large SUVs, and pickups. If BEV demand is slower to materialize but consumers are choosing hybrids (conventional and plug-in) instead, in a partial move toward lower-emission product alternatives, companies such as Toyota, Honda, and Ford could benefit.

07

ALIGNING BEV GOALS

with Domestic Economic and Political Priorities

Beyond competition between companies, BEVs have become an arena for competition between nations and regions as well. With policies that support BEV infrastructure, consumer adoption, and onshore manufacturing, many governments are looking to use the industry's transition as an opportunity to build or maintain their national or regional leadership in the automotive sector.

For their part, companies have been eager to align with these nationally framed goals. For incumbent automakers in the U.S. like General Motors and Ford, growing policy support for the transition to BEVs and a "build American" ethos could help them against international competition. Meanwhile, they and their competitors will simultaneously be vying to sell into international markets, including countries such as China where BEVs have seen the most uptake and fastest growth. One marker of success for any firm competing in BEVs will be achieving sales outside their home country, either through exports of finished vehicles or local production. Thus, growth in any country's BEV demand can be framed as an opportunity for all BEV producers.

Across the world, we can see this tension between global market ambitions and national economic and political priorities at play clearly in the EU, the U.S., and China.

First, in the EU: In 2017, fearing exclusion from battery supply chains dominated early by Korean and Chinese firms, the EU began work on a coordinated policy to ensure a viable sufficiently scaled EU-wide production base for both batteries and other BEV drive train components. This is evident so far in announcements of major battery plant investments by a mix of new firms based in Europe (e.g. start-up Northvolt in Sweden, Britishvolt in the United Kingdom, and Automotive Cells in France) plus automakers Tesla and Volkswagen Group. BloombergNEF estimates the continent could see its share of global battery production rise to 31 percent by 2030 from just 7 percent last year.[82]

Second, in the U.S.: In this politically charged era, the U.S. has moved more slowly but is increasing acceleration and force around a patriotic theme of rebuilding the economy around domestic investments in BEV manufacturing and battery production capacity. The idea of "build American" found resonance with voters and put political pressure on companies such as GM that closed plants to simultaneously announce new investments in those same regions for BEVs; the emergence of Lordstown Motors, a BEV pickup truck start-up, was an early manifestation. In 2021, the current administration has articulated a clearer, stronger focus on building up domestic manufacturing of BEVs as a source of new "good jobs"—with an explicit goal of boosting union-represented jobs. The American Jobs Plan, released in April 2021, proposed major

[82] https://europe.autonews.com/suppliers/next-electric-car-battery-champion-could-be-european

investments in four areas: 1) Tax credits for clean vehicle manufacturing; 2) Incentives to open new battery production facilities; 3) Access to low-cost capital to produce advanced vehicles; and 4) Retooling of dormant factories.[83]

Bipartisan support for some of these goals may well be within reach via the now-renamed "Bipartisan Infrastructure Investment and Jobs Act." But other goals will be contested due to the usual partisan divide and also how they conflict with other political realities such as: U.S. automakers will attempt to source some BEV production in Mexico, drawing on an already large production base there, and relying on the revised NAFTA accords to placate those who would advocate for an exclusive U.S. investment focus. And automakers with nonunion plants in the U.S.—including Japanese, Korean, and German OEMs as well as Tesla—will resist government policies that favor union-built BEVs (via higher consumer subsidies) over the BEVs they will build.

Incumbent automakers are showing their willingness—and even enthusiasm—to align with nationally framed goals through their proactive announcements of investments in both R&D and manufacturing in the U.S. The most prominent action so far is GM's announced battery plant investments (with LG Chem subsidiary LG Energy Solution) in Lordstown, Ohio, and Spring Hill, Tennessee, plus its production-plant investments in Factory Zero (Hamtramck, Michigan) and Spring Hill, along with its promise to build two more U.S.-based plants in the next few years. Since there seems to be bipartisan support for "build American" policies, we are likely to see a prolonged period in which incumbent automakers will trumpet every plan for building their BEV products and sourcing BEV suppliers on U.S. soil. Ford announced that it will build a new assembly plant near Memphis in Tennessee and three battery plants (with SK Innovation), two in Kentucky and one in Tennessee. Tesla has a new plant under construction in Austin, Texas.

