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The New War of the Currents:
The Race to Win the Electric Vehicle Market

This is not a vehicle that you're going to take 8 people in and drive across the country with. This is not its purpose. Its purpose is your daily vehicle to use most of the time.

—Mark Perry, Director of Product Planning for Nissan Leaf[1]

We will not stop until every car on the road is electric.

—Elon Musk, CEO of Tesla[2]

In July 2020, the world was stunned as emerging automaker Tesla became the world's most valued automaker by market share, surpassing long-time leader Toyota. A company that had only four models in production surpassed century-old auto giants, shaking the very core of the automobile market. Over the previous decade, electric vehicles (EVs) had gone from a conceptual idea to a realistic solution for everyday transportation. During that time, Nissan lost its status as the market leader in the EV segment to Tesla.

The original war of the currents was the race among Thomas Edison, George Westinghouse, and Nikola Tesla to introduce competing electric-power-transmission systems in the late 1880s and early 1890s. In 2020, the new war of the currents was about who could win the EV market. The approaches that Tesla and Nissan took to develop their products and manage their production varied drastically, with both automakers focusing on their unique strengths. As new entrants entered the EV market, the question remained whether the strategies that helped Tesla and Nissan become leaders in the emerging EV market would help them to maintain that lead.

Rise of Electric Vehicles

People widely used light-duty vehicles (i.e., passenger cars) for day-to-day transportation. These vehicles could be classified, based on the type of fuel and propulsion mechanism used (e.g., powertrain), as gasoline,

[1] "Interview with Mark Perry, Nissan LEAF," YouTube video, 10:00, posted by "David Herron," December 3, 2009, https://www.youtube.com/watch?v=yIkDJS3oFNo&t=80s (accessed Dec. 18, 2020).

[2] "Official Trailer: *Revenge of the Electric Car*," YouTube video, 2:01, posted by "RevengeElectric," December 7, 2010, https://www.youtube.com/watch?v=jkRIu5a6Sb0 (accessed Dec. 18, 2020).

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diesel or electric vehicles. EVs were powered by electricity and could be classified into two types: hybrid and plug-in/battery (PEVs or BEVs). A hybrid EV (e.g., a Toyota Prius) had at least two types of fuel sources, most commonly gas and electric, combining the advantages from both fuels. Depending on the primary power source, hybrid vehicles could be further divided into hybrid EVs (HEVs), which used internal-combustion engines (ICE), and plug-in hybrid EVs (PHEVs), which used electricity as a primary source. Conversely, a plug-in or battery EV (e.g., a Nissan Leaf or a Tesla Model S) was completely powered by electricity stored in batteries and had no additional energy source.

The design of and experimentation with EVs had been around since the 18th century.[3] Due to their low noise levels, EVs gained popularity in the early 1900s. However, the introduction of more affordable ICE, gasoline-powered vehicles like the Model T and low gas prices in the United States during the period made it difficult for EVs to survive. In the 1930s, new developments in battery technology led to a second wave of interest in EVs. However, this interest did not sustain due to concerns about the limited distance that EVs could travel (i.e., the vehicle's range) and the lengthy charging time.

In the 1990s, a new push for passenger EVs in the United States began due to the government's push toward green energy. Government bodies such as the California Air Resources Board (CARB) launched the low-emission vehicle (LEV) program as early as 1990.[4] The LEV program mandated that big automakers focus on alternate fuels in an effort to reduce emission levels. These regulations led to the development of HEVs and PEVs as electric vehicle alternatives to ICE cars. In response to the regulations, in 1996, General Motors (GM)[5] launched EV1, a fully electric vehicle with battery technology developed from collaborative efforts with government research centers. The car was only offered for lease and rapidly gained popularity among consumers. Many believed that GM was at least two to three years ahead of its next closest competitor in PEV technology. Still, the company decided to shut down production in 1999. GM believed that the demand for EV1 did not materialize as expected and reclaimed the cars. The decision was controversial, and owners protested against it because they did not want to end their leases. Later, the company discontinued its PEV products and shifted its focus toward HEVs.[6] Other leading automotive companies like Honda also followed GM's footsteps by reclaiming their PEV products.

Toward the end of the first decade of the 2000s, the emission-control norms on vehicles tightened, shifting companies' focus toward improving PEVs, since they had zero emissions. Various governments backed PEV research and development by providing funds and tax benefits for customers. This created a dilemma for traditional automakers: whether to focus on conventional, gasoline-based cars or invest in developing EVs.

Over the period from 2000 to 2010, significant improvements in PEVs' range, efficiency, and charging time finally made them more commercially viable. Due to the small number of moving parts in an EV, modern PEVs converted about 77% of the energy from their batteries to the wheels. As a comparison, gasoline vehicles converted only 12% to 30%.[7] As a result, the fuel cost of driving an EV was 50% less compared to equivalent gasoline vehicles, leading to significant operational savings.

[3] Massimo Guarnieri, "Looking Back to Electric Cars," 2012 Third IEEE HISTory of ELectro-technology CONference (HISTELCON), Pavia, Italy, September 5, 2012.

[4] "Low-Emission Vehicle Program," California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/low-emission-vehicle-program/about (accessed Nov. 12, 2020).

[5] Jim Motavalli, "GM's EV1 Lives On, With EV2 on the Way," PluginCars, July 3, 2013, https://www.plugincars.com/gm-ev-1s-live-ready-ev-2-127656.html (accessed Nov. 12, 2020).

