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DRIVING A GREEN FUTURE

A RETROSPECTIVE REVIEW OF CHINA'S ELECTRIC VEHICLE DEVELOPMENT AND OUTLOOK FOR THE FUTURE

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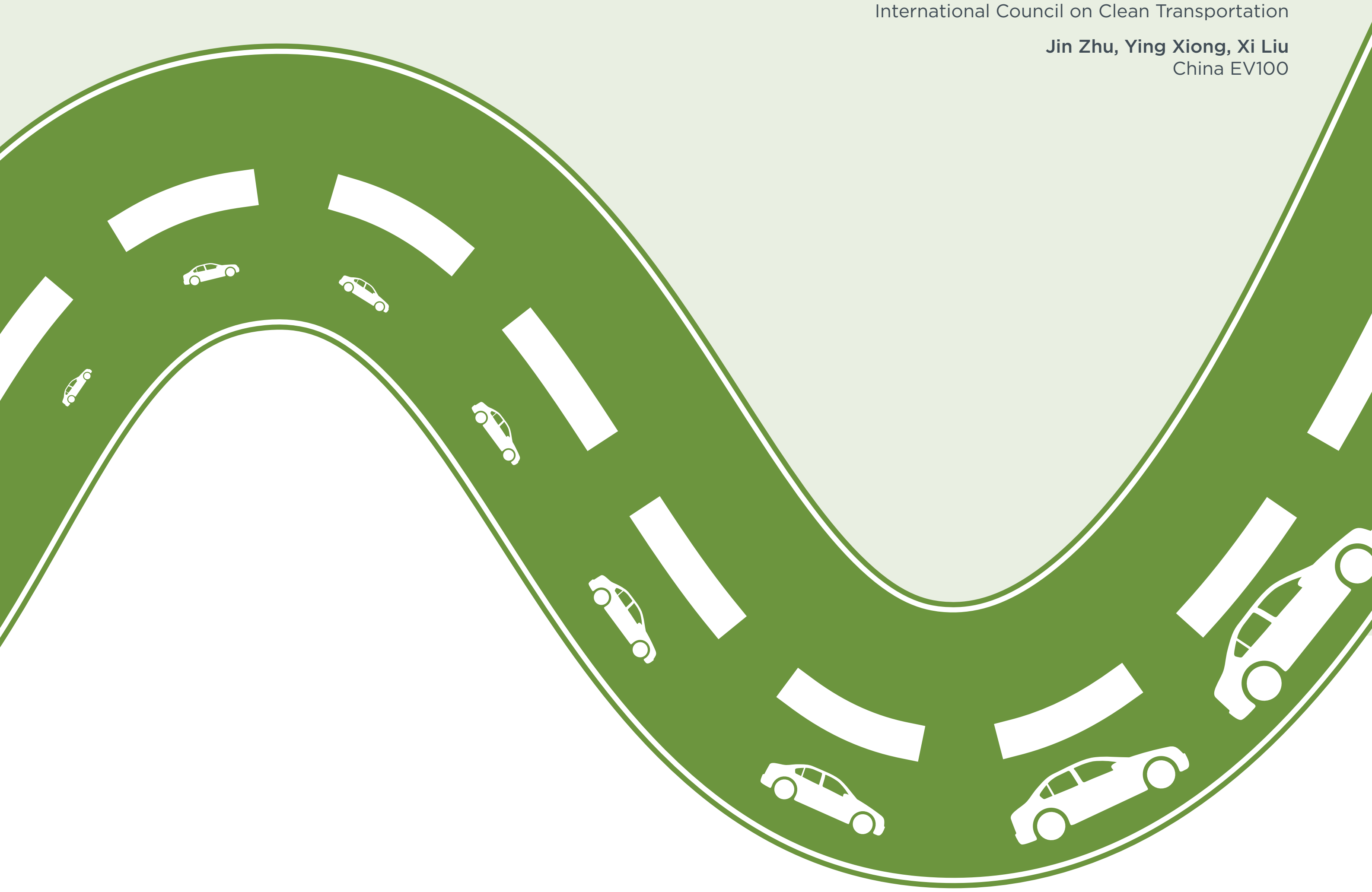

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ABOUT THE ICCT

The International Council on Clean Transportation (ICCT) is an independent nonprofit organization founded to provide first-rate, unbiased technical research and scientific analysis to environmental regulators. Its mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation to benefit public health and mitigate climate change.

ABOUT CHINA EV100

China EV100 is a nonprofit organization and third-party think tank aiming to encourage the development of the electric vehicle and intelligent and connected vehicle industries. By providing a platform without boundaries across industries, disciplines, ownership, and departments, it promotes convergence and collaborative innovation across multiple fields through research and communication.

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ACRONYMS

BEV	battery electric vehicle
DC	direct current
EV	electric vehicle
FAW	First Automobile Works
FCV	fuel cell vehicle
FYP	Five-Year Plan
GHG	greenhouse gas
HEV	hybrid electric vehicle
LFP	lithium iron phosphate
MIIT	Ministry of Industry and Information Technology of People's Republic of China
MOF	Ministry of Finance of the People's Republic of China
MOST	Ministry of Science and Technology of the People's Republic of China
NDRC	National Development and Reform Commission
NEBRPC	New Energy Battery Recycling Professional Committee
NEV	new energy vehicle
NMC	lithium nickel manganese cobalt oxide
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
R&D	research and development
SAE	Society of Automotive Engineers
SAIC	Shanghai Automotive Industry Corporation
ZEV	zero-emission vehicle

EXECUTIVE SUMMARY

China's landmark electric vehicle pilot program, "Ten Cities, Thousand Vehicles," marked its 10th anniversary in 2019. Over the past decade, China has rapidly created the world's largest electric vehicle market, and it today accounts for half of the world's electric cars and more than 90% of electric buses and trucks. Now China is entering a new era of its electric vehicle development, in the context of both increasingly fierce global competition and the nation's new pledge to achieve carbon neutrality by 2060. This will require an updated and more holistic electric vehicle strategy for the long term.

This report first unfolds China's amazing electric vehicle development journey. Figure ES1 illustrates the four major stages of China's electric vehicle development by highlighting the key national strategies and plans that collectively defined the electric vehicle growth path and the concrete policies of three types—pilot programs, incentives, and regulations—that drove the market in the past decade. Prior to 2009, China was debating about a path toward a world-leading auto industry and identified new energy vehicles as a fast lane. From 2009 to 2012, with a confirmed electric vehicle development strategy, China introduced new energy vehicle pilot programs on a massive scale; a number of cities prioritized deployment in public fleets and there was tremendous government support in the forms of investment in research and development and direct subsidies. The following five years, from 2013 to 2017, witnessed rapid growth of China's electric vehicle industry and market. This was driven by air quality and oil security goals, in addition to the desire to achieve the auto industry's revitalization goals. After 2018, China began to shift from primarily subsidizing the industry to providing a combination of incentives and regulations to further release the market's potential. This policy shift, together with increasing market openness and competition, showed China's increased confidence in its electric vehicle strategy and the maturing of its electric vehicle market.

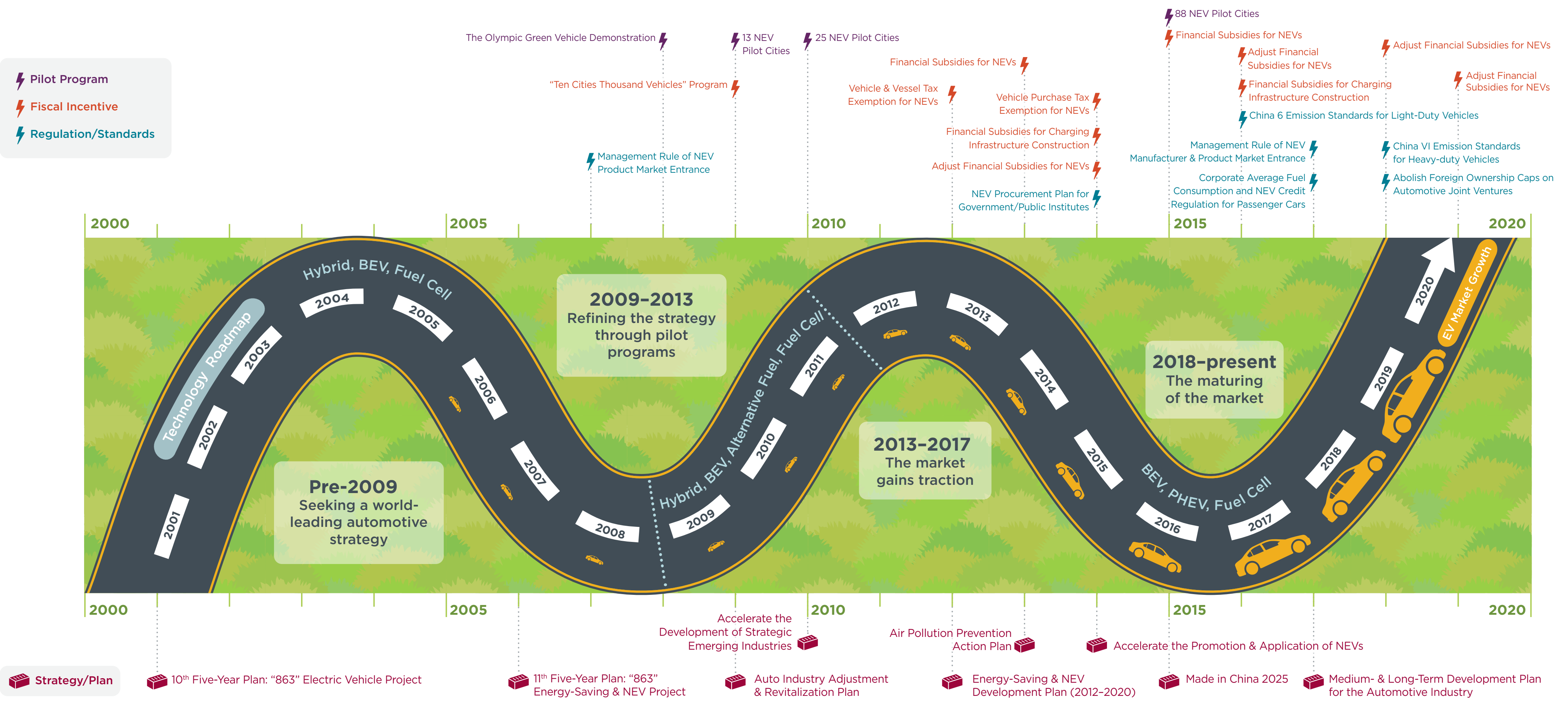

Figure ES1. Historical development of China's electric vehicle industry

This report also quantitatively compares China's electric vehicle market, industry value chain, electric vehicle and battery technology evolution, competitiveness, and long-term development vision with other leading electric vehicle markets, including the United States and Europe. Figure ES2 summarizes a part of our global comparative analysis among the three markets.

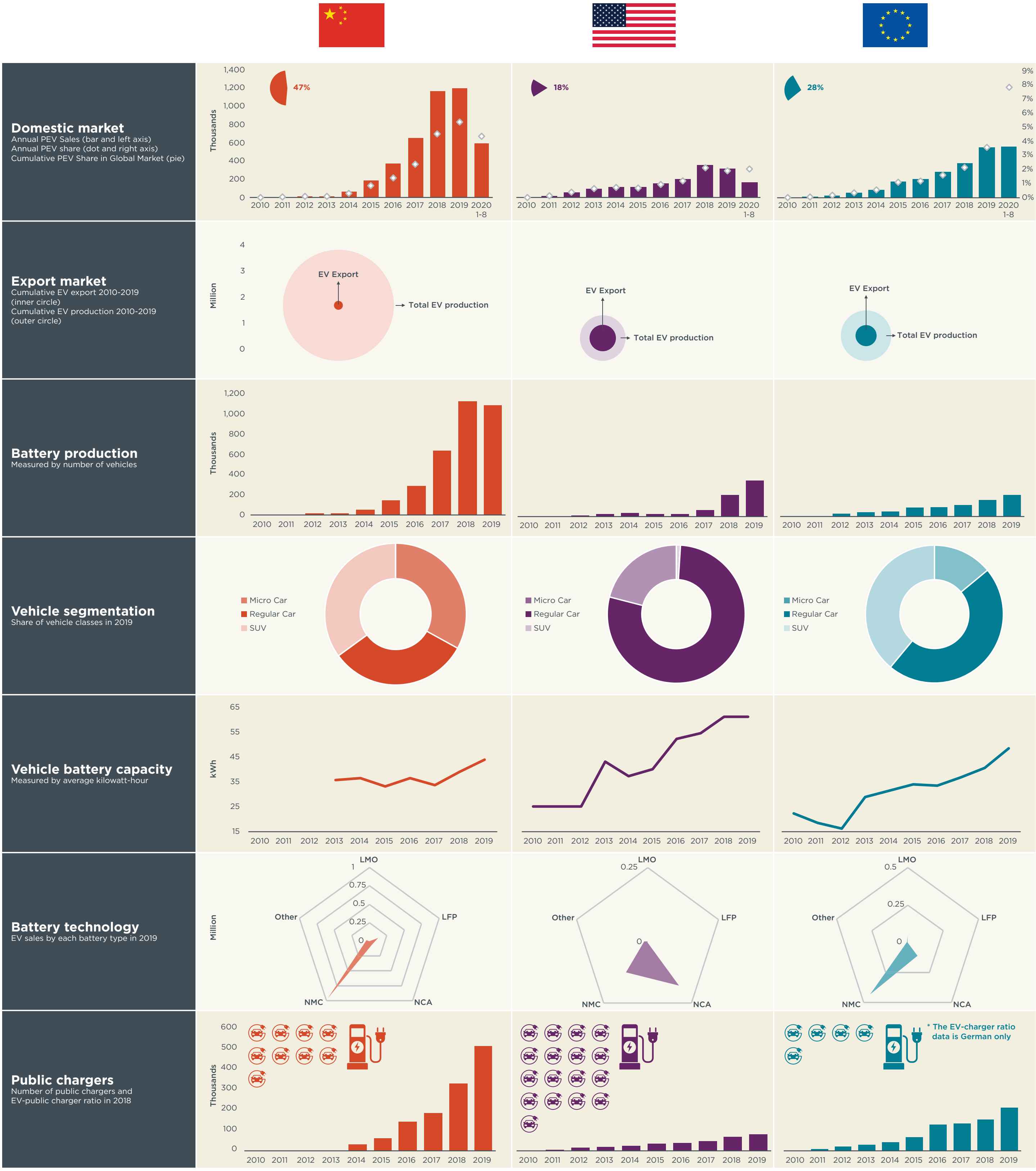

Figure ES2. Comparison of key electric vehicle development indicators in China, the United States, and Europe.

Through this analysis, we identified seven findings regarding China's electric vehicle development to date:

1. Regarding overall performance, as of 2020, China has cultivated the world's largest electric vehicle market, industry, and the largest number of leading electric vehicle city markets. This was accomplished in the short span of a decade, and the nation's cumulative electric vehicle sales in the past decade represent 47% of the world's total.
2. However, in the first half of 2020, China lost ground to Europe in terms of electric vehicle market penetration. Europe's electric vehicle market share climbed sharply from an annual average of 3% in 2019 to around 8% in the first half of 2020 and it is still climbing. Germany's electric vehicle market share hit 17.5% in October 2020. The reasons behind China's electric vehicle market share dropping by more than 40%, and Europe's increasing to nearly 60% in the first half of 2020, can be expressed in one word: policy. European vehicle manufacturers introduced more than 30 new models in the last half of 2019 in order to position themselves to hit the 2021 CO_2 emission standards and avoid billions in penalties. This regulatory hammer and the fiscal incentives for electric vehicles adopted in six European countries in response to COVID-19 combined to provide a powerful driver for market uptake. The reverse is true in China, where a decline in fiscal incentives in 2019 combined with vehicle fuel efficiency standards and a new energy vehicle sales mandate that follow rather than lead the market, and do not include robust enforcement provisions or penalties, has led to a sharp drop in electric vehicle sales.
3. Regarding brand competitiveness, Chinese electric car brands have not been widely embraced by the global market. Within the light-duty vehicle segment, China's electric vehicle strategy has primarily focused on satisfying the domestic market and there has been little emphasis on exporting. In 2019, less than 1% of China's electric car production was sold to other parts of the world. That ratio is significantly lower than those in the United States and Europe, and this implies there is potential for Chinese manufacturers to enhance their global competitiveness. Additionally, as the Chinese electric vehicle market increasingly opens to foreign brands, the latest trend shows that Chinese brands are losing to their foreign competitors in some of the most profitable vehicle segments in the domestic market. The exceptions, however, are the so-called new forces of new energy vehicles, startups like NIO, Li Auto, and Xpeng, which have begun to show vitality in the higher-end sport utility vehicle (SUV) market.
4. On research and development capacity, China has a wide lead over the United States and Europe in battery supply chain. China has a homegrown electric vehicle supply chain with a dominant supply of critical raw materials and competitive advantages in battery production. Regarding technology development of advanced components, including semiconductors, China is currently lagging but slowly narrowing the gap with global rivals. China owns the most technology and development patents in the fields of fast charging and wireless charging, but compared with other leading regions has the least number of patents in areas like battery management system, hydrogen storage, fuel cell production and operation, and powertrain control for plug-in hybrids.
5. With respect to electric vehicle technologies, China's decade-long pilot and subsidy programs were designed to drive electric vehicle technology advancement, and battery capacity and energy density were key indicators in recent years. As a result, the average battery capacity for pure electric cars increased significantly in the past 5 years. However, this pace of improvement appears to be slower than in the United States and Europe, possibly due to technical and market factors. Battery technology in China has experienced a

quick turn from lithium iron phosphate (LFP) batteries to energy-dense lithium nickel manganese cobalt oxide (NMC) batteries, and a similar trend is also found internationally.

6. China's early electric vehicle market strategy was to push the application of electric vehicles in government and public fleets. As a result, electric buses and micro electric cars that are largely used in car-sharing fleets are some of the most successful niche markets of electric vehicles. With an increasing focus on the private market, electric vehicles began to gain traction in mainstream car segments and SUVs in the past 2 years. However, the electrification of the commercial truck segment is still nascent, and the policy tools for electrifying these vehicles are far less robust than those that apply to cars, despite commercial trucks' disproportionally large contribution to the nation's air and climate pollutant emissions and oil consumption.
7. On charging infrastructure, China has made great strides as far as absolute number of chargers installed to support rapid electric vehicle market growth. However, considering China's electric vehicle growth targets, there is still a gap in meeting the charging needs of electric vehicle users in the coming years.

The last part of this report contains interviews our research team conducted with five international experts who have years of experience in electric vehicle technology, policies, and collaboration with China. These interviews shed light on what has made China the world's largest electric vehicle market, what China can offer to the rest of the world in the global transition to zero-emission transportation, and what else China needs to consider to sustain its electric vehicle success in the future. China's success is built on a foundation made of the following aspects:

» *A clearly articulated vision for industry strategy*. In the early 2000s, China chose new energy vehicles—primarily electric-drive vehicles, for a national strategy to jump-start its auto industry. This decision was based on the nation's competitive advantages and unique mobility needs.
» *Top-down planning with clear development targets and policies adapted to achieve them*. Under its national vision, China established high-level industrial plans that set clear targets. These plans and targets have been the backbone for policy continuity in driving electric vehicle growth.
» *Aligned industry, energy, and environmental goals*. Linking China's electric vehicle goals to air quality and industrial competitiveness is especially powerful because it aligns multiple government agencies in different fields around the same interests; this, in turn, reduces barriers to implementation and motivates the use of additional policy levers. These concerted efforts from multiple agencies at central and local levels greatly accelerated the electric vehicle growth in the past half-decade.
» *Multi-stakeholder partnerships are used to form key strategies and create roadmaps.* When it comes to turning plans into action, China forms government-industry-academic-research partnerships to coordinate decision-making, financing, and implementation. This mechanism enabled quick transformations from laboratory prototype models to real-world electric vehicle products. Top experts from multi-disciplinary backgrounds play a key role in navigating the technology roadmap of China's electric vehicle industry development.
» *Fiscal and regulatory policies help to launch and grow the market.* China introduced decade-long pilot and central subsidy programs to initiate the electric vehicle market, and innovative regulatory mandates ensured continued industry innovation, investment, and model availability.
» *Motivated cities*. After plans come from the central government, local governments are where policy innovation and implementation occur. Leading markets like

Beijing, Shanghai, and Shenzhen developed strong policies that initially provided a spark for industrial growth, and then spurred electric vehicle uptake several times higher than other local markets and brought improved air quality. These cities demonstrated that fast regional economic growth can go hand-in-hand with stronger environmental policies and electric vehicle goals.