"Buy American" is another strand in this web of economics and politics. Initial appeals to environmentalists had some success but also revealed that attitudes toward BEVs are often divided by political lines. Tesla has been successful because it's been at the leading edge of new technologies, along with its experience-oriented pitch that its vehicles are "fun and exciting to drive" and its appeal to green sensibilities. BEV marketing now aims for broad appeal (e.g., GM's "Everybody In" campaign) but will also vary its messaging according to the target audience. Dodge, for example, aware of its dependence on a V-8-powered high horsepower "muscle car" image honed via

[83] https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/18/fact-sheet-the-american-jobs-plan-supercharges-the-future-of-transportation-and-manufacturing/

the *Fast and Furious* franchise, suggests that its move towards electrification will not be "electric cars" but rather "American E-muscle."[84]

There's plenty of room for varying BEV marketing by target audience, and that may be essential. It's unclear if suggestions to "buy American" and "build American" will result in enough motivation for U.S. consumers to purchase their first BEV. Consumers will surely still have concerns about the availability and convenience of recharging. Yet a patriotic message about BEV adoption will resonate if the geopolitical competitive dynamics intensify.

And, finally, in China: China is the world's biggest BEV market in both absolute sales and sales growth (up to 2020), as well as the dominant force so far in BEV manufacturing and supply chains, particularly for batteries, due to investments in production capacity and prior moves to secure raw materials from varied sources. Incumbent automakers headquartered outside China operate there through mandatory joint ventures (JVs)—for BEVs, including conditions about using China-sourced batteries and motors—and limited exports. Tesla, as it passed the survival threshold, opened its second factory worldwide in Shanghai, notably without the requirement of a JV, and Chinese consumers now generate roughly 20 percent of Tesla's overall sales

Within China, OEMs—whether originating as State-Owned Enterprises (SOEs) (e.g., SAIC), founded as ICEV producers (e.g., Geely, Chery), or migrating from an adjacent sector (e.g., BYD, originally a battery maker)—are the focus of Chinese economic aspirations at national, regional, and urban levels; first to dominate the huge domestic market and second to become successful global exporters of BEVs, a goal that largely eluded them in the past for ICEVs. Other leading start-ups, such as Nio and Lucid, are Chinese firms whose early strategies consist of targeting wealthy customers in both China and the U.S. From any of these firms' perspective, the chances of staying in the small group that scales quickly and gains competitive advantage are greatest if the Chinese and American BEV markets grow at a rapid clip, in positive correlation.

Portraying the effort to accelerate BEV diffusion as a zero-sum contest in which the U.S. loses if China wins is completely at odds with the realities of needing BEVs, as the most promising vector for emissions reduction, to be adopted everywhere along very steep growth curves. But the free market, pro-globalization era—in which any proposed "build American" policies would face pushback as government meddling in the economy, is over, and the framing of geopolitical competition around new technologies is here to stay. Governments

[84] https://www.motorauthority.com/news/1132838_dodge-confirms-electric-muscle-car-for-2024

With policies that support BEV infrastructure, consumer adoption, and onshore manufacturing, many governments are looking to use the industry's transition as an opportunity to build or maintain their national or regional leadership in the automotive sector… For their part, companies have been eager to align with these nationally framed goals.

will be making economic and regulatory policies for BEVs that prioritize domestic (or, for the EU, regional) economic and political priorities.

Indeed, the call to bolster U.S. national competitiveness vis-à-vis China will underpin the likely persistence of "build American" and "buy American" arguments and actions. The risk of falling behind China in crucial new technology domains is increasingly at the foreground of political policy debates, given the galvanizing power of appeals to geopolitical competition and the bipartisan opportunities of uniting against a common foe. Firms that align with those policies will reinforce the prospects for a virtuous circle of forward momentum toward a BEV tipping point.

But don't expect automakers to release ads with a "let's beat China, buy an American-built BEV" message; they can't risk their stake in China sales and Chinese production.

Opening out to a broader perspective, those enabling policies for BEV adoption that have a domestic focus but not a geopolitical framing are likely to have the biggest short-term impact on U.S. consumer mind-sets. Educate consumers with everyday access to a garage or driveway parking spot about the relative ease of installing a 220V charger for daily top-offs at overnight electrical rates. Incentivize grid modernization and eliminate cross-jurisdictional regulatory complexity (e.g. town or city vs. state vs. federal) that can interfere with those at-home installations. Focus federal investments in charging infrastructure on two priorities: availability along interstate highways during long trips and access for urban homeowners and renters who park on the street. If framing BEV production around a need to "beat China" means the U.S. will fast-track policy actions supporting these charging infrastructure initiatives, bring it on.

Reducing emissions is a global challenge of increasing urgency and the primary actors featured in this report—incumbent automakers and start-ups with ambitions to scale—must balance domestic economic and political priorities with that global perspective of necessity.

08 WHAT TO WATCH

as Each OEM's Strategy Unfolds

At time of writing, we see considerable momentum for BEVs, driven by apparent convergence of corporate strategies and policy priorities. These may seem like lofty ambitions, but they are also appropriate when it comes to the urgency of making rapid progress on decarbonization. Still, this may prove to be a fragile moment if synergies among these developments aren't maintained or encouraged by investors.