[6] *Who Killed the Electric Car?* was a popular documentary that discussed the various factors that influenced the demand of the EV1 and GM's decision on phasing out its first PEV. See the film's website at: https://www.whokilledtheelectriccar.com/ (accessed Nov. 12, 2020).

[7] "All-Electric Vehicles," US Department of Energy, Office of Energy Efficiency & Renewable Energy, https://www.fueleconomy.gov/feg/evtech.shtml (accessed Nov. 12, 2020).

Modern PEVs were powered by servo motors, which provided precise control of torque and speed. PEV manufactures used this ability to provide additional features such as connected mobility, autopilot, driving assistance, and regenerative braking—all of which could help to attract more customers. In addition, the fewer moving elements found in PEVs compared to conventional vehicles helped to reduce required maintenance activities, such as oil changes and replacing worn-out parts. This further helped to reduce the long-term cost of owning a PEV. One unique advantage of PEVs was that they could be improved over time by software upgrades. For example, Tesla introduced a dog mode that monitored air conditioning, locked the doors, and displayed that a dog was in the car to notify others.

Market Segment

From 2015 to 2019, the market share for EVs (PHEVs and PEVs) in the United States nearly tripled from 0.7% to 2%.[8] Furthermore, estimates projected the market would continue to grow at a rate of more than 20% per year until 2035.[9] Considering the benefits of EVs over conventional gasoline vehicles, many countries are initiating plans to phase out gas-powered vehicles. For example, the Netherlands announced its plan to require all new vehicles sold to be zero-emission by 2030.[10]

The market share for the different types of passenger vehicles is shown in **Exhibit 1**. Since the technology involved for gasoline vehicles versus HEVs versus PEVs can vary drastically, each market segment was dominated by a different set of manufacturers, each of whom had developed advanced innovations specific to their products. Toyota launched the Prius, its first HEV, in 1999. The Prius became the most sold hybrid in the United States, giving Toyota a commanding lead in the HEV segment. As of 2019, Toyota had a market share of 52% in the US HEV segment (see **Exhibit 2**).

In the PEV market, Nissan established an early lead when it entered in 2010. However, Tesla rapidly gained market share over the next decade with the launch of the Model S. Over the next decade, Tesla became the dominant player in the PEV segment. In 2019, Tesla cars accounted for 79% of all PEVs sold in the United States, as shown in **Exhibit 2**. By the end of 2019, Tesla and Nissan were the two largest (by market share) PEV manufacturers in the world.

PEV Market: Barriers to Entry

PEVs began to gain popularity among new customers starting after 2015. However, even though it was an emerging segment in the automobile sector, some consumers remained hesitant to buy PEVs, believing that the product was not mature yet and that the number of PEV choices available in the market was limited. In addition, the components inside a PEV were completely different from a traditional gasoline vehicle, making it difficult for people to understand the new technology. New infrastructure such as charging stations, destination chargers, and service stations were required for refueling and servicing PEVs. Despite recent growth in this infrastructure for PEVs, the scale of it remained minuscule when compared to the infrastructure available for gasoline vehicles.

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[8] "FOTW #1136, June 1, 2020: Plug-In Vehicle Sales Accounted for about 2% of All Light-Duty Vehicle Sales in the United States in 2019," US Department of Energy, Office of Energy Efficiency & Renewable Energy, June 1, 2020, https://www.energy.gov/eere/vehicles/articles/fotw-1136-june-1-2020-plug-vehicle-sales-accounted-about-2-all-light-duty (accessed Nov. 12, 2020).

[9] "Electric Vehicle Market Worth 27 Million Units by 2030," MarketsandMarkets, https://www.marketsandmarkets.com/PressReleases/ev-component-and-infrastructure.asp (accessed Nov. 12, 2020).

[10] "Measures to Reduce Greenhouse Gas Emissions," Government of the Netherlands, https://www.government.nl/topics/climate-change/national-measures (accessed Nov. 12, 2020).

One of the most significant challenges faced by the PEV market segment was the charging time required to refuel cars. Consumers did not want to wait long for their cars to recharge. Even the most efficient charging time was around 70 minutes for a full charge, which was much higher than the time it took to refill a gas tank. This made PEVs less suited for long-distance trips because it significantly increased the overall trip time. Battery life was also an area of concern because it deteriorated over time. Because of this, EVs' aftermarket value depreciated rapidly. In addition, PEV batteries contained lithium and cobalt. Mining these minerals at huge quantities put stress on the environment, so PEV manufacturers were required to ensure sustainable sourcing and adequate reverse logistics to recycle these minerals for end-of-life batteries.

Nissan

Nissan Motor Co., Ltd., was a Japanese automaker founded in 1933. The name "Nissan" was a contraction of the two words in its holding company's name, *Ni*hon *San*gyo. Nissan started out as a vertically integrated conglomerate. The company initially owned foundries and auto parts manufacturing. During the second world war, Nissan acquired multiple businesses, becoming the fourth-largest company in Japan. In 1933, DAT Truck company started its affiliation with Nissan subsidiaries, establishing the firm's presence in automobile manufacturing. The alliance eventually evolved into a new product line, "Datsun." As of 2020, Nissan motors was the sixth-largest automobile manufacturer in the world, with multiple product lines such as Datsun and Infiniti. In 1999, the company formed an alliance with Renault, and in 2016, with Mitsubishi, making the alliance the fourth-largest automotive manufacturer in the world.[11]

Nissan had close relations with the United States because the company's initial manufacturing plants were inspired by ones in Detroit. In 1952, Nissan started manufacturing parts in the United States and launched its own vehicle in 1969. Nissan grew exponentially, establishing multiple manufacturing plants in North America. In 2014, Nissan was the largest automobile manufacturer in the continent.[12] In 2019, Nissan had sales of $107 billion in the United States, selling over 540,000 cars and 800,000 trucks.[13] The products from Nissan could be classified as cars, SUVs, trucks, and commercial vehicles, contributing 42%, 47%, 8%, 3% to Nissan's total sales, respectively.