Looking into the next decade, the key question concerns how China can sustain its electric vehicle success. We offer a few recommendations.

» *An updated vision for full electrification and a long-term plan to help achieve industrial, air quality, and climate change mitigation goals*. Having now the benefit of looking back at the past 10 years, China's vision is due for an update that builds toward a fully electrified transport sector. Setting more ambitious new energy vehicle goals for 2030 and beyond, including a target date for a fully electrified transportation sector (or a set of target dates for fully electrified fleets for various transportation segments including passenger cars, mid- and heavy-duty vehicles, etc.), would accelerate investment. It would also ensure that China meets and organically integrates its near-, mid-, and long-term goals for achieving world-class air quality; realizing its industrial leadership ambitions; securing its energy independence targets; and fulfilling its climate change mitigation goals. Especially after President Xi's pledge for carbon neutrality by 2060, it is time for China to establish near-, mid-, and long-term greenhouse gas (GHG) emission reduction goals for the transportation sector, and to use electric vehicles as the core technological path to meet those goals. Take the European Union as an example: The proposed European Climate Law would establish a legally binding target of net-zero economy-wide GHG emissions in 2050 (climate neutrality). Based on the economy-wide target, the European Union is developing sectoral policies to achieve the necessary emission reductions. For the transport sector, the European Green Deal included a non-binding target to reduce transport sector emissions 90% by 2050. Among the key measures to achieve this transport target are the European Union's 2030 CO_2 standards for passenger cars, vans, and trucks. In the near term, to revive the economy hit by COVID-19, several national governments in Europe have launched stimulus packages to boost new electric vehicle sales and accelerate the replacement of older vehicles. This combination of near-, mid-, and long-term targets and the development of sectoral strategies and policies helps ensure that the whole economy is on a consistent path to climate neutrality. To address pressing environmental challenges, it is also crucial for China to now develop a long-term strategy to electrify the heavy-duty truck sector and the non-road sector; there needs to be an initial focus on ports, airport vehicles and equipment, and construction equipment. All of these sectors contribute substantially to air and climate change pollutant emissions and to energy consumption. Finally, a decarbonized transportation system does not pertain solely to vehicular technology advancement, and would also require tremendous parallel efforts to decarbonize China's power grid.

» *Pivot to a new set of regulatory and market-driven approaches.* While China's initial policy playbook of pilot programs, government subsidies, and procurements proved a great success in bringing China to the forefront of global electric vehicle development in the past decade, China needs to quickly pivot to a new set of regulatory and market-driven approaches. This includes strengthening new energy vehicle regulations, complementing vehicle fuel efficiency standards with technology-forcing and enforceable GHG emission standards, and enhancing innovative fiscal and taxation policies to drive the mainstream consuming market and link electric vehicle growth more closely with environmental benefits.

    » First, establish a hybrid regulatory program of vehicle fuel efficiency and GHG emission standards similar to the partnership established in the United States between the Department of Transportation's (DoT) fuel economy standards and the Environmental Protection Agency's (EPA) GHG emission standards. While the DoT's standards are industry-driven, shorter-term, and lack strong enforcement, the EPA's standards are climate-driven, long-term, and propelled by the Clean Air Act's stringent penalty provisions.

  - Second, the environmental ministry in China, with authority from China's Air Pollution law to enforce emission standards, could consider establishing long-term GHG emission standards for light- and heavy-duty vehicles from 2025 to 2030 and beyond. Such actions would be consistent with policy trends in major markets such as Europe and California, and likely the new U.S. administration.
  - Third, fiscal and taxation incentives are an important complement to regulatory standards. When the electric vehicle market was in its infancy, fiscal subsidies placed a significant but justifiable strain on the national budget. As the market grows, several countries have switched to programs that create a new tax on conventional-fuel vehicles to pay for long-term incentives for electric vehicles. This is called bonus-malus in Europe and feebate in North America. Such a program would allow for durable, long-term financial support for the electric vehicle transition even while electric vehicle sales continue to grow over time. We recommend a graduated fee on petrol vehicles that varies depending on vehicle GHG emissions, as it provides incentives for manufacturers to produce more efficient vehicles while funds are also used to offset the higher cost of electric vehicles until cost parity is achieved.

- *Vitalize the mainstream private consuming market and city markets.* China has been extremely successful in engaging government, corporate, and fleet users of electric vehicles. To fully release the electric vehicle market potential in the upcoming decades, the mainstream private consumer market will be the key. Future innovations in technologies, policies, business models, and partnerships need to focus on the needs of such mainstream markets. For example, new generations of electric vehicle consumers are increasingly demanding autonomous, connected, and smart features from their cars, and this will largely revolutionize the traditional functionalities of automobiles. China's ministries could implement the next phase of new energy vehicle policies to push greater city innovation. A first step could be to select regions of top priority and set aggressive timetables for fully electrified transport. Local governments would then need special authority over registration, taxes, fees, and city access, among other things, and central funding support to electrify their entire urban areas in phases; such phases could involve fleets, taxis, and ride-hailing vehicles, private drivers, urban trucks, and inter-city trucks. In order to meet China's decarbonization target of a carbon-neutral economy in 2060, China should set a GHG reduction target for the transport sector of approximately 80% compared to 2020 in 2050. Leading cities would need to embrace this challenge during the 2025–2035 time frame.
- *Secure a full-electrification vehicle technology path and transition to smart electromobility.* If we say the race of global automotive technologies in the current decade is mainly about electrification, then the next chapter will be focused on intelligent and connected electromobility—a system that is far beyond just vehicle technology itself. On vehicle technology, China has prioritized battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs). These are the three technologies that collectively defined new energy vehicles and they are essential to lead to fully electrified mobility in the future. BEVs are leading and will achieve cost parity across most segments first from a global perspective. In the passenger vehicle sector, BEV technology is far ahead of FCV technology in maturity, scale, and cost reduction. As a result, the near-term focus should be on charging infrastructure for BEVs, and industry collaboration and pilot demonstrations are timelier for FCVs. If we take a long-term perspective, a full-

electrification path might just be the start of transforming mobility's future. We see its prelude today already in the three major markets—China, Europe, and the United States. Starting from the mid-term, China should combine a full-electrification path with intelligent, autonomous driving and a cooperative vehicle infrastructure system to meet future demands from intelligent and connected vehicles. This will require a deeper revolution within the automotive industry to organically integrate vehicle, electronics, internet, and infrastructure technologies and to expand the scope of the supply chain from the traditional parts like batteries, motors, and onboard control systems to include chips, sensors, high-definition map systems, artificial intelligence, and cloud-based control systems.

» *Secure independent technical capacity in key supply chain areas and strengthen life-cycle management of electric vehicles.* China's electric vehicle success in the past decade benefited from globalization, relatively free international trade, and collaboration in technologies. The increasingly complex dynamics of intergovernmental relations, however, will introduce greater uncertainty for China's continued electric vehicle growth. In this context, China needs to further strengthen its domestic technology and research capacities, with focus on key supply chain bottlenecks, charging or battery swapping infrastructure that would accommodate the rapid growth of electric vehicles, and future mobility patterns such as mobility-as-a-service. In order to achieve the full environmental benefits of electric vehicles on a life-cycle basis, policies need to be developed to promote sustainable and low-carbon practices from cradle to grave. This includes battery and vehicle design, production, usage, and proper battery recycling.

» *Leverage global electric vehicle platforms and strengthen collaboration in one focal area—electric trucks*. Even with international relations becoming increasingly complicated and unpredictable, there are still several opportunities for China to collaborate internationally to achieve sustained and even more aggressive electrification goals; these include collaborating with subnational governments like the State of California on advancing the electrification of commercial trucks, the use of global forums such as the Society of Automotive Engineers (SAE) and United Nations frameworks to harmonize vehicle and charging standards, and working with non-governmental platforms like the International Zero-Emission Vehicle Alliance on collaborative research and continued electric vehicle progress exchange. In regions in China and throughout the world with high freight activity and serious air-quality issues, decarbonizing heavy-duty vehicles is an immense unmet challenge. Many Asian, European, and North American countries are developing strategies for zero-emission ports and shipping. China could develop partnerships with government, port, fleet, charging, and research leaders to establish ultralow-emission freight zones and to make the electrification of local and regional trucks the target of initial support.

Although China is at the leading edge of global vehicle electrification, China's path toward global leadership has at times been rocky, and it is not yet complete. China has continued to work, revise, and improve its long-term strategies, and central, provincial, and local policies. Technology and market changes require that policies in China remain a work in progress and continue to adapt to meet industry, mobility, oil security, air quality, and climate change goals in the years and even decades ahead.

1. INTRODUCTION

In 2019, China's landmark electric vehicle pilot program, "Ten Cities, Thousand Vehicles," marked its 10th anniversary. Over the past decade, China has rapidly created the world's largest electric vehicle market. It accounts for half of the world's electric cars and more than 90% of electric buses and trucks. China's public charging infrastructure rivals those of the United States, Europe, and Japan combined. China is home to innovative and high-production battery technology, new mobility business models, and diverse electric vehicle models that are spreading globally.

Although China is at the leading edge of global vehicle electrification, China's path toward global leadership has been somewhat rocky and is not yet complete. China has continued to work, revise, and improve policies from central, provincial, and local governments. For example, incentive design, regulatory requirements, local promotion practices, and charging infrastructure policies have been revised over time to meet changing demands and expand the nascent market. Technology and market changes require that China's policies remain a work in progress and adapt to meet industry, mobility, oil security, air quality, and climate change goals in the years ahead.

This research project reviews the historical development of China's electric vehicle market and investigates the lessons, challenges, and underlying reasons for the rapid growth. This is a retrospective study that describes and assesses that history with international comparisons and reflects on the lessons via interviews with global leaders who have closely tracked China's progress and can share insights on its market challenges. The backdrop of this study is that China has long sought a path to "leapfrog" its way to develop globally leading automotive technology, and electric vehicles present such an opportunity.

Beyond helping China's leaders assess progress to date and consider future policies, the work is expected to support governments around the world seeking to learn from China's experience and similarly accelerate their own markets. In so doing, the project will help policymakers learn from the past decade and ensure greater success toward a clean transport future.

The paper is divided into eight parts. Chapter 2 provides a detailed historical review of China's electric vehicle program, which developed in four stages. Chapters 3 to 6 critically investigate the results of the 10 years of China's new energy vehicle development in the global context; we do this via data-driven comparisons between China and other leading electric vehicle markets with respect to key development indicators like the electric vehicle market and industry, supply chain, vehicle and battery technologies, and charging infrastructure. Chapter 7 is an outlook for the future and briefly compares long-term visions of electric vehicle development in select auto markets. The last chapter summarizes key lessons from our historical review, global comparative analysis, and interviews with international electric vehicle policy experts. We also propose a set of actions for China to consider in sustaining its electric vehicle success for decades to come.

Although China's "new energy vehicle" policies have referred to all electric-drive technologies, the analysis below focuses on the dominant technologies in light-duty vehicles, and plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) are together referred to as electric vehicles. In certain contexts, the terms electric vehicles and new energy vehicles are used interchangeably.

2. A RETROSPECTIVE OF CHINA'S KEY ELECTRIC VEHICLE DEVELOPMENT MILESTONES

This chapter provides a historical review of China's new energy vehicle program, including the development of electric vehicles through four key stages up to the end of 2019. The term new energy vehicle has covered the suite of China's policies and programs to support electric-drive vehicle technologies (hybrid, plug-in hybrid, battery-electric, and fuel cells), but as we will describe, there have been shifts in technology emphasis over the years. For each stage, we detail the major strategies, plans, policies, and overarching performance of the electric vehicle market.

2.1 PRE-2009: SEEKING A WORLD-LEADING AUTOMOTIVE STRATEGY

The year 2009 was a milestone in China's electric vehicle development. That year, then President Hu Jintao, in his annual speech to the Chinese People's Political Consultative Conference, declared that developing new energy vehicles "conformed with the nation's current conditions." This formally signaled that developing new energy vehicles was a national strategy.

The first seeds had been planted by the late 1990s. China was long eager to find a "passing lane" for its auto industry to become a global leader. By the early 2000s, China had already built a sizable car industry, but it was more big than strong. The best cars built and sold in China were mostly designed by Western companies and manufactured by foreign joint ventures. After a decade of catch-up, there seemed to still be a major gap between Chinese automakers and their global competitors in conventional internal combustion engine technology. China's accession to the World Trade Organization in 2001 accelerated the opening up of its markets and brought additional pressure to form a new automotive strategy (The State Council Information Office, 2018).

The potential "passing lane" emerged when new energy vehicles were suggested by a chief adviser to China's State High-Tech Research and Development Project. This was also known as the "863 Project," a name that reflects its establishment in March 1986. It had gained prestige for its role in launching China's space program and much of the nation's techno-industrial policy, and the project continued to play an important role until coming to an end in 2016. New energy vehicles put China and its industry leaders on a path to develop advanced automotive technologies, and offered China the opportunity to leapfrog over advanced combustion engine technologies, which dominate markets in the West, straight to zero-emission electric-drive vehicles.

As a result, in 2001, new energy vehicles were incorporated into the 863 Project for the 10th Five-Year-Plan (FYP), China's primary national planning document. China also developed its first new energy vehicle technology roadmap, the "Three-by-Three Research and Development Strategy." It included three new energy vehicle technologies as pillars—fuel cell, hybrid, and electric—and three component technologies: powertrain control systems, driving motors, and batteries. These guided China's new energy vehicle development for the next 15 years.

The 863 Project invested ¥880 million ($135 million[1]), during 2001–2005 and engaged a select group of industry and university partners to develop prototype models under the three main technology paths. These included First Automobile Works (FAW), Dongfeng, Chana, and Chery, which focused on hybrid cars; a partnership between Shanghai Automotive Industry Corporation (SAIC) and Tongji University to develop fuel cell powertrains (China Association of Automobile Manufacturers, 2004); and

1 All conversions shown in round brackets in this paper are based on a conversion rate of 6.5418 CNY : 1 USD as of Dec 3, 2020.

Tsinghua University, Beijing Institution of Technology, Foton, and Beijing Bus Co. collaborating on the development of fuel cells and battery electric buses (Sina, 2002). Notably, the 10th FYP's 863 Project also launched the first group of four city partners, Beijing, Tianjin, Wuhan, and Weihai, around 2004; these were the testbeds for new energy vehicle technologies.

In the 11th FYP, the 863 Project's new energy vehicle program escalated in size and scope, and more regions and industry players joined (Ministry of Science and Technology of the People's Republic of China, 2007). Beyond the technological advancement it spurred, the 863 Project set an important precedent in forming China's unique four-way partnership among government, industry, universities, and research institutions. This partnership has been key to collectively navigating and executing the nation's new energy vehicle strategy. By late 2006, the Energy-Saving and New Energy Vehicle Key Project Advisory Committee was formally established with 13 initial top experts from auto companies, battery and component suppliers, and research institutes.

Also during the 11th FYP, China sought to move new energy vehicles from the laboratory, research and development (R&D), and demonstration phases to production. In 2007, the National Development and Reform Commission (NDRC) released the *Management Rule of New Energy Vehicle Product Market Entrance* (2007), which defined and stipulated the terms and criteria for mass producing new energy vehicle products. The rule allowed manufacturers to commercialize their electric vehicle prototypes. Following that, China debuted 500 home-made new energy vehicles at the 2008 Beijing Olympic Games. At this stage, few domestic Chinese companies had a firm grasp of critical technologies, and the industry had not established a supply chain. While it did not go flawlessly, the Olympics demonstration elevated aspirations and forced domestic automakers to move farther and faster than they otherwise would have. After 2008, China was even more determined to forge a world-class auto industry with new energy vehicles at the center of the strategy.

2.2 2009–2013: REFINING THE STRATEGY THROUGH PILOT PROGRAMS

An automotive strategy linked to new energy vehicles appeared to be well-timed. The global financial crisis in 2008, along with volatile oil prices, affected the energy security and economies of China and other countries. In the United States, the Obama administration launched a massive economic stimulus plan, which included billions of dollars for U.S. clean energy industries (Ball, 2019). This reaffirmed China's commitment to developing new energy vehicles. By 2010, a new energy vehicle industry was prioritized as one of China's top emerging industries of strategic importance (State Council, 2010). With this move, new energy vehicle technologies were further elevated and became a critical part of China's broader mission for a more energy-independent future, even as its mobility demands grew dramatically.

The State Council, China's powerful cabinet, provided another push in March 2009 by issuing the *Auto Industry Adjustment and Revitalization Plan* (State Council, 2009). The plan set forth China's first official goal for massive new energy vehicle deployment: to reach production capacity of 500,000 battery, plug-in hybrid, and hybrid electric vehicles, accounting for 5% of new passenger car sales, by 2012. The central government set aside ¥10 billion ($1.5 billion) for grants and discounted loans to support industry investments. The plan called for establishing large-scale pilot programs with centrally planned electric urban buses, sanitation and mail trucks, and taxis, and then expanding gradually to the commercial and private sectors. China's science and finance ministries jointly launched the "Ten Cities, Thousand Vehicles" program (Ministry of Finance of the People's Republic of China [MOF], 2009) with a vision for 10 cities to add 1,000 new energy vehicles annually, for a total of 30,000 new energy vehicles nationwide over three years.

Thirteen cities—Beijing, Shanghai, Shenzhen, Wuhan, Hangzhou, Chongqing, Changchun, Dalian, Jinan, Hefei, Changsha, Kunming, and Nanchang—were part of the program from 2009 to 2010. The NDRC and the industry, finance, and science ministries jointly administered the program and then approved seven new pilot cities for a second stage: Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan, and Guangzhou. Later in 2010, the ministries approved five more cities for a third stage: Shenyang, Hohhot, Chengdu, Nantong, and Xiangyang (MOF, 2010; Huang, 2010). These 25 pilot cities together represented more than 30% of the national vehicle stock and were the headquarters for many auto manufacturers (Gong et al., 2017). Five of the cities—Shanghai, Changchun, Shenzhen, Hangzhou, and Hefei—were named forerunners in developing private new energy vehicle markets.

Large subsidies were granted to support the implementation of these pilot programs. *The Notice on Implementing Energy Saving and New Energy Vehicle Pilot Program* detailed vehicle eligibility, technical criteria, and subsidy amounts (MOF, 2009). Participating cities were required to match subsidies from the central government for consumer purchases and to build and maintain charging infrastructure. The combined subsidy size from national and local governments was meant to offset the upfront cost difference between new energy vehicles and similar conventional vehicles, and that meant larger subsidies for larger vehicles. For example, battery-electric buses received central subsidies of as much as ¥500,000 ($76,432) per vehicle, and fuel cell buses received as much as ¥600,000 ($91,718) per vehicle.

