



TRANSITION TO A GLOBAL ZERO-EMISSION VEHICLE FLEET: A COLLABORATIVE AGENDA FOR GOVERNMENTS

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ACKNOWLEDGEMENTS

Drew Kodjak, Mark Wenzel, Alberto Ayala, Lezlie Kimura-Szeto, and Catherine Dunwoody provided key input and guidance on the report. Thanks also go to colleagues Uwe Tietge, Dan Rutherford, Zifei Yang, and Hui He for their support with data and information, and to Peter Mock, Sarah Chambliss, Stephanie Searle, John German, and Anup Bandivadekar for their review of the report. Input from Pierpaolo Cazzola and members of the International Zero-Emission Vehicle Alliance is greatly appreciated. The International Zero-Emission Vehicle Alliance provided financial support.

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TABLE OF CONTENTS

Executive Summary	iv
I. Introduction	1
Electric vehicle adoption, projections, and goals.....	3
Benefits of increased electric vehicle deployment.....	7
Barriers to increased electric vehicle deployment.....	8
II. International actions to promote electric vehicles	11
China.....	11
Europe.....	12
Japan	14
United States	15
Overview of actions	16
Intergovernmental electric vehicle initiatives	18
III. Electric vehicle policy effectiveness	21
Research to date	21
Emerging best-practice principles	23
Recommended research	25
IV. Summary findings regarding global collaboration	28
Implications for future zero-emission vehicle goals.....	28
Concluding discussion	31
References	34

LIST OF FIGURES

Figure ES-1. Annual global electric vehicle sales	v
Figure 1. World vehicle sales, production, and manufacturing headquarters in 2014 by major region.....	1
Figure 2. Annual global electric vehicle sales	3
Figure 3. Highest-selling electric vehicle manufacturers and regions where electric vehicles were sold.....	4
Figure 4. Electric vehicle 2010-2014 sales share for selected regions and 2020-2030 sales share projections for U.S., EU, China, Japan, and the world from various studies	5
Figure 5. Life cycle energy losses and loads in converting primary fossil fuel energy to conventional internal combustion and battery electric vehicles	7
Figure 6. Energy sources and life cycle greenhouse gas emissions in 2014 for conventional and electric vehicles on average U.S. and California electricity grids	8
Figure 7. Incremental technology cost of electric and conventional vehicles through 2025.....	9
Figure 8. Electric vehicle sales share, new registrations, and charging in 2014 in Europe.....	12
Figure 9. Electric vehicle share, new registrations, and public charging infrastructure in 2014 in various U.S. states	16
Figure 10. Illustrative scenario for increased 2020-2035 zero-emission vehicle deployment goals.....	31

LIST OF TABLES

Table 1. Selection of national electric vehicle sales goals for 2020-2030.....	6
Table 2. Summary of government electric vehicle promotion actions in selected areas.....	17
Table 3. Summary of intergovernmental electric vehicle initiatives	20
Table 4. Summary of major findings related to electric vehicle policy effectiveness.....	22
Table 5. Electric vehicle adoption barriers and policy actions	25
Table 6. Metrics, examples, and potential zero-emission vehicle goals for leading governments.....	29

EXECUTIVE SUMMARY

Governments around the world are implementing policies to promote electric vehicles to reduce oil consumption, climate-related emissions, and local air pollution and to stake out an industrial leadership position in the new advanced technology. Electric vehicle promotion efforts across the world are increasingly diverse, with many governments, automakers, and advocates pushing to promote awareness and sales of advanced electric-drive vehicles, as well as the necessary regulatory, charging infrastructure, and financial support. Yet there are key questions about which policy actions are working well, about how the various efforts around the world compare, and about whether best policy practices to promote electric vehicles are emerging.

This report synthesizes recent information on global electric vehicle activity to help scope out an agenda for increased collaboration among governments around the world to promote the transition to a zero-emission vehicle fleet. Although the report emphasizes plug-in electric vehicles, the transition to a zero-emission vehicle fleet will also include hydrogen fuel cell electric vehicles. The report summarizes global adoption trends and national targets, as well as major electric vehicle promotion policies (e.g., consumer incentives and charging infrastructure support) for select markets around the world. In addition, the report summarizes research to date on the effectiveness of various electric vehicle promotions to investigate emerging best practices on electric vehicle policy. Building from these areas, and intergovernmental efforts to date, the report points toward an agenda for increased international cooperation and joint research to accelerate electric vehicle deployment.

Global electric vehicle sales are increasing, especially in particular regions. Figure ES-1 summarizes electric vehicle sales by major automobile market. Global annual electric vehicle sales reached approximately 100,000 in 2012, 200,000 in 2013, and 300,000 in 2014. As indicated in the figure, the electric vehicle sales growth in the United States was greater in 2012 and 2013, whereas sales growth in China and Europe was greater in 2014. Within Europe, the leading markets by sales volume are France, Germany, the Netherlands, Norway, and the United Kingdom. Based on this assessment, these regions — China, Europe, Japan, and the United States — differ in the electric vehicle promotion actions they implement, their policy incentives and infrastructure, and the electric vehicle deployment patterns they see.