Early research on PEVs

Nissan began experimenting with electric-powered vehicles as early as 1974, producing PEVs such as the Nissan Laurel C130-EV in limited numbers. Nissan launched its first vehicle powered by a lithium-ion battery (Li-ion battery), the Altra, in 1997. Sony developed the battery. The Altra had a range of over 100 miles. The design of the Altra was more like a minivan, and it served as a fleet vehicle for companies. The improved technology along with the increased range helped build confidence among customers that PEVs were a possible alternative to gas-powered vehicles.

This knowledge accumulation of battery-powered vehicles opened new possibilities for sustainable zero-emission product lines from Nissan. In 2009, Nissan set up a holistic approach[14] toward zero-emission mobility,

[11] Sean McLain, "Nissan Formally Takes Controlling Stake in Mitsubishi Motors," *Wall Street Journal*, October 21, 2016.

[12] Bertel Schmitt, "Who Makes the Most Cars in North America? Who Has the Largest Auto Factory in the U.S.? Don't be Embarrassed, Few Get It Right," *Daily Kanban*, February 27, 2015, https://dailykanban.com/2015/02/27/makes-cars-north-america-largest-auto-factory-u-s-dont-embarrassed-get-right/ (accessed Nov. 12, 2020).

[13] "Nissan Unveils 'Leaf,' the World's First Electric Car Designed for Affordability and Real-World Requirements," Nissan press release, January 3, 2020, https://europe.nissannews.com/en-GB/releases/release-2523-nissan-unveils-leaf-the-world-s-first-electric-car-designed-for-affordability-and-real-world-requirements (accessed Nov. 12, 2020).

[14] "Nissan Group Reports December 2019 and 2019 Calendar Year U.S. Sales," Nissan press release, January 3, 2020, https://usa.nissannews.com/en-US/releases/release-103b1d052fdcd89776fbcfb58d00a83f-nissan-group-reports-december-2019-and-2019-calendar-year-us-sales (accessed Nov. 12, 2020).

providing a wide range of eco-friendly vehicles consisting of PEVs and PHEVs. Nissan viewed PEVs as a product line that some "greener" customers might want, given their interest in reducing emissions. In 2010, the company capitalized on the new market segment opportunity and started launching multiple electric-powered concept cars such as the Nuvu, which was designed for urban customers. The Nuvu helped Nissan to test the potential market reach for PEVs, as well as showcase its capabilities.

World's first mass-produced PEV

Nissan launched its first commercial PEV, the Leaf, in 2010. Nissan focused on developing a car suitable for daily usage that would be attractive to a wide number of customers. Nissan's design team purposefully made the Leaf as a hatchback in order to appeal as a short-range urban vehicle. Nissan viewed the Leaf as a secondary car, for local use. It optimized the range of the Leaf to 73 miles, which, when compared to commuters' average daily travel of 31.5 miles[15] in the United States, was more than sufficient. In addition, the company also considered the fact that the majority of American households had more than one car, averaging 1.9 cars per household.[16] This provided the opportunity to market the Leaf as a secondary local transportation car. The main objective for the Nissan Leaf team was to have consumers accept the product and recognize it as a viable commercial car.

The Nissan Leaf received multiple awards, including European Car of the Year and Greenest Vehicle of the Year in 2011. The car demonstrated so much promise that Nissan started mass production immediately after the launch and focused on the European, American, and Japanese markets. In the United States, the sales of Leaf increased drastically, doubling for the first few years and then stabilizing around 10,000 cars per year (see **Exhibit 3**). In December 2019, Nissan announced that 450,000 Nissan Leafs had been sold worldwide.[17] From 2010 to 2020, the Leaf was the only PEV product line Nissan launched.

Focus on PEV operations

Nissan utilized its existing global presence for the production of gasoline-powered vehicles to expand into PEV operations. The scaling up of production for the Leaf was rapid. The company originally started its Leaf manufacturing in Japan and then expanded it into the United States and Europe. As of March 2013, within three years of launch, Nissan had operational manufacturing plants in each of its targeted markets.

Battery

The battery was the most important component in a PEV. Nissan took a custom design approach and developed its own Li-ion batteries for households. In 2007, the Automotive Energy Supply Corporation (AESC) was formed as a joint venture between Nissan and two other Japanese companies to manufacture Li-ion batteries.[18] Nissan initially decided to vertically integrate all battery sourcing from the joint venture. The shape of the Nissan Leaf's battery was custom designed and rectangular (see **Exhibit 4**). This meant that the batteries could not be used in any other products, which resulted in an increase in production cost. The unique battery also created complications with replacement because there were no alternate sources available. Nissan eventually realized that single-sourcing the battery from the joint venture was more costly as compared to

[15] "American Driving Survey, 2014–2017," AAA Foundation for Traffic Safety, February 2019, https://aaafoundation.org/american-driving-survey-2014-2017/ (accessed Nov. 12, 2020).