The subsidy program and its design principles were handed down through the succeeding 10 years with modifications to their associated technical criteria. Between 2009 and 2016, the Chinese central government is estimated to have spent at least ¥12.6 billion ($1.9 billion) on subsidies for new energy vehicles (Ministry of Industry and Information Technology of People's Republic of China [MIIT], 2019a). Considering the matching funding from cities and the billions in additional support that do not show up in these budgets, such as major outreach events like the Shanghai World Expo in 2010 (Tillemann, 2016), the total governmental subsidies for new energy vehicles was substantially greater than the estimated amount. Beyond direct purchase subsidies and R&D investment, there were additional tax incentives. In 2012, MOF and the Administration of Taxation waived the annual vehicle and vessel tax on new energy vehicles (MOF, 2012a) and the purchase tax for new energy buses (MOF, 2012b).

To attract even more financial support, some local governments set more ambitious new energy vehicle development targets than they were assigned in the "Ten Cities, Thousand Vehicles" program. For example, Shenzhen planned to deploy 9,000 vehicles in its public fleets; also for public fleets, Beijing planned to deploy 5,000, Shanghai 4,150, and Guangzhou 2,600. If these local targets were met, China's total new energy vehicles in the public fleet would have reached about 53,000 by the end of 2012 (Gong et al., 2017). Additionally, the five private new energy vehicle demonstration cities promised to have a total of 129,000 new energy private cars on the road in three years.

However, the results from this early pilot program were ultimately dismal. In late 2011, only about 40% of the public fleet goals were met among the 25 cities (Gong et al., 2017). By the end of 2012, only seven had met their 1,000-vehicle target (Economy, 2014). The total number of new energy vehicles deployed in the public fleet was only about 23,000, and 4,000 more were deployed by private consumers (Wei et al., 2013).

In retrospect, there were some clear lessons. The new energy vehicle model offerings were limited, and the early generations of technologies were not mature enough to satisfy real-world operating needs (Wang, 2019). Exacerbating this, local protectionism from some city governments fragmented the early industry by allowing many public fleets and public car buyers to buy the new energy vehicles made in their region only. The R&D activities of manufacturers were dictated by government funding and technical criteria rather than by the market. Despite the substantial financial support, an essential element—a comprehensive charging infrastructure ecosystem—was still minimal.

The hard-learned lessons of 2009–2012 helped clarify China's goals. Leaders saw enough progress to narrow focus down to plug-in electric vehicles, aka BEVs, PHEVs, and FCVs in all subsequent new energy vehicle policies. This left out conventional hybrids. The 12th FYP increased the new energy vehicle R&D budget for the 863 Project to ¥1.4 billion ($214 million) and this was primarily to fund battery technologies (ChinaNews, 2013). The long-term goals were also redefined. In 2012, the State Council published the *Energy-Saving and New Energy Vehicle Development Plan (2012–2020)*; it targeted the annual production and sale of 500,000 plug-in electric vehicles by 2015, rising to 2 million by 2020, and bringing cumulative new energy vehicles to 5 million by the end of 2020 (State Council, 2012). An additional ¥4 billion in special funding was authorized to support the plan's implementation, and the focus was on developing new energy vehicle models and key parts (ChinaNews, 2013). Because of the early setbacks, it was widely recognized that there was a need for another round of stronger policy with incremental adjustments to track market conditions as they emerged and to meet the ambitious goals.

2.3 2013–2017: THE MARKET GAINS TRACTION

When an "airpocalypse" of intense urban air pollution swept across China in the winter of 2013, it further spurred China's nascent new energy vehicle market. To alleviate traffic gridlock, in 2011, the city of Beijing launched a quota system for new car registrations and set an initial annual limit of 240,000 (Beijing Municipal Government, 2011). New car buyers needed to enter a lottery to win a license plate and register a vehicle. Responding to the pollution in late 2013, Beijing announced that it would cut the limit to 150,000 new vehicles starting in 2014, and that 20,000 of the registrations were assigned to new energy vehicles. Going further, the allowance for new energy vehicles steadily increased to 60,000 over the next three years while the total number of new license plates remained the same (Xu, 2013). This essentially required that 40% of Beijing residents seeking new license plates to legally drive there needed to purchase electric vehicles to do so in 2017. This remains among the most effective policies in the world to stimulate electric vehicle sales.

Policy innovation did not stop there. An air quality alert system was created, and in 2015, Beijing issued its first red alert. This limited the use of conventional cars to alternate days, but new energy vehicles were allowed to drive in the central city without restriction. The combination of favorable new energy vehicle treatment in the license plate quota and traffic control policies prompted a rush of new energy vehicle buying. At the end of 2013, Beijing's new energy vehicle deployment was only a few thousand, mostly a legacy from the Olympics clean-vehicle push. By 2017, however, the total shot up to 60,000, and two-thirds of them were private cars. This signaled diminished reliance on government fleet purchases.

Through 2013, new energy vehicles took on greater policy importance. China's environmental ministry highlighted widespread new energy vehicle applications in its 10 principal measures (*Air Pollution Prevention Action Plan*) to achieve healthy air quality (State Council, 2013). Under local pressure and following central government guidance, new energy vehicle targets were soon included in provincial and local clean air plans (Li, 2019). Beijing aimed for 200,000 new energy vehicles by the end of 2017 (Zhou, 2013). "Reducing air pollution" was formally included as a third strategic goal of new energy vehicle development as the subsidy program was extended; this was in addition to the aforementioned goals of a leapfrog for the nation's auto industry and improving energy security. As a result of learning from the past, the subsidy program was revised to ensure governments at all levels prioritized new energy vehicles in their fleets and to reduce local industry protection (MOF, 2013).

In 2014 and 2015, participating cities in the new energy vehicle pilot program climbed from 25 to 88, and cities became the leading edge in developing creative policies to accelerate electrification. Two megacities—Tianjin and Hangzhou—followed Beijing in providing new vehicle registration and road access privileges to new energy vehicles (Li, 2014). Many others offered adequate and affordable charging to electric vehicle owners, and some reduced ownership costs by waiving or reducing annual vehicle and parking fees. Still others promoted car-sharing, rental, and fleet purchases of new energy vehicles (Cui et al., 2018; He et al., 2018). In 2015, the 30 leading cities accounted for 84% of the nation's new energy vehicle market.

The emerging city policies then led to the adoption of new guidelines for local governments. The policies were cataloged in the 2014 *Guidance on Accelerating the Application of New Energy Vehicles* and dispersed for greater adoption (State Council, 2014). The document pushed for the creation of a completely electric vehicle ecosystem by focusing on six areas: building standardized charging infrastructure to match electric vehicle growth; nurturing innovative business models like electric car-sharing; adopting incentives to stimulate purchases; expanding new energy vehicles in all public, government, and corporate fleets; cracking down on local protectionism; and raising consumer awareness. The guidelines were implemented by policies like an expanded central tax waiver (MOF, 2014a), new energy vehicle fleet procurement requirements (National Government Offices Administration, 2014), and charging infrastructure subsidies (MOF, 2014b). China updated its national new energy vehicle subsidy program in 2015 to make it nationwide rather than just in the 88 cities, affirm its continuity through 2020, and signal a gradual phase-down (MOF, 2015).

The emerging new energy vehicle success was evident. More than 300 Chinese cities were actively promoting new energy vehicles, and this was an end to the "Ten Cities, Thousand Vehicles" era and the beginning of a national new energy vehicle market. China's market exploded from 18,000 vehicles in 2013 to more than 330,000 in 2015, making it the world's largest such market. President Xi Jinping mentioned that developing new energy vehicles was the "only way to lead China's auto industry from big to strong" (Yang, 2014). The 2015 release of *Made in China 2025* cemented new energy vehicles as a key strategy of the Xi administration; its purpose was to ensure that homegrown Chinese companies develop world-leading electric vehicles, batteries, and other vital parts production (State Council, 2015a). This seemingly put China firmly on the path to becoming the industrial giant in electric vehicles.

However, whether China's new energy vehicle industry would be big and robust was severely tested in the new energy vehicle subsidy fraud scandal of 2016. At least five manufacturers, mainly bus makers, were caught illegally reaping a large amount of subsidies (Yan & Dou, 2016). This came to light after an independent business magazine exposed a suspicious jump in new energy vehicle sales among some bus manufacturers in December 2015 alone—comparable to several times normal annual production (Chen, 2016). This led to questions of how such a large number of new energy vehicles could be made within such a short time. Soon, it was confirmed through a government investigation jointly conducted by the four new energy vehicle supporting ministries that the companies used a variety of fraudulent methods, including overstating production with incomplete vehicles, forging transaction receipts, bribing car registration authorities, installing dysfunctional batteries, and even reusing batteries in different vehicle bodies (Yan & Dou, 2016).

The embarrassing fraud brought some clear lessons. The policy that was designed to support the new energy vehicle industry ultimately hurt the market. Giving full trust to a fast-growing, profit-driven industry without adequate supervision led to an inflated market, sometimes without real consumers. The huge subsidies did effectively attract innovation and increase scale, but vaguely defined quality requirements also allowed too many gold-diggers and taught policymakers another tough lesson.

Authorities restructured the new energy vehicle subsidy program in late 2016. The subsidies were linked to performance by rewarding greater electric range and higher energy efficiency, both of which require genuine technological advancement. Additionally, the subsidies were set to incrementally ramp down and be phased out after 2020 (Cui et al., 2017). The program added enforcement provisions, including requiring proof of the actual sale and use of the new energy vehicles. Commercial electric vehicles had to demonstrate at least 30,000 kilometers of odometer mileage to receive the subsidy. The government promised random inspections, and fraudulent activities became subject to severe penalties (Cui, 2017). At the same time, China tightened its minimum technology requirements for new energy vehicles following the subsidy scandals. Models must meet more than 40 detailed technical standards—including seven on batteries, two on electric driving motors, four on whole-vehicle safety, and three on energy efficiency to qualify for government incentives (MIIT, 2017a).

As the direct subsidies were being scaled back in early 2017, China introduced an innovative policy that would start in 2019. The new dual-credit system set mandatory standards for increased new energy vehicle production alongside existing fuel efficiency standards, with credit trading between the standards. Under the rule, automakers that produced or imported more than 30,000 conventional-fuel cars annually were required to generate new energy vehicle credits by deploying electric vehicles in addition to meeting corporate fleet average fuel efficiency standards (Cui & He, 2016; Cui, 2018). The new energy vehicle credit requirements were for 10% of companies' conventional car production or import volume in 2019 and 12% in 2020. The actual electric vehicle share of new vehicle sales might be approximately half of those percentages due to electric models getting multiple credits per vehicle. Companies falling behind on their efficiency standards or new energy vehicle requirements can buy credits from greener competitors. These new energy vehicle standards resemble the California Zero Emission Vehicle regulation and resulted from a two-year partnership between experts in China and California called the China–U.S. Zero Emission Vehicle Policy Lab (California Air Resources Board, 2017). The policy underscored a significant shift—from carrot to stick—in China's national new energy vehicle policy.

Also to foster the market, the central government focused on addressing the charging infrastructure barrier. Guidance documents in 2015 set targets for 12,000 public charging stations and 4.8 million home and public charging points. The network would be able to charge 5 million new energy vehicles by 2020 (NDRC, MOF, MIIT, & Ministry of Housing and Urban-Rural Development, 2015). The documents laid a blueprint for a national fast-charging network to link China's megacities (State Council, 2015b). To facilitate this, cities in 2016 were eligible for subsidies of as much as ¥120 million ($18 million) to build charging infrastructure (MOF, 2016).

Vehicle environmental regulations played a crucial role in accelerating electric vehicle market penetration during this time frame. Specifically, China required the corporate-average fuel efficiency of new cars to be less than 5 liters per 100 km (L/100km) by 2020 and less than 4 L/100km by 2025. Between 2016 and 2018, China introduced a set of world-class emission limits for new cars and trucks that forced automakers to apply near-zero emission technologies. These rules, combined with stronger enforcement measures stipulated in China's newly amended *Clean Air Law*, are expected to drive up conventional internal combustion vehicles' costs to meet the standards and, therefore, help bring electric vehicles to cost parity.

In 2017, China announced a longer-term plan to transition to a mainstream new energy vehicle market after more than a decade of learning the hard way. The *Medium- and Long-Term Development Plan for the Automotive Industry* (MIIT, 2017b) set a goal for annual new energy vehicle production to reach 2 million by 2020 and account for 20% of all new vehicle production by 2025. Considering China's vehicle market size, this would mean the annual output of 7 million new energy vehicles in China in 2025, equivalent to the world's cumulative new energy vehicle production from 2010–2019.

2.4 2018–PRESENT: THE MATURING OF THE MARKET

China's electric vehicle market soared in 2018. More than 1 million vehicles were produced and these accounted for more than half of global sales. But other, more critical clues suggest the nation's new energy vehicle industry is maturing as China continues to fine-tune its subsidy, infrastructure, and industrial policies. In this era, the Chinese central government further strengthened its determination to move away from its initial policy playbook for growing its traditional auto industry, which contained subsidies, government procurement, and tariff or nontariff barriers to foreign market entry. Instead, China is increasingly letting the market and competition do more of the work.

The national-level subsidy phase-out, announced in 2015, gathered speed in the 2018–2020 period. Electric cars with less than 150 km of electric range no longer qualified for the subsidy in 2018, and the threshold was raised to 250 km in 2019. Subsidy levels for higher electric ranges were halved, as well (He & Cui, 2019), and this indicated confidence in the industry's ability to sustain itself as new energy vehicle regulations pushed companies to higher production. The new energy vehicle credit requirements for manufacturers are designed to ensure sustained growth throughout the period when subsidies decline. At the same time, government fiscal support is shifting from vehicles to charging infrastructure. Driven by multi-level incentives, China built 770,000 charging posts—one for every four electric vehicles—by the end of 2018 (Ming, 2019). As a result, private electric vehicle buyers began to outpace the public sector and fleet consumers (Ren et al., 2019).

China has also shifted toward greater openness to global competition in the auto sector and key supplier industries. In mid-2018, China said it would abolish the foreign ownership limit on local auto companies and remove the restrictions on new energy vehicle joint ventures (Ministry of Commerce of the People's Republic of China, 2018). Foreign companies making electric vehicles can now manufacture vehicles in China without first forming a joint venture with a domestic counterpart, and this unlocks greater investments. The ownership limit was put in place 25 years ago to compel foreign companies to bring their technologies in exchange for access to the Chinese market, and it helped then-weak domestic automakers to mature.

The new policy spurred increased investment by global automakers. Through 2018, foreign brands had a small presence in China's electric market, with a share of about 5% (MacDuffie & Shih, 2019). A month after the 2018 rule was issued, Tesla agreed to build its Shanghai electric vehicle factory in the city's newly approved Lingang free-trade zone (Ding, 2019).

China's rapid electric vehicle development, its remarkable electric vehicle market size, and its increasingly open policies are also shaping traditional auto giants' strategies internationally. Traditional carmakers have expanded their partnerships in China. BMW joined with Great Wall Motors to produce an electric version of its Mini brand in China (BMW, 2018). Volkswagen is investing €4 billion in 2020 in China, with around 40%

going toward e-mobility (Volkswagen, 2019). Volkswagen sees China as its top market, with more than half of its global 4 million annual battery electric vehicle volume there by 2028 (Witter, 2018). Toyota is catching up on electric vehicles and mobility momentum with new partnerships with BYD, CATL, and Didi (Toyota, 2019a; Toyota, 2019b; Toyota, 2019c). This is a broader trend: Of a total of $300 billion in global electric vehicle investment, $137 billion has been poured into China, with about half from European automakers (Lienert, Shirouzu, & Taylor, 2019; Lienert & Chan, 2019).

In addition to global players, this era also features the sprouting and blooming of Chinese domestic electric vehicle startups, and with this unprecedented innovations. A key milestone in China's electric vehicle industry's history is when Nio became the first Chinese electric vehicle manufacturer listed on the New York Stock Exchange in 2018. Increasingly, non-state-owned brands like BYD, Nio, Li Auto, and Xpeng are capturing the attention of the global auto industry, and they represent new forces of auto manufacturing in China. Today, some of these companies are becoming the most successful fundraisers in the global stock market. They are often referred to as rivals of the United States-originated electric vehicle leader Tesla. This did not happen in the Chinese traditional car industry ever. New collaborations and business models are also emerging, such as the investment from internet giants Baidu and Tencent in Nio, from Alibaba in Xpeng, and SAIC and Alibaba's collaboration on vehicle infotainment system; these are driven by the trend of intelligent and connected electric vehicles, and all the revolutionary service solutions they offer to electric vehicle users.

Now, the competition will grow fiercer. China's 2018–2019 policies helped level the playing field between domestic electric vehicle makers and their foreign rivals. This has helped improve China's overall business environment ranking globally from 78th to 46th (Koty, 2018). In turn, the "catfish effect," making weaker competitors better themselves with the introduction of a strong competitor, will push China's electric vehicles and battery suppliers.

"Some will fall, some will survive, not all will thrive … That will be left to the market to decide," said a senior leader from the Chinese industry ministry in response to the recent market downturn and potential competition and challenges facing China's electric vehicle industry (Yang, 2019). In any case, China is determined to join—if not lead—the global auto industry's green leap toward electrification.

Figure 1 depicts China's remarkable electric vehicle development history, highlighting how the various strategic and planning milestones line up with the new energy vehicle policy milestones, incentives, and electric vehicle growth.

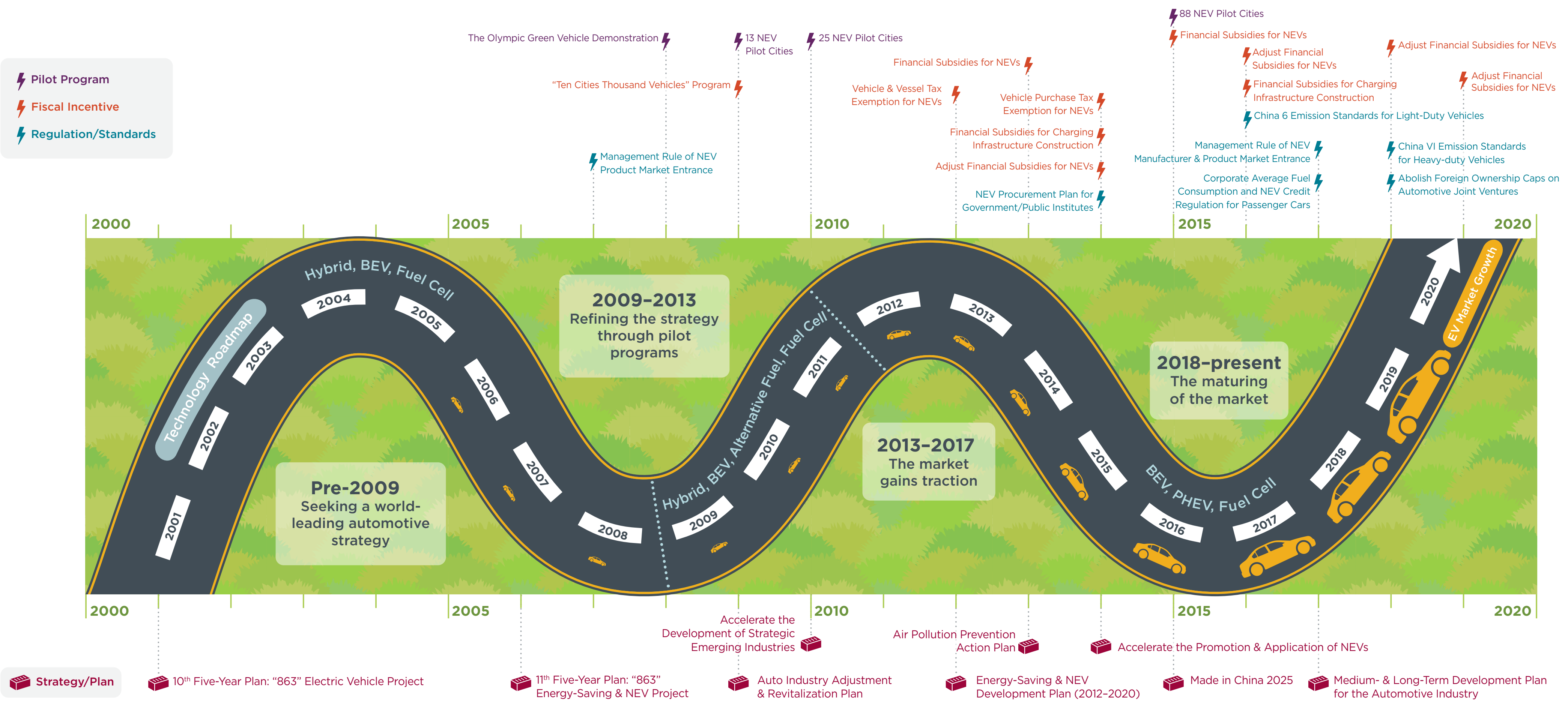

Figure 1. Comparison of key electric vehicle development indicators in the four historical stages.

