General Motors: From Disruptee to Disruptor?
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On January 28, 2021, General Motors (GM) CEO Mary Barra announced on LinkedIn that "General Motors plans to be carbon neutral by 2040...and an aspiration to eliminate tailpipe emissions from new light-duty vehicles by 2035" as part of its zero-crashes, zero-emissions, zero-congestion vision. Since then, GM has unveiled a line of Mini EVs in China, the Cruise Origin in San Francisco, and Ultium technology upon which future EVs will be based. All three are expected to launch in 2022. A newswire from WSJ has journalists wondering how GM will follow through with this bold commitment. While GM is an incumbent in the automobile industry, it is a disruptor in the EV market. After a dabble with the EV1, followed by a step forward with the Chevy Bolt EV, GM is now confidently striding ahead and diversifying to foreign, ridesharing, luxury, delivery, and even aerial EVs. Will GM succeed at disrupting the disruptors?

The Auto Industry: ICE Vehicles vs. EVs

The traditional gas engine car, hereafter referred to as the ICE (internal combustion engine) vehicle, dominates road transportation nowadays. But if current trends continue, soon EVs (electric vehicles) will outnumber ICE vehicles.[1] In fact by the time you read this article, the status quo may have already changed.

A super-brief history

EVs are a battery-powered version of ICE vehicles. Starting from the first patents in 1807, ICE vehicles have evolved from coal-powered to Otto cycle to electric-starter in 105 years, dominating road transportation ever since.[1] [2] Whereas ICE vehicles are powered by an internal combustion engine fueled by gasoline, EVs are powered by a battery fueled by electricity (Exhibit 1). EVs first appeared (rather, reappeared post-1912) in 1981 and 1996 with the Volkswagen Golf 1 CitySTROMer and GM EV1, but didn't really take off until 2008 with the Tesla Roadster. The CitySTROMer was experimental and only 25 were made,[3] and most likely GM built (and retracted) the EV1 in response to California enacting (and retracting) the Zero Emission Vehicle regulation.[4] [5] Meanwhile Tesla's mission is "to accelerate the advent of sustainable transport by bringing compelling mass market electric cars to market as soon as possible."[1] Just as the engine type is what distinguishes EVs from ICE vehicles, so the battery is the main distinguishing factor between EVs. Additionally, EVs differ by country, charging station availability, method of distribution, hybrid vs. fully electric, luxury vs. low-end/mass-market/slow-speed, and self-driving technology. Exhibits 2 through 6 survey and compare the leading EV (and battery) brands.

Suppliers

With regards to supply, EVs largely depend on batteries, which are their main limiting factor for cost and performance. In particular EV range, efficiency, and acceleration all depend on the energy stored in the battery (Exhibits 7-8). Batteries are composed of cells which include an anode, cathode, electrolyte, and separator. Once the cells are manufactured, they are combined into modules of 4 to 444 cells incorporated into a case with terminals. The next and last step in the EV supply chain is packing the modules, electrical connections, and cooling equipment into a battery pack.[1] While the steps of the supply chain can be broken up and conducted in different locations, assembly typically occurs near the vehicle assembly location. For example, the Automotive Energy Supply Corporation (AESC) produces battery cells, modules, and packs for Nissan Leaf in their Sunderland, England plant but also sends modules to Spain for use in electric vans.[1 6] GM's Michigan plant and Tesla's Gigafactory use battery cells produced both onsite and abroad, but module and battery packing is done onsite.[6]

The EV battery supply for the US mostly comes from the US, with almost all pack assembly occuring domestically, and about 30% of cell production occuring abroad. Excluding Tesla EV batteries brings this percentage up to 82%.[6] For other countries it is difficult to obtain battery supply data for EVs specifically, since the Harmonized Commodity Description and Coding System categorizes battery cells and modules together with all other battery parts, and categorizes battery packs together with all other lithium-ion batteries.[6] However the top lithium-ion battery suppliers globally are LG Chem, CATL, Panasonic, Samsung SDI, and BYD (Exhibit 3a). In addition to various factories of the above, the top 15 lithium-ion battery producing factories include Panasonic-Tesla (US), CATL-SAIC (China), EVE Energy (China), and Tesla (US) (Exhibit 3b). LG Chem has the greatest market share globally and supplies Volkswagen, GM, Ford, Geely, Renault, and Hyundai. Next is China's CATL (Contemporary Amperex Technology) which supplies BMW, Volkswagen, Daimler, Toyota, and Honda. Panasonic is Japan's number one battery manufacturer and supplies Tesla, Toyota, Honda, and Ford Motors. Samsung SDI supplies Fiat and BMW, and additionally recycles Samsung phone batteries for cobalt.[7] BYD not only makes EVs, but also supplies lithium-ion batteries to their own cars as well as Toyota's.[1] Some EV firms have partnerships with battery companies, notably: Tesla-Panasonic Gigafactory, Toyota-Panasonic, GM-LGChem Ultium, SAIC-CATL, and Nissan-Tokin-NEC joint venture AESC.[1 10]

Battery suppliers further rely on supply of the metals used in batteries. In the past, EVs such as the EV1 used lead acid batteries, but these had short range and were much heavier than the ICE system (Exhibit 2). With the development of the nickel metal hydride (NiMH) battery, Toyota was able to develop the hybrid Prius in 1997. Then with a 53 kWh lithium-ion battery, the Tesla Roadster in 2008 became the first modern all electric vehicle.[1] However demand for manganese is outpacing supply (Exhibit 9), prompting some manufacturers to switch from the lithium-nickel-manganese-cobalt-oxide batteries used in most EVs (like the 2008 Tesla Roadster, 2008 BYD F3 Dual Mode, 2010 JAC J3, and 2011 Nissan Leaf) to lithium-nickel-cobalt-aluminum-oxide batteries (used in Tesla Models S, X, and 3 and the upcoming GM-LGChem Ultium).[1 10] In fact metal prices have surged along with EV battery manufacturing capacity in recent years:[6] Cobalt prices have tripled since 2016, prompting battery makers such as Samsung SDI and Panasonic to invest in recycling and low-cobalt solutions.[7] Electric motors require neodymium, a rare earth metal for which 95% of the supply is produced by China, and for which prices quadrupled in 2010 when China restricted supply.[8] As a result, Toyota is working hard to develop a motor that does not depend on rare earth metals. Increased supply of EV battery cells has kept EV battery costs low though...so far.[1 6]

Distributors and Customers

To meet demand from buyers in the US, EV manufacturers must sell their vehicles through a dealership. Hence Nissan Leaf vehicles are sold at Nissan dealerships, and BMW i3 vehicles are sold at BMW dealerships. Dealer franchise laws require this in order to create competition between multiple dealers selling the same brand, thus preventing monopoly. However Tesla sells their cars directly to customers through the internet. Having moved all sales online in February 2019, they continue to fight for the right to sell their own cars through their own (online) stores. Meanwhile their showrooms serve the purpose of educating customers on Tesla technology and the future of automobiles, rather than just having a customer come in to find a car and negotiate a price. Tesla has changed the way cars are sold.[1]

Globally, the top EV buyers are China followed by the US, Europe, and Japan (Exhibit 10). Within national markets however, EVs hold the greatest market share by far in Norway, followed by Iceland, Sweden, the Netherlands, Finland, and China (Exhibit 11). In the US, buyers include the general public, rental car companies,[1] government fleets, delivery fleets, and rideshare spinoffs. While the two largest US rental car companies (Enterprise and Hertz) have been reducing EVs due to low demand,[1] other EV purchases are in the works: The INVEST in America Act which passed the House on July 1, 2021 plans to transition the entire US federal light-vehicle fleet to EVs by 2050, electrify the transportation system, and ensure access to EVs for underserved communities.[9] GM's Brightdrop delivery solution expects its first EVs to be delivered this year (2021), with partner FedEx Express slated to be the first recipient.[10] GM's Cruise, Tesla, Ford, and Hyundai-Aptiv are all in process of developing EV ridesharing services featuring their own EVs.[11] In future we may even be seeing EVs produced for drones and the airline industry.[10] [12]

Substitutes

Obviously ICE vehicles and EVs, and their respective fuels and parts and materials, are substitutes for each other. According to experts: "Over the next generation...electric cars may (or may not!) become a significant substitute for those powered by combustion engines. If they do, this will have a cascading effect, causing substitution in many other parts of the car."[8] For example, because EV batteries are heavier than ICE vehicle batteries, BMW is investigating carbon fiber substitutes for steel car bodies. If ICE vehicles are replaced by EVs, ICE transmissions and exhaust systems servicers too will become as irrelevant as buggy whip makers. As a result of the threat of substitution by EVs, OPEC has been carefully managing the price of oil for decades to discourage investment in alternative energy substitutes. To counter that, environmentalists are favoring high gas taxes.[8] The effects of EVs and ICE vehicle substitution are far-reaching indeed.