[16] "Household, Individual, and Vehicle Characteristics," US Department of Transportation, Bureau of Transportation Studies, https://www.bts.gov/archive/publications/highlights_of_the_2001_national_household_travel_survey/section_01#:~:text=Interestingly%2C%20while%20the%20mean%20number,have%20more%20vehicles%20than%20drivers (accessed Nov. 12, 2020).

[17] Mark Kane, "Nissan LEAF Sales Hit 450,000: World's #1 Selling EV, But Not for Long," *InsideEVs*, January 20, 2020, https://insideevs.com/news/393890/nissan-leaf-sales-450000/ (accessed Nov. 12, 2020).

[18] https://www.envision-aesc.com/en/aboutus.html (accessed Nov. 12, 2020).

sourcing from multiple, competitive external suppliers. In 2016, Nissan announced its plan to diversify its battery sourcing in order to leverage cost benefits and stay competitive in the market.[19]

Leaf supply chain

Introducing a PEV into its factory operations did not cause any major disruption to Nissan's supply chain. Nissan had an established process for introducing new products into production. The ramp-up and manufacturing of the Leaf went smoothly; the existing machinery in the factory and global suppliers were capable of manufacturing all the new components (except for the battery pack). Nissan set up new battery plants near its United States, United Kingdom, and Japan facilities for the battery pack. This allowed the company to reduce transportation costs and enticed governments to provide higher incentives for the vehicles to be locally manufactured. Similar to manufacturing, Nissan had no problem distributing the Leaf to all its targeted markets because Nissan already had a well-established global dealership network.

Charging network

Nissan partnered with more than 30 governments and their agencies to establish the charging network for the PEV cars. Nissan also launched an at-home charger that could be installed to charge the vehicle overnight. The growth of the infrastructure varied for different nations. This resulted in cases where the demand for PEVs was greater than the supply of charging capacity. Nissan also partnered with third-party PEV charging providers in order to boost the infrastructure. In 2019, the company partnered with EVgo, an electric charging network company,[20] to provide free charging for the Leaf at its sites for two years, attracting customers for both Nissan and EVgo.

Tesla

Founded in 2003, Tesla started as an electric racing car company.[21] Tesla launched its first electric sports car, the Roadster, in 2008. The Roadster had a range of 200 miles and a top speed of 125 miles per hour. The Roadster was the first step in Tesla's master plan for launching models. Specifically, Tesla's plan was to "create a low volume car, which would necessarily be expensive. Use that money to develop a medium volume car at a lower price. Use that money to create an affordable, high volume car."[22]. The medium-volume car, the Model S, launched in 2012 as phase 2 of the master plan. The company then launched the high-volume, low-cost car, the Model 3, in 2017. The Model 3 became the most-sold PEV in the United States by 2019, with sales doubling from 2018 to 2019.[23]

Approach to design

At its inception, Tesla was the first new company in over a century to become a major automobile company in the world. This placed it in a unique position, allowing it to think outside of the box as compared to traditional automakers, who were often slow to respond to market changes and relied heavily on empirical knowledge. Tesla considered itself a technology company rather than an automobile company. For example, it followed

[19] "Redefining the Battery for a Beautiful Energy World," Autoevolution, https://www.autoevolution.com/news/nissan-could-pull-plug-on-in-house-ev-battery-production-86583.html (accessed Nov. 12, 2020).
[20] "Nissan and EVgo Launch 'Nissan Energy Perks by EVgo,'" Nissan press release, November 25, 2019, https://usa.nissannews.com/en-US/releases/release-532fc811177df41991d8d82183090dd1-nissan-and-evgo-launch-nissan-energy-perks-by-evgo (accessed Nov. 12, 2020).
[21] As part of its overall business, Tesla also focused on providing energy solutions in the form of solar panels, battery packs, and solar tiles to large corporations and households. See "Tesla Inc," Reuters, https://www.reuters.com/companies/TSLA.O (accessed Dec. 16, 2020).
[22] Elon Musk, "Master Plan, Part Deux," Tesla blog, July 20, 2016, https://www.tesla.com/blog/master-plan-part-deux (accessed Nov. 12, 2020).
[23] Mark Kane, "US Plug-In Electric Car Sales Charted: January 2019," *InsideEVs*, February 4, 2019, https://insideevs.com/news/342616/us-plug-in-electric-car-sales-charted-january-2019/ (accessed Nov. 12, 2020).

processes similar to agile product development,[24] wherein subsets of large projects were solved iteratively. Tesla provided the same hardware for all its models and enabled features on a subscription basis. This enabled Tesla to provide "over the air" updates similar to software updates one would find on a laptop, continually improving features over the life of a car. This was a significant advantage compared to the traditional auto-manufacturing approach, where all the R&D was completed before the product launch.[25]

Elon Musk guided the company to follow a systematic design process called "first principle thinking." In this approach, a complex task was broken down with reasoning and each feature or aspect was examined to find the most efficient way to achieve its basic function without settling for the norm. "Through most of our life, we get through life by reasoning by analogy, which essentially means copying what other people do with slight variations."[26]

The original Model S base version had a range of 208 miles, which was equivalent to eight gallons of gas (assuming the US 2017 average of 25.2 miles per gallon).[27] This was a giant leap for PEVs because they were no longer constrained by the range of the vehicle. Tesla incorporated in the Model S the sports features from its predecessor, the Roadster. The car was able to accelerate from 0 to 60 miles per hour in less than 5.5 seconds.[28] The Model S secured maximum safety ratings under both European and American standards. The company emphasized the software controlling the electric motors. The possibility of multiple motors coupled with software integration made independent control of the speed and torque of the front and back wheels possible, allowing the vehicle to be more efficient in situations where one of the wheels was stuck or slipping.