3. ELECTRIC VEHICLE MARKET AND PRODUCTION

This chapter critically investigates the 10 years of China's new energy vehicle development in terms of the electric vehicle market and production. The analysis shows China is the world's largest producer of electric vehicles and is home to the majority of top electric vehicle city markets in the world. The analysis also reveals that China's electric vehicle development strategy is mainly focused on its domestic market, and this has created numerous domestic electric vehicle brand champions, but no strong global brands.

3.1 NATIONAL MARKET

China surpassed the United States to become the world's largest electric vehicle market in 2015 and it maintained its leading position through the end of 2019 (Figure 2). In 2019, China sold 1.2 million light-duty electric vehicles, or 52% of the world total. China is also the country with the largest electric vehicle stock. By the end of 2019, China's cumulative light-duty electric vehicle sales reached 3.7 million, accounting for 47% of the global stock (EV-volumes, 2020). Still, it is worth noting that in the first eight months of 2020, Europe experienced tremendous electric vehicle growth as a result of tightened CO_2 emission standards for new cars and COVID-19 stimulus policies. In this period, Europe sold 570,000 plug-in cars, and that is an approximately 50% increase compared with same time span in 2019. In comparison, China sold 592,000 electric cars, approximately 25% fewer than the same period in 2019. The United States' plug-in car market also contracted by 22% and only sold 167,000.

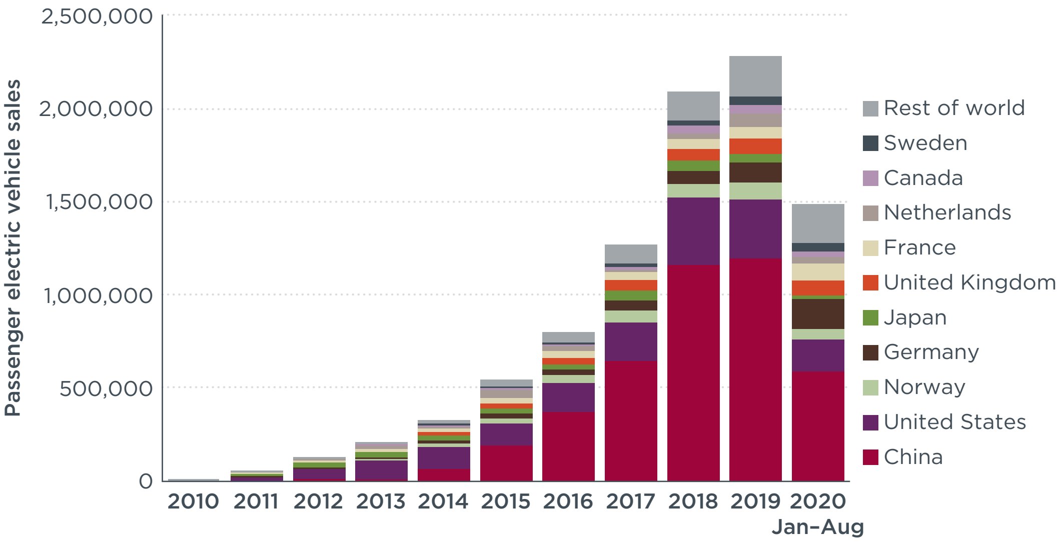

Figure 2. Global light-duty electric vehicle sales from 2010 to August 2020 by market.
Note: Based on EV-volumes (2020).

The market share of light-duty electric vehicles in China has kept rising in the past decade. Figure 3 presents the electric vehicle share of new light-duty vehicle sales in seven of the top 10 national light-duty vehicle markets from 2010 to August 2020 and the global average for comparison. Three of the top 10 markets—India, Brazil, and Russia—are not shown, as they had negligible electric vehicle share. China was below the global average through 2013 but quickly overtook other markets from 2014 to 2018. In 2019, China achieved an electric vehicle share of 5.3%, which was more than double the global average and the highest among the top vehicle markets; it was followed by the United Kingdom with 3.4% and Germany with 3.1%. Note, however, some of the smaller vehicle markets, such as Norway with 58%, Iceland with 25%, the Netherlands with 15%, and Sweden with 12% of electric vehicle shares in 2019, were not included in this analysis.

Starting from 2020, major European car markets saw significant increase in electric vehicle market penetration. By August 2020, the United Kingdom, Germany, and France all surpassed 7% electric vehicle market share, a significant rise from their 2019 levels. Meanwhile, in China in the same period, the electric vehicle market share fell to 4.3%, and the United States roughly kept at the same level as in 2019.

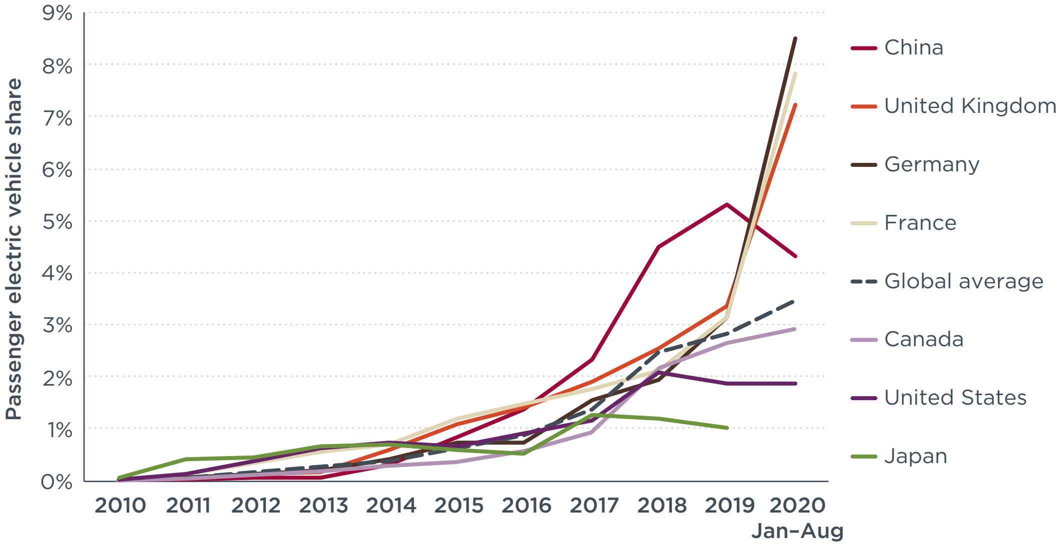

Figure 3. Electric vehicle share of new light-duty vehicle sales for the largest light-duty vehicle sales markets from 2010 to August 2020. *Note*: Based on EV-volumes (2020).

Although this report focuses on light-duty vehicles, heavy-duty vehicles also present a great opportunity for China to further electrify. Electrification of the commercial truck segment is still nascent, and the policy tools for electrifying these vehicles are far less than those for cars, despite of their disproportionally large contribution to the nation's air pollution, climate pollutant emissions, and oil consumption. New electric sanitation vehicles constituted 1.7% of sales in 2019, and electric dump trucks and tractors were less than 1%. For buses, China has made great progress in electrifying urban buses, but further efforts need to be made to electrify coach buses, as electric coach buses were less than 4% of new vehicle sales in 2019.

3.2 NATIONAL PRODUCTION

Via its new energy vehicle policies, China has sought to be both the world's largest electric vehicle market and world-leading from an industrial production standpoint. Figure 4 shows how light-duty electric vehicles were deployed globally for 2010–2019, according to where sold (vertical axis) and produced (horizontal axis). It indicates that China's light-duty electric vehicle market is relatively self-sufficient and isolated as there are relatively low numbers of imports and exports. Globally, 79% of light-duty electric vehicles were sold in the same region where they were produced; this means that most automakers are moving production to be close to markets and that overall trade involving electric vehicles has been limited. China exported less than 1% of its light-duty electric vehicle production, and that is small compared with other major markets. Japan exported around 451,100 light-duty electric vehicles, or 66% of its production, and South Korea, 204,000, or 74% of production. The United States exported 35% of its electric vehicle output, and Europe, 17%. China thus has plenty of opportunities for expanding electric vehicle shipments abroad as markets grow and competition increases.

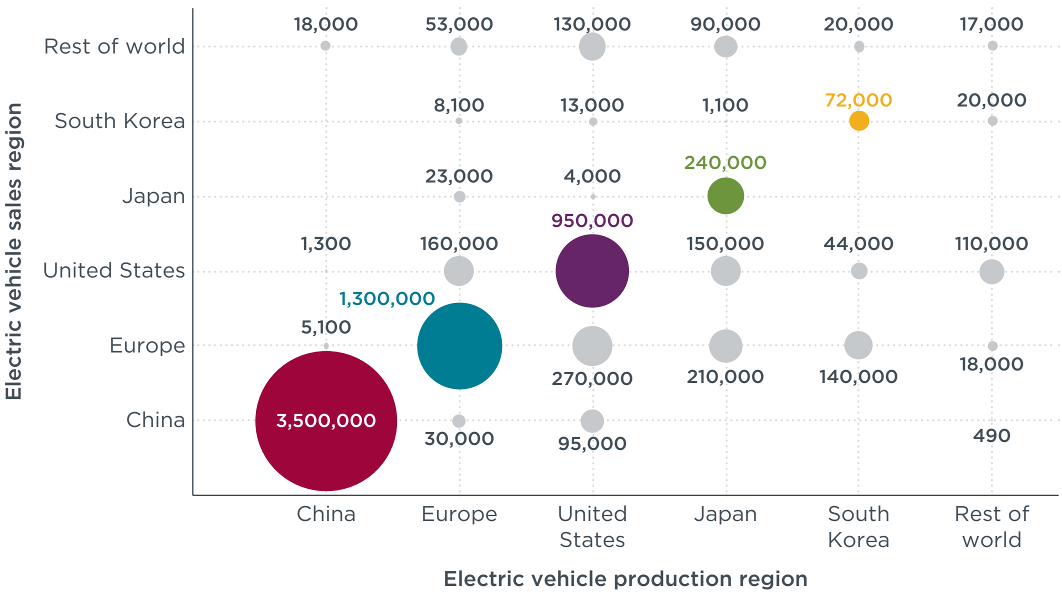

Figure 4. Total new 2010–2019 light-duty electric vehicles deployed by where were sold (vertical axis) and produced (horizontal axis). *Note*: Based on EV-volumes (2020).

Another way to put China's progress in perspective is by examining the auto companies based in each country that have reached higher levels of light-duty electric vehicle sales. Figure 5 shows auto companies that have reached a large economy of scale in global sales (i.e., greater than 200,000 cumulative sales globally). The colors of bars represent where the original equipment manufacturer (OEM) headquarters are for each model. Of the 13 auto companies that have reached a large economy of scale, four were Chinese brands. These are BYD, BAIC, Geely, and SAIC. Other regions have two to three brands that made the top 13, and these are the United States-based Tesla and General Motors, Europe-based BMW, Volkswagen, and Renault, and Japan-based Nissan, Mitsubishi, and Toyota.

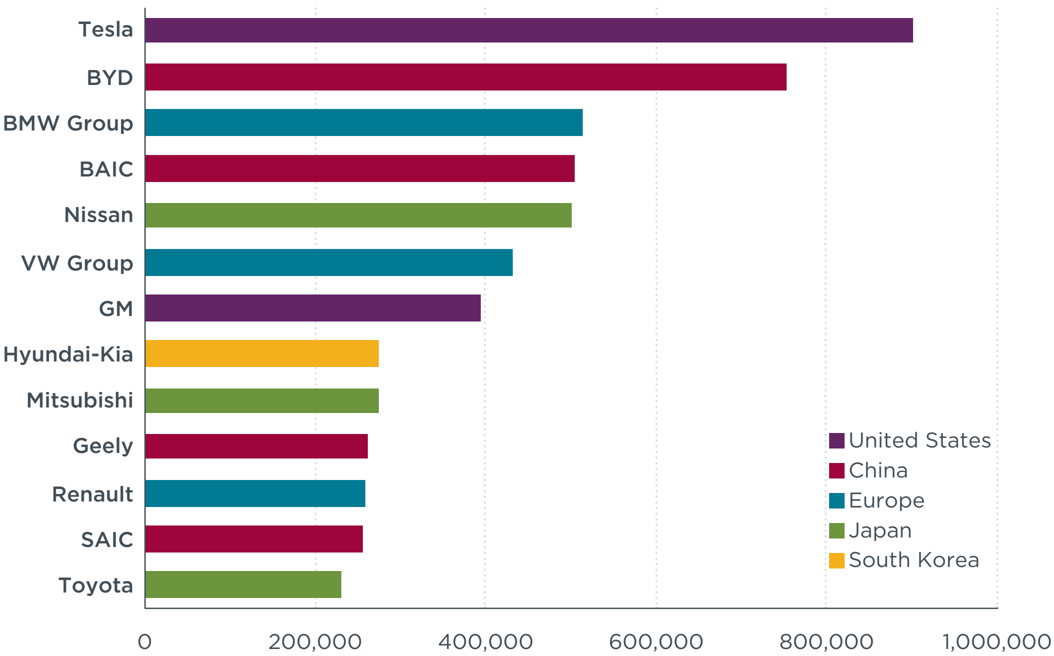

Figure 5. Leading manufacturers in terms of cumulative global light-duty electric vehicle sales 2010-2019. *Note:* Based on EV-volumes (2020).

Figure 6 shows the top 20 models based on cumulative light-duty electric vehicle sales from 2010 to 2019. The colors of bars represent where the vehicle assembly countries are for each model. Though that the Nissan Leaf and BMW 5-Series vehicles are produced at different assembly plants, we treat Nissan Leaf as a Japanese model and BMW 5-Series as a European model below for simplicity. Of the top 20 models with the most cumulative electric vehicle sales from 2010 to 2019, 9 are Chinese models, and that compares with 4 each in the United States and the European Union, and 3 in Japan.

Although some China-based companies have taken advantage of the huge domestic market and have grown into the world's leading producers (Figures 5 and 6), these Chinese brands have few exports. They do not have the same level of brand effect as some of the other major companies. One reason for this is that the China market has far more companies competing, and major powerful passenger vehicle brands that appeal to both domestic and global consumers have yet to be formed.

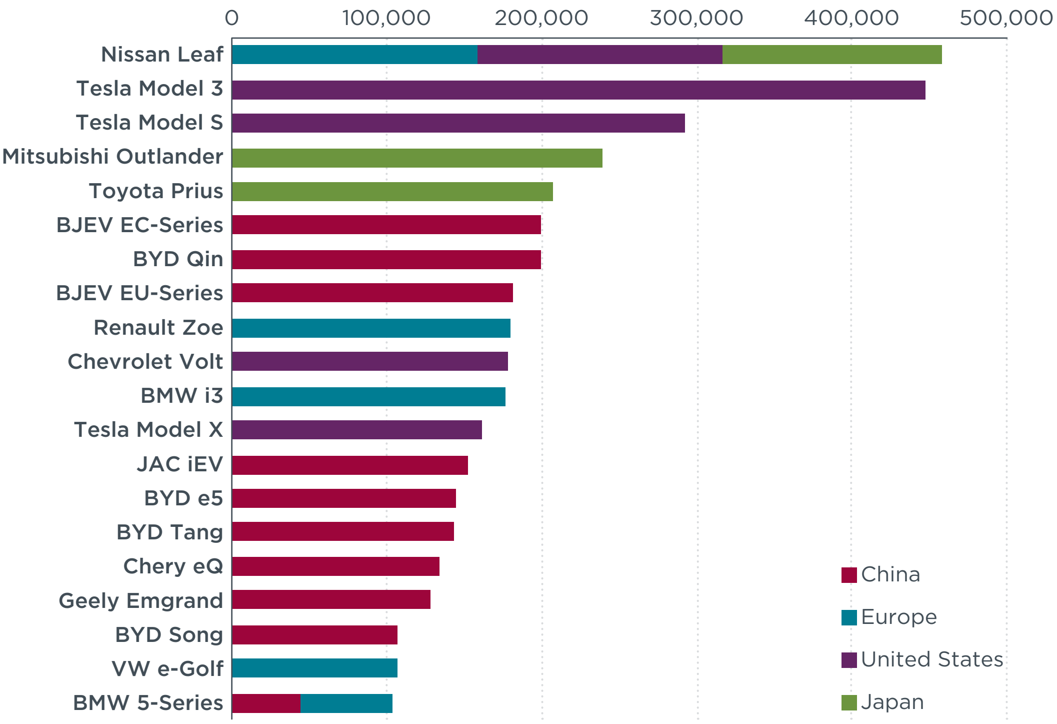

Figure 6. Top light-duty electric vehicle models sold in terms of cumulative global sales 2010–2019. *Note*: Based on EV-volumes (2020).

Though the focus of this report is the light-duty vehicle sector, the above statement was only relevant to light-duty electric vehicles. Chinese brands do have international influence in the commercial vehicle market. For example, BYD accounts for more than 20% of the European battery-electric bus market, and more than 65% of the Chilean market and nearly 30% of the Japanese market.

3.3 LOCAL MARKET

Since China's initial "Ten Cities, Thousand Vehicles" program in 2009, cities have consistently been the frontier for accelerating electrification in China. Guided by the central government and sometimes provincial governments, cities develop goals and plans and then create and implement a suite of policies to support them. Cities are where the most innovative and aggressive policy measures have begun, and they are later followed by other cities. Many cities provide substantial financial support for electric vehicle purchases on top of the central government subsidies. As highlighted earlier, other powerful city tools include giving electric vehicle owners special privileges in acquiring license plates and access to the urban core when other vehicles are restricted (Cui et al., 2018; He et al., 2018).

The leading China markets compare favorably with the most successful electric vehicle markets globally. Figure 7 shows cumulative electric car sales through 2019 in the 25 metropolitan areas worldwide with the highest totals (Hall et al., 2020). China is home to six of the top 10 local-level markets by absolute cumulative electric car sales—Shanghai, Beijing, Shenzhen, Hangzhou, Guangzhou, and Tianjin—and 14 of the top 25. Shanghai ranks first with more than 310,000 electric car sales through 2019, followed by Beijing with 300,000. The figure also shows the electric vehicle share of new car sales in 2019 (right axis). In terms of electric car shares, Liuzhou, with 24%, follows the Norwegian cities of Bergen, 67%, and Oslo, 64%, to rank third globally. Of the 13 major cities shown with more than a 10% electric share, seven are in China. As a result of China's promotion of BEVs as a major strategy in restructuring the auto industry, the sales and model availability of BEVs far outweigh PHEVs.