Exhibit 8 lists the differences between EVs and ICE vehicles. Overall EVs are more efficient, environmentally friendly, novel (more software and autonomous driving capabilities), and convenient (low maintenance, low cost of operation). Meanwhile ICE vehicles have greater familiarity, security,[13] range, and acceleration. The **main advantage of EVs** is efficiency: Basically ICE vehicles convert fossil fuels to horsepower and exhaust, while EVs take fossil fuels/nuclear energy/renewable energy that have already been converted to electricity and exhaust, and convert that electricity to horsepower (Exhibit 7). The difference is that EVs

1) use nuclear and renewable energy sources
2) shift fossil fuel conversion and exhaust from the car to the electric plant
3) shift refueling from 10-15 minutes at the gas station to 3-12 hours at home.[1] [14]

Meanwhile the **main advantage of ICE vehicles** is efficiency at higher speeds: "In terms of comparisons between the gas engine and electric motor, they work very differently with regard to the power demands of a car. Gas engines generate low power at low speeds and high power as speed increases before falling again...Electric motors demand high current and offer lots of power at slower speeds, but while accelerating, it demands less current and offers less power."[1] As for what happens at zero speed, EV motors "recharge their batteries when braking, which reduced the amount of energy lost as heat," whereas for ICE engines, "when braking, energy is lost as heat."[1] So efficient driving (moderate speeds for ICE vehicles, slow speeds for EVs)[15] and using renewable energy sources (possible for EVs, not possible for most ICE vehicles) have very different meanings for EVs versus ICE vehicles.

EVs are catching up to ICE vehicles in terms of range: The range of an EV, or how many miles it can drive per battery charge, averages between 62 and 390 miles as of 2020.[14] [16] This is still lower than the average ICE vehicle range of 240 to 703 miles per tank of gas in 2016 (Exhibit 8). However upcoming EVs, such as the 2022 Tesla CyberTruck and various GM models powered by GM-LGChem Ultium technology, will achieve ranges upwards of 500 miles (Exhibit 2).

Closely related to EVs are Hybrids, Plug in Hybrid Electric Vehicles (PHEVs), and extended range EVs. Hybrids use both a gas engine and an electric motor whose battery is charged by regenerative braking and the ICE. PHEVs are similar but the battery is charged by plugging into an outlet. Lastly, extended range EVs such as the Chevy Volt[2] use an ICE engine to extend the range of the EV when battery is low.[1]

Additional substitutes for EVs and ICE vehicles include motorcycles, mopeds, bicycles, buses, subways, and high-speed railways. Recently, shared micromobility services (dockless bicycles, e-scooters) are on the rise globally.[17] Efficient ICE vehicles are also being developed,[15 18] and are part of the US path to oil independence and IEA path to sustainable recovery.

Complements

There are four main complements to EVs:

Chargers

EV chargers, also known as EVSEs (Electric Vehicle Supply Equipment), are categorized based on access (public, private), charging power (slow, fast/ultrafast), and plug type (Type 2, Tesla Supercharger).[1 17] Charging stations in the US primarily consist of home chargers, ChargePoint AC and DC charging spots, Electrify America charging spots, Tesla AC EVSEs, and Tesla Supercharger DC EVSEs. Of these, Tesla AC EVSEs often have one setting for non-Tesla EVs and one for Tesla EVs, and Tesla Superchargers are only compatible with Tesla EVs.[1] There must be a high enough availability of EV chargers, and short enough charge time, in order to make driving EVs feasible. While China is aggressively championing electric vehicles through legislation[17] driven by an urgent climate situation and leads the world in EV chargers,[16] US adoption of EVs is lagging due to concerns such as lack of charging stations (aside from Tesla charging stations and forthcoming GM-EVgo charging stations)[19] and the impact of severe weather.[14] WSJ recently conducted an experiment in which eight journalists in four countries were each given an EV to experience for three weeks, including road trip driving.[19] Their findings match the above observations.

Replacement batteries

EV batteries do, in fact, need to be replaced: A study by the National Renewable Energy Laboratory suggests that EV batteries may last 12 to 15 years in moderate climates and 8 to 12 years in severe climates.[14] EV batteries are both more expensive and complex to replace than ICE vehicle batteries.[20]

Repair

Unlike ICE vehicles, EVs require little to no maintenance: no oil changes, emission checks, timing belt and transmission fluid changes, or spark plug replacements.[1 20] However when it comes to repairing damaged EVs, 97% of auto mechanics are not qualified to do so.[1] Tesla has their own Service Centers for repairing Tesla EVs, but repair shops and qualified mechanics for other EVs are currently lacking.[1]

Software

Entertainment software and user interfaces are becoming a key part of the EV experience. In September 2018 Volkswagen and Microsoft announced Automotive Cloud, a strategic partnership to bring communication, personal, and navigation solutions to Volkswagen EVs, including future Microsoft Office and Skype integration.[1] In January 2021 GM's Cruise and Microsoft announced a partnership to leverage Microsoft Azure for collaboration, storage, artificial intelligence, and machine learning capabilities as well as exploration of scaling solutions for digital supply chains.[21] Increased EV battery power is making new software features, and partnerships, possible.

Entry Barriers

The main entry barriers to the EV industry are:

Supply

Both EV and battery manufacturers are competing for an increasingly scarce supply of the materials required to manufacture EV batteries and electric motors.[7 8 22] The scramble to meet 2021 average fleet emissions targets or face fines has already led to supply bottlenecks in Europe.[23] On the other hand if a new entrant happens to have access to these natural resources, controls the supply chain, or manages to develop a better energy source, they will have an upper hand in the EV industry. For example, Tesla's purchase of Grohmann Engineering effectively knocked out rival Mercedes-Benz's production capacity.[23]

Technology

Even if an entrant has the material resources, developing EVs requires a significant amount of technological expertise including: vehicle design, EV technology, and the ability to keep up with constant advances in a fast-moving industry. Even established ICE vehicle companies like GM had difficulty figuring out how to make EV technology work for an EV with more than 50 miles of range: "Just turning on the car required finding the perfect sequence of electrical signals from more than a dozen modules...Then there was the battery. Lithium-ion chemistry was a new thing 10 years ago, and the Volt team quickly discovered how much of a pain in the neck it is."[2] Tesla has open-sourced their technology,[24] stating that "Technology leadership is not defined by patents, which history has repeatedly shown to be small protection indeed against a determined competitor, but rather by the ability of a company to attract and motivate the world's most talented engineers."[24] This is good news for entrants without prior automobile expertise, such as Tesla. This also means EV industry incumbents are more focused on new technology, and less interested in retaliating against new entrants.[8]

Distribution

In the US, entrants such as Tesla not previously established in the automotive industry have an additional entry barrier: access to distribution channels.[1] New entrants will have to create their own distribution channels by either setting up dealerships, fighting franchise laws to sell their vehicles online like Tesla, or coming up with a new solution entirely.

Regulation

There are many sustainability initiatives, federal EV subsidies, and emissions regulations[9 15 17 18] boosting EV sales for all firms in the EV industry. The key word here is all. Most likely these incentives will prove more beneficial to incumbents than new entrants, due to network effects, economies of scale, and the greater familiarity and experience that incumbents have with the regulatory system.[8] Meanwhile existing automobile manufacturers must meet increasingly strict fuel efficiency targets or else face heavy fines.[2] For example, Daimler in Europe faces a $1.1 billion fine this year if it doesn't cut fleet average CO_2 emissions.[23]

High Cost of Failure

While a successful EV is a very lucrative product, mistakes in the EV industry tend to cost consumers their lives, new entrants their capital investments, and the entire EV industry its reputation. Due to their high-power batteries and autonomous driving capabilities, EVs have different ways to succeed as well as fail compared to ICE vehicles, the difference being that EV technology is less well understood. As demonstrated by the Sudden Unintended Acceleration (SUA) crashes affecting all vehicles from all manufacturers with electronic throttles,[13] as well as the Chevy

Bolt EV battery fires of 2017-2020,[25] [26] accidents are common in such a new and high-power industry. Failed experiments like the EV1 cost GM $1 billion and was a public relations disaster.[2] The high costs of failure inhibit the competitiveness of both new entrants in the EV industry, as well as the entire EV industry relative to traditional industries.

Rivals

GM's primary rival is Tesla, the EV industry leader in sales and profit worldwide (Exhibits 5-6).[6] However there are many other EV companies, of diverse specialties, ranging from mass-market to designer to luxury. Even relatively small companies can have relatively large success, for example BMW is small by industry standards but its average return on invested capital from 2000-2009 was 50% greater than the industry average.[8] The top-selling EV companies globally are mostly based in the US, Europe, and China.[6] Some EV companies are in cross-border partnerships with each other, like GM-SAIC, Volkswagen-SAIC-FAW-JAC, Renault-Nissan-Mitsubishi, BMW-Great Wall Motors, and Toyota-BYD.[1]

Major Rivals In the US

Tesla

Tesla is the world's first all electric car company, and its 2008 Tesla Roadster was the first modern all electric EV. Following the Roadster with a range of 244 miles, Tesla released the Model S with a range of 265 miles in 2012, Model X with a range of 289 miles in 2016, Model 3 with a range of 310 miles in 2017, Model Y with a range of 316 miles in 2020, and will release the CyberTruck with a range of 500 miles in 2022.[1] [27] Tesla specializes in luxury EVs.