Battery

Tesla partnered with Panasonic for its Li-ion battery technology and established a joint battery manufacturing plant within its Gigafactory 1.[29] Tesla used a single-source strategy for all its batteries. It worked closely with Panasonic on the research and development of the new battery technology. The battery had circular form factor (see **Exhibit 5**), similar to the batteries used in laptops. This enabled a cheaper mass-production process and easier automation of the battery production. The individual batteries' small size also allowed the possibility of placing all the batteries on the car floor bed. This proved advantageous for the car's stability because concentrating the weight at the bottom of the car made the vehicle less likely to roll over, improving the car's safety.

Supply chain and operations

Tesla partnered with Lotus Cars (Lotus) for developing the Roadster and utilized Lotus's manufacturing and suppliers. For the initial production of the Model S, Tesla acquired production plants in Fremont, California, and Tilburg, Netherlands. Tesla heavily relied on its Fremont factory for manufacturing its cars until 2019. This led to a centralized supply chain wherein cars were shipped across the world from a single location.

[24] Pranjal Mehta, "What Is Agile Development," Clutch, August 24, 2018, https://clutch.co/developers/resources/what-is-agile-development (accessed Nov. 12, 2020).

[25] Lou Shipley, "How Tesla Sets Itself Apart," *Harvard Business Review*, February 28, 2020, https://hbr.org/2020/02/how-tesla-sets-itself-apart (accessed Nov. 12, 2020).

[26] Mayo Oshin, "Elon Musks' [*sic*] '3-Step' First Principles Thinking: How to Think and Solve Difficult Problems Like a Genius," Mission.org, August 30, 2017, https://medium.com/the-mission/elon-musks-3-step-first-principles-thinking-how-to-think-and-solve-difficult-problems-like-a-ba1e73a9f6c0 (accessed Nov. 12, 2020).

[27] Collin Woodard, "Average Fuel Economy in the U.S. Rises to 24.7 MPG," *Motortrend*, January 11, 2018, https://www.motortrend.com/news/average-fuel-economy-u-s-rises-24-7-mpg/#:~:text=Reuters%20reports%20that%20the%20U.S.,an%20average%20of%2025.2%20mpg (accessed Nov. 12, 2020).

[28] "Tesla 0–60 Times," 0–60 Specs, https://www.0-60specs.com/tesla/ (accessed Nov. 12, 2020).

[29] "Panasonic and Tesla Sign Agreement for the Gigafactory," Tesla blog, July 30, 2014, https://www.tesla.com/blog/panasonic-and-tesla-sign-agreement-gigafactory (accessed Nov. 12, 2020).

Eventually, Tesla decided to build its future factories from the ground up. New factories dedicated to building PEVs provided the company with the flexibility to customize layouts and operations without any constraints. For example, Nevada had large lithium (raw material for batteries) deposit, so building a factory dedicated to battery production there improved the flow of Tesla's overall operations while ensuring local raw-material availability. In 2014, Tesla began the construction of its first Gigafactory at an estimated cost of $5 billion.[30] By 2021, Tesla expected to have completed construction such that it would have production-capacity capabilities in the United States, Europe, and China. This would allow it to serve local markets and reduce overall material movement. The product lines handled in each Tesla factory are summarized in **Table 1**.

Table 1. List of Tesla's factories and operations as of 2020.

Factory	**Location**	**Opening Date**	**Products and Usage**
Lotus Cars	Hethel, United Kingdom	2006–2008	Manufacture Roadsters in the United Kingdom
Tesla Factory	California, United States	2010	Integration of battery, powertrain, and final assembly of Model S, Model 3, Model X, and Model Y
Tesla Facilities	Tilburg, Netherlands	2013	Final assembly of Model S and Model X, with major components from Fremont, California
Tesla Gigafactory 1 (Giga Nevada)	Nevada, United States	2016	Production of Li-ion batteries and electric powertrains
Tesla Gigafactory 2	New York, United States	2017	Energy-generation and storage products
Tesla Gigafactory 3 (Giga Shanghai)	Shanghai, China	2019	Final assembly of Model 3

Data sources: "Tesla Factory," Tesla, https://www.tesla.com/factory; Martin Eberhard, "Lotus Position," Tesla blog, July 25, 2006, https://www.tesla.com/blog/lotus-position; "Tesla Motors Opens Assembly Plan in Tilburg, Netherlands," Tesla press release, August 27, 2013, https://www.tesla.com/blog/tesla-motors-opens-assembly-plant-tilburg-netherlands?redirect=no; and Fred Lambert, "Tesla Makes Gigafactory 3 in China Official, Plans to Start Production in 2 Years," Electrek, July 10, 2018, https://electrek.co/2018/07/10/tesla-gigafactory-3-china-official-production/ (all accessed Dec. 18, 2020).