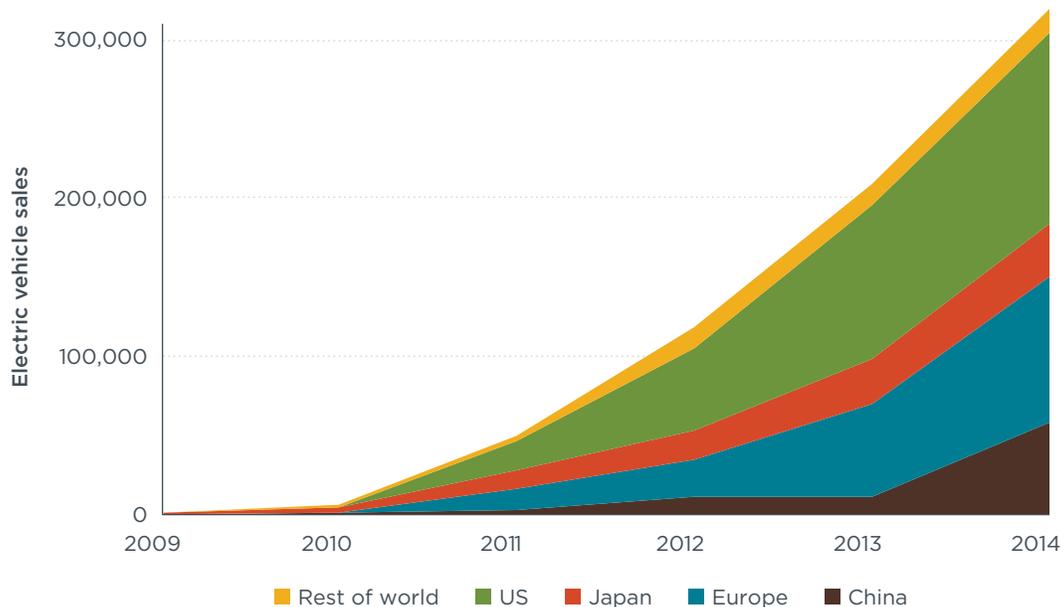


Figure ES-1. Annual global electric vehicle sales

Based on this report’s findings, we draw the following three conclusions:

Policy action by leading governments is spurring electric vehicle deployment.

The most comprehensive electric vehicle promotion actions globally are in Norway, the Netherlands, and California, and these actions are resulting in electric vehicle deployment that is more than 10 times the average international electric vehicle uptake. More broadly, the actions of the governments of China, France, Germany, Japan, the Netherlands, Norway, the United Kingdom, and the United States are leading with policy incentives and infrastructure investments, and these countries make up over 90% of the world’s electric vehicle market.

Best practices in electric vehicle promotion policies are emerging. From the early electric vehicle promotion activity, best practices to accelerate electric vehicle deployment are beginning to emerge. Increasingly stringent efficiency standards, electric vehicle research and development support, and national electric vehicle planning appear to be necessary but insufficient actions to grow the electric vehicle market. Consumer incentives that reduce the cost of ownership are important to improve the consumer proposition on the new advanced electric technologies. Increasing the availability of home, workplace, and public electric charging infrastructure is also of high importance, and several leading automobile markets (e.g., Japan, Norway, and parts of the United States) have far more extensive charging infrastructure per capita than others. It is becoming increasingly clear that a comprehensive portfolio of national, state, and local actions is critical for the increased deployment and use of electric vehicles.

Greater international collaboration could better leverage existing efforts to promote zero-emission vehicles. This assessment points to several possible ways that governments can better collaborate and coordinate. The establishment of a zero-emission vehicle deployment target (e.g., 35% of automobile sales being zero-emission vehicles and 30 million annual global zero-emission vehicle sales) and an electric mobility target (e.g., at least 15% of vehicle use being electric) for

2035 would help in establishing a common long-term global electric-drive vision. Such goals would send clear signals about the pace of development and amount of resources that will be needed. Further coordinated research on policy effectiveness would help prioritize government actions that are most important in increasing zero-emission vehicle uptake and use.

The transition of the automobile sector to electric drive will require not only sustained policy incentives but also increased communications about progress and policy learning. In these early years in the transition, there is much to learn from every region's experience in the rollout of zero-emission vehicles. Developing the new zero-emission vehicle market will require global scale, in the tens of millions of vehicles, to achieve lower cost and long-term success. Automakers are learning from their first- and second-generation electric vehicles and increasingly developing global electric vehicle platforms and launching them in multiple markets. Similarly, governments ideally will have to continue to learn from initial policy experiences and embrace common international best policy practices in many markets across the globe. International collaboration will be a critical step toward greater volume and a long-term market transformation to a zero-emission vehicle fleet.

I. INTRODUCTION

Governments around the world are implementing policies to promote electric vehicles to reduce oil consumption, reduce climate-related emissions, reduce local air pollution, and stake out an industrial leadership position in the new advanced technology. Efforts across the world are increasingly diverse, with many governments, automakers, and advocates pushing to promote awareness and sales of advanced electric-drive vehicles, as well as the necessary regulatory, charging infrastructure, and financial support. From the early electric vehicle promotion policy actions, best practices to accelerate electric vehicle deployment are beginning to emerge.

Many nations are looking to become the leading markets for electric-drive technology. Based on several vehicle market statistics, illustrated in Figure 1, electric-drive technology might be most likely to develop in several particular regions. Just five regions, China, Europe, Japan, South Korea, and the United States, dominate the world automobile market, making up 75% of world vehicle sales and 76% of world vehicle manufacturing (OICA, 2015a, b). Further, these five vehicle markets are the epicenter of most research and development, engineering, design, and investment decisions related to the launch of new vehicle technologies. Of the 50 largest vehicle manufacturers, 43 manufacturers that represent 97% of global vehicle sales are headquartered in these five regions (OICA, 2014). Looking to both make and sell the new technologies, these five regions have the greatest interest and opportunity in developing and growing the electric vehicle market.