Ford

Ford released its first all electric EV, the Ford Focus Electric, with a range of 76 miles in 2012.[27] Since then it has released the Ford Mustang Mach-e, a midsize crossover, with a range of 305 miles in 2021.[1]

Other

Other US EV manufacturers include all electric vehicle companies Rivian (specializing in trucks) and Fisker (specializing in designer cars).

Major Rivals Outside of the US

Volkswagen

Volkswagen is the largest automobile manufacturer in the world,[1] and has EV sales second only to those of Tesla (Exhibit 6). Following experiments with the Golf CitySTROMer in the 1970s, it launched its EV lines e-Golf with a range of 83 miles in 2015, and ID with a range of 260 miles in 2021.[27] Volkswagen has joint ventures with Chinese automakers SAIC Motor, FAW Motor Co, and JAC Motors.[1]

Nissan

Nissan is best known for its Nissan Leaf, a mass-market hatchback which was launched in 2010 and became the world's best selling all electric EV by 2018 with cumulative sales of 300,000.[1] Soon after, the Tesla Model 3 surpassed it with 365,000 sales in one year (Exhibit 5). Besides the Leaf, Nissan has seven EV lines including the e-NV200 utility van and Esflow sports car, none of which have reached the same popularity as the Leaf.

Toyota

Toyota is best known for its Toyota Prius, the world's first hybrid EV. The Prius was the top selling hybrid vehicle by cumulative sales for the first twenty years after its launch in 1997.[1] With regard to all electric EVs, Toyota produced the RAV4 EV from 2000-2003[27] and again from 2012-2014 in collaboration with Tesla,[1] but stopped production in 2014. Production started again in 2021 with the RAV4 Prime PHEV.[27] Toyota has plans for a line of six EVs in the future.[1]

BMW

BMW manufactures urban electric eco-friendly vehicles under the i sub-brand started in 2011. Its first all electric EV was the i3 which became the world's third best selling EV two years after its introduction in 2014, and remained so until December 2016. This was followed by the iX3 SUV in 2020, i4 sedan in 2021, and upcoming iNEXT crossover.[1] Currently only the i3 is in production in the US.[27]

BYD

BYD (Build Your Dreams) started as a mobile phone battery manufacturer in Shenzhen, China in 1995. Since then it moved on to make rechargeable batteries for automobiles and renewable energy, then electric motors in 2002, then ICE vehicles such as the 2005 F3, and then EVs with the launch of its first model in 2008: The F3 Dual Mode. BYD also produces the Qin PHEV, e6, and all electric Tang SUV.[1] [27] Its investors notably include Warren Buffett.[1]

Mercedes-Benz

Mercedes-Benz currently has two all electric EV lines, the Smart series and the EQ series, none of which are offered in the US.[27] They include the Smart fortwo, Smart forfour, EQC SUV with a range of 245 miles, and EQV minivan with a range of 212 miles.[28] [29] Mercedes has partnered with China's Geely to produce a new generation of Smart EVs, and will launch four new EQs by 2022: the EQA, EQB, EQE, and EQS.[30] [31]

Evolving Trends

The EV market share of the auto industry has grown exponentially from 2010 to 2018 (Exhibit 10). Global EV sales increased throughout this time, but the exponential trend was broken in 2019 and 2020, possibly due to the Covid pandemic. While market data post-2020 is not yet available, the trend in market share matches the J.P. Morgan estimate that EVs will account for 7.7% of total market share by 2025.[1] As for sales, evidently the only trend is a lack of trends.

Simultaneous to the slow in vehicle sales growth, global energy-related CO_2 emissions decreased from 2018-2020 (Exhibit 12). However the IEA Tracking Sustainable Recoveries report projects that they would bounce back to a new all-time high by 2023 under 2020 policies even with sustainable recoveries, and that the only way to continue the decreasing trend is by mandating net-zero emissions by 2050 as outlined in the IEA Roadmap.[18]

Supply of EV batteries has grown even faster than demand, driving down battery prices from 2010-2019.[6] Meanwhile supply of metals required in EV batteries is not enough to meet production demand if current production rates continue. Thus metal prices have surged since 2016 (Exhibit 9).[6] [7] [8] It will be interesting to see how long these trends continue.

General Motors Company

Within the traditional automobile industry, GM is an established incumbent. In its 113 year history, GM has experienced success followed by crisis,[32] followed by recovery[33] under new leadership. Following initial success of the Detroit manufacturing plant, as the company grew it began to stagnate in bureaucracy and heavy government involvement, earning it the nickname "Government Motors." In particular GM had to be bailed out by the government in 2009.[33] But the low point was in 2014 with the Chevy Cobalt ignition switch crisis: A malfunction resulted in 124 deaths, 275 injuries, and company costs in excess of $2 billion [22]. In typical GM style, the problem was handed off to someone else: Mary Barra, the first female CEO of GM. Not only did she stop the malfunction from happening again, console customers and their families, and keep the GM stock price at a steady low, but she also built up an inclusive, stable, diverse company culture that turned the company 180 degrees and brought it back to its current $90 billion market cap [19].

Since the Great Depression, GM has occasionally dabbled in more futuristic vehicles, coming out with about one model per decade [17]. Interestingly, GM rolled out the first EV in the US: the EV1 in 1996. However GM removed all EV1's from the roads within 3 years [4][5]. This prompted Elon Musk to found Tesla [5], catalyzing the rise of the EV market. Now the traditional automobile industry, and its leading incumbent, have a whole new market of competitors to contend with.

The "New" GM's Past EV Journey

GM's response to the EV market has been to turn the tables, becoming itself a disruptor in the EV market. Its investment in EVs over the years has made use of the following strategies:

Chevy Bolt EV

In 2013 GM joined the race to make the first EV with at least 200 miles of range and an affordable price on par with the national average of about $33,000 [37]. By end of 2016, production of the Chevy Bolt EV, with a range of over 200 miles and a price of $37,500 before incentives, had begun. Production of the Tesla Model 3, with a range of 310 miles [1] and a price of $35,000 before incentives, began soon after in early 2017. With 2017 sales second only to Tesla's Model S [1], the Chevy Bolt EV marked GM's change from disruptee to disruptor [7].

Lead by Mary Barra, the Chevy Bolt EV team worked in typical Skunk Works [38] style to outpace Nissan, Volkswagen, Tesla, and the other contenders in the race to mass-market. It was a **small team** of **good people**: The company's senior leaders and the most important figures on its electrification team both initiated and cimprised the core of this project. It achieved great **inventiveness** in great **secrecy**: Their initial "meeting" in the virtual reality room of GM's Design Center turned into a brainstorming session that ended up producing a viable path to achieving 200 miles. And the team achieved **high-quality designs** with **limited time and resources**: Working with LG, the team achieved a Chevy Bolt EV acceleration of 0 to 60 mph in 7 seconds using improved battery composition that required less cooling and enabled more cells to be put in the battery pack. Once the battery was ready, their engineers hacked together the front of a Chevy Sonic and the rear of a Buick Encore into a "Soncore," slapped on the battery and motor, and hence got right to work on chassis controls, vehicle dynamics, and suspension tuning once the real body was in development. From 2014-2015, 100 prototypes were tested and refined at a feverish pace across the nation across a wide variety of scenarios, working quickly to make thousands of changes to the car. Touting the roominess, connectivity, and "how the trunk opening is shaped so you can slide in that bookshelf you bought at Ikea," Barra says, "No one's gonna buy 200 miles if it doesn't come with a great vehicle." [38]

Unfortunately the Chevy Bolt EV's success was marred by a series of recalls in 2020 due to battery fires [44][45]. The cause appears to be not one but two rare manufacturing defects [44] in battery cells manufactured by LG Chem in South Korea, whereas the Chevy Bolt EVs using cells from GM Michigan are not affected by the recall [45]. The Hyundai Kona EV, which uses LG Chem battery cells, was also recalled around the same time. GM is having owners limit the battery charge to between 10% and 90%, either manually or by a software update issued to dealers, while it seeks a permanent fix. Tesla is suspected to have used a similar tactic for the Model S and Model X by reducing the range through an OTA update unbeknownst to customers, but GM has confirmed that they can't do this via OTA. [45]

Wuling Hongguang Mini EV

GM continued to refine its affordable EV game, achieving massive success in China with the launch of the Wuling Hongguang Mini EV in July 2020. The result of a joint venture with SAIC, it is a low-end slow-speed EV costing only $4k-5k. It has a maximum speed of 62 mph and a 9.2 kWh battery with a 75 mile range. [23] In 270 days it sold over 270,000 EVs, achieving Chinese EV sales second only to the Tesla Model 3 in 2020, and exceeding the Tesla Model 3 in 2021 [24]. Though lacking in airbags, it is both lighter and has more trunk space than the modern Mini Cooper. It is marketed toward China's young and working classes, touting an affordable price and economical size.