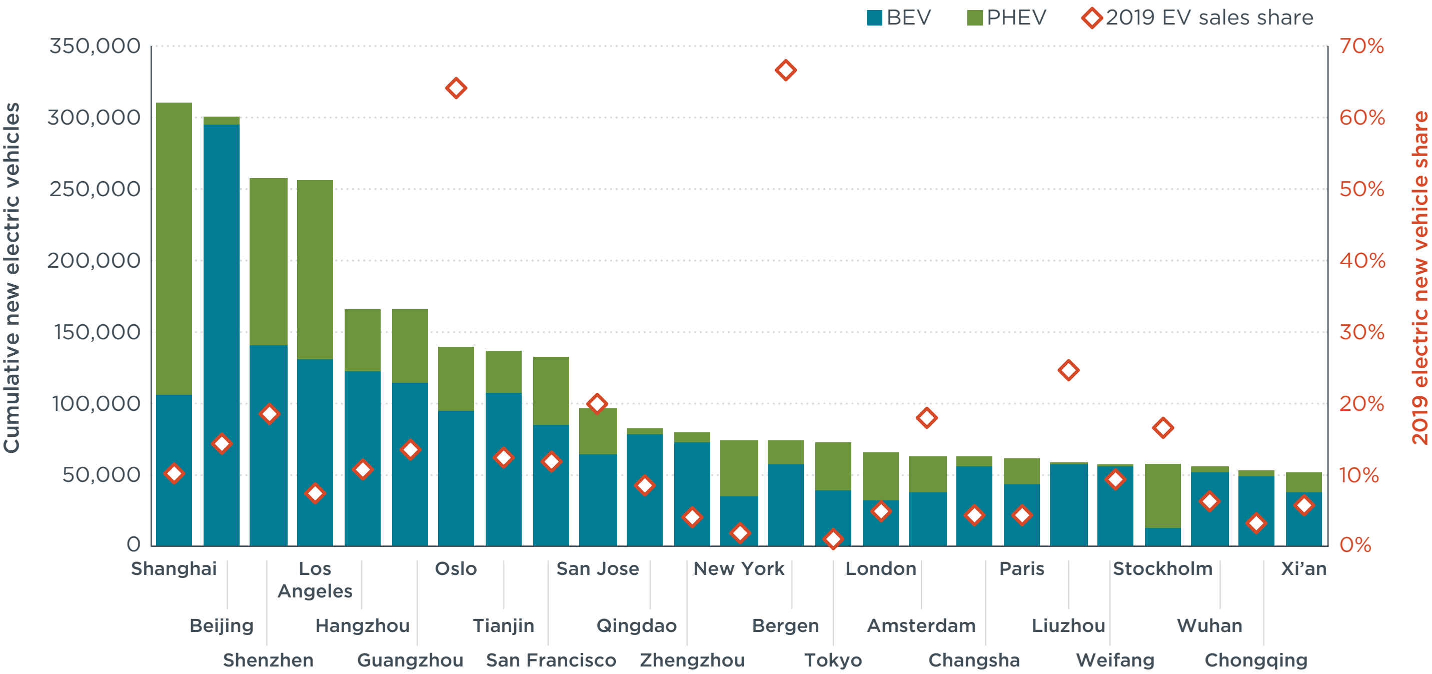

Figure 7. Cumulative electric car sales through 2019 and 2019 electric vehicle share of new car sales in the 25 cities with the most electric cars.

4. SUPPLY CHAIN

After decades of state investment, China has a wide lead over the United States and Europe in batteries and has built up a relatively complete and strong electric vehicle supply chain. From a research and development perspective, China performs well in its number of patents in several areas, including charging, BEV, and universal technologies. China has considerable production and reserves of some vital raw materials and has been very effective in filling in supply chain gaps where it does not have raw material resources; this has been achieved via investment overseas to secure raw materials or build up capacity in chemicals conversion and midstream products. Further down the supply chain, China is the leader in battery capacity, both in terms of number of electric vehicle sales with Chinese batteries and total battery cell production capacity. China is also the only country that has a dedicated policy and specific guidelines for recycling new energy vehicle batteries. However, there is a significant gap between China and its international rivals in the development of other key components along the supply chain, including semiconductors.

4.1 TECHNOLOGY PATENTS

Figure 8 shows the share of the number of patents by technology for key markets (Chen et al., 2019). This metric can reflect R&D efforts and which countries hold vital technologies. China has a significant advantage in fast charging and wireless charging, with half of the patents in these two areas. Though less impressive than its leading role in charging technologies, China also has about a quarter of all patents in BEV and universal technologies, second only to Japan. However, in PHEV and FCV technologies, China has less than 5% of the total patents. Japan is the leader in all but charging technologies in terms of patents, especially in FCV, PHEV, and hybrid electric vehicle (HEV) technologies, where it has about half of the patents.

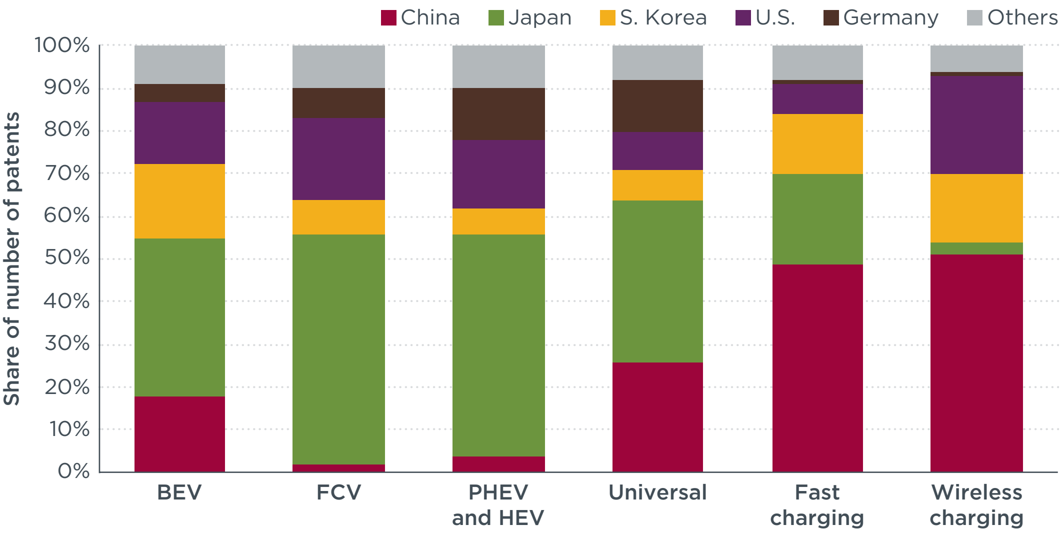

Figure 8. Share of electric-drive vehicle-related patents by technology in major markets, 2018. Data from Chen et al. (2019).

4.2 BATTERY RAW MATERIALS AND CHEMICALS

Current raw materials production is concentrated in just a few regions of the world. Figure 9 shows the region's share of 2019 production of key raw materials used in electric vehicle batteries on the left half of the circle and that same region's share of reserves on the right half of the circle (Slowik et al., 2020). The biggest producers of lithium are Australia (54.5%), Chile (23.4%), and China (9.7%). The Democratic Republic of Congo stands out as the primary producer of cobalt, with over 70% of production and more than half of global reserves. Nickel mining is concentrated in Indonesia and the Philippines. China accounts for 4% of nickel production and 3.1% of reserves. Over 60% of rare-earth metals and natural graphite are produced in China, and China also has considerable reserves.

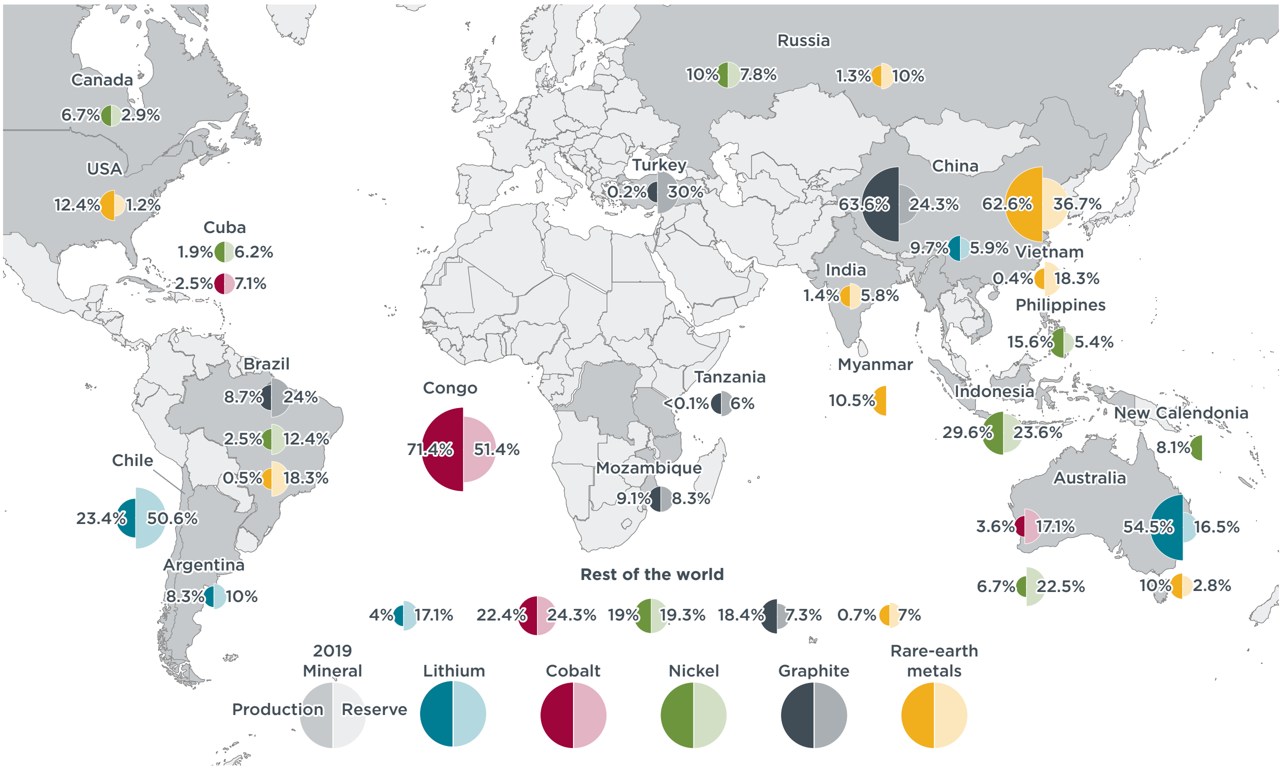

Figure 9. Global distribution of known raw material reserves as of 2019 production.
Source: Slowik et al. (2020).

While the regions included in Figure 9 are where the mines are, it can be a different story as to who owns the mined materials. Chinese companies have been making investments in the mining sector overseas to secure raw materials supply. For example, Tianqi, a Chinese manufacturing company, controls over half of the shares in Talison Lithium in Greenbushes, Australia, and about a quarter of SQM, which owns the lithium mine on the Atacama salt flats in Chile. Jiangxi Ganfeng controls about half of the Mount Marion lithium project in Australia and over 80% of the Mariana lithium brine project in Argentina (Sanderson, 2019). China's global production share of lithium increases to 28% when considering China's ownership of foreign production. Similarly, China's share of cobalt production jumps from a negligible share to 23% when adding up its ownership shares overseas (McKinsey & Company, 2019).

In order to become the batteries used in electric vehicles, raw materials go through a series of steps in the supply chain. These include mining, chemical processing, cathode and anode production, cell manufacturing, and final application. Chemical processing is one of the highest value areas along this supply chain, as is cell manufacturing.

Figure 10 shows China's global supply share in midstream products such as chemicals, cathode, and anode (Kumar, 2020). It is clear that China is the leader in building capacity in these markets and has done a very effective job of filling in the supply chain gaps where it does not have raw material resources. China accounts for 51% of lithium chemicals supply, 62% of cobalt chemicals supply, and 52% of nickel supply. These are the three key elements that go into the cathode. As a result, China accounts for 61% of the global cathode supply. Since China has the biggest mine production of graphite, it takes up 86% of all anode supply made by either natural or synthetic graphite (Benchmark Minerals Intelligence, 2020).

Lithium is the most essential element required in all major battery chemistries. Of the five major Tier 1 chemical manufacturing companies that supply lithium chemicals—Albemarle, Ganfeng, Tianqi, Livent, and SQM—four have chemical conversion assets in China.

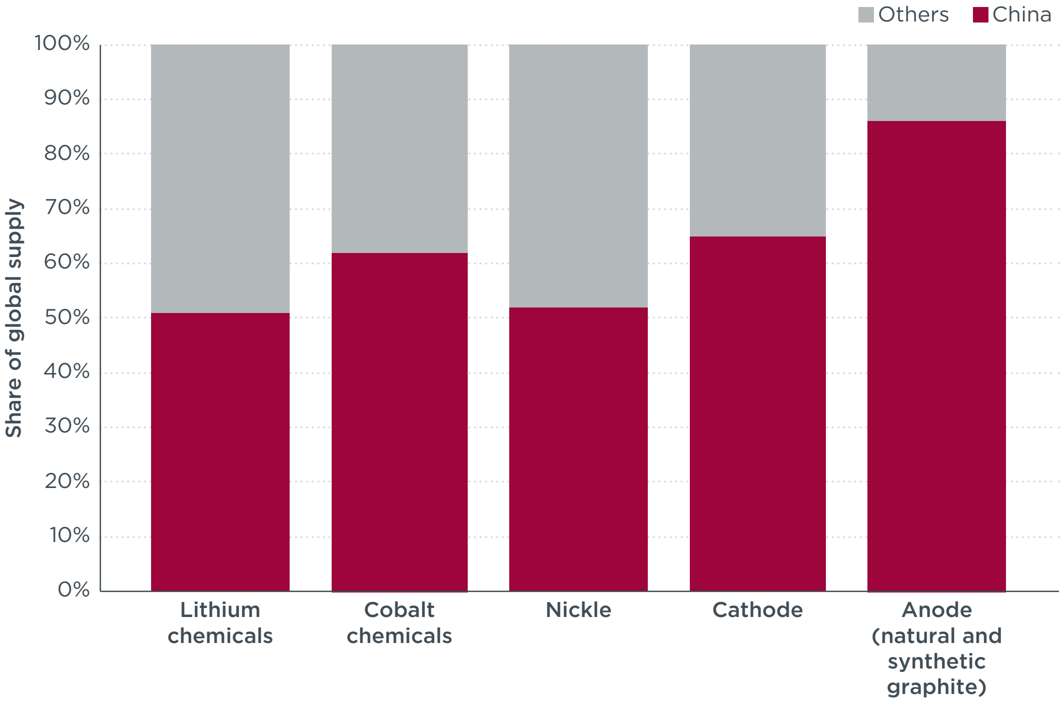

Figure 10. China's share of global supply in midstream products of electric vehicle batteries.

4.3 BATTERY SUPPLY

Battery production

Figure 11 depicts the historical light-duty electric vehicle sales by battery supplier headquarters (Slowik et al., 2020). The share of electric vehicle sales by Chinese battery suppliers has grown from less than 10% in 2012 to approximately half of total sales since 2017. Meanwhile, the share of electric vehicles with Japanese batteries has dropped over the years due to the strong growth in China's domestic electric vehicle market, which is dominated by batteries made by Chinese companies.

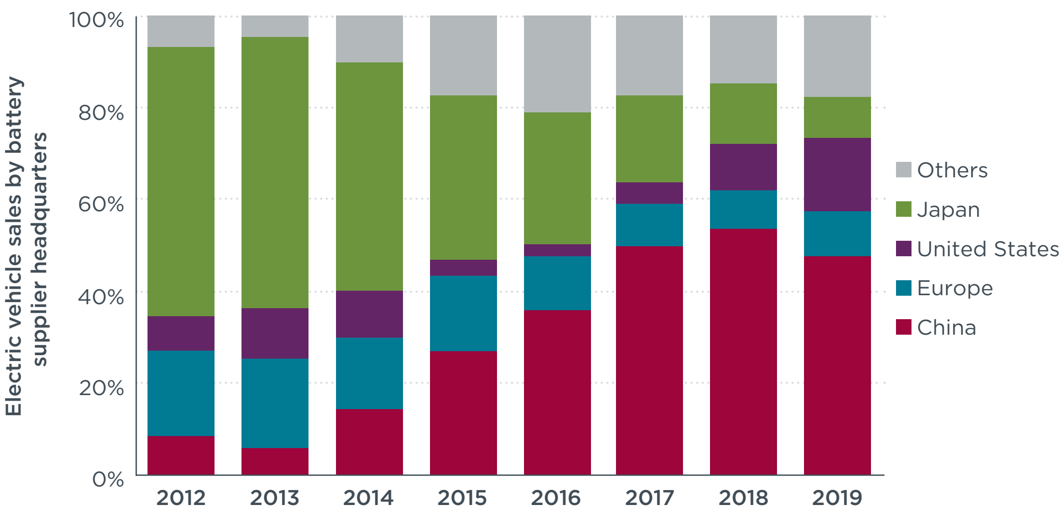

Figure 11. Light-duty electric vehicle sales by battery supplier headquarters.

Figure 12 shows the estimated announced battery production capacity in gigawatt hours (GWh) from 2019 to 2025 (Slowik et al., 2020). China is the leader in battery cell production capacity and is likely to remain so in the future. China provided a third of global battery production capacity in 2019, and this share is expected to stay stable through 2025. Global battery capacity is expected to exceed 1,000 GWh in 2025. China, Europe, South Korea, the United States, and Japan, which account for 80% of the total capacity, are expected to continue dominating the market.

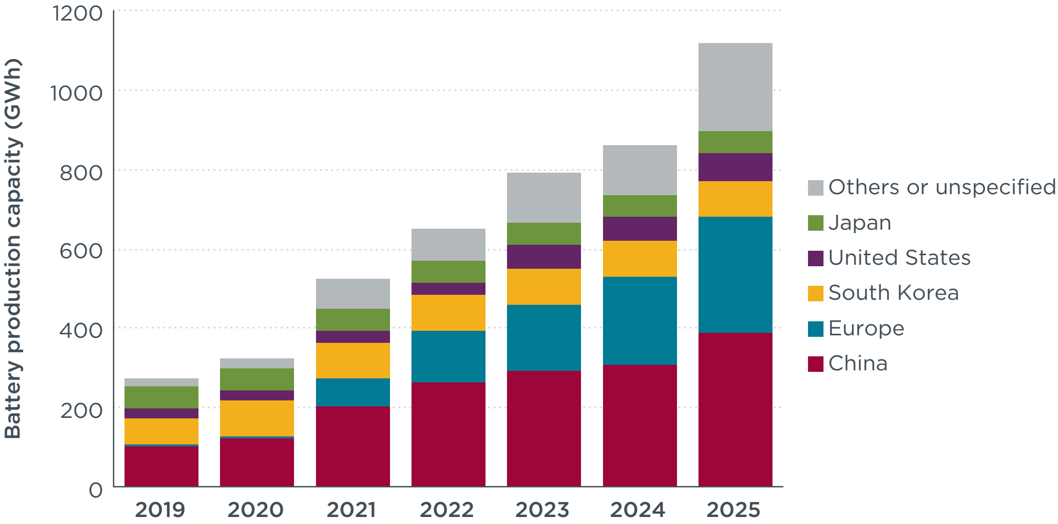

Figure 12. Estimated announced battery production capacity for 2019–2025, by region.

Battery recycling

Battery recycling practices will have a profound effect on long-term zero-emission vehicle (ZEV) battery material supply. Although many countries have had end-of-life vehicle or battery recycling policies for many years, vehicle traction batteries are generally not explicitly addressed in these regulations. China is the only country that has a dedicated policy on new energy vehicle batteries recycling and specific guidelines (MIIT, 2019b).

As indicated in Figure 13, the total spent battery recycling capacity exceeded 98,000 metric tons in 2018 globally, and most of those were lithium-ion batteries (Mayyas et al., 2018). European countries account for about half of these capacities, while China accounts for approximately a third. The United States follows this at around 10%, and Canada and Japan are both at around 6%. It is estimated that China's recycling of traction batteries could reach 20,000 metric tons, or 27 GWh in 2020, and 80,000 metric tons, or 110 GWh in 2025 (New Energy Battery Recycling Professional Committee, 2020). To deal with the challenges of securing raw materials and reduce cost, efforts need to be made to reuse and recycle batteries in the next decade as more electric vehicles reach the end of life.