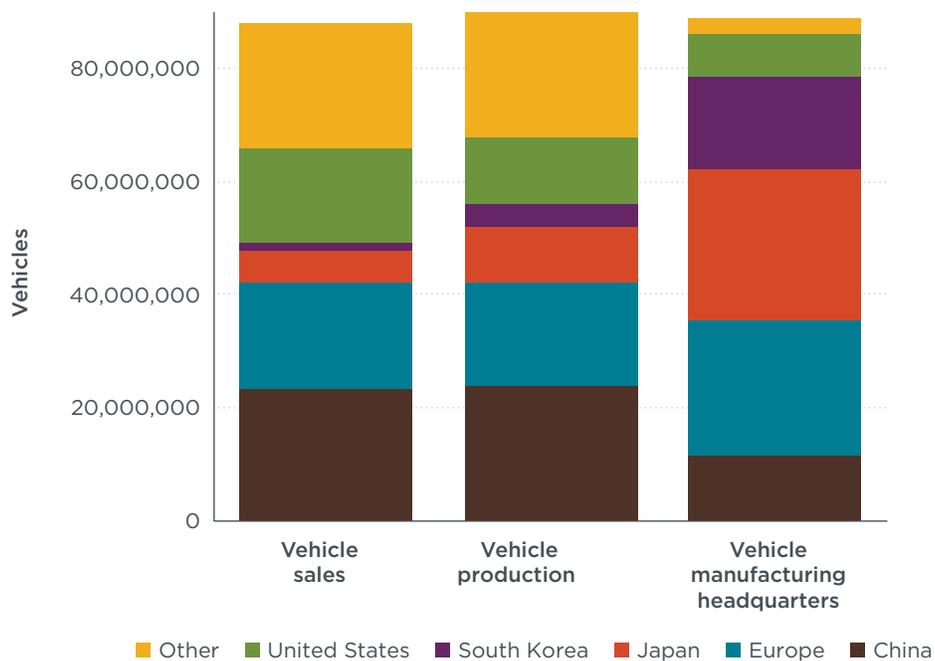


Figure 1. World vehicle sales, production, and manufacturing headquarters in 2014 by major region

However, it is too early to tell which markets will lead in a shift to an electric vehicle fleet. The electric vehicle market, in 2015, is in its nascent stage. Electric vehicle sales in 2014 amounted to more than 300,000 vehicles, less than 0.5% of the annual global sales of approximately 68 million passenger cars (and 88 million total vehicles) per year (OICA, 2015b). However, there are pockets within the five major automobile markets, and several vehicle manufacturing companies, that are demonstrating electric vehicle leadership. Every major automaker is launching new plug-in electric vehicle models annually, electric vehicle sales continue to increase, and several companies in particular are beginning to show early leadership. Moreover, the markets of Norway, the Netherlands, and California are illustrating how policy leadership can increase electric vehicle sales shares by an order of magnitude higher than the global average adoption rate even while the technology has limitations in terms of its relatively high cost, low consumer awareness, limited public charging infrastructure, and only modest model availability.

The primary objective of this report is to help scope out an agenda for improved global collaboration among leading governments that are seeking to accelerate the shift to zero-emission vehicles. This report builds on previous regional and national work to synthesize the existing body of knowledge on government cooperation, results to date, and potential gaps in the interest of furthering the understanding and growth of a global electric vehicle industry. The report is organized as follows.

- » **Section I** summarizes global adoption trends, targets, future projections, benefits, and barriers for electric vehicles.
- » **Section II** summarizes major electric vehicle promotion policies around the world.
- » **Section III** reports on research findings to date on the effectiveness of various electric vehicle promotion policies and distills a research agenda for international cooperation and research to promote electric vehicle deployment.
- » **Section IV** provides a final summary discussion related to global goals and collaboration to promote the transition to a global fleet of zero-emission vehicles.

ELECTRIC VEHICLE ADOPTION, PROJECTIONS, AND GOALS

Since 2009, the early electric vehicle market has shown steady growth globally. Figure 2 depicts approximate electric vehicle sales growth from 2009 through 2014, highlighting four major regions' electric vehicle sales based on Mock & Yang (2014) and EV Sales (2015). This increasing global trend for electric vehicles represents more than a 90% annual average sales growth over the 2011-2014 period.