Accordingly, this section will set out markers for visible, measurable progress toward the goals that GM and other traditional OEMs openly describe as "aspirational." It's clear that multiple stakeholders are involved in the corporate statements associated with those goals.[85]

The most important monitoring task is to examine, critically, whether these firms are supporting what other critical stakeholders are doing even as they pursue their own strategy. The aspirational goals won't be reached if companies are saying one thing about a far-off strategic commitment, or even taking actions in that regard, only to then undercut it with their lobbying and public-relations activities and with political contributions to opponents of those goals. Such political activities are often justified by corporations as necessary to maintain political "balance" or to keep "access." But other stakeholders, including consumers, readily interpret them as hypocritical and as something that undermines credibility. Automakers such as GM and Toyota rapidly pivoted from supporting the Obama-era emissions standards to rolling them back during the Trump era, and now they've reversed course again in response to the Biden administration's reinstatement of tougher standards. Observers of these moves are already accusing these firms of being unreliable. Nothing would boost the credibility of GM and its peer OEMs more than taking a stand on the urgency of decarbonizing automotive mobility and sticking with it.[86]

Several more easily measurable metrics can also be tracked by investors and analysts who want to assess whether automotive OEMs are staying the course in their BEV goals:

- Plan for reducing Scope 3 emissions (see, for example, the Engine No. 1 analysis of GM). Is the OEM setting specific, challenging intermediate goals

[85] Mary Barra, GM Chair and CEO, said when announcing GM's 2035 goals, "General Motors is joining governments and companies around the globe working to establish a safer, greener and better world. We encourage others to follow suit and make a significant impact on our industry and the economy as a whole." https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2021/jan/0128-carbon.html Toyota's Bob Carter, GM's head of sales for North America, said, "For the industry to reach an all-electric future it's going to take combined efforts between automakers, government, dealers, suppliers, and of course, most importantly, consumers." https://www.greencarreports.com/news/1132471_toyota-says-it-isn-t-anti-ev-suggests-it-ll-build-more-evs-if-demand-exists

[86] For a creatively labeled example of this viewpoint, see "CSR Needs CPR: Corporate Sustainability and Politics," T. Lyons et al, California Management Review, Vol. 60(4), 5 –24 (2019), which argues, "It is time for [sustainability] metrics to be expanded to critically assess firms based on the sustainability impacts of their public policy positions. To enable such assessments, firms must become as transparent about their corporate political responsibility (CPR) as their corporate social responsibility (CSR)." https://cmr.berkeley.edu/assets/documents/promo/csr-needs-cpr-preview.pdf

and reporting progress on dependable intervals? Specifying the goals and providing reliable progress reports is more important than the question of whether every goal is met on time.

- A BEV product plan that corresponds to the overall strategic goal of eliminating new ICEV sales. While changes to the product plan can be anticipated in response to consumer reactions to different models in the BEV portfolio, it's a dangerous sign when an OEM retreats steadily from announced plans for investing in new products. (A suitable example here is GM's past underinvestment in new products for Saturn after a successful launch of that brand.)

- Completion of charging-infrastructure installations that are directly affected by the OEM's actions, the actions of its alliance partners, or the government initiatives that it actively supports. Coordinated action, and consistent corporate support, lessen the financial risk of forward investing into charging infrastructure ahead of demand that breaks the "chicken-egg" cycle of range anxiety.[87]

- Automotive OEM progress in building and strengthening software capabilities, including winning a decent share of software talent in competition with tech firms.

- Not making too many promises that aren't met. Delay, obfuscation, or statements regarded as "greenwashing" will activate—or even supercharge—latent investor and larger-public skepticism about big automakers.

The white paper by David Victor, commissioned by Engine No. 1 for the ExxonMobil campaign, emphasizes the need to pay attention to which firms in the fossil-fuel industry learn and adjust most quickly in their movement toward carbon neutrality (in a section on "What to Watch as the Industry Responds").[88] In comparison with the challenges facing the fossil-fuel industry, this report's view of the automotive industry both agrees with and differs from Victor's assessment.

We agree that openness to learning will be as crucial for the automotive OEMs as it is for the fossil-fuel companies. In other words, these companies should take actions expeditiously and evaluate them rigorously;

[87] Maintaining corporate support for government's role in creating BEV charging infrastructure is a good example of "CSR needs CPR." Political opposition to a federal role in funding BEV charging stations has already dramatically reduced the allocation in the 2021 infrastructure bill; familiar criticisms of "centralized planning" and "picking winners" are evoked amid a deferential nod to the market mechanism that will supposedly fund whatever charging stations are truly in demand. If automotive OEMs support those political opponents of charging infrastructure, they will be perceived, rightfully, of hypocrisy and their BEV goals will lose all credibility.