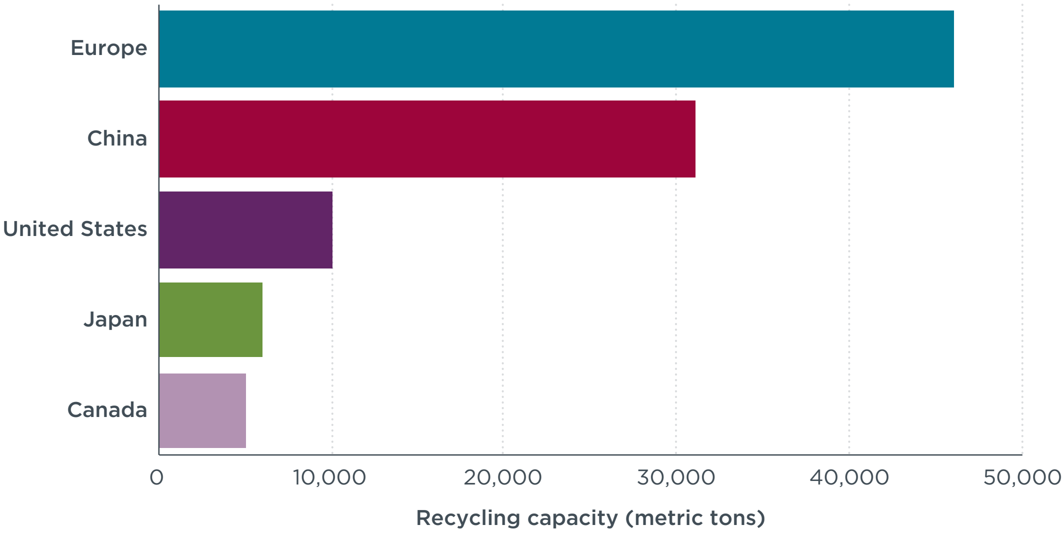

Figure 13. Recycling capacities of spent batteries in metric tons, 2018.

4.4 SEMICONDUCTOR PRODUCTION

Semiconductors are widely used in electric vehicles, and they support vehicle power systems and auxiliary digital functions. Electronic control of the vehicle power system needs semiconductor products to realize current control (EV100 Plus & Roland Berger, 2020). High-performance semiconductor products could reduce energy loss, allow faster battery charging, and lower battery costs (EV100 Plus & Roland Berger, 2020; Askren & Andress, 2020). Vehicle auxiliary functions such as navigation assistance, autonomous driving, vehicle software updates, and other touch-screen activities, also need hardware support from semiconductor products like blind-spot sensors, onboard cameras, and high-performance chips for screens (Manufacturing Business Technology, 2018).

Despite the significance of semiconductor products' application in making more efficient, affordable, and multi-functional electric vehicles, automobile semiconductor production is still China's weak link. As Figure 14 shows, in 2019, only one Chinese automotive semiconductor company made the global top 20, and the United States, Europe, and Japan are the key players for automotive semiconductor production. The global automotive semiconductor industry is very mature, combined with high barriers of establishing supply chain and going through product verification cycle, this makes it difficult for new enterprises to build scale. Additionally, on product sales revenue, China fell far behind Europe and the United States in 2019. Mainland China's $1 billion in revenue in 2019 was merely 2.5% of the global automotive semiconductor industry.

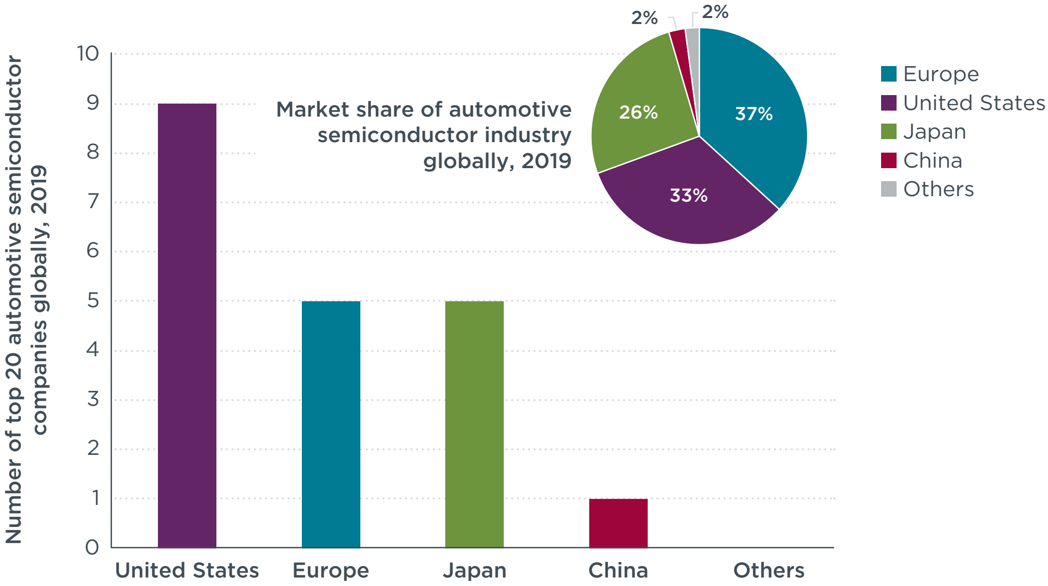

Figure 14. The global top 20 automobile semiconductor companies and their market share by revenue, 2019. *Note:* Figure is recreated with data from China EV100 and Roland Berger (2020).

5. TECHNOLOGY ADVANCEMENT

China's decade-long pilot and central subsidy programs were designed to drive the advancement of electric-drive vehicle technologies. Specifically, after 2015, the central subsidy was closely tied to vehicle performance parameters such as electric range, energy efficiency, battery energy density, and power output. As a result, vehicle and battery technologies have been evolving with noticeable improvements in several key technology and performance indicators. This section's analysis shows that while micro cars remain the largest vehicle segment in China's electric vehicle market, their market share has been shrinking in the past 5 years. Meanwhile, sport utility vehicles (SUVs) have gained substantial growth. The average vehicle battery capacity has increased by about 23% from 2010 to 2018. Battery technologies are shifting away from lithium iron phosphate (LFP) and to lithium nickel manganese cobalt oxide (NMC); this is partially driven by cost control considerations, but most dominantly by policies that favor longer range and higher energy density.

5.1 VEHICLE SEGMENTATION

Figure 15 shows light-duty electric vehicle sales in key markets from 2010 through 2018 by vehicle segment. Inexpensive micro electric cars have contributed the most to China's light-duty electric vehicle market growth in the past decade, but this trend is diminishing. The share of microcars in light-duty electric vehicle sales in China has decreased from 72% in 2013 to 54% in 2015 and 33% in 2018. This reflects the historical evolution of China's electric vehicle industry from one angle. Before 2015, the technical requirements for electric vehicles to qualify for the central subsidy were not stringent enough to drive production of mainstream models by major automakers. These early policies turned out to benefit niche vehicle manufacturers who produced neighborhood or off-road microcars. These companies were able to quickly adapt their production lines to produce micro electric vehicles. After 2015, the technical criteria for the subsidy policy and recently also the new energy vehicle mandate policy have demanded longer electric range and greater battery capacity. This has promoted larger, mainstream vehicle models. It is also the case that market demand for electric SUVs and multi-purpose vehicles (MPVs) was also increasing, similar to the general trend of conventional fuel light-duty vehicles (Yang, 2018). The contribution of electric SUVs and MPVs to China's light-duty electric vehicle sales increased from 6% in 2014 to 21% in 2016 and 35% in 2018.

In the early years, microcars were also popular in Japan, Europe, and the United States. But these markets quickly began to turn to full-size cars and SUVs. The reasons behind the shrinking microcar segment in these markets vary. One important reason is that, in the early 2000s, though microcars accounted for a large share in some countries, the total absolute sales were not many—from a few hundred to at most a few thousand. As the technology matured and more models came to market, consumers had more choices, and thus demand shifted to other segments. Another reason is that city cars in Japan and Europe are treated as microcars here for global comparison. Still, they have always existed for conventional vehicles and are a category of passenger cars. For example, in Europe, city cars have constituted about 10% of annual sales since 2010 (Bieker et al., 2019). Mitsubishi's i-MiEV in Japan, which stopped production after 2015, and Renault's Zoe, Smart's Fortwo, and Smart's Forfour in Europe made up most of the micro electric vehicle sales in these areas. Meanwhile, in China, the microcar is not a mainstream conventional vehicle category and mainly exists for electric vehicles nowadays.

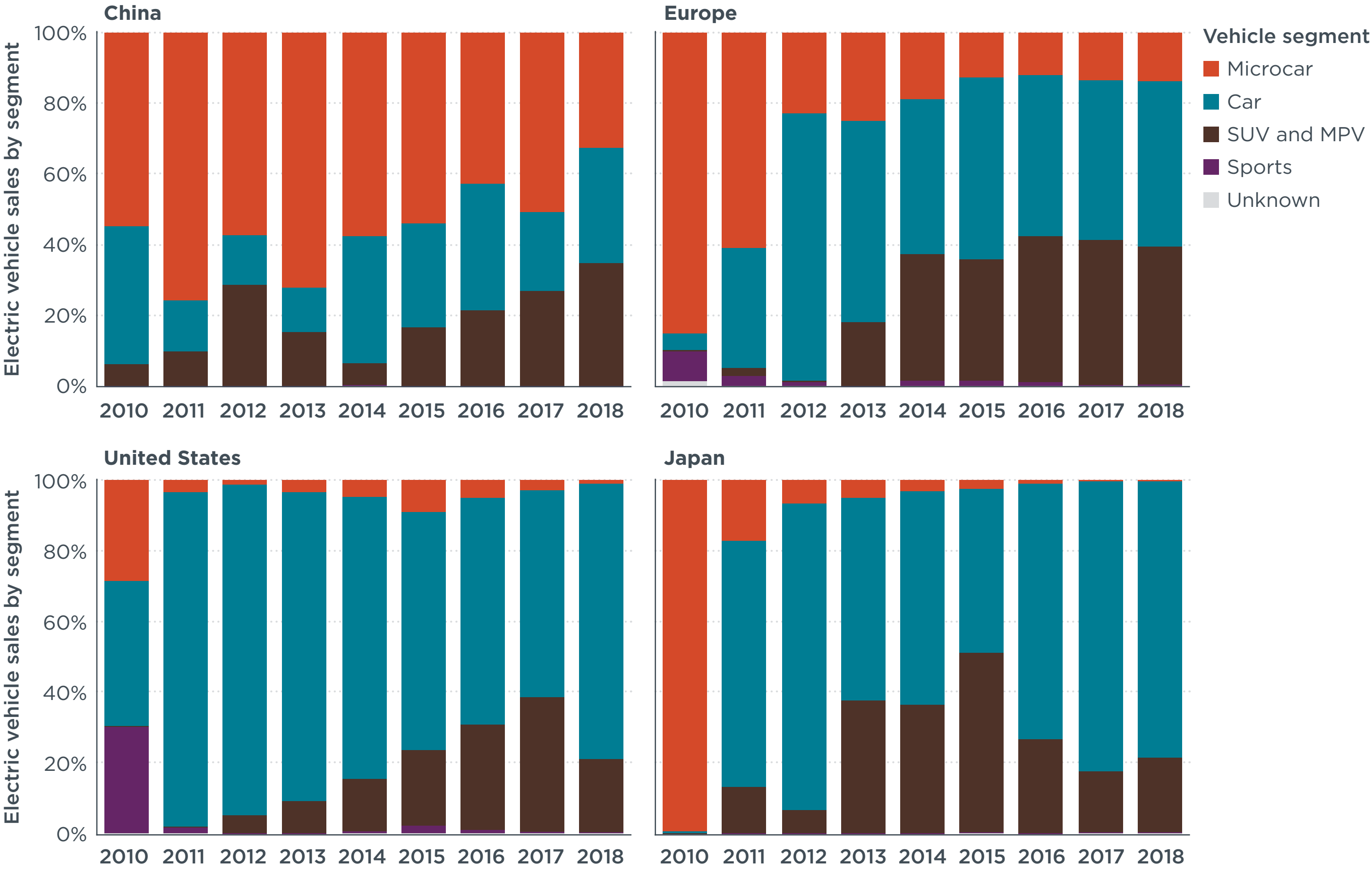

Figure 15. Light-duty electric vehicle sales by market from 2010 to 2018 by vehicle segment.
Note: Based on EV-volumes (2020).

As the Chinese electric vehicle market increasingly opens to foreign brands, the latest trend shows that Chinese brands are losing to their foreign competitors in some of the most profitable vehicle segments. Figure 16 shows electric vehicle sales by brand origin in the first half of 2020, after the Chinese market opened up to more foreign brands. Domestic brands were dominant in the sales of electric microcars (A00), small cars (A0), and compact cars (A), and foreign brands began to win the market for larger car segments (B, C). Many of the high-end luxury cars fall in these two segments. For example, Tesla took up almost 80% of sales in segment B, and Mercedes-Benz, Audi, and BMW accounted for more than 90% of sales in segment C in the Chinese market. For SUVs and MPVs, Chinese electric vehicle new entrants are starting to have impact by offering high-end luxury models and competing with international brands. BYD, NIO, Li Auto, WELTMEISTER, and Xpeng, the best-selling electric vehicle new entrants, took up 56% of the electric SUV market. Overall, domestic brands dominated electric SUV and MPV sales in China, with over 85% of the market share in the first half of 2020. While vehicle sales were affected by COVID-19 in this period, we expect that consumer preferences for brands shown here were less affected.

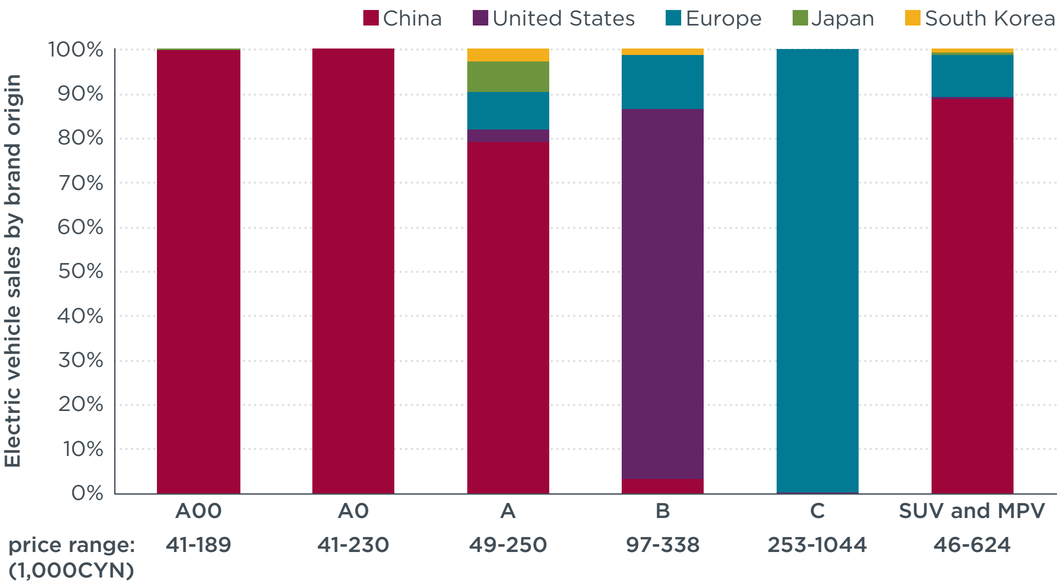

Figure 16. Light-duty electric vehicle sales share by market by segment and brand origin, January–June 2020.

5.2 VEHICLE BATTERY CAPACITY

Figure 17 shows the sales-weighted average battery capacity in China and other regions from 2012 through 2019. Over the years, BEV model availability has increased and consumers have had more choices. At the same time, the average battery capacity for BEV models in China also increased. The battery capacity for the most popular models has shifted upward, and we are seeing more models with capacity over 80 kWh in recent years. These reflect battery technology development, changes in policies that favor longer range, manufacturer strategy, and shifts in consumer preferences. Nevertheless, the average BEV battery capacity in China is still less than the global average.

We also looked at the trends for PHEVs but did not observe a similar pattern. Overall, the average battery capacity of a PHEV has not changed much over the years. This is because there is no range anxiety and no country, including China, has a policy that encourages longer PHEV range.

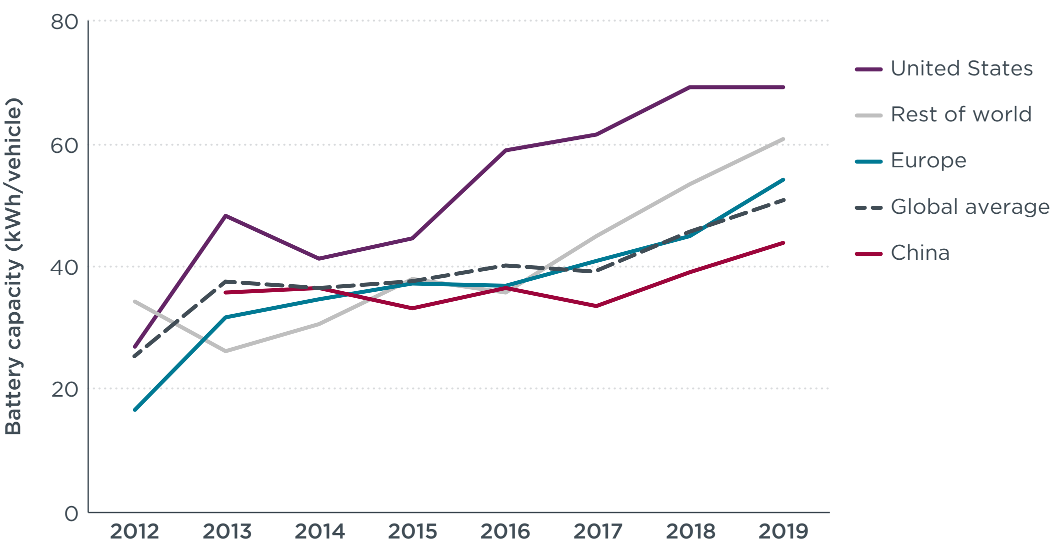

Figure 17. Battery capacity for light-duty battery electric vehicles, 2012 to 2019. *Note:* Based on EV-volumes (2020).

5.3 BATTERY TECHNOLOGY

Figure 18 shows the share of new electric vehicle sales by battery chemistry. Cost control, performance, and safety concerns are pushing innovation. There is a clear trend of the increasing share of NMC and lithium nickel cobalt aluminum oxide (NCA) batteries. Nickel-rich cathode chemistries are expected to capture a larger market share as customers push for more range and power, and the reduction in cobalt also helps to lower cost. Unlike the western markets, LFP has been a major player and seems to be making a comeback in China, partially driven by battery performance requirements (higher acceptance of shorter range BEVs in China than in other countries, possibly due to shorter urban travel needs) and the impending shortage of nickel and cobalt. BYD is the major player in producing and using LFP batteries. Meanwhile, policies that favor higher energy density and range drove a growing share of NMC batteries in China. The growth in NCA batteries in the United States is primarily driven by Tesla, with considerable uptake after 2017 due to the release of the more affordable Model 3. The trend in Europe is similar to that in the rest of the world, where NMC and NCA batteries continue to grow and captured about 70% and 20% of the market in 2019, respectively; the share of lithium manganese oxide (LMO) batteries keeps decreasing and was less than 10% in 2019.