In developing the Wuling Hongguang Mini EV, GM partnered with Wuling Motors and state-owned SAIC of Shanghai. This gives a boost to GM's zero-emissions score, as GM holds a role in the manufacturing process [23]. GM China holds a 44% stake, while SAIC holds 50.1%. But the plans don't stop there. Next up for the venture are the Mini EV Macaron which has received 45,000 orders in 10 days, and the Mini EV Cabrio set to launch in 2022. [24] In the words of Mary Barra: "We're not developing models to participate in a segment. We're developing models to win in a segment" [25].

This slow-speed EV, the most affordable EV in China, has no competitors...yet. However BYD and BAIC are stepping up their game [23]. And reverse innovation [18], bringing the technology back to the US or elsewhere, is unlikely to happen in the near future: Unlike in China, congested roads and air pollution are not as urgent in the US compared to issues like severe weather and "range anxiety" (a term referring to the stress caused by driving an EV when battery is low). In particular, cold weather drains battery power [39] and extreme weather drains battery life [14]. But reverse innovation could be in the distant future.

Cruise

Perhaps GM's most disruptive strategy yet, is the acquisition of Cruise to develop an AV (autonomous vehicle) rideshare service. The acquisition, which occurred in 2016 for an all-in price of $1 billion, catapulted GM ahead of competitors Uber and Lyft [22]. Meanwhile GM values the global autonomous vehicle industry market opportunity at $8 trillion, including $5 trillion for ride-hailing; $2 trillion for freight; and $500 billion each for data insights and in-vehicle experiences [27]. By using AVs rather than human drivers, GM's Cruise lowers its operating costs compared to Uber and Lyft. Furthermore, GM has made advancements in decreasing costs of vehicle production and software development [27]. In the words of Dan Ammann, President of GM prior to becoming CEO of the GM majority-owned autonomous vehicle subsidiary: "We're bringing an extremely disruptive, transformational technology to a multitrillion-dollar market opportunity."

Cruise is a self-driving car startup that has operated an employee ride-hailing service in San Francisco since 2017. Its vehicles are based on the Chevy Bolt EV, and as seen in Exhibit 12 they feature no steering wheel, no pedals, and no manual controls as of 2019. The first-generation version with steering wheel gave San Francisco foodbank deliveries, piloted a WalMart delivery program, and tested hundreds of thousands of miles of fully autonomous driving on the streets of

San Francisco in 2020 [31]. The 2019 prototype without steering wheel has been scrapped due to failure of Cruise's 2018 petition to bypass a steering wheel airbag requirement, among other safety requirements [28]. Instead, Cruise unveiled the Cruise Origin in 2020 and will file an exemption petition for it [29]. The Cruise Origin features no steering wheel, pedals, manual controls, or rearview mirrors, and will be manufactured by GM at Factory Zero in Detroit [35]. The plan is to use the Origin to reduce pollution and save people money on ridesharing in San Francisco [30], eventually expanding to 100,000s of AVs across multiple states in the US [31].

GM and Cruise have entered a long-term strategic relationship with Microsoft to accelerate the commercialization of self-driving vehicles, announcing in January 2021 that "Our mission to bring safer, better and more affordable transportation to everyone isn't just a tech race – it's also a trust race. Microsoft, as the gold standard in the trustworthy democratization of technology, will be a force multiplier for us as we commercialize our fleet of self-driving, all-electric, shared vehicles." [35] According to the press release: "Cruise will leverage Azure, Microsoft's cloud and edge computing platform, to commercialize its unique autonomous vehicle solutions at scale. Microsoft, as Cruise's preferred cloud provider, will also tap into Cruise's deep industry expertise to enhance its customer-driven product innovation and serve transportation companies across the globe through continued investment in Azure...In addition, GM will work with Microsoft as its preferred public cloud provider to accelerate its digitization initiatives, including collaboration, storage, artificial intelligence and machine learning capabilities. GM will explore opportunities with Microsoft to streamline operations across digital supply chains, foster productivity and bring new mobility services to customers faster." [35] Combined with equity investments from Japan's SoftBank Vision Fund and Honda in 2018, the equity investment from Microsoft brings the post-money valuation of Cruise to $30 billion [22].

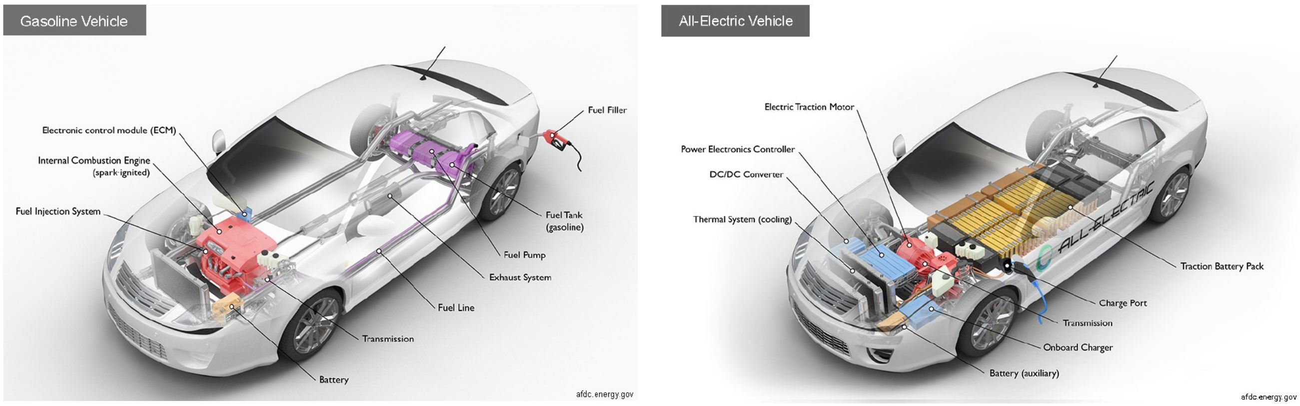
GM's Cruise will be competing with Alphabet Waymo, Pony.ai, AutoX, Amazon Zoox, and upcoming ridesharing services by Tesla, Ford, and a Hyundai-Aptiv joint venture [33].

Bumpy Road Ahead

Clearly, GM has gone from automobile industry incumbent to EV market disruptor. From the EV1, to the mass-market Chevy Bolt EV, to the low-end Wuling Hongguang Mini EV, it has achieved increasing success in the EV market while transforming its attitude from indifference to "developing models to win in a segment." Will AVs continue the trend of success? Can GM prove to doubters that the EV1 incident 24 years ago, government bailout 12 years ago, Chevy Cobalt incident 7 years ago, and Chevy Bolt EV recalls last year won't repeat? The IEA is tracking emission trajectories [15], buyers/investors/rivals are watching product performance, and experts are saying overshooting growth undermines real strategy [34].

Exhibits

Exhibit 1: How an ICE works (left). How an EV works (right).



Source: https://afdc.energy.gov

Exhibit 2: Comparison of EV batteries with ICE

Battery	Vehicle	Range	Acceleration
ICE	Average	62 to 390 miles	
Lead-acid	1981 Volkswagen Golf 1 CitySTROMer	37.3 miles[3]	
Lead-acid	1996 GM EV1	100 miles[5]	0 to 50 mph in 6.3 seconds[5]
NiMH	1997 Toyota Prius (hybrid)		
Lithium-nickel-manganese-cobalt oxide	2008 Tesla Roadster		
Lithium-nickel-manganese-cobalt oxide	2008 BYD F3 Dual Mode		
Lithium-nickel-manganese-cobalt oxide	2010 JAC J3		
Lithium-nickel-manganese-cobalt oxide	2011 Nissan Leaf		
Lithium-nickel-cobalt-aluminum oxide	2012 Tesla Model S		
Lithium-nickel-cobalt-aluminum oxide	2015 Tesla Model X		
Lithium-nickel-manganese-cobalt oxide [A]	2016 Chevy Bolt EV	192 miles[2]	0 to 60 mph in 7 seconds[2]
Lithium-nickel-cobalt-aluminum oxide	2017 Tesla Model 3		
Lithium-nickel-cobalt-aluminum oxide	2021 GM-LGChem Ultium various models		
Lithium-ion [B]	2022 CyberTruck		