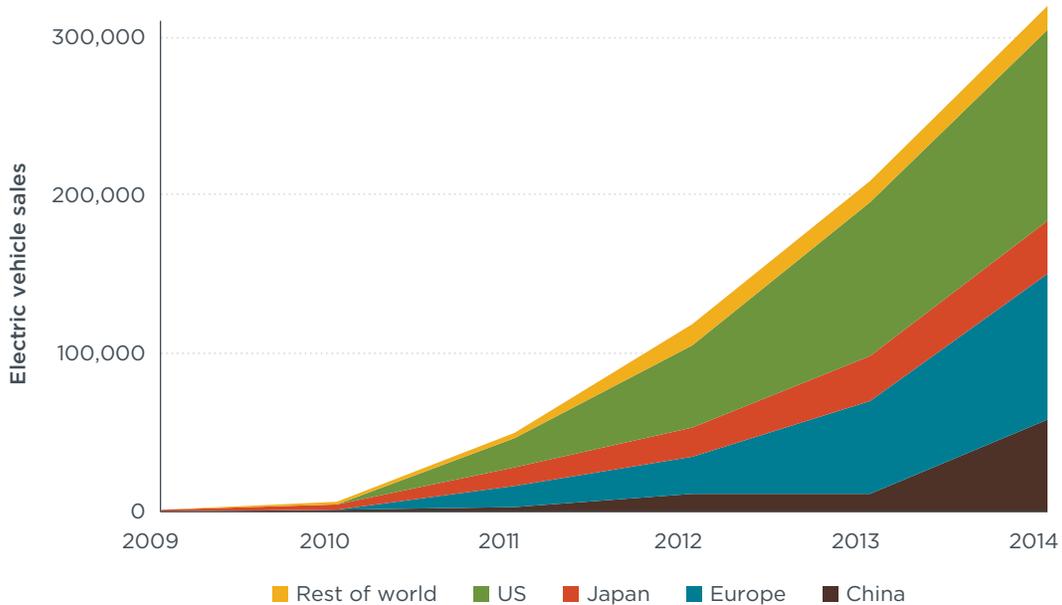


Figure 2. Annual global electric vehicle sales

Overall, this trend has resulted in global cumulative electric vehicle sales of 50,000 in 2011, more than 150,000 in 2012, more than 350,000 in 2013, and more than 700,000 in 2014. As shown in the figure, the 2014 electric vehicle sales are dominated by four major regions, with approximately 17% in China, 29% in Europe, 10% in Japan, and 37% in the United States. The figure also shows that electric vehicle sales growth in the United States was greater in 2012 and 2013, whereas sales growth in China and Europe was greater in 2014.

For further background on the current state of the industry, the global sales of electric vehicles by manufacturer are depicted in Figure 3. The figure shows the 15 highest selling electric vehicle manufacturers and their sales in the four major regions. Based on best available data (EV Sales, 2015; Hybridcars, 2015; evobsession.com, 2015), these 15 companies represent 96% of global electric vehicle sales, and each sold at least 2,000 electric vehicles in 2014. In particular, companies like Renault-Nissan (26% of world 2014 electric vehicle market), Mitsubishi (12%), and Tesla (10%) are especially showing market development, each with plug-in electric vehicle sales of more than 30,000 per year and launches in multiple regions (EV Sales, 2015). General Motors, Ford, and Toyota are next, with 6%-8% each of global electric vehicle sales, mostly from sales of plug-in hybrid electric vehicles (PHEV) in the U.S. market. After the top six, five of the next eight companies, led by BYD, are focused almost exclusively on the China market. Not shown in the figure are 10 major companies that are top-20 overall global auto manufacturers — Hyundai, Fiat-Chrysler, Honda, Suzuki, Peugeot Citroën, SAIC, Mazda, Dongfeng, Changan, and Tata — each of which had fewer than 2,000 global electric vehicle sales in 2014.

Although the electric vehicle growth is small in comparison to the overall automobile market that is dominated by gasoline and diesel vehicles, there are many reasons that governments will persist in what could be a decades-long transition to a predominantly electric-drive vehicle fleet. Any rigorous transportation planning exercise leads to the basic finding that climate change stabilization goals (e.g., 450-ppm, 2°C increase) will require a large-scale shift from the internal combustion of petroleum fuels to electric-drive (e.g., see IEA, 2012; Deetman et al., 2013; Greenblatt, 2015; Williams et al., 2011). Studies imply that electric-drive vehicles powered by ultra-low carbon electricity or hydrogen will be needed, as efficiency standards and attempts at curbing transport activity and availability of sustainable low-carbon biofuels will likely not be sufficient if the transportation sector is to meet its global carbon reduction goals.

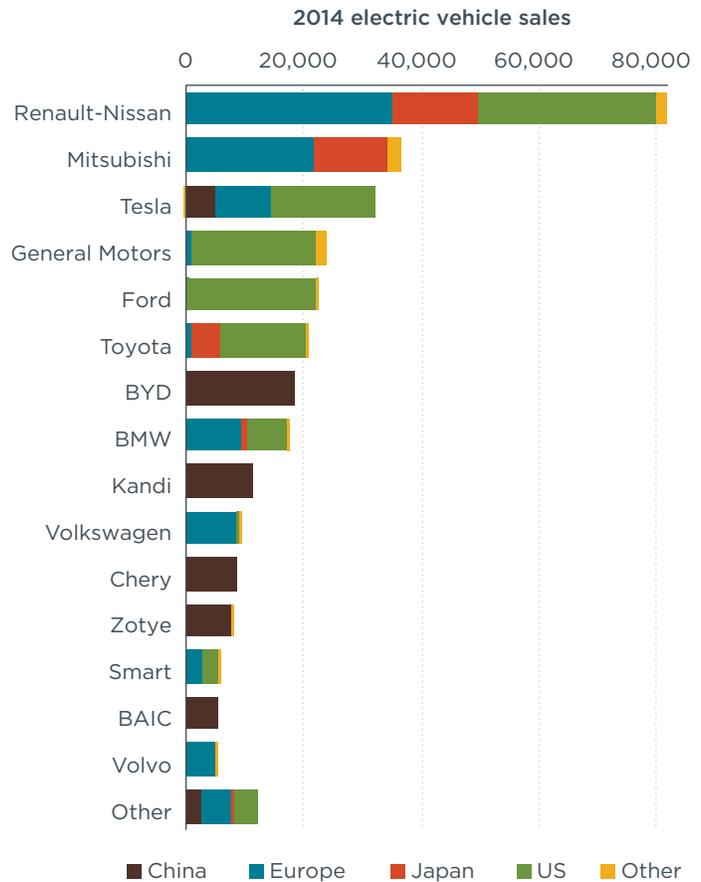


Figure 3. Highest-selling electric vehicle manufacturers and regions where electric vehicles were sold