[88] Specifically, "Today, the firms that are taking this new challenge seriously are not all striving to perfect the same playbook because nobody—not firm managers nor sage analysts—reliably knows what is best. In this context, success must be measured not simply by allocation of effort but by whether firms are designing their strategies to learn quickly," page 21. https://reenergizexom.com/wp-content/uploads/2021/03/Energy-Transformations-Technology-Policy-Capital-and-the-Murky-Future-of-Oil-and-Gas-March-3-2021.pdf

Above all, hold these firms to their stated strategic commitments... Don't challenge the idea that bold and aspirational actions will be needed.

they should understand and tackle the inertial and internal political forces that will pose barriers; and they should be ready to adjust strategies and tactics based on the full set of tests, trials, pilots, prototypes underway.

When it comes to automotive OEMs, we come to a different conclusion. In our assessment, their transition to sustainable energy in personal mobility is less daunting than the situation the fossil-fuel industry faces. Again, OEMs possess system-integrator capabilities; hold a role within the sector's institutional structure that has entailed responsibility for meeting regulations on safety and quality and emissions; and have previously invested in electrification-related R&D, based on "know more than you make." All of this puts them in a very credible position to become leaders in the transition to BEVs.[89]

In summary, investors, analysts, and consumers need to evaluate incumbent OEMs vis-à-vis these realities. Recognize that these OEMs are already stronger in supply-chain management and manufacturing than the challenger start-ups are. Acknowledge that batteries aren't a major problem: scale is increasing; cost is dropping; cells are supplied by alliance partners; and, with OEM integrating them into product designs, new battery chemistries will ease supply-chain pinch points. Pay attention to the bigger challenge of software, but remember that, just as BEV start-ups can hire automotive engineers to learn new capabilities, automotive OEMs can hire software engineers.[90] Above all, hold these firms to their stated strategic commitments, monitor whether their political activities support and reinforce those commitments, and call out serious contradictions and signs of greenwashing. Be patient when not all goals are reached or are achieved later than planned. And don't challenge the idea that bold and aspirational actions will be needed from both private and public sectors due to the urgent climate situation we collectively face.

[89] Whether the same statement can be made for OEM capabilities for AVs is a worthy topic for a separate inquiry, but given the relative timeframes for EV vs. AV commercialization, it is safe to say that while "all AVs will be EVs," not all EVs will be AVs. That is, we'll see many years of BEVs that have advanced driver assistance features (mostly SAE level 2) before the widespread implementation of Level 4 AVs. Incumbent OEMs have clear advantages over (most to all) BEV start-ups and tech new entrants in that time window. Plus, remember that start-ups aren't enough to achieve the necessary goals for the decarbonization of mobility.

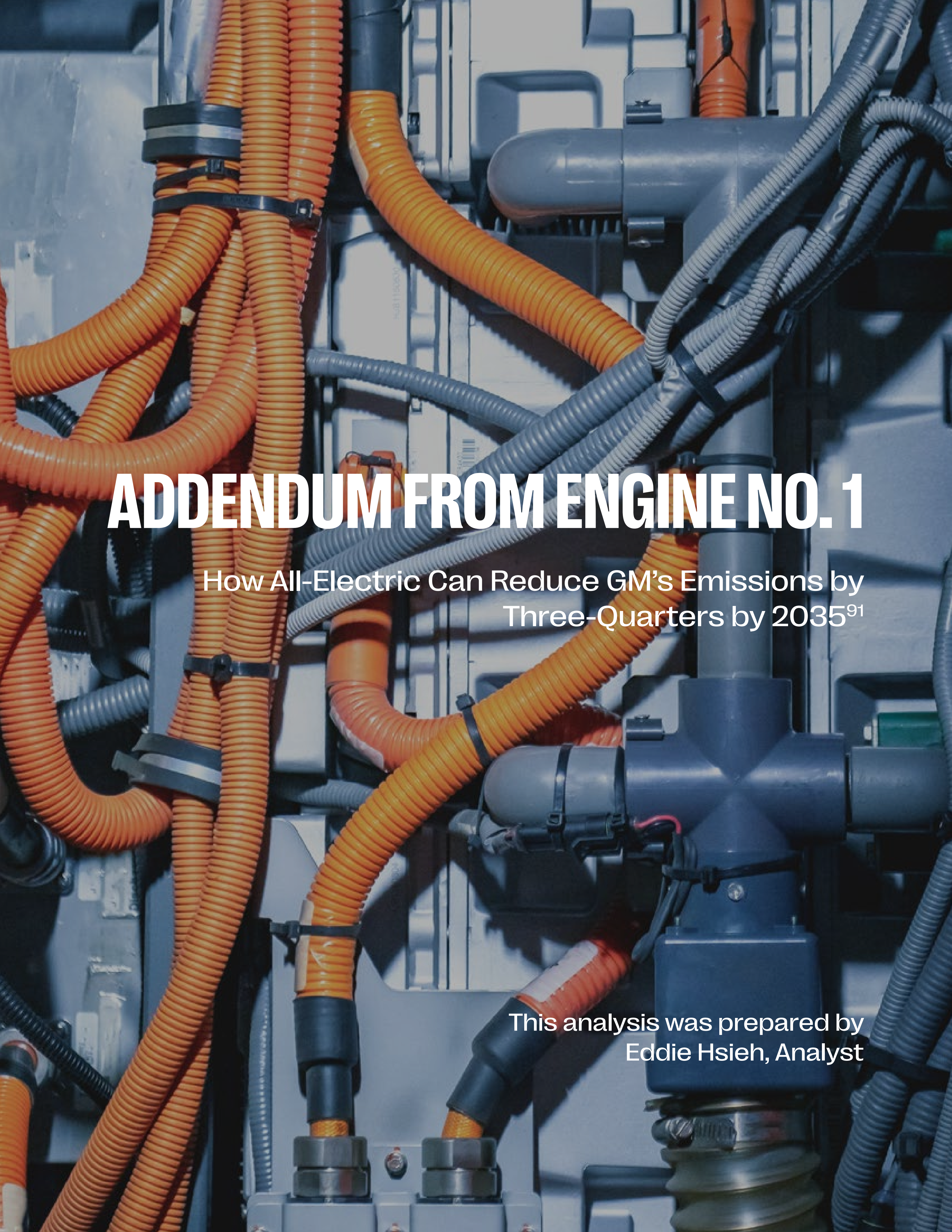
[90] Though difficult to assess externally, the progress of automotive OEMs in building and strengthening their software capabilities—and their ability to win a decent share of the software talent labor market in competition with tech firms—is another metric worth regular monitoring and assessment.