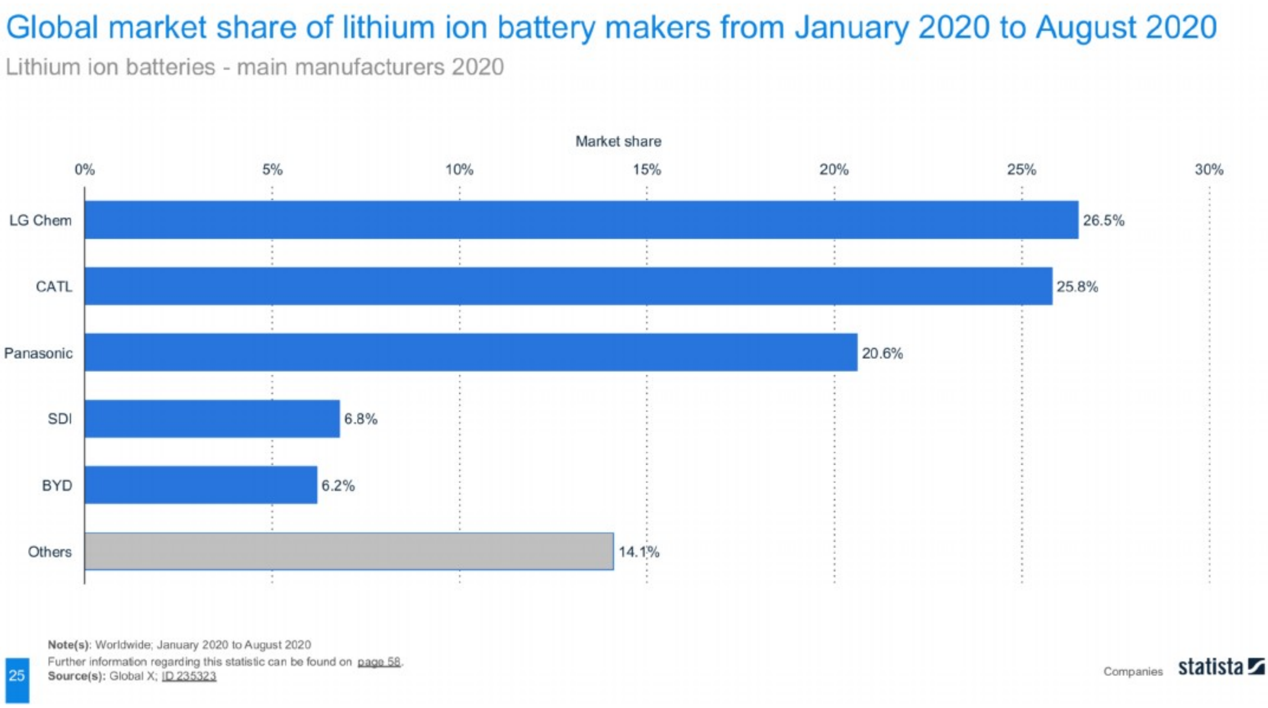
Sources: Compiled by case-writer from various sources, Exhibit 8 (ICE), [A][B]

[1]
ICE: range ~350 miles, acceleration 0 to 60mph in 8.4 seconds (Exhibit 7)
Lead-acid:
1981 Volkswagen Golf 1 CitySTROMer, range 37 miles
1996 GM EV1, range 50 miles
NiMH: 1997 Toyota Prius (hybrid), range better
Li ion (most common **lithium-nickel-manganese-cobalt oxide**):
2008 Tesla Roadster, 53 kWh, range 244 miles
2008 BYD F3 Dual Mode
2010 JAC J3, range 81 miles
2011 Nissan Leaf, range 73 miles
(**lithium-nickel-cobalt-aluminum oxide**) 2012 Tesla Model S
(**lithium-nickel-cobalt-aluminum oxide**) 2015 Tesla Model X
2016 Chevy Bolt EV
(**lithium-nickel-cobalt-aluminum oxide**) 2017 Tesla Model 3, range 250-300+ miles
2018 Nissan Leaf, range 151 miles
2019 Tesla Model Y, range 300 miles
Sprint 2019 BYD Tang SUV EV, range 310-373 miles
2021 GM-LGChem Ultium various models (GM-LGChem joint venture in-house **lithium-nickel-cobalt-aluminum oxide),** best range 450 miles, future version 500-600 miles

2022 CyberTruck, range 250-500 miles, best acceleration 0 to 60mph in 2.9 seconds

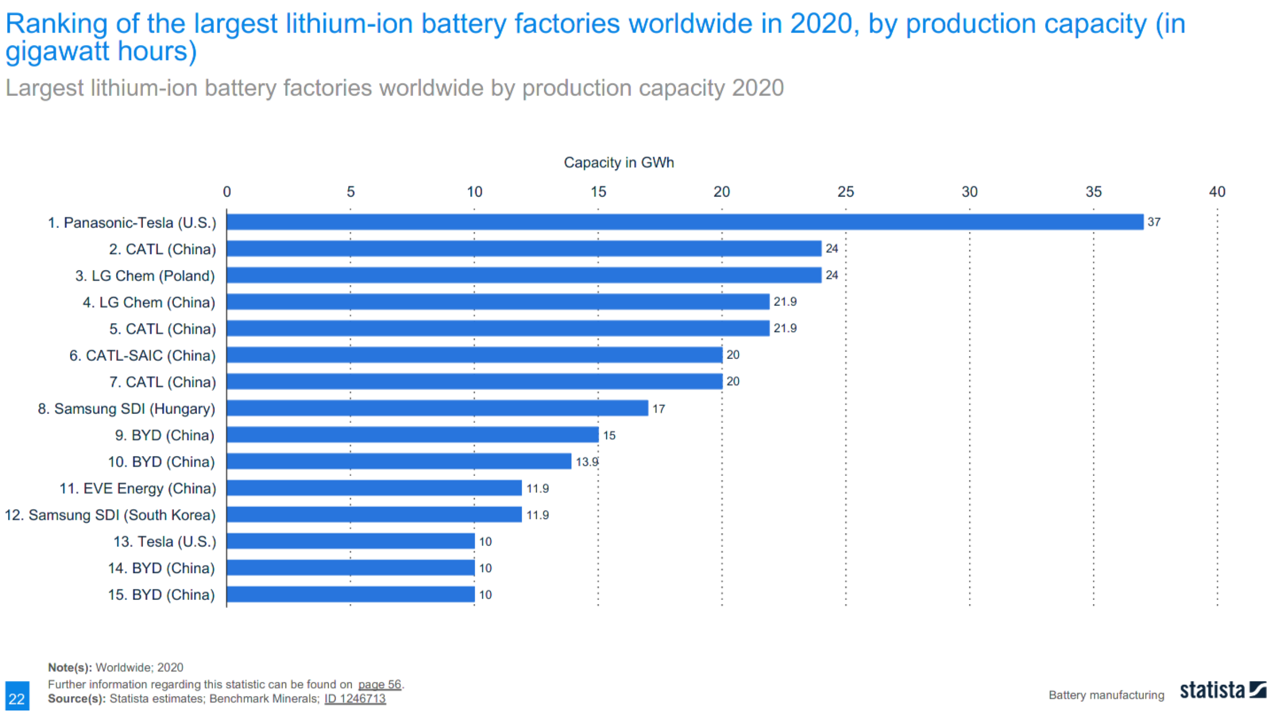
Exhibit 3: Top lithium-ion battery producers globally

a) by market share



Source: Statista. Dossier: Lithium-ion batteries worldwide. (2021)

b) by production capacity



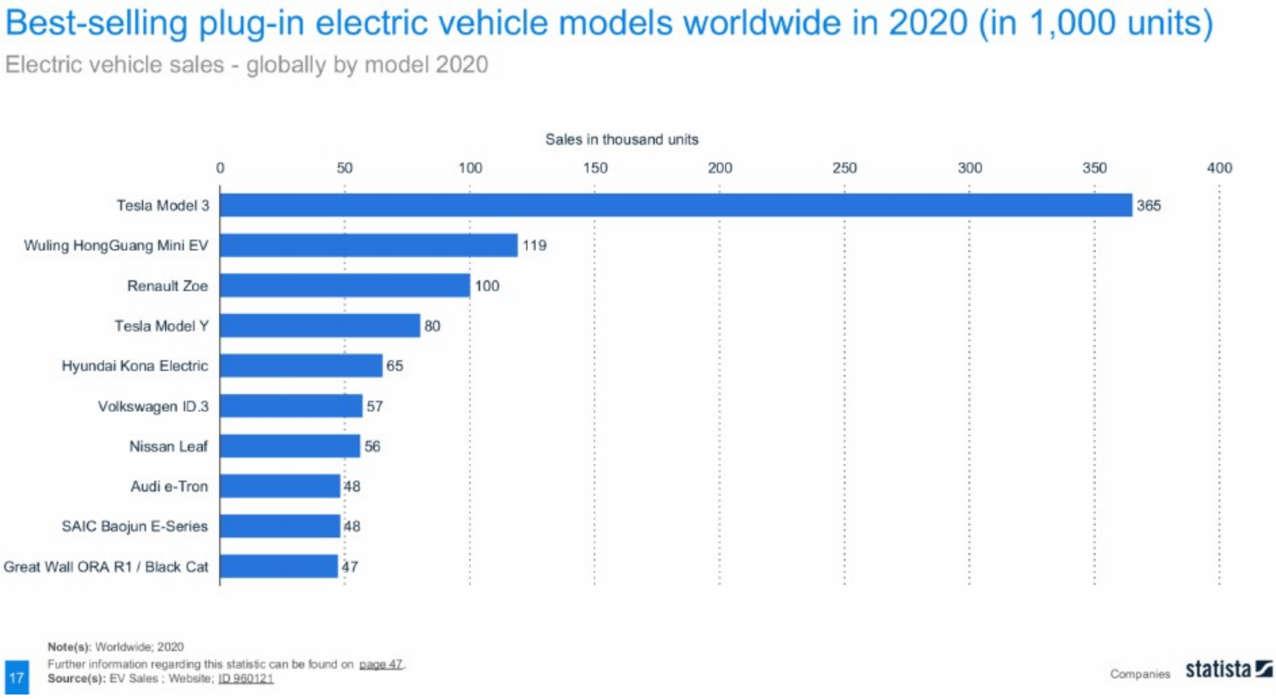
Source: Statista. Dossier: Lithium-ion batteries worldwide. (2021)