Production ramp-up

During the initial ramp-up in 2010 from 100 Roadsters a year to 100 Model Ss a week, Tesla faced challenges in configuring the equipment to facilitate mass production and train its production labor force on assembly and maintenance.[31] Tesla's Silicon Valley mentality motivated it to use extensive automation throughout production. This led to further disruptions and machine failures. In addition, Tesla's overreliance on the Fremont plant and complications with its automated process led to large disruptions in its supply network, contributing to long lead time and delays for orders. Tesla eventually shifted its focus from complete automation into dedicated zones of full and partial automation. The company was not able to scale up production at its desired rate. As a result, Tesla had to reduce its delivery estimates from 5,000 cars in 2012 to

[30] "Tesla Gigafactory," Tesla, https://www.tesla.com/gigafactory (accessed Nov. 12, 2020).
[31] Joe Barkai, "Tesla Will Have a Tough Time Ramping Up Production. Here's Why," *IndustryWeek*, June 28, 2017, https://www.industryweek.com/operations/continuous-improvement/article/22021117/tesla-will-have-a-tough-time-ramping-up-production-heres-why (accessed Nov. 12, 2020).

3,000 cars.[32] The company's approach of rethinking established processes simplified complex problems in some cases, but also complicated established processes in others. For example, Tesla tried to fully automate the general assembly of electrical components involving wires and cables, which increased both the cost and complexity of the process. Tesla also experienced similar disruptions while ramping up production of the Model X and the Model 3. To quote Musk on the ramp-up of Model 3, "We're going to go through at least six months of production hell."[33]

Originally, Tesla vertically integrated all of its battery production, electric powertrain production, and charging solutions. This vertical integration enabled the company to create close interaction between the design and production teams and launch improvements in short time periods. Due to its vertical integration, Tesla was highly dependent on its battery and powertrain plants for its overall throughput. Any delays at these facilities would make it difficult to scale up production for the global market.

Marketing and distribution

Tesla relied heavily on word of mouth for its marketing. Enabling current customers to share their stories and engaging them in forums was one of the main strategies the company focused on for its marketing. The company did not spend on marketing advertisements, thereby reducing the overall cost of the vehicle. Tesla also owned its own galleries and stores, but only for display purposes—the company completely relied on an online purchase model for sales. This enabled Tesla to accumulate orders and update order statuses in real time. Tesla initially maintained an order book that was more than its production capacity and only in 2019 did it begin to catch up with the demand. In order to reduce the cost of distribution, Tesla performed last-mile delivery of the cars to its customers. This, however, proved challenging, because it required Tesla to maintain its own distribution network—in some cases, it had to ship vehicles across the country.

Charging network

Tesla invested significantly in its charging technology and infrastructure, spending more than 26% of its revenue in 2019 on improving both.[34] The company decided to establish its own charging stations capable of providing super-fast charging. The supercharging station locations were chosen in a strategic manner that enabled the customer to spend time either dining or shopping while the car was charging. Tesla also incorporated software features that considered the distance to the next charging station on the trip. This enabled the software to suggest the level of charge needed at the current station so that the vehicle could reach the next station within the available range and optimize overall trip time. Tesla also introduced household and destination charging, which made charging at home, in garages, and public places possible. As of 2019, Tesla operated more than 730 supercharging stations with the number of supercharging stations increasing rapidly at an average rate of 30% from 2016 to 2019.

Future Growth

The growth of EVs in the decade leading up to 2020 altered the automobile industry landscape. As consumers, industries, and governments became more concerned with the environmental implications of vehicle emissions, PEVs were in a position to potentially be the vehicles of the future. Government tax benefits for PEVs and rising fuel prices motivated many automakers to focus on the development of new PEV lines

[32] Jay Cole, "Tesla Model S—Over 2,400 Sold, 2,750 Built in Last Quarter of 2012," *InsideEVs*, February 20, 2013, https://insideevs.com/news/317209/tesla-model-s-over-2400-sold-2750-built-in-last-quarter-of-2012/ (accessed Nov. 12, 2020).

[33] Matthew DeBord, "Elon Musk on Model 3: 'We're Going to Go through at Least 6 Months of Production Hell,'" *Business Insider*, July 29, 2017, https://www.businessinsider.com/elon-musk-says-model-3-faces-production-hell-2017-7 (accessed Nov. 12, 2020).

[34] "Q4 and FY2019 Update," Tesla report, https://ir.tesla.com/static-files/b3cf7f5e-546a-4a65-9888-c928b914b529 (accessed Nov. 12, 2020).

and encouraged start-ups with innovative products. Leading auto manufacturers such as Ford, GM, and Audi announced dedicated budgets for the research and development of new PEV or PHEV lineups. GM announced its plan to launch more than 10 EV models before 2024.[35] Start-ups like Rivian (focused on pick-up trucks) and Nikola (focused on trucks) were introducing PEVs to new market segments.