Many studies have, in turn, sought to model and project the deployment of electric vehicle sales under various market and policy conditions. The projections, forecasts, and scenario analyses on future electric vehicle deployment are too numerous to discuss. Figure 3. shows there were more than 300,000 electric vehicle sales in 2014, or about 0.3% of overall global vehicle sales, and about 0.5% of global car sales, excluding commercial heavy-duty vehicles. From the many analyses and projections, the potential increase in electric vehicle sales could vary greatly, depending on region as well as policy drivers, technology progress, market conditions, and other factors.

Figure 4 summarizes projections from numerous studies that analyzed future electric vehicle deployment¹. In the figure, as well as throughout this report, electric vehicles or “zero-emission vehicles” include the three major technology types – plug-in hybrid, full-battery electric, and hydrogen fuel cell. Several studies (e.g., NRC, 2013b) indicate that fuel cell electric vehicle technology might have greater potential in the long term 2050 contest. However, most of the recent trends and data on electric vehicles are more exclusively focused on plug-in electric vehicles, due to their increased availability, marketing, and sales in recent years. Generally studies that assumed greater technical

¹ BCG, 2011; Berhart, Kleimann & Hoffmann, 2011; Bharat Book, 2014; CARB, 2011; Dunne, 2013; Element Energy, 2013; ETS Insights, 2014; Greene et al., 2013, 2014 ; IEA, 2011; IEA, 2013b; Malins et al., 2015; McKinsey, 2014; Navigant, 2013, 2014; NRC, 2013.

advancement, such as in battery technology, and increased policy support in areas such as R&D, infrastructure, and regulation, found 20% to more than 50% electric vehicle shares were possible in leading electric vehicle markets in the 2025-2030 time frame. However, studies that considered lesser policy support and lesser technical advancement generally found that the electric vehicle market, in various countries and globally, could remain as low as 5%-10% in the 2025-2030 time frame.

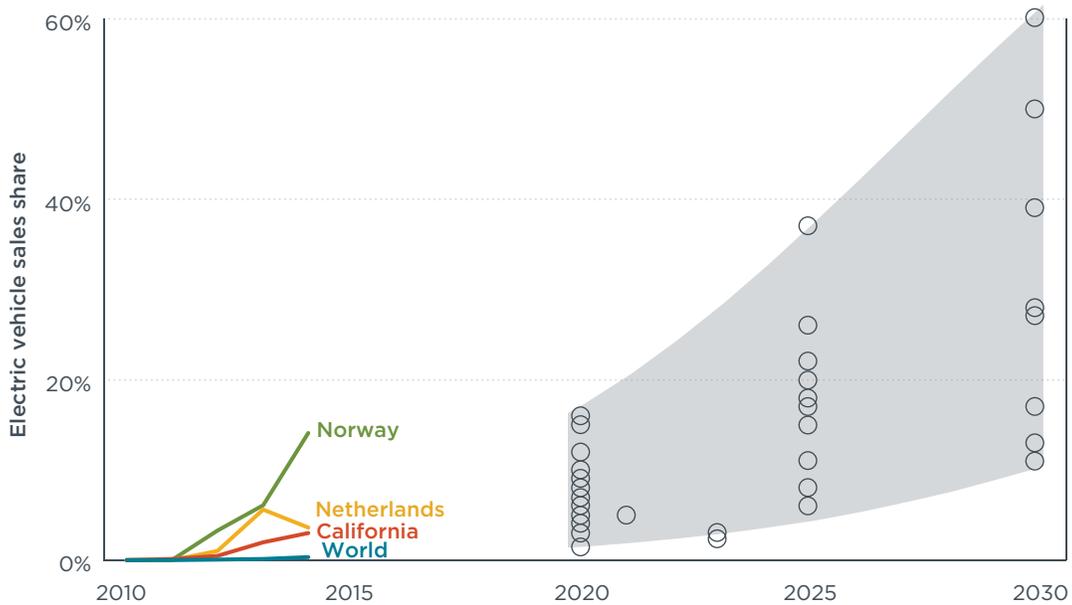


Figure 4. Electric vehicle 2010-2014 sales share for selected regions and 2020-2030 sales share projections for U.S., EU, China, Japan, and the world from various studies

To be on a trajectory toward long-term climate goals, many governments have established interim targets, incentives, and long-term policy to accelerate the electric-drive vehicle market share. Table 1 shows national goals several countries have used as milestones for electric vehicle deployment. Generally the national governments have set and announced these goals in terms of a cumulative stock (e.g., 1 million vehicles by a given date). Together these goals, if simply summed, amount to at least 15 million electric vehicles globally by 2020, and more than 25 million vehicles in the 2025-2030 time frame.