Exhibit 4: Major players

	Manufacturer	Country	Specialty	Partners	Top-Selling EV (2021)	Range (2021)	Price (2021)
US	GM	US	slow-speed	LG Chem, SAIC, Cruise	Wuling Hongguang Mini EV	110 miles	$5,500
	Tesla	US	luxury	Panasonic	Model 3	353 miles	$48,990
	Ford	US	hybrid	Toyota	Escape PHEV	520 miles	$35,000
outside of US	Volkswagen	Germany	mass-market	SAIC, FAW, JAC	ID.4	250 miles	$43,995
	Nissan	Japan	mass-market	AESC, Renault, Mitsubishi	Leaf	226 miles	$38,270
	Toyota	Japan	hybrid	Panasonic, BYD, Ford	RAV4 Prime PHEV	600 miles	$40,000
	BMW	Germany	luxury	Great Wall Motors	530e PHEV	340 miles	$57,200
	BYD	China	batteries	Toyota, Mercedes-Benz	Han EV	376 miles	$32,800
	Mercedes-Benz	Germany	luxury	Geely, BYD, BAIC	EQC	245 miles	£76,990

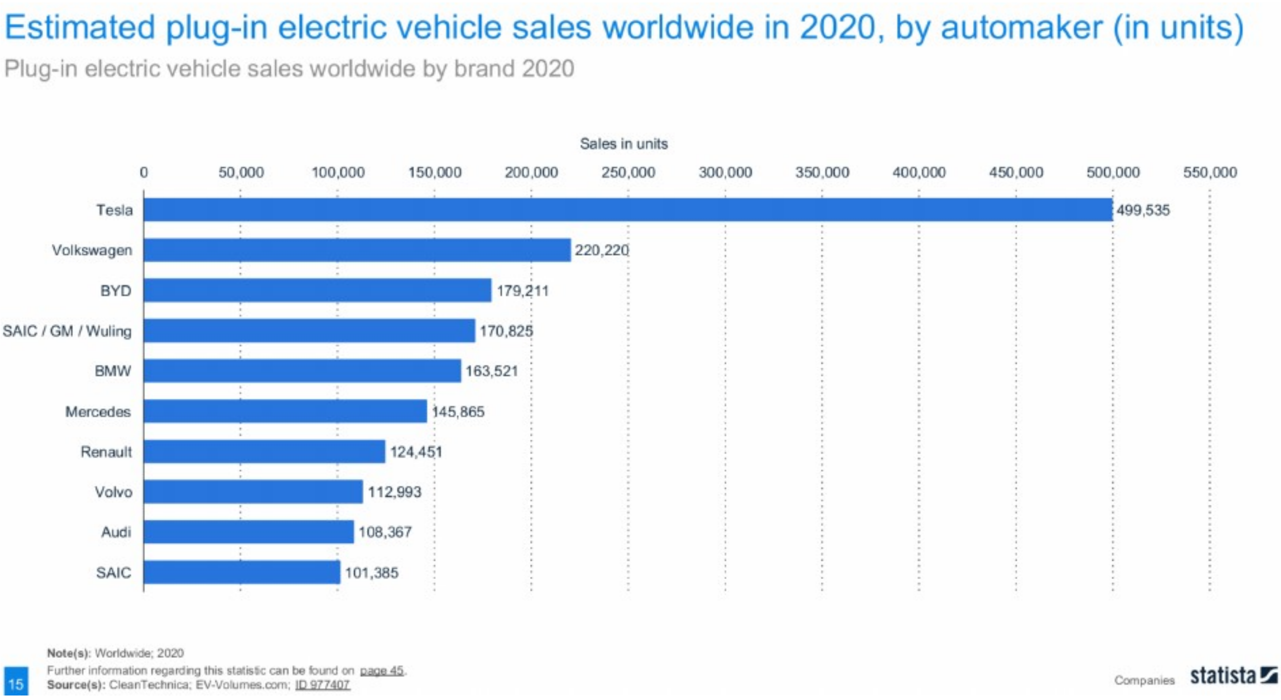
Sources: Compiled by case-writer from various sources. [1][25][54][55][56][60][61][62]

Exhibit 5: Top EV models by global sales 2020



Source:

Exhibit 6: Top 10 EV automakers by worldwide vehicle sales 2020



Source:

Exhibit 7: Well-to-wheel emissions of EVs compared to ICE vehicles, 2019

We compute and compare well-to-wheel emissions of EVs and ICE vehicles. It is important to use well-to-wheel emissions in order to account for emissions from electricity production.

Additionally, there may be emissions or loss of efficiency from transporting gasoline and electricity, which we ignore for sake of simplicity. The overall result is that ICE vehicles convert about

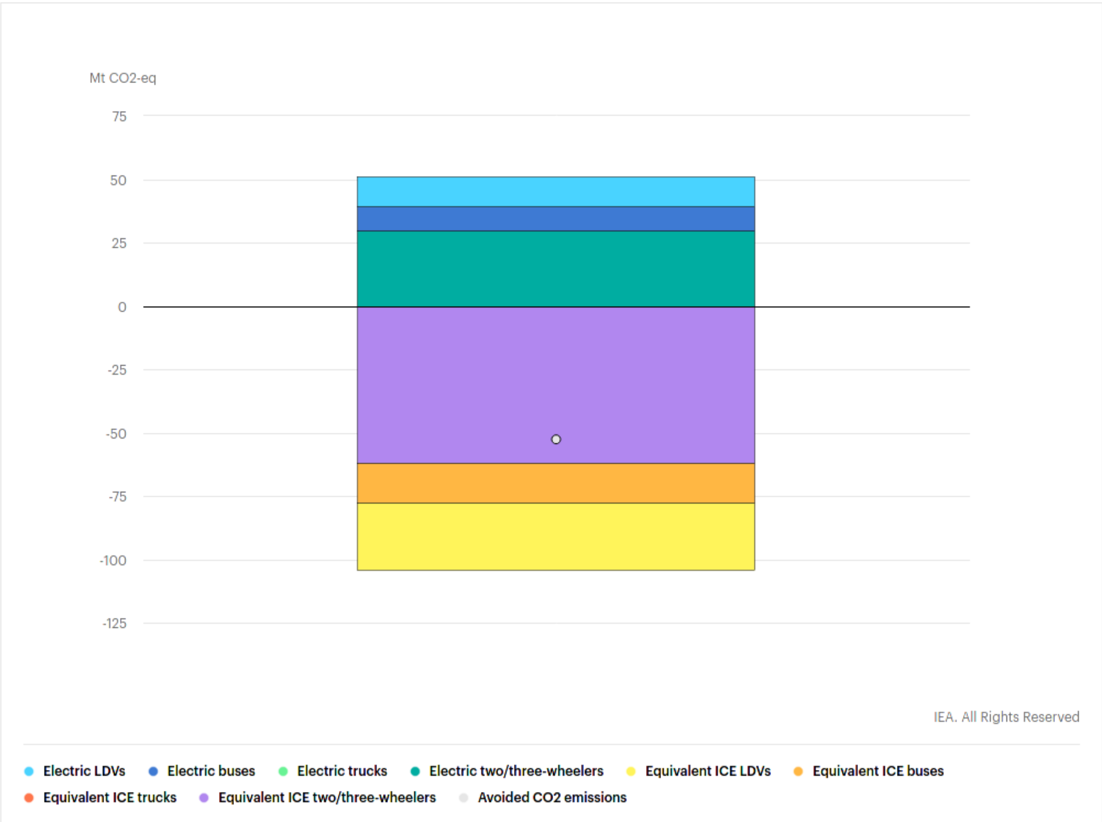
((90%(5.052) gasoline + 10%(3.555) ethanol)/5.698 petroleum)(12%-30% gasoline to wheel)
= 10%-26%

of the energy in petroleum to power at wheels [9][10][11], compared to EVs which convert about

(17% electricity from renewables)(100% renewables to electricity)(77% electricity to wheel)
+ (1% electricity from petroleum)(3412/11205 electricity/petroleum)(77% electricity to wheel)
+ (21% electricity from nuclear)(3412/10442 electricity/nuclear)(77% electricity to wheel)
+ (25% electricity from coal)(3412/10551 electricity/coal)(77% electricity to wheel)
+ (36% electricity from natural gas)(3412/7732 electricity/natural gas)(77% electricity to wheel)
= 37%

of the energy in fossil fuels/nuclear/renewables to power at wheels [40][9][11][12], according to 2019 US energy data.