CONCLUSION

The growing acceptance and internalization of the reality of climate change is changing hearts and minds. Still, many inertial forces, and the entrenchment of fossil-fuel interests and habits, are dragging down the pace at which mobility becomes electric. To accelerate this pace, it is first essential to recognize that the end of the internal combustion engine is nigh, tied as it is to the pending decline in demand for oil and gas. Second, be mindful that Tesla sales—and start-up BEVs in general—are not enough to achieve the speed of transition to electrification that is needed to avoid destructive levels of global temperature increase in the coming decades. Automotive OEMs, the incumbents in the ICEV ecosystem, are urgently needed as participants in the BEV transition.

The good news is that those OEMs fully possess the capabilities to be strong actors in that transition by virtue of past investments in learning about BEV technologies, in addition to everything that carries over from ICEV to BEV in their existing capabilities, plus their recent strategic boldness in setting ambitious targets for phasing out ICEVs. Backing the efforts of a leading firm—and we suggest General Motors as a plausible candidate—is a worthwhile way to start. We highlight GM's advantages, why we are relatively confident it will continue its current trajectory despite considerable uncertainty, and what investors should watch in order to be sure that GM is staying the course and building an early lead into a sustained advantage.

Supporting other incumbent OEMs, or nudging them as necessary, is also important. Not all incumbent firms will succeed in making the transition, and the fruits of the transition will not be evenly divided. But the more quickly we see scale-up in the electrification of mobility, the better the outcome in wider efforts to prevent dangerously increased global temperatures. Furthermore, scale and pace both build cultural momentum, and these are in turn fueled by that momentum. Virtuous cycles are more attainable now than at any time in history—from reciprocal reinforcement among corporate strategic actions, from investor commitment of capital, from consumer enthusiasm, and from government policies that incentivize and support the transition while paying attention to equity of access and the impact on skills and employment. We can easily fail if any of the key actors sit on the fence or decide to side with inertial forces or fossil-fuel die-hards. It is critical that we make the right choices at this time. Our children will be watching.



ADDENDUM FROM ENGINE NO. 1

How All-Electric Can Reduce GM's Emissions by Three-Quarters by 2035[91]

This analysis was prepared by
Eddie Hsieh, Analyst

Globally, the transportation sector produces 14 percent of the world's greenhouse gas (GHG) emissions, amounting to nearly seven gigatons of CO_2 equivalent ($GtCO_2e$) emissions annually.[92] And that number grows each year. Indeed, it is the fastest-growing source of CO_2 in the world.[93] Automakers, through the products they sell and their influence on the automotive supply chain, can play a key role in reversing this impact. (Please read John Paul MacDuffie's report for more detail on the role legacy automakers play in mitigating climate change.)

GM is the fifth-largest global automaker by volume. We believe the company's commitment to go all-electric by 2035 is crucial in driving down the auto industry's GHG emissions.