Many of these countries have also indicated their aspirations for nearly all new vehicles to be electric-drive or have near-zero emissions in the 2035-2050 time frame. Leading countries and companies are providing R&D funding for battery development to spur innovation, decrease battery costs, and increase manufacturing economies of scale to help achieve these goals. Many countries are offering attractive fiscal and other incentives for prospective electric vehicle consumers and users (Mock & Yang, 2014; Jin et al., 2014). Leading research (e.g., see Greene et al., 2014a, b) indicates that sustaining such policy and technology improvements will be necessary to facilitate the decades-long transition to electric-drive fleets. The goals and underlying policies are discussed in more detail in the sections that follow.

Table 1. Selection of national electric vehicle sales goals for 2020-2030

Region	Electric vehicle cumulative sales target by 2020 (or before, as specified)	Electric vehicle cumulative sales target for post 2020
Canada (Ontario)	0.3 million ^a	
China	3 million ^a	14 million (2025)
Denmark	0.2 million	
France	1-2 million	
Germany	1 million	6 million (2030)
India	6-7 million ^b	
Japan	0.6 million ^a	1 million (2030) ^a
Netherlands	0.2 million	1 million (2025)
Norway	0.05 million (2018)	
South Korea	0.2 million	
Spain	1 million (2014)	
Sweden	0.6 million	
United Kingdom	0.5 million ^a	
United States	1 million (2015)	
United States (eight states) ^{c,d}		3.3 million (2025)
United States (California) ^c	0.5 million ^a	1.5 million (2025)

Based on ADEME, 2010; BMUB, 2014; Governor's Interagency Working Group on Zero-emission Vehicles, 2013; CARB, 2011; CEM, 2015b; IEA, 2011; METI, 2010; MIIT, 2015; NESCAUM, 2014; OLEV, 2013; Ontario, 2009; U.S. DOE, 2011

^a Approximate, based on sales or sales share target

^b Includes two-wheel and hybrid vehicles

^c California, Massachusetts, Connecticut, Oregon, Maryland, Rhode Island, New York and Vermont

^d Includes plug-in and hydrogen fuel cell electric vehicles

The various countries' electric vehicle targets in Table 1 have differing applicability by technology. Several of the targets include hybrid and plug-in electric vehicles, and many of the targets and their associated government planning documents predominantly refer to plug-in electric vehicles. Fuel cell electric vehicle targets often are included in government dialogue and analytical scenarios about future electric vehicle deployment, but no countries have specific hydrogen fuel cell electric vehicle targets. With nearly every global automaker selling at least one plug-in electric model, and with more than 300,000 plug-in electric vehicles sold in 2014, much of the global electric vehicle deployment and policy action is currently centered on passenger plug-in electric vehicles. However, Japan, Germany, the United Kingdom, the Netherlands, California, and others also have strong initiatives to advance hydrogen infrastructure as fuel cell electric vehicles come to market — with more than 18,000 such fuel cell vehicles projected in California alone through 2020.

Because plug-in electric automobiles make up the vast majority of the electric vehicle market today, the scope of this report is more focused on passenger plug-in electric vehicles. It is acknowledged, though, that to meet long-term climate goals, zero-emission electric-drive technology will likely include widespread diffusion of plug-in electric technology into heavy-duty vehicles as well as hydrogen fuel cell electric vehicle technology following the more near-term plug-in electric passenger vehicle deployment.

BENEFITS OF INCREASED ELECTRIC VEHICLE DEPLOYMENT

Governments around the world are attempting to surmount the prevailing barriers and accelerate the electric vehicle market for various reasons. The anticipated benefits and the common barriers that stand in the way of the emerging electric vehicle market are summarized to provide further background for the report.

Compared to conventional vehicles, electric vehicles have two fundamentally superior technical features: greater on-vehicle efficiency and greater upstream energy source flexibility. Figure 5 illustrates the efficiency advantage of electric-drive technology versus a conventional petroleum-driven vehicle based on U.S. EPA (2012, 2014) and Lutsey (2013). Electric vehicle use, defined as the percentage of energy delivered to the vehicle that is ultimately used to overcome the vehicle road load, is about 4 times more efficient than conventional internal combustion gasoline engine efficiency, which is about 10%-20% (Lutsey, 2013). Conventional gasoline and diesel vehicles have greater thermodynamic energy losses, friction losses, fuel pumping losses, accessory loads, and transmission losses. The use of other alternative fuels, such as biofuels, can offer low-carbon energy sources but has supply limitations and is subject to the same combustion inefficiency disadvantage. On the other hand, electric-drive vehicles avoid most of these losses on the vehicle by using highly efficient electric powertrains, in addition to allowing for reduced upstream fossil energy use. As shown, moving from mostly fossil to 50% renewable energy sources for electricity further reduces the primary fossil-based energy requirements of electric vehicles.