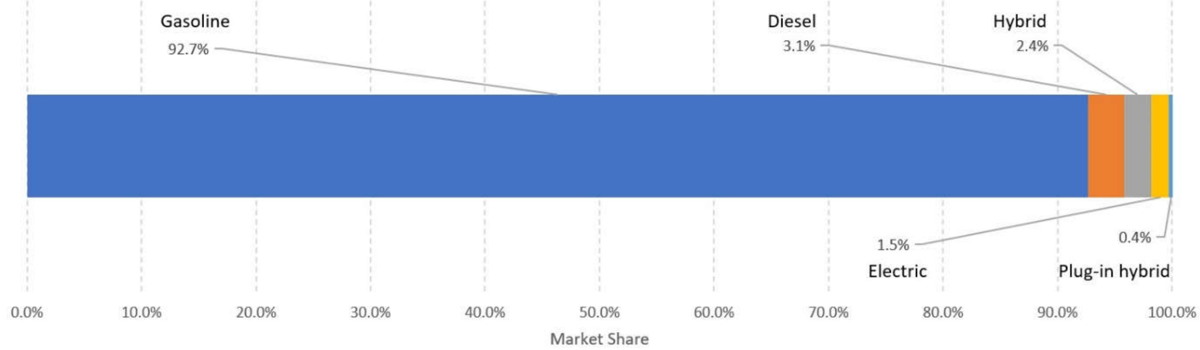
For market leaders Tesla and Nissan, the challenge was to continue to maintain a leadership position in a rapidly growing and increasingly competitive EV market. Tesla continued to try diversifying its product line into pick-up truck and truck segments, with the addition of the Cybertruck and the Semi-Truck models. Nissan was set to launch an EV version of the Altima in 2020 in order to reach a wider customer base. In addition, Nissan decided to migrate its entire Infiniti[36] product line into hybrid and EVs. Introducing new models and targeting new segments was necessary for growth. However, would Tesla and Nissan be able to scale their business models and operations in order to support this growth? Was one competitor in a better position than the other to take the lead in this next evolutionary phase of the EV market? The new war of the currents had truly just begun.

[35] Loren McDonald, "GM's 10(+) Future EV Models: Our Estimated Specs & Sales Volume," *CleanTechnica*, March 9, 2020, https://cleantechnica.com/2020/03/09/gms-10-future-ev-models-our-estimated-specs-sales-volume/ (accessed Nov. 12, 2020).
[36] Laurence Frost and Naomi Tajitsu, "Nissan's Infiniti Vehicles to Go Electric," *Reuters*, January 16, 2018, https://www.reuters.com/article/us-autoshow-detroit-nissan-infiniti-idUSKBN1F52TN (accessed Nov. 12, 2020).

Exhibit 1

The New War of the Currents:
The Race to Win the Electric Vehicle Market

Market Share by Powertrain

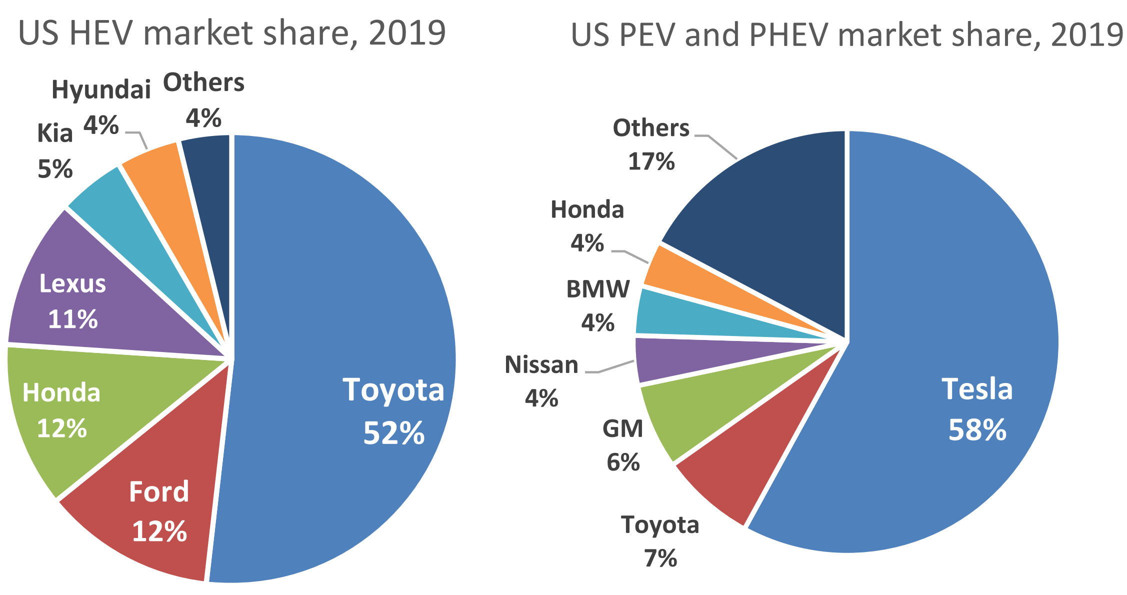


Data source: National Automobile Dealers Association "Market Beat," May 2020.