In this brief Engine No. 1 analysis, we highlight GM's current and future carbon footprint in the transition to battery electric vehicles (BEVs).[94]

The Forecast

To forecast GM's future GHG emissions, we focused on three key inputs: 1) GM's current Scope 1, 2, and 3 emissions;[95] 2) the lifecycle emissions of internal combustion engine vehicles (ICEVs) vs BEVs; and 3) the speed at which GM transitions to BEVs.

To construct the current emissions baseline, we rely on GM's Scope 1, 2, and 3 statements, which have received independent third-party verification.[96] In 2019, Scope 3[97] emissions comprised 98 percent of GM's

[91] Funds and investment vehicles managed by Engine No. 1 may currently beneficially own shares of certain of the companies discussed herein, including General Motors. Please see Important Information at the end of this report.

[92] https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[93] The IPCC estimates 49 $GtCO_2e$ annual GHG emissions, with 7.0 $GtCO_2e$ coming from transport. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[94] In 2020, GM's global market share was 8.7 percent as reported in its 2020annual report: https://investor.gm.com/static-files/f1b9d4ef-a7c1-4768-8789-c15985d72fab

[95] We define BEVs as full battery electric vehicles.

[96] Scope 1 emissions occur from sources controlled or owned by an organization. Scope 2 emissions are associated with the purchase of energy consumed by the organization. Scope 3 emissions are all other indirect emissions that occur in a company's value chain, including in the use of an organization's products. See https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

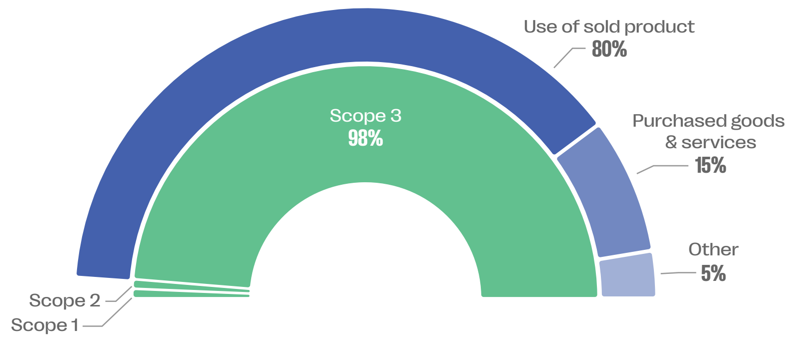
[97] GM's sustainability reporting is available at https://www.gmsustainability.com/downloads-and-archives.html

[98] Indirect emissions: think emissions from the burning of fossil fuels to power GM's gas and diesel cars over the lifetime of the vehicle (use of sold product) and the emissions from the manufacture and transportation of vehicle components (purchased goods and services)

FIGURE A.1

GM 2019 GHG Footprint

Scope 3 emissions comprise 98% of GM's 2019 total greenhouse gas footprint



Source: GM https://www.gmsustainability.com/downloads-and-archives.html

total GHG footprint. (See Figure A-1.) While GM plans to make progress on Scope 1 and 2,[98] we believe that reduction of Scope 3 emissions (specifically use of sold product) is the central opportunity for GM to make its most significant positive impact on the environment.

In GM's case, we believe that the solution to reducing Scope 3 emissions lies in battery electric vehicles. With zero tailpipe emissions, BEVs are a greener alternative to ICEVs. Even considering emissions associated with manufacturing and electricity generation,[99] the lifecycle GHG footprint of a midsize BEV is 19 to 69 percent lower than is that of a comparable ICEV today.[100] This gap will continue to widen as the world transitions to renewable energy.[101]

We estimate baseline per-vehicle Scope 3 emissions of GM's average BEV to be roughly half that of its average ICEV.[102] To forecast future Scope 3 emissions, we incorporate our projection of GM's unit sales and BEV mix. Currently, GM BEV mix is roughly 3 percent,[103] but with GM's Lordstown battery plant set to be operational in 2022, we expect a step-up in BEV sales starting 2023 as GM begins scale production of its Ultium batteries. By 2025, we expect GM's four battery plants to generate a total capacity of at least 140GWh, enough to power 2 million electric vehicles. This is consistent with GM's target of more than 1 million BEV sales by 2025 and our expectation of around 1.4 million. From there,

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[99] GHG emissions from GM's facilities and electricity purchased and used by GM. GM is committed to reduced absolute Scope 1 and 2 GHG emission by 72 percent by 2035. https://www.gmsustainability.com/_pdf/resources-and-downloads/GM_2020_SR.pdf

[100] There are several factors that influence the "use phase" emissions of an electric vehicle, including power-train efficiency and the source of electricity (nonrenewable versus renewable). While we can expect incremental improvements to efficiency, we believe the main driver of cleaner BEVs will come from the transition to renewable energy.