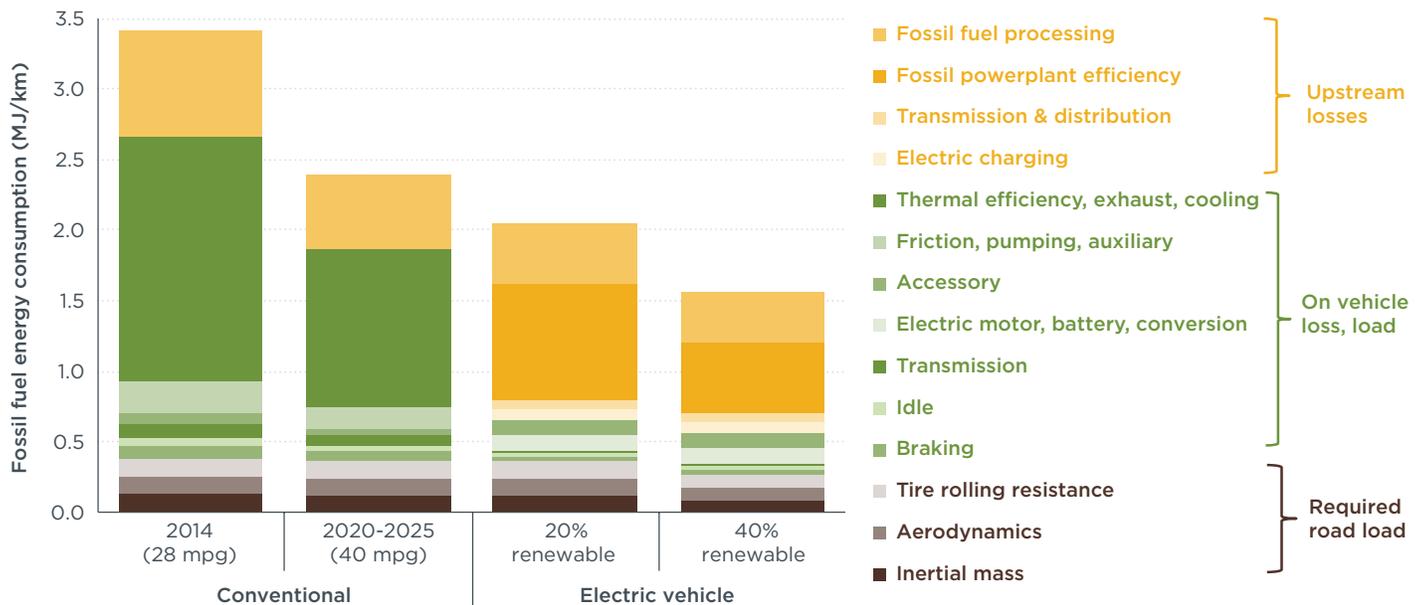


Figure 5. Life cycle energy losses and loads in converting primary fossil fuel energy to conventional internal combustion and battery electric vehicles

Electric vehicles, beyond consuming less energy, enable greater use of low-carbon and renewable energy sources than are available from conventional petroleum-based fuels. These technical advantages lead to the potential for greatly reducing petroleum use, air pollution, and carbon emissions.

Figure 6 provides a U.S.-based snapshot of primary energy sources and greenhouse gas emissions for the average conventional new U.S. car, an average electric vehicle

on the average U.S. grid, and the same electric vehicle on the lower-carbon California grid in 2012 (Based on U.S. EPA, 2013, 2014). Although, not shown, fuel cell electric vehicles have well-to-wheel fossil energy use that is similar to plug-in electric vehicles as hydrogen is similarly increasingly produced from renewable sources. Similar dynamics are seen elsewhere around the world. Figure 6 shows the average model year 2014 U.S. passenger car at 28 miles per gallon on the adjusted on-road EPA fuel economy label values resulting in 320 gCO₂/mile in tailpipe emissions, and 400 gCO₂/mile in tailpipe-plus-fuel production emissions. This compares with a 0.34 kilowatt-hour (kWh)/mile all electric Nissan Leaf, which results in 42% (average U.S. grid) and 74% (average California grid) lower greenhouse gas emissions. The electric vehicle assumptions include 7% transmission and distribution losses and 10% charging losses. Also for comparison, the 2014 hybrid Toyota Prius achieves 50 miles per gallon on the adjusted on-road EPA test cycle and results in 222 gCO₂/mile in tailpipe-plus-fuel production emissions.

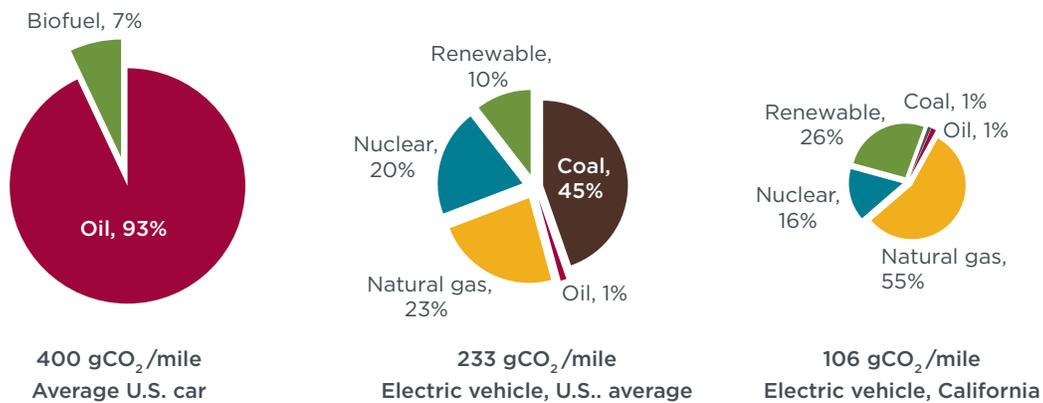


Figure 6. Energy sources and life cycle greenhouse gas emissions in 2014 for conventional and electric vehicles on average U.S. and California electricity grids

Figure 6 illustrates the multiple benefits of shifting vehicular travel from conventional petroleum sources to more highly efficient vehicles and more diversified and low-carbon energy sources. The dynamic shown in the figure is similar to elsewhere around the world, where average electricity use is primarily fossil fuel-based, but particular regions and adopted policies are moving the electric grid toward lower-carbon primary energy sources.