This agrees with Argonne National Laboratory estimates that US annual well-to-wheel CO_2 emissions per vehicle are 3,774 pounds of CO2 equivalent for EVs, but 11,435 pounds of CO2 equivalent for ICE vehicles [13]. This also matches the IEA 2019 data on well-to-wheel emissions from EVs and avoided well-to-wheel emissions from ICE vehicles:



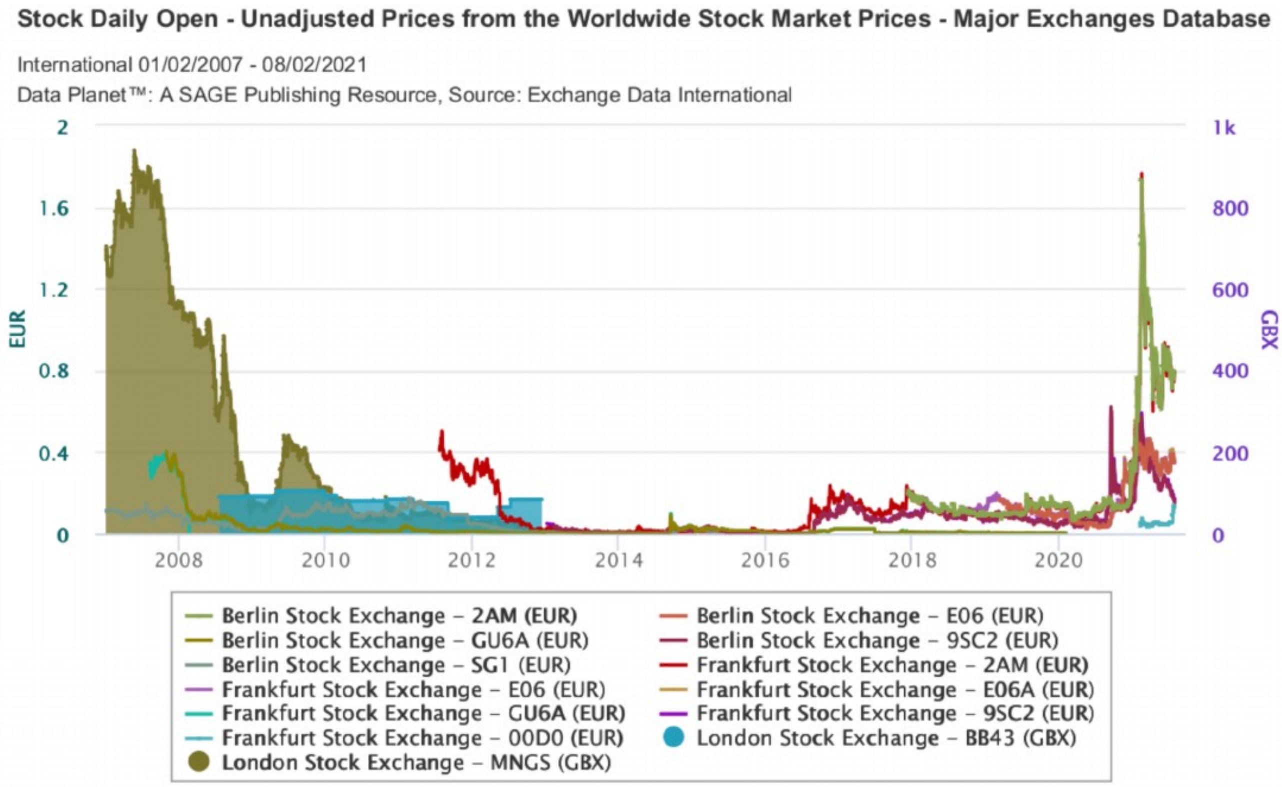
Source: IEA, Net and avoided well-to-wheel GHG emissions from the global electric vehicle fleet, 2019, IEA, Paris https://www.iea.org/data-and-statistics/charts/net-and-avoided-well-to-wheel-ghg-emissions-from-the-global-electric-vehicle-fleet-2019

Exhibit 8: ICE vehicles vs. EVs

	Gasoline Vehicle	All Electric Vehicle
Efficiency	Converts 10%-26% of energy in petroleum to power at wheels	Converts 37% of energy in fossil fuels/nuclear/renewables to power at wheels
Range	240 to 703 miles [9][48]	62 to 390 miles [9][36][48]
Acceleration (Average)	0 to 60 mph in 7.1 seconds [42]	0 to 60 mph in 5.5 seconds [43]
Recharge Time	10 to 15 minutes [1]	3 to 12 hours, superchargers can reach 80% in 30 minutes [1][9]
Maintenance	Oil change, emission check, timing belt change, transmission fluid change, coolant change, spark plug replacement, replacement battery [1] [41]	Replacement battery [14][41]
Cost of Operation Per Year (Average)	$1117 [41]	$485 [41]

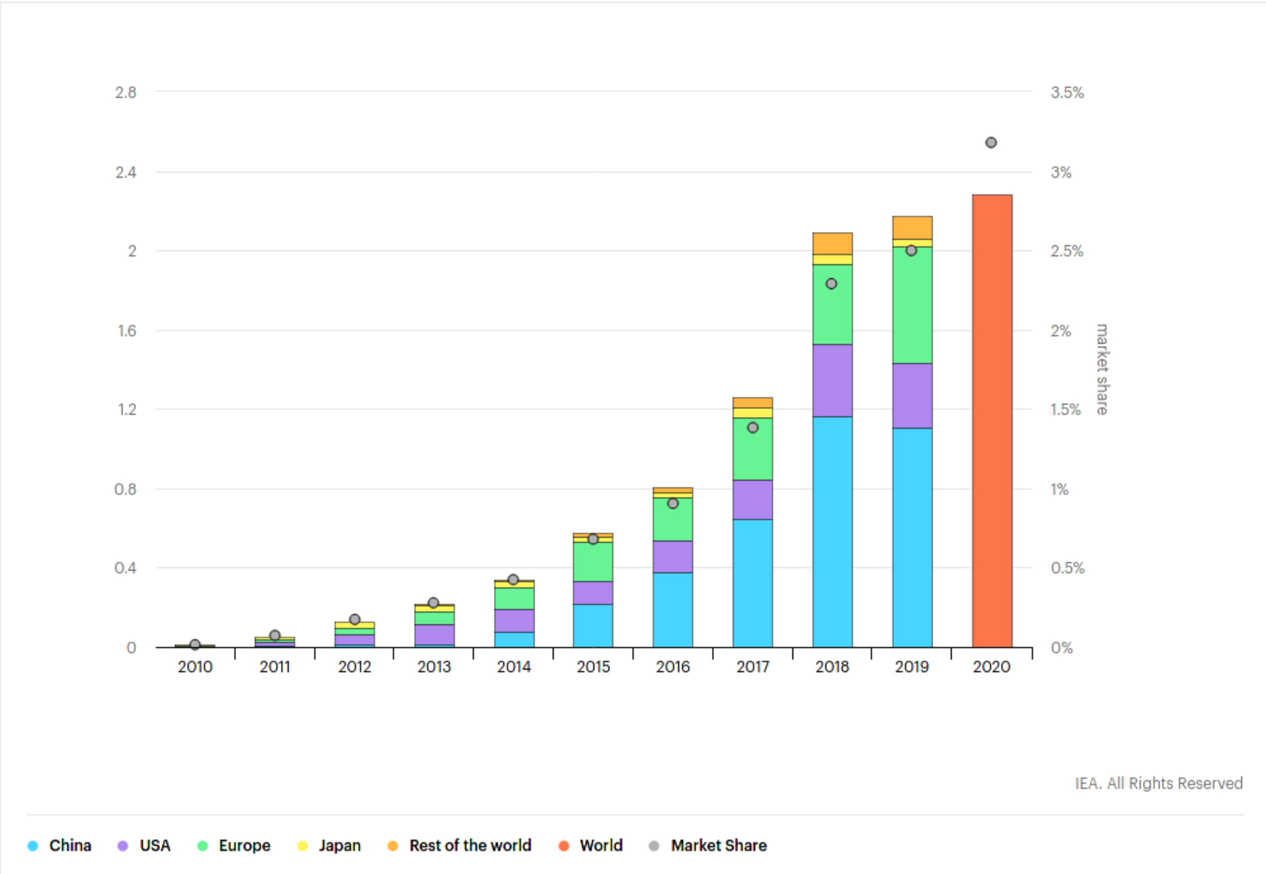
Sources: Compiled by case-writer from various sources, Exhibit 6 (Efficiency).