Exhibit 2

The New War of the Currents:
The Race to Win the Electric Vehicle Market

Market Share of HEV and PEV Segments

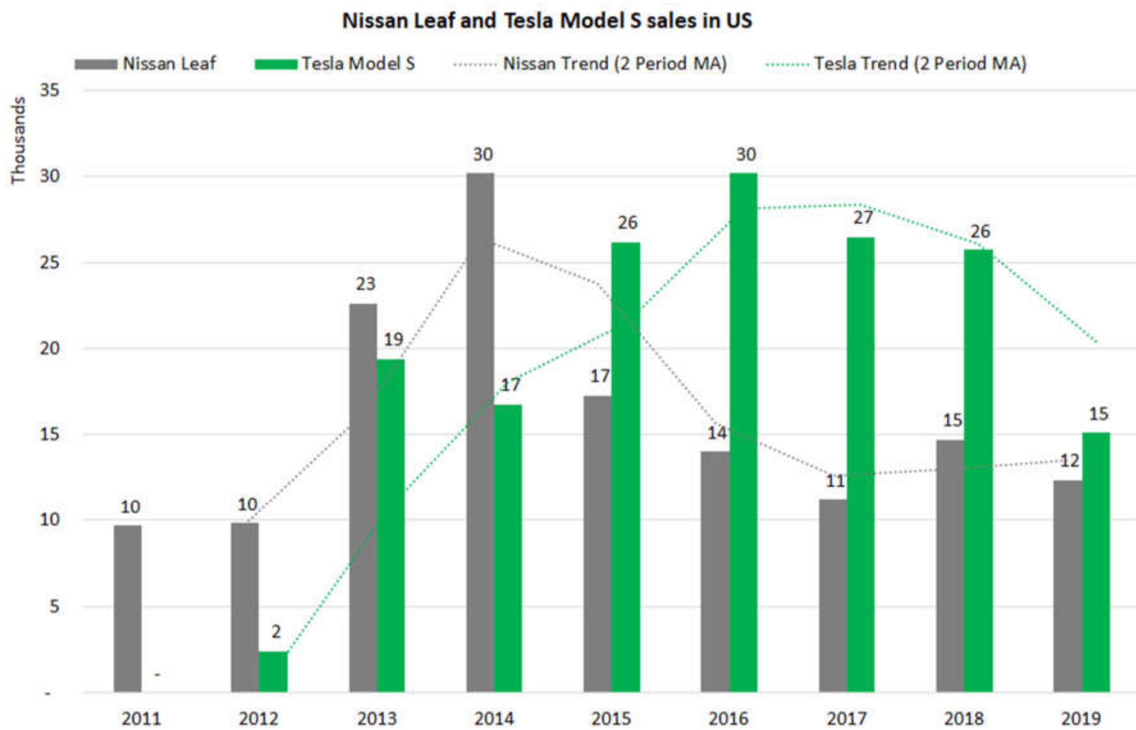


Data source: "US HEV Sales by Model," US Department of Energy Alternative Fuels Data Center, https://afdc.energy.gov/data/10301 (accessed Dec. 16, 2020).

Exhibit 3

The New War of the Currents:
The Race to Win the Electric Vehicle Market

Sales of Nissan Leaf, Tesla Model S in the United States

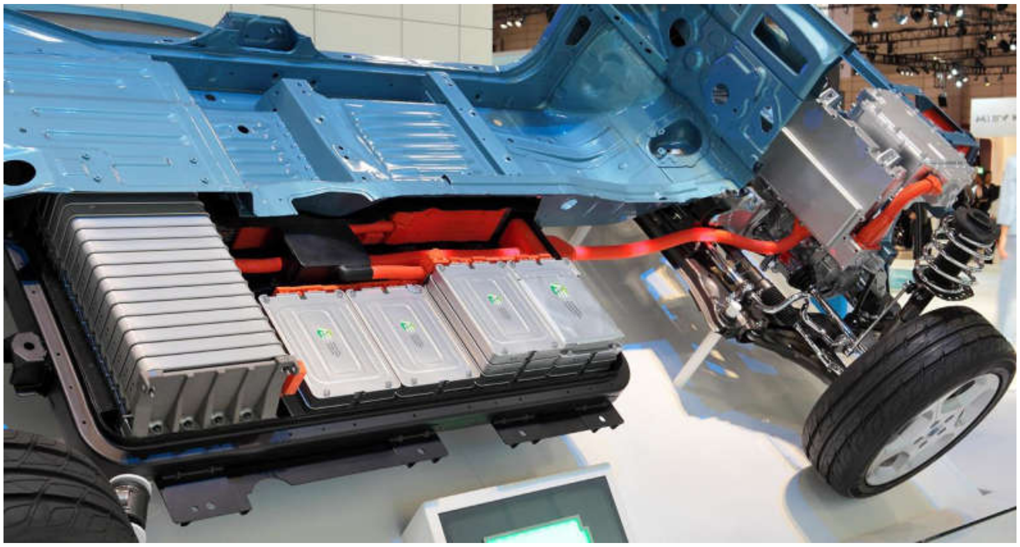


Data source: "US HEV Sales by Model," US Department of Energy Alternative Fuels Data Center, https://afdc.energy.gov/data/10301 (accessed Dec. 16, 2020).

Exhibit 4

The New War of the Currents:
The Race to Win the Electric Vehicle Market

Battery Shape and Location in Nissan Leaf



Source: "Nissan Leaf at the 2009 Tokyo Motor Show," posted under Creative Commons (CC BY-SA 3.0) by "Tennen-Gas," October 23, 2009, https://commons.wikimedia.org/wiki/File:Nissan_Leaf_012.JPG (accessed Dec. 16, 2020).

Exhibit 5

The New War of the Currents:
The Race to Win the Electric Vehicle Market

Battery Shape and Location in Tesla Model S

Source: "The Chasis [*sic*] of Tesla Model S," posted under Creative Commons (CC BY-SA 4.0) by "Tokumeigakarinoaoshima," November 29, 2015, https://commons.wikimedia.org/wiki/File:The_chasis_of_Tesla_Model_S.jpg; and "Batteries 2170 18650," posted under Creative Commons (CC BY-SA 4.0) by "Jzh2074," June 1, 2018, https://commons.wikimedia.org/wiki/File:Batteries_2170_18650.png (both accessed Dec. 16, 2020).