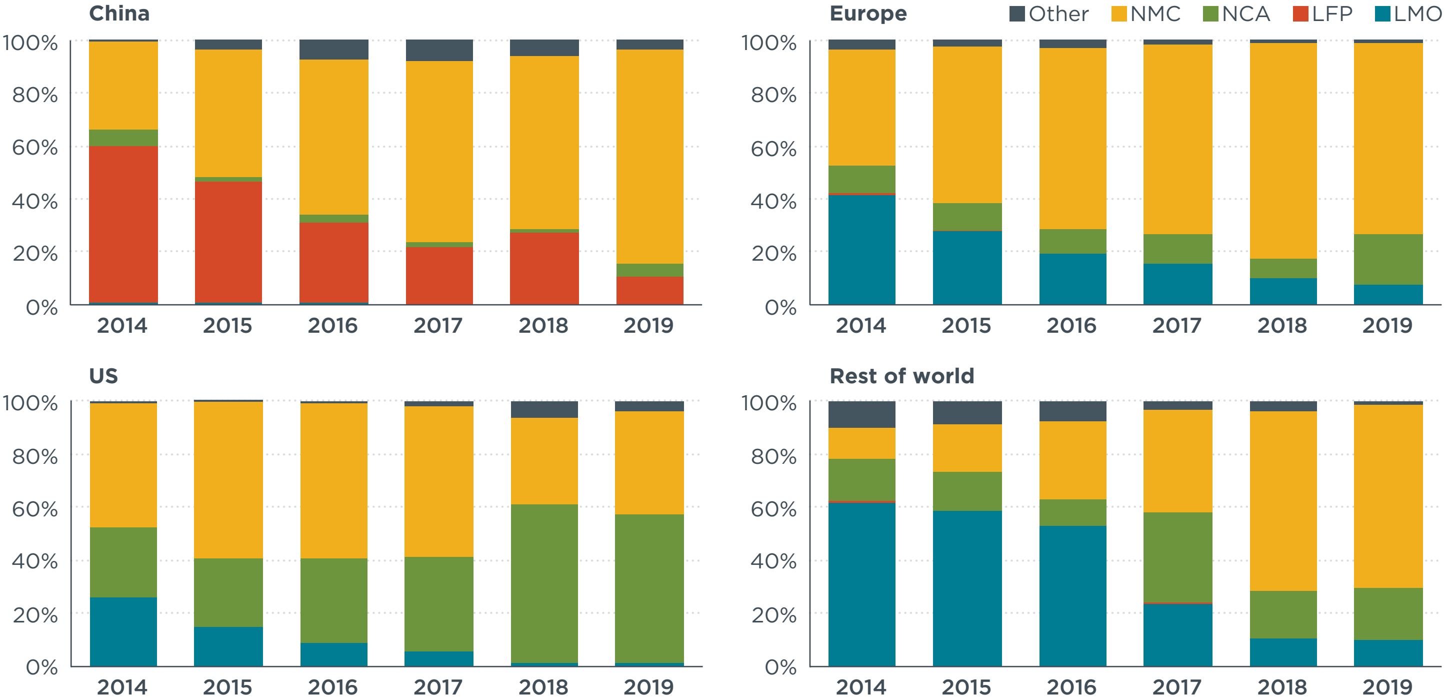

Figure 18. Share of new light-duty electric vehicle sales by battery chemistry. *Note*: Based on EV-volumes (2020).

6. CHARGING INFRASTRUCTURE

China has made great strides in building the necessary charging infrastructure to support rapid electric vehicle market growth. Figure 19 shows the global public charger stock from 2011 to 2019 by market (Hall & Lutsey, 2020). Starting in 2013, China experienced much higher growth in the number of public charge points than other markets. In 2016, China surpassed Europe and became the market with the largest public charging network. In 2019, China's share exceeded 50% of the global total, rivaling those of the United States, Europe, and Japan combined. Including public and home charging, by September 2019, the total charger stock in China reached 1.1 million. Of those, about 40% were public and 60% private, and about 40% were direct current (DC) fast charging and 60% were Level 2 charging (China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019). In 2019 alone, China built more than 180,000 public charge points.

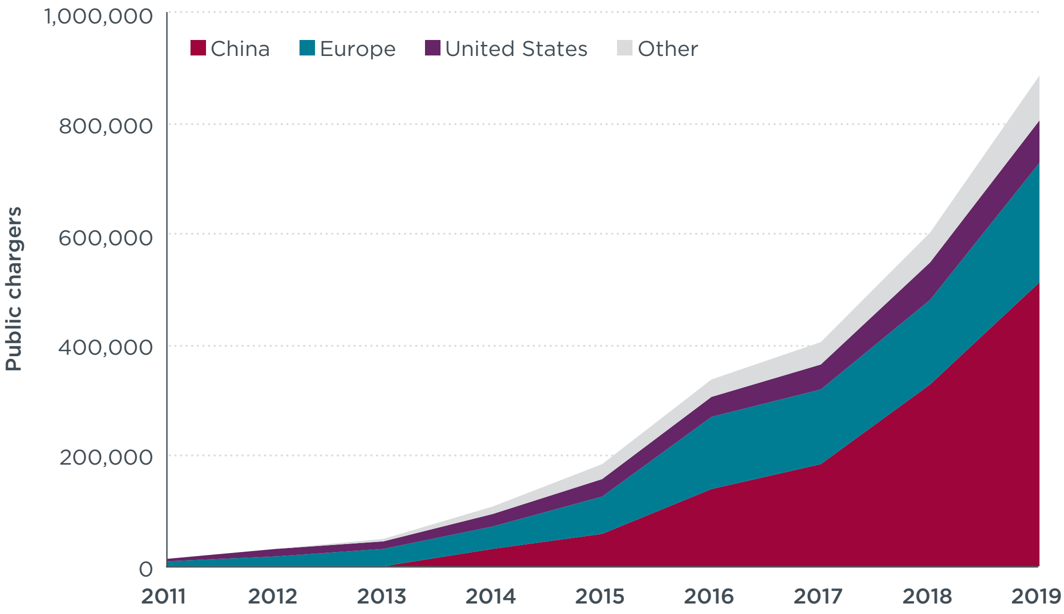

Figure 19. Global public electric vehicle charger stock from 2011 to 2019 by market.

Figure 20 compares the public charger availability in China with other major markets using two additional metrics: the number of public charge points per million population and the number of electric cars per public charge point (Hall & Lutsey, 2020). In terms of charging per capita, China lags behind other markets that are aggressively moving to electrify. China's 200 public charge points per million population are less than half the rate of most European countries and less than a tenth of the ratio in the Netherlands and Norway. By electric-vehicles-to-public-charger ratio, however, China's 8.5-to-1 is among the lowest in analyzed countries, indicating that Chinese electric vehicle users have better access to public chargers than in other countries. That said, much more charging will be needed in all of these markets as the electric vehicle market grows and as charging infrastructure needs evolve with local conditions. Governments and operators in China and elsewhere are moving from simply putting more charge points on the ground to better catering to identified consumer needs and more strategic placement of public charge points to match trends.

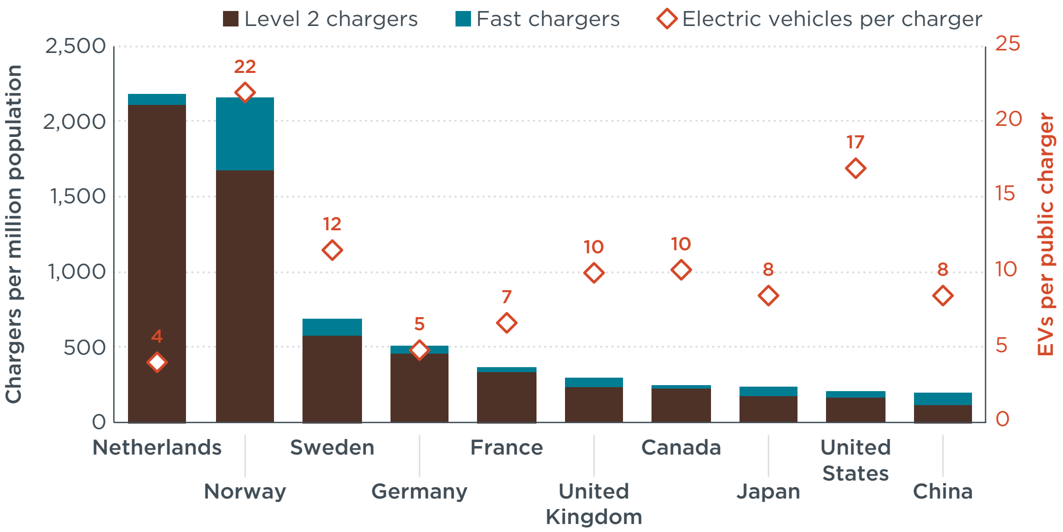

Figure 20. Public charge points per million population by type and electric vehicles per public charge point in major markets.

7. VISION FOR THE FUTURE

The fourth industrial revolution is well underway and a transition in the automotive industry away from internal combustion engines is a centerpiece. A key question is: How soon will an era of fully charged mobility come? This section compares the long-term ambitions of vehicle electrification among leading electric vehicle markets and also provides a near-term progress update on how major auto markets are adjusting their automotive strategies in response to the current recession and pandemic.

Driven by demands for healthier air quality, climate change mitigation, energy conservation, and more, an increasing number of governments are embracing a long-term, fossil-fuel-free vision of their auto industry. As of today, more than a dozen regions, mostly European countries, have proposed timelines to transition to all zero-emission vehicles within the next three decades; this is illustrated in Figure 21, which is based on Cui et al. (2020). Smaller auto markets like Norway and the Netherlands envision a quicker switch to full electrification, while major markets with substantial domestic auto industries, like the United Kingdom, Germany, and France, are expecting this shift over a longer period between 2030 and 2050. The United States, the world's second-largest auto market, is absent from this global "race to electric vehicles" in that its federal government has not set any electric vehicle target. China and other major Asian auto markets (Japan, South Korea, and India) also do not have an official commitment to full electrification. China just released an industrial development plan for the new energy vehicles for 2021–2035, and it proposed a target of 20% new energy vehicles in the market by 2025 (State Council, 2020). Also worth noting is that subnational markets have also committed to full electrification (Wappelhorst & Cui, 2020). For example, California recently published an executive order committing to 100% zero-emission passenger cars and light-duty trucks in new vehicle sales by 2035, and 100% zero-emission medium- and heavy-duty vehicles in operation by 2045 where feasible. British Columbia, Canada, has adopted legally binding regulation requiring that sales of all new light-duty vehicles be zero-emission by 2040.

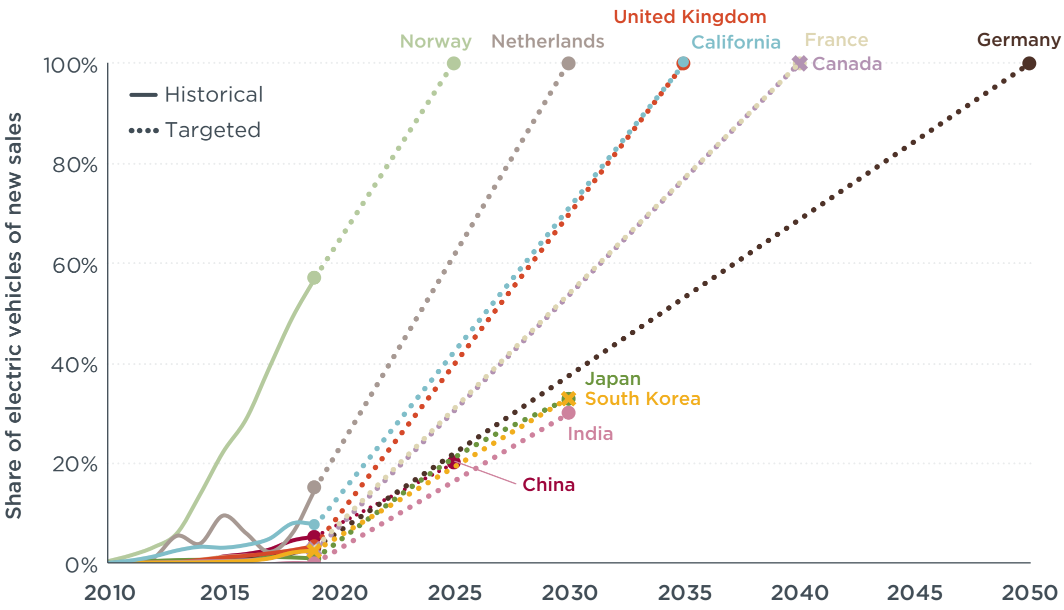

Figure 21. Full electrification commitment for new passenger cars versus historical electric vehicle penetration in select markets.

The recent economic downturn and COVID-19 have profoundly impacted the automotive industry worldwide. New sales of light-duty vehicles in the three major markets—China, the United States, and Europe—contracted between approximately 20% and 40% in the first half of 2020, compared with the same period last year. The market patterns in the three regions were mostly homogeneous, as sales dived to a historical low due to pandemic-related lockdowns and then rebounded to various extents resembling a "V"-shaped curve (Mock et al., 2020).

The electric vehicle market, however, has presented a quite different story. Though the electric vehicle market was expanding rapidly from 2017 to 2018 and also slowed down globally after 2019, developments in the three major markets were quite different. New electric vehicle sales in China declined by 42% in the first half of 2020 compared with the same 6-month period in 2019, and by 25% in the United States. By comparison, Europe's electric vehicle market increased by 57% during this period (Irle, n.d.).

The different electric vehicle market performance was mainly due to the different strategies and policies undertaken in the three regions. A month-to-month sales track showed that the single deepest electric vehicle market plunge in China during the past year occurred in July 2019, when the central government began to dramatically withdraw the subsidies for new electric vehicle purchases. This downward trend was reversed only after China prolonged the subsidy program and tax breaks for electric vehicles in March 2020. Europe's strong electric vehicle growth was largely driven by the region's mandatory CO_2 emission standard for new cars and a more recent green recovery program that features significant electric vehicle purchase premiums (Mock et al., 2020). The United States, on the other end, did not introduce any green stimulus related to electric vehicles. The United States federal government's recent move to loosen vehicular GHG regulations has also contributed to its electric vehicle slowdown.

Admittedly the crisis presented both challenges and opportunities for the global auto industry. But Europe quickly adjusted its automotive strategy to a greener one, and it reaffirmed its determination to make the long-term shift to full electrification.

8. CONCLUSIONS AND KEY FINDINGS

In this part, we first summarize the important features of China's electric vehicle development. Then we distill key lessons that have made China the world's largest electric vehicle market from various sources of evidence—our historical review, international comparative analyses, and interviews with international electric vehicle policy experts. For this study, we interviewed five global experts from different backgrounds; each has decades of experience in assessing vehicle technology and developing energy and environmental policies, and a long collaboration with China. Lastly, based on our analyses and the inputs from international experts, we highlight potential questions and choices about how China might further stimulate and sustain the development of electric vehicles.

We arrive at seven key findings about China's electric vehicle development in the past decade. They are grouped into three issue areas:

On overall market performance,

1. In just more than a decade, China has emerged as the world's largest national electric vehicle consumer market and producer. The nation's cumulative electric vehicle sales in the past decade represent 47% of the world's total. With the great success of its city pilot programs, China has also cultivated a number of leading electric vehicle city markets. In 2019, the majority of the world's top electric vehicle city markets were hosted in China.
2. However, in the first half of 2020, China lost ground to Europe in terms of electric vehicle market penetration. In Europe, the electric vehicle share of the passenger car market climbed sharply from an annual average of 3% in 2019 to around 8% in the first half of 2020 and it is still climbing; in October 2020, Germany hit 17.5% electric vehicle market share. The reasons behind China's electric vehicle market share dropping by more than 40%, and Europe's increasing by nearly 60% in the first half of 2020, can be expressed in one word: policy. European vehicle manufacturers introduced more than 30 new models in the last half of 2019 to position themselves to hit the 2021 CO_2 emission standards and avoid billions in penalties. The regulatory hammer—combined with fiscal incentives for electric vehicles adopted in six European countries in response to COVID-19—provide a powerful driver of market uptake. The reverse is true in China, where a decline in fiscal incentives in 2019 combined with vehicle fuel efficiency standards and new energy vehicle sales mandates that follow rather than lead the market, and do not include robust enforcement provisions or penalties, has led to a sharp drop in electric vehicle sales.

On industrial competitiveness,

3. On brand competitiveness, the Chinese electric car brands have not been widely embraced by the global market. Within the light-duty vehicle segment, China's electric vehicle strategy has primarily focused on satisfying its domestic market and little on exporting. In 2019, less than 1% of China's electric car production was sold to other parts of the world. The ratio was significantly lower than those in the United States and Europe. This implies there is potential for Chinese manufacturers to increase their global competitiveness. As the Chinese electric vehicle market increasingly opens to foreign brands, the latest trend shows that Chinese brands are losing to their foreign competitors in some of the most profitable vehicle segments. There is one exception, though, as the so-called new forces of new energy vehicles, aka startups like NIO, Li Auto, and Xpeng, are beginning to show vitality in the higher-end SUV market.
4. On research and development capacity, China has a wide lead over the United States and Europe in the battery supply chain. China dominates in the supply

of critical raw materials and has competitive advantages in battery production. Regarding technology development of advanced components including semiconductors, China is currently lagging but slowly narrowing the gap with global rivals. Compared with other leading regions, China owns the most technology and development patents in the fields of fast charging and wireless charging, but the least number of patents in areas like battery packaging, hydrogen storage, fuel cell production and operation, and powertrain control for plug-in hybrids.

5. On electric vehicle and battery technologies, China's decade-long pilot and subsidy programs were designed to drive electric vehicle technology advancement, and battery electric capacity and energy density were key indicators in recent years. As a result, the average battery capacity for pure electric cars increased from 35 kWh to 44 kWh, about 23%, in the past 5 years. Nevertheless, China's average battery capacity in 2019 remains lower than that in the United States and Europe, possibly due to technical and market factors. Battery technology in China has experienced a quick turn from LFP to energy-dense NMC batteries, and a similar trend is also found internationally.
6. Looking at the electrification process in different vehicle sectors, China's early electric vehicle market strategy was to push the government and public fleet application of electric vehicles. As a result, electric buses and micro electric cars that are largely used in car-sharing fleets are some of the most successful niche markets of electric vehicles. As more focus was placed on the private market, electric vehicles began to gain traction in mainstream car segments and SUVs in the past 2 years. However, the electrification process for the commercial truck segment is still nascent, and the policy tools for electrifying these vehicles are far less than those for cars, despite of their disproportionally large contribution to the nation's air pollution, climate pollutant emissions, and oil consumption.

On charging infrastructure,

7. China has made great strides as far as absolute number of chargers installed to support rapid electric vehicle market growth. However, the public charger density in China remains low. China's public charger per capita ratio lags behind the other markets, even while its ratio of electric vehicles to public chargers is higher than many European markets.

A snapshot three-market comparison on the key development indicators discussed above is provided in the figure below.