[101] https://theicct.org/publications/global-LCA-passenger-cars-jul2021. The gap varies by region and is widest in Europe, where there is the highest penetration of renewable energy in the grid.

[102] EU's "Fit for 55" proposal targets 40 percent renewable energy mix by 2030. China's National Energy Administration also has a draft policy of 40 percent by 2030. The Biden administration has set a goal of 100 percent renewable energy mix by 2035.

[103] Our estimate of Scope 3 emissions/vehicles is largely based on vehicle-efficiency data from the EPA (https://www.fueleconomy.gov/) and country-level renewable energy penetration.

[104] Three percent EV mix in 2020 based on Engine No. 1 analysis.

FIGURE A.2

GM Sales Projections to Reach 100% BEVs by 2035

15-year sales projections for GM split by internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs)

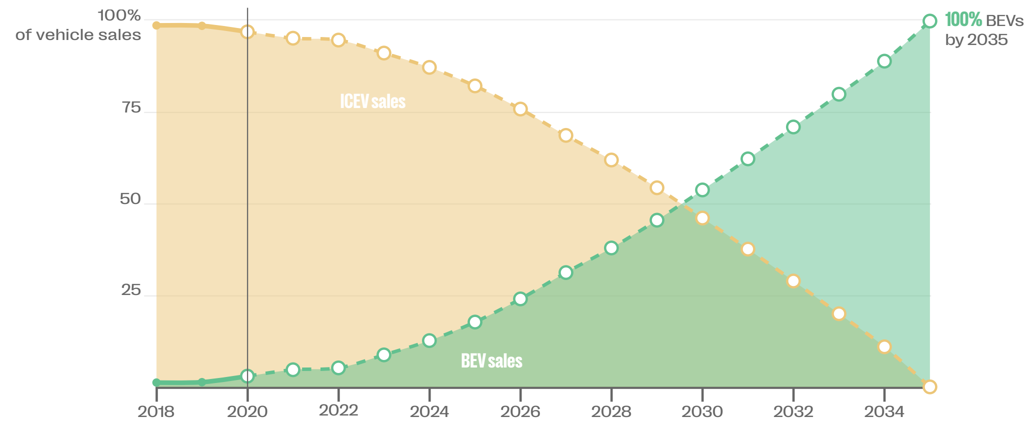
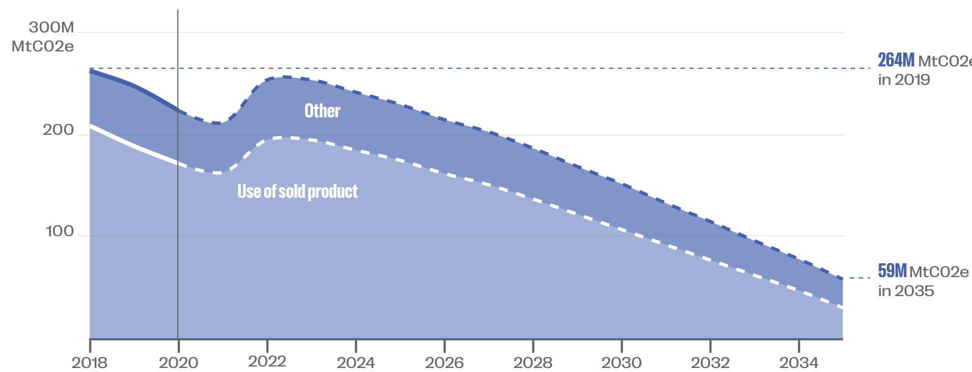


FIGURE A.3

GM Scope 3 Emissions Projected to Fall 78% By 2035

The transition to BEVs is forecast to reduce GM's emissions by over 200M MtC02e/yr (baseline model)



we model consistently increasing BEV mix until GM reaches full BEV-only production and sales in 2035. (See Figure A-2.)

Combining our per-vehicle Scope 3 emissions forecast and sales forecasts demonstrates the total potential reduction in GM's Scope 3 emissions over time. Over the next two years, we expect rising Scope 3 emissions due to an industry-wide rebound in auto sales and increasing truck mix. However, as industry-unit sales level off and BEV mix ramps up, we believe that GM's GHG footprint will resume its steady decline in 2024 onward.

The environmental impact of this transition to BEVs is enormous: we see GM's Scope 3 total falling by 78 percent from 2018 to 2035. (See Figure A-3.) This would be equivalent to a 205 MtCO2e/year reduction in GHG emissions. As a corporation that only makes up 0.1 percent of the world's market cap, GM can potentially remove 0.4 percent of the world's annual GHG emissions.[104]

We can also think about this impact on the environment in dollar terms. At a social cost of carbon of $100/tCO2e,[105] reducing emissions by 205 MtCO2e would equate to a ~$20 billion benefit to society each year.