Exhibit 9: Manganese stock prices 2007-2021



Source: Exchange Data International. (2021, August 4). *Stock daily open - unadjusted prices: Stock daily open - unadjusted prices | | Berlin Stock Exchange | Frankfurt Stock Exchange | London Stock Exchange | 2AM | E06 | GU6A | 9SC2 | SG1 | 2AM | E06 | E06A | GU6A | 9SC2 | 00D0 | BB43 | MNGS, 01/02/2007 - 08/02/2021*. [Data set]. Data Planet™ Statistical Datasets: A SAGE Publishing Resource. https://doi.org/10.6068/DP17B14706FAA2

Exhibit 10: Global electric car sales by key markets, 2010-2020



Source: IEA, Global electric car sales by key markets, 2010-2020, IEA, Paris
https://www.iea.org/data-and-statistics/charts/global-electric-car-sales-by-key-markets-2015-2020

Exhibit 11: Top countries by EV market share of car market

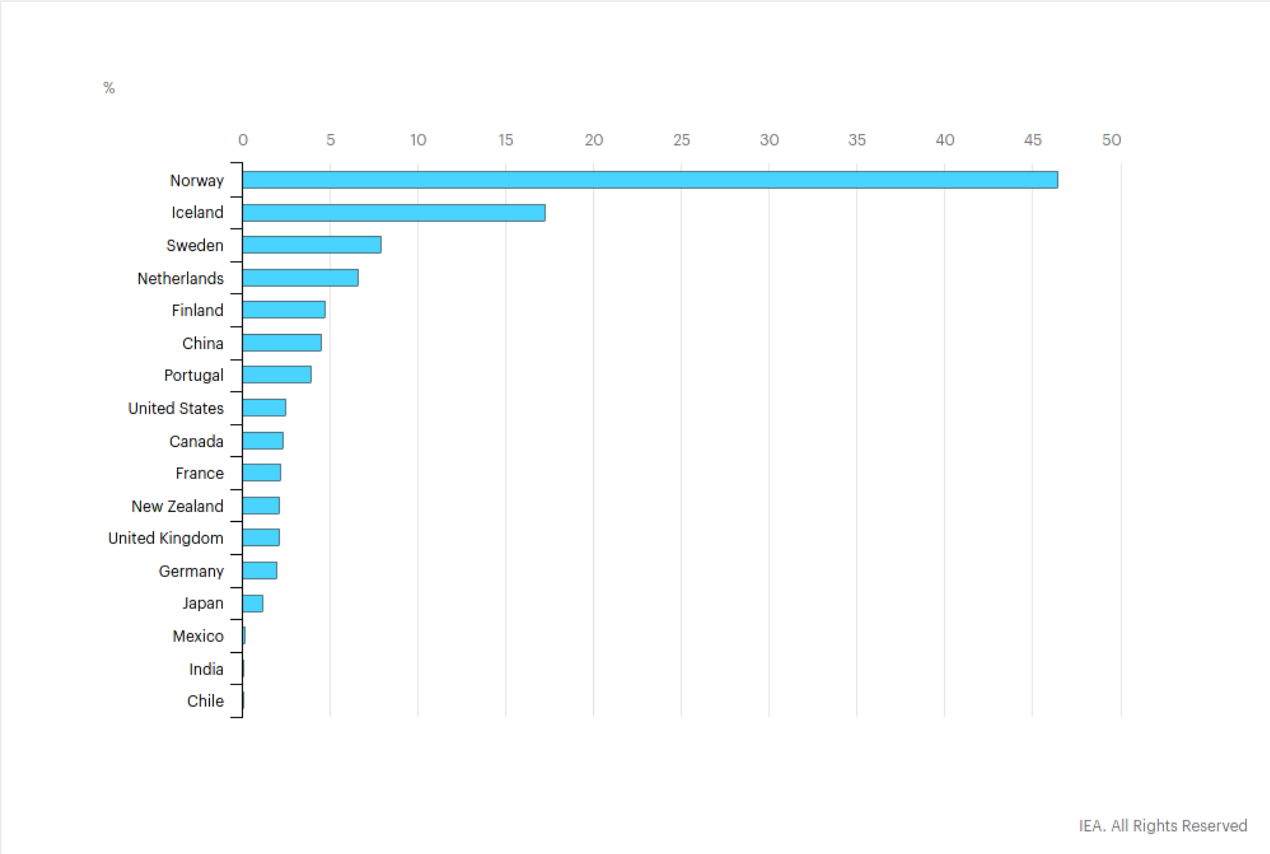


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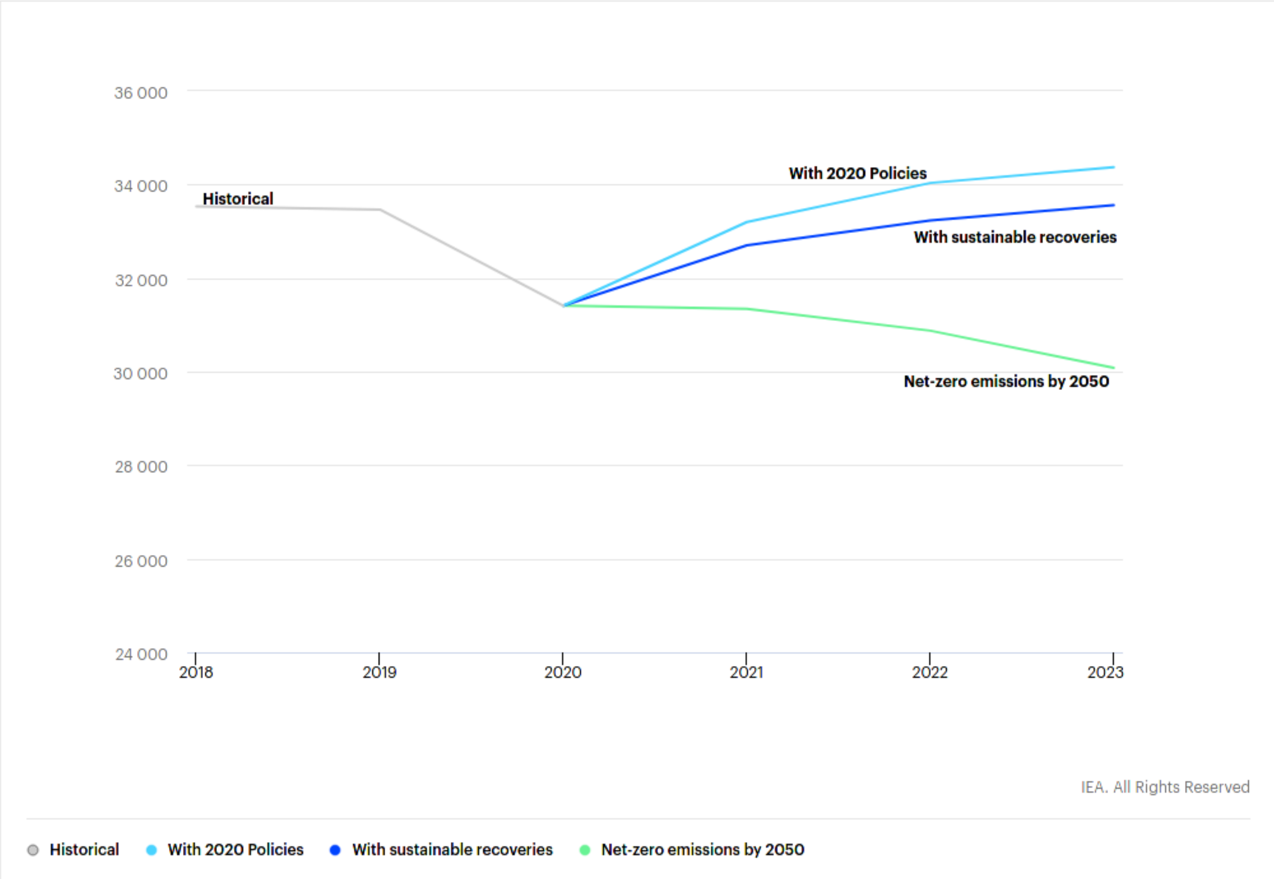
Exhibit 12: IEA projected energy-related CO2 emissions under different sustainable recovery trajectories, 2018-2023



Source: IEA, Energy-related CO2 emissions under different sustainable recovery trajectories, 2018-2023, IEA, Paris https://www.iea.org/data-and-statistics/charts/energy-related-co2-emissions-under-different-sustainable-recovery-trajectories-2018-2023

Exhibit 13: Cruise AV 4th-generation (left). Cruise Origin (right).

Source: https://youtu.be/MvP82IsGqNc (left). https://medium.com/cruise/the-cruise-origin-story-b6e9ad4b47e5 (right).

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