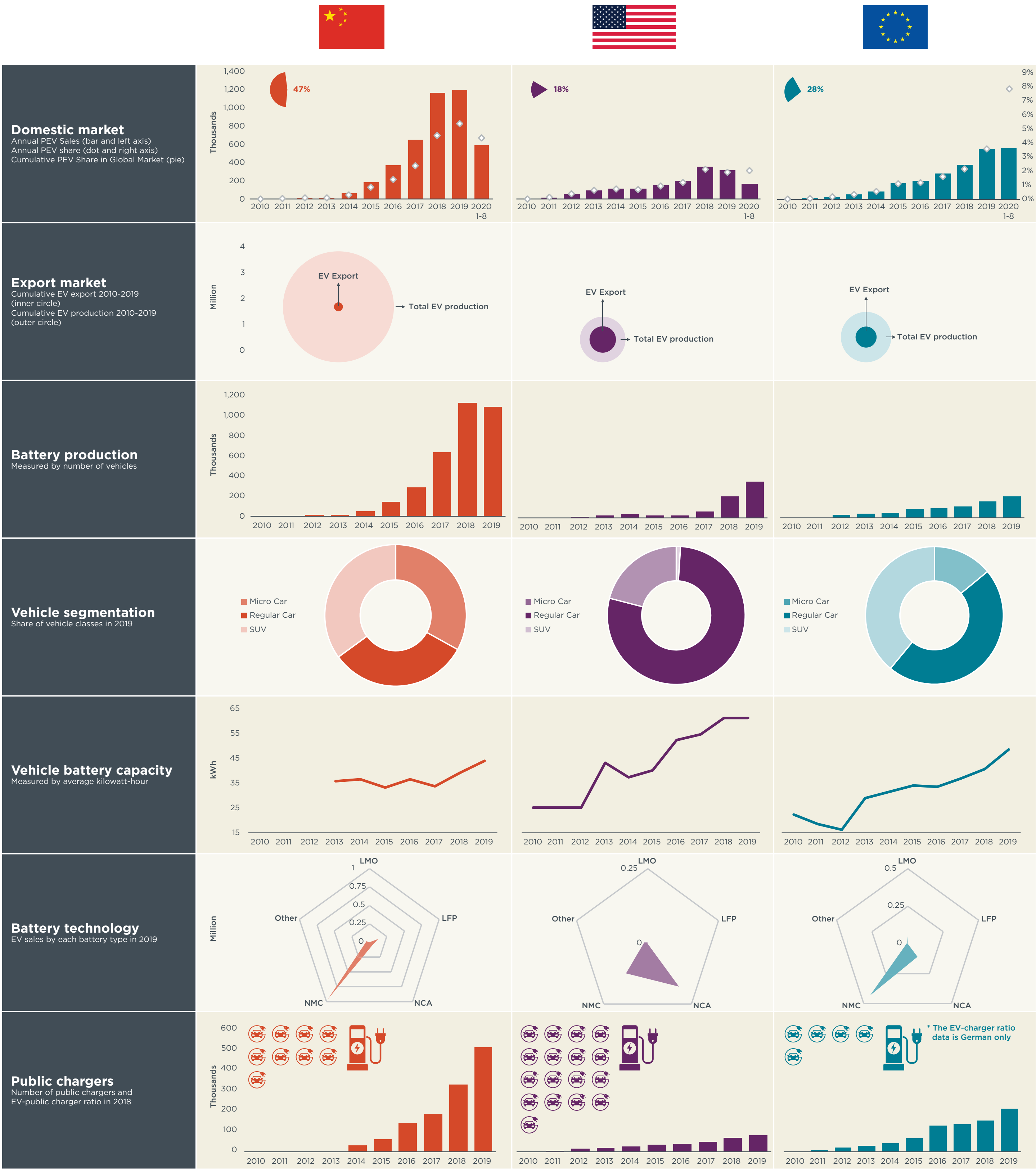

Figure 22. Comparison of key electric vehicle development indicators in China, the United States, and Europe

8.1 WHAT MAKES CHINA THE WORLD'S LARGEST ELECTRIC VEHICLE MARKET

Our retrospective review of China's electric vehicle development revealed that China's success is built on a foundation that includes a clearly articulated vision, consistent planning, coordinated action, city-level innovation and leadership, policy implementation, and the continued adaptation of policy tools to meet the changing market. The following elaborates on these high-level takeaways and includes quotes from the international experts in the text boxes.

A clear vision of the strategy for the industry. In the early 2000s, China chose new energy vehicles, primarily electric-drive vehicles, for a national strategy to jump-start its auto industry. This decision was based on the nation's competitive advantages and its unique mobility needs. From 1 million in 2005 to hundreds of millions today, China's widespread use of electric bikes and scooters established early consumer confidence. The continually improving lithium ion battery industry, which initially powered cell phones and laptops, provided the critical element in the value chain. As China's high-speed rail network covered inter-city travel, buses and small urban cars for shorter urban trips were the ideal focus for electrification. Once these technologies matured, the vehicle classes in the middle could be filled in, making for a unique and increasingly successful strategy in China. Electric vehicles have now evolved to be a core solution to address China's goals for future mobility, industrial development, energy security, and air quality.

> "China shows clear near-term alignment with global clean transport developments. China's role as the leading developer of the global electric vehicle market and the top driver for automaker investment is evident. The evidence for China's success includes China accounting for nearly half of global electric vehicle sales and China's battery development driving economies of scale that help the prospects for similar success in global markets. China's rapid electric passenger vehicle and electric bus uptake through 2019 demonstrates the ability to leapfrog to electric vehicle technology if steady and comprehensive policies are adopted. This could have profound implications for other markets that aim to record similar progress."

Top-down planning. Flowing from its national vision, China's Five-Year-Plans are now world-famous for setting a top-down agenda for economic development and coordinated national ministry action. These have been the backbone of strategic and policy continuity in China's new energy vehicle development. The underlying industrial plans set detailed development goals and targets, including market size and technology penetration rates, and identified the policies and funding required to meet the goals. Policies like the "Ten Cities, Thousand Vehicles" pilot projects, subsidy programs, tax breaks, and technical standards all grew from these macro-level plans.

> "China's rapid development of the electric vehicle market is impressive. Exemplary aspects of China's policies that were consistently cited were its clear, ambitious new energy vehicle targets—2 million vehicle sales by 2020, 20% passenger car share by 2025—that are reinforced by strong new energy vehicle regulation, consistent subsidy support, and aligned local policies."

Aligned industry, energy, and environmental goals. China's electric vehicle strategy was initiated with the prospect of building a strong, world-class car industry. Over time, electric vehicles were increasingly considered as a critical path toward enhancing national energy security and conservation and reducing air pollutant emissions. Multiple ministries were then motivated to coordinate, and these concerted efforts at the central and local levels have dramatically accelerated the electric vehicle growth in the past half-decade.

> "Linking China's electric vehicle goals to air quality and industrial competitiveness is especially powerful because it vests national, city, and industry leaders with aligned interest."

Multi-stakeholder partnership. When it comes to turning central plans into action, China forms *government-industry-academic-research (官产学研)* partnerships to coordinate decision-making, financing, and implementation. This mechanism enables quick transformation from laboratory prototype models to real-world electric vehicle products. In this partnership, the government dominates the R&D and steers the project and also serves as a consumer of the final products; universities and research institutes provide technologies; and industry receives matching government funding to commercialize the vehicle technology. The mechanism was most effective in the early technology-demonstration stage, when both the consumer market and industrial motivation were lacking.

Fiscal and regulatory policies to launch and grow the market. China has crafted the most innovative policy toolkit to help launch the largest electric vehicle market in just one decade. This includes pilot programs, central and local electric vehicle purchase subsidies, tax breaks, and a suite of measures tailored to local conditions. Such local measures include fiscal and nonfiscal measures like licensing, road access, parking, and charging incentives, and government-private partnership in building electric vehicle taxi and ride-hailing fleets.

Motivated cities. After plans come from the central government, local governments are where policy innovation and implementation occur. Leading markets like Beijing, Shanghai, and Shenzhen developed strong policies that initially provided a spark for industrial growth; these, in turn, spurred electric vehicle uptake several times higher than other markets and brought improved air quality. Take the Shenzhen example: It developed aggressive local policies, accomplished world-leading electric bus and taxi fleet conversions, and helped bring about a 70% reduction in fine particle pollution to achieve European Union-level air-quality standards. It did so in less than a decade, and the region's economy more than doubled.

> "China's system provides a template for others to follow of setting a national policy alongside linked-but-stronger leading regional new energy vehicle policies, such as Hainan's 2030 clean-energy-vehicle goal and city policies in Beijing, Shanghai, and Shenzhen."

8.2 HOW WE ENVISION CHINA'S CONTINUED SUCCESS IN ELECTRIC VEHICLE DEVELOPMENT IN THE FUTURE

An updated vision for a full-electrification path and a long-term plan to help achieve industrial, air quality, and climate mitigation goals. With the value of looking back at the past 10 years, China's vision is now due for an update that builds toward a fully electrified transport sector. China is in the leading position to demonstrate to the world a vision to accomplish this. The nation's emerging global dominance in electric bikes, scooters, smaller urban cars, buses, and all of their underlying technologies shows it can now include urban delivery trucks and regional and long-haul trucks in a bolder vision for fully electrified road transport. Setting more-ambitious new energy vehicle goals for 2030 and beyond, including a target date for a fully electrified transport sector (or a set of target dates for fully electrified fleets for various transportation segments including passenger cars, mid- and heavy-duty vehicles, etc.), would accelerate investment. It would also ensure that China meets and organically integrates near-, mid-, and long-term goals for achieving world-class air quality, realizing its industrial leadership ambitions, securing its energy independence targets, and also fulfilling its climate change mitigation goals.

> "China could improve to ensure it is better aligned with cutting-edge global transport developments. City and national governments around the world have set goals for 100% zero-emission vehicles sales by 2030–2040. It would be very influential for China's global positioning and to accelerate investments if China announced its national and city-level new energy vehicle percentage goals for 2035 and beyond."

Especially after President Xi's pledge of carbon neutrality by 2060, it is time for China to establish near- and long-term GHG emission reduction goals for the transportation sector, and to use electric vehicles as the core technological path to meet those goals. Take the European Union as an example. The proposed European Climate Law would establish a legally binding target of net-zero economy-wide GHG emissions in 2050 (climate neutrality). Based on this economy-wide target, the European Union is developing sectoral policies to achieve the necessary emission reductions. For the transport sector, the European Green Deal included a non-binding target to reduce transport sector emissions 90% by 2050. Among the key measures to achieve this transport target are the European Union's 2030 CO_2 standards for passenger cars, vans, and trucks. In the near term, to revive the economy hit by COVID-19, several national governments in Europe have launched stimulus packages to boost new electric vehicle sales and accelerate the replacement of older vehicles. This combination of near-, mid-, and long-term targets and the development of sectoral strategies and policies helps ensure that the whole economy is on a consistent pathway to climate neutrality.

Such a top-down goal would help China set strong new energy vehicle regulations, including for commercial trucks, and pay enormous dividends by pushing China's early movers to more lucrative global vehicle segments. For example, BYD's explosive growth in the electric bus segment has empowered many cities globally to commit to 100% zero-emission buses (see C40 Cities, n.d.). If China's leading companies could achieve economies of scale first in larger mainstream passenger vehicles and commercial trucks, they would be in the leading position to meet the burgeoning global demand for zero-emission vehicle technology.

To address pressing environmental challenges, it is also crucial for China to now develop a long-term strategy to electrify the heavy-duty truck sector and the non-road sector, with an initial focus on ports and airport vehicles and equipment and construction equipment. These sectors contribute substantially to air and climate change pollutant emissions and to energy consumption.

Finally, a decarbonized transportation system does not rely solely on vehicular technology advancement, and would also require tremendous parallel efforts toward cleaning up China's power grid.

Quickly pivot to a new set of regulatory and market-driven approaches. While China's initial policy playbook—pilot programs, government subsidies, and procurement—has proved a great success in placing the country at the forefront of global electric vehicle development in the past decade, China has not yet put the automotive industry on target to meet its original 2025 goals. Additionally, based on the major drop in China's electric vehicle market since late 2019 and the slow recovery of the industry after the hit of COVID-19, there is a great need for consistent electric vehicle supportive policies, including new energy vehicle regulations and fiscal and taxation policies.

> "China's incentives appear to be phasing down too soon. It is too soon to know if this is a misstep; however, it will put more pressure on new energy vehicle regulatory requirements to sustain growth if the incentive phase down is too soon. Instead of phasing out the incentives, the fiscal policy could be re-designed to offer a durable price signal until electric vehicles reach cost parity and to shift to incentivizing only the most attractive mainstream models or higher-volume segments, rather than niche luxury and microcars."

There are several areas of great potential for innovative policies to be developed and leveraged in China. China has adopted a market-based policy tool—the new energy vehicle dual credit policy modeled after California's ZEV regulation—and a set of vehicle fuel efficiency regulations. However, there are no robust enforcement provisions in these efficiency standards and the regulatory agency does not have legal authority to impose deterrent fines on noncompliant companies. The recommendation is to complement these standards with market-pushing and enforceable GHG emission standards adopted by the Ministry of Ecology and Environment. Such a program would be similar to the partnership established in the United States between the U.S. Department of Transportation's (DOT) fuel economy standards and the U.S. Environmental Protection Agency's (EPA) GHG emission standards. While the DOT's standards are industry-driven, shorter-term, and lack strong enforcement, the U.S. EPA's standards are climate-driven, long-term, and propelled by the Clean Air Act's stringent penalty provisions. The environmental ministry in China, with authority to enforce emission standards from China's Air Pollution law, could consider establishing long-term GHG emission standards for light- and heavy-duty vehicles from 2025 to 2030 and beyond. Such actions would be consistent with the policy trends in major markets such as Europe and California and likely the new U.S. administration.

In addition, fiscal and taxation incentives are an important complement to regulatory standards. China has been among the top governments to address the electric vehicle barriers of model availability and vehicle affordability by using policy tools like central subsidies. When the electric vehicle market was in its infancy, fiscal subsidies placed a significant but justifiable strain on the national budget. As the market grows, several countries have shifted to establishing programs that create a new tax on conventionally fueled vehicles to pay for long-term incentives for electric vehicles. Such programs are called bonus-malus in Europe, and feebate in North America, and they allow for durable, long-term financial support for the electric vehicle transition even while electric vehicle sales continue to grow over time. We recommend that China implement a graduated fee on petrol vehicles that varies depending on vehicle GHG emissions; this would provide incentives for manufacturers to produce more efficient vehicles while funds are also used to offset the higher cost of electric vehicles until cost parity is achieved.

China can also adopt policies to ensure that ample, conveniently located, smart charging infrastructure grows in unison with the market. This means collaborating with the Netherlands, Germany, and California on the emerging charging requirements and guidelines to future-proof the infrastructure for smart charging, time-of-use pricing, and grid integration services. China could also gain from California and Japan's work on hydrogen delivery and network planning. As the electric vehicle market grows, it will be critical for China to integrate any policies in its system, including better communication of the societal benefits and national-level and city-level coordination. China could also leverage its information technology expertise and city policies to ensure that it leads electric freight logistics and mobility-as-a-service electric ride-hailing applications.

Vitalize the mainstream private consuming market and city markets. China has been extremely successful in engaging government, corporate, and fleet users of electric vehicles. To fully release the electric vehicle market potential in the coming decades, the mainstream private consumer market will be the key. Future innovations in technologies, policies, business models, and partnerships need to focus on the needs of such mainstream markets. For example, new generations of electric vehicle consumers are increasingly demanding autonomous, connected, and smart features from their cars, and this will largely revolutionize the traditional functionalities of automobiles. China's ministries could implement the next phase of new energy vehicle policies to push greater city innovation. A first step could be to select the regions of top priority and set aggressive timetables for a fully electrified transport sector. The local governments would need special authority over vehicle registration, taxes, fees, and city access, among other things, and would need central funding support to electrify their entire urban areas in phases, such as fleets, taxis, and ride-hailing, private drivers, urban trucks, and inter-city trucks. In order to meet China's decarbonization target of a carbon-neutral economy in 2060, China should set a GHG reduction target for the transport sector of approximately 80% compared to 2020 in 2050. Leading cities would need to embrace this challenge during the 2025–2035 time frame by experimenting with new policies, deploying more charging infrastructure, and supporting the freight industry. Beyond Hainan province, which already plays this role, markets like Beijing, Shanghai, and Shenzhen are natural leaders that could set an example for the rest of the nation.

Secure a full-electrification vehicle technology path and transition into smart electromobility. This recommendation is to address a particular question from Chinese policymakers regarding the future technology option or path for electric vehicles in China. If we say the race of global automotive technologies in the current decade is mainly about electrification, then the next chapter will be about intelligent and connected electromobility—a system that is far beyond just vehicle technology itself. With vehicle technology, after decades of innovation, development, and experiments, China has recently prioritized three new energy vehicle technologies—BEVs, PHEVs, and FCVs—that are essential to lead to fully electrified mobility in the future. Among the new energy vehicle technologies, China has been mainly focusing on BEVs over the past decade but is paying more attention to FCVs. From a global perspective, BEVs are leading and will achieve cost parity across most segments first. Given this, setting a timeline for how long PHEV support will continue would be helpful. BEV technology is far ahead of FCV technology in maturity, scale, and cost reduction. As a result, the time is right to focus more on charging infrastructure for BEVs, whereas industry collaboration and pilot demonstrations would be timelier for FCVs. There was agreement that FCV technology may ultimately be necessary for some commercial vehicle segments, such as tractor-trailers that need to travel long distances of 500 km per day or more.

> "The technical hurdles of ensuring that hydrogen availability be made widespread with lower cost per energy unit than diesel and derived from renewable sources are obvious. It is important that China sustain momentum on BEV progress, where it is leading but not yet certain of success across global markets, without switching to an emphasis on fuel cells."

If we take a long-term perspective, a full-electrification path might just be the start of transforming mobility's future. We have seen its prelude today already in the three major markets—China, Europe, and the United States. Starting from the mid-term, China should combine a full-electrification path with intelligent, autonomous driving, and a cooperative vehicle infrastructure system to meet future demands in intelligent and connected vehicles. This will require a deeper revolution of the automotive industry to organically integrate vehicle, electronics, internet, and infrastructure technologies as well as to expand the scope of the supply chain from the traditional parts like batteries, motors, and onboard control systems to include chips, sensors, high-definition map systems, artificial intelligence, and cloud-based control systems.

Secure independent technical capacity in key supply chain areas and strengthen life-cycle management of electric vehicles. Although China's electric vehicle success in the past decade greatly benefited from the dividends of globalization, relatively free international trade, and collaboration in technologies, the ongoing dynamics of intergovernmental relations will introduce greater uncertainty for China's continued electric vehicle growth. In this context, China needs to further strengthen its domestic technology and research capacities, with focuses on key supply chain bottlenecks, charging or battery swapping infrastructure that would accommodate the rapid growth of electric vehicles, and future mobility patterns such as mobility-as-a-service. In order to achieve the full environmental benefits of electric vehicles on a life-cycle basis, policies need to be developed to promote sustainable and low-carbon practices from cradle to grave, including battery and vehicle design, production, usage, and proper battery recycling.

Leverage global electric vehicle platforms and strengthen collaboration in one focal area—electric trucks. Even as international relations become increasingly complicated and unpredictable, there are still several opportunities for China to collaborate internationally to achieve sustained and even more aggressive electrification goals. These include collaborating with subnational governments like the state of California on technological and policy exchanges, the use of global forums such as the SAE and United Nations frameworks to harmonize vehicle and charging standards, and engaging non-governmental platforms like the International Zero-Emission Vehicle Alliance (ZEV Alliance, n.d.) on collaborative research and continued electric vehicle progress exchange.

> "To investigate future charging infrastructure and grid integration needs, as well as develop more durable new energy vehicle incentive frameworks, collaborations with the International Zero-Emission Vehicle Alliance could be constructive."

One clear opportunity is in building a fully electrified freight system. This is an immense unmet challenge in port regions in China and throughout the world where there is high freight activity and serious air-quality issues. China could develop partnerships with government, port, fleet, charging, and research leaders to establish ultralow-emission freight zones, and initially support the electrification of local and regional trucks. Leading freight areas like Shanghai and Shenzhen could be the pioneers for eventual national action, as pilot cities were for passenger vehicles. Similarly, partnerships to tackle the joint problems of electric vehicle grid integration, smart charging, and the use of higher shares of renewable energy warrant consideration.

> "Commercial truck technology is a major opportunity where local and carbon emissions are disproportionally high around the world but where California and China could align their future zero-emission regulations to spur global development like they have done for light-duty vehicles. Increased openness to allow foreign manufacturing companies to enter China without a joint venture, as in the case of Tesla, will increase investment and competition and improve the broader attractiveness of electric vehicles."

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