This analysis is dependent upon several factors, including but not limited to GM achieving its electrification commitment, global governments cooperating in transitioning to renewable energy, and GM's suppliers reducing the footprint of their own operations. While the transition to BEVs will not be easy or cheap,[106] we cannot understate the importance of the example GM intends to set. Only under this aggressive scenario can we see passenger-vehicle emissions declining by a compound annal growth rate of 9 percent. That would barely exceed the 8 percent annual reduction[107] in global GHG emissions that would be necessary to meet the temperature goals of the Paris Agreement (i.e., that global warming is ideally limited to 1.5 degrees Celsius compared to pre-industrial levels).[108]

Future Considerations

Engine No. 1 applauds GM's commitment to an all-electric fleet. Over the past year, GM has increased its BEV investment from $20 billion to $35 billion, putting the company on an accelerated path to reach some 50 percent BEV penetration by 2030. To us, this additional $15 billion looks well spent. Without this additional investment, we estimate that GM would be on a slower path to all-electric, reaching only 30 percent BEV penetration in 2030. We estimate that by pulling forward BEV production from this "low-investment" scenario to our current "base-case" scenario, GM will reduce its aggregate GHG emissions by nearly 350 MtCO2e from now through 2035. At $100/tCO2e, GM will achieve an additional $35 billion positive impact on society, vastly outweighing its $15 billion incremental investment in BEVs while putting it in a better position to compete for market share in the growing BEV market and create long-term shareholder value.

Following the same logic, we can estimate the additional reduction in emissions

105 GM's market cap is $71 billion versus the Bloomberg World Exchange market cap of $118 trillion as of July 26, 2021. Global GHG emissions reached 49 GtCO2e in 2010 according to IPCC.

106 The World Bank estimates cost of carbon at $40 to $80 per metric ton, and for an increase to $135 by 2030. We apply a flat $100/tCO2e across all years for ease of calculation. https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf

107 GM alone is investing $35 billion in electric and autonomous vehicles through 2025. https://plants.gm.com/media/us/en/gm/ev.detail.html/content/Pages/news/us/en/2021/jun/0616-gm.html

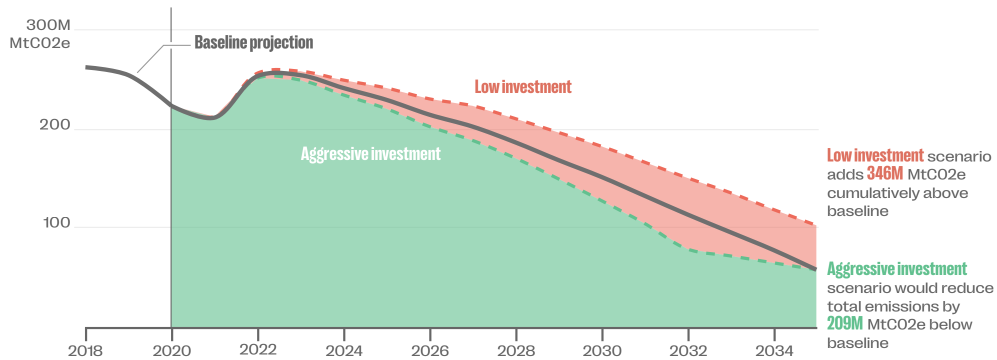
108 https://www.unep.org/resources/emissions-gap-report-2019

109 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

FIGURE A.4

BEV Investment Scenarios Yield Diverging Emissions Outcomes Over Next 15 Years

An aggressive investment approach is projected to reduce total emissions by over 200M MtC02e by 2035



Baseline projection based on current GM BEV investment of $35bn, and 50% EV penetration by 2030. “Low Investment” projection based on 20% BEV and 20% hybrid penetration in 2030. “Aggressive Investment” scenario based on BEV penetration of 25% by 2025, and 100% by 2032.

possible if GM were able to move even faster. (See Figure A-4.) Recognizing that GM is likely to be capped by battery capacity, we modeled the company’s impact on emissions if it reached BEV penetration of 25 percent by 2025[109] and 100 percent by 2032 in an even more aggressive scenario. In our model, we estimate this could save an incremental 209 MtCO2e or an equivalent over $20 billion positive impact over the base case.

Accelerating the transition to BEVs is a major investment. It could come with near-term impacts to profits and cash flow. But we believe further investments in BEVs should consider the chance to gain market share and preserve or expand margins, as well as eliminate significant emissions. The opportunity to create both long-term shareholder and societal value cannot be ignored.

[110] Twenty-five percent BEV penetration would equate to some two million units, the maximum output capable assuming GM can fully ramp all four battery plants to a total 140GWh run rate by 2025.

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