In global terms, electricity generation is powered by approximately 67% fossil sources (coal, oil, natural gas), 13% nuclear, and 20% renewable, based on IEA (2012) figures. Although most electricity is currently from fossil sources, hydrogen has the potential to displace fossil energy sources in the future with low carbon emitting nuclear, wind, solar photovoltaic, biomass, and hydroelectric power. Most countries have separate, parallel power sector initiatives to decarbonize their electric grids, and some also have related projects to integrate renewable hydrogen production into these energy initiatives.

BARRIERS TO INCREASED ELECTRIC VEHICLE DEPLOYMENT

Despite the potential fuel saving and climate mitigation benefits of new electric vehicle technology, major studies point to clear and present barriers to its widespread adoption. These barriers range from technical vehicle issues and adequate charging infrastructure to broader consumer and economic questions. The potential barriers for

prospective electric vehicle consumers include vehicle cost, range, charge time, battery life uncertainty, vehicle model choices and availability, charging infrastructure, and awareness and understanding of the technology (e.g., NRC, 2013a; 2015).

Of the several technology barriers to the increased deployment of electric vehicles, one key barrier is the elevated incremental upfront vehicle cost compared to conventional vehicles. Among the most substantial incremental cost components are those for electric vehicle battery packs. Incremental technology costs for battery electric and plug-in hybrids have been estimated to be about \$8,000-\$16,000 greater than for conventional vehicles, based on battery pack costs above \$500/kWh; however, estimated battery pack costs for the 2015-2020 time frame have decreased considerably (CARB, 2011; NRC, 2013b). Notably, Nissan and Tesla have committed to higher volumes and already have suggested they are in the \$240-\$375/kWh range (Abuelsamid, 2010; Cole, 2013).

Figure 7 illustrates the estimated optimistic and mid-range electric vehicle technology costs in the 2015-2025 time frame (NRC, 2013b). The underlying battery cost estimate for high-energy battery electric vehicles (BEV) moves from \$550-\$650/kWh in 2010 to \$240-\$350 in 2025 based on Nelson et al. (2011). The NRC analysis also projects that electric motor prices would decline by about half, from \$12/kW to \$6/kW, in that time frame. A key assumption in such estimates is that competitive high-volume production (i.e., over 100,000 units per year) is achieved to reduce per-unit costs. Recent analysis indicates market-leading companies in 2014 are manufacturing battery packs at \$300/kWh (Nykvist & Nilsson, 2015). This latest analysis indicates that battery pack costs are falling faster than the optimistic projections shown in the figure, with technology leaders essentially achieving projected 2020 costs in 2015.

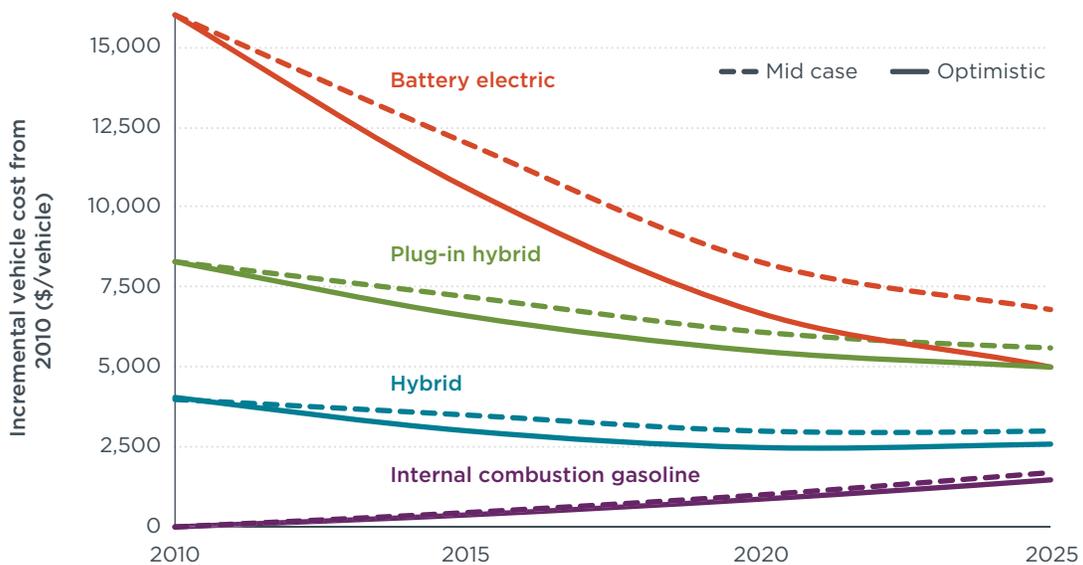


Figure 7. Incremental technology cost of electric and conventional vehicles through 2025

The question of electric vehicles' incremental cost is interrelated with vehicle range, as they both relate fundamentally to the battery pack capacity. Most early battery electric vehicle models, including the Nissan Leaf and BMW i3, have real-world average electric ranges of approximately 75 to 100 miles, and the Tesla Model S offers a range of more

than 200 miles (U.S. EPA, 2015a). Two next-generation General Motors models give an indication of improvements on the way. The all-electric Chevrolet Bolt has an announced range of 200 miles and plug-in hybrid Chevrolet Volt will see an increased range to about 50 miles (Colias, 2015). These represent more than double the current all-electric 2015 Chevrolet Spark range of 82 miles and at least a 30% increase from the 2015 Chevrolet Volt range of 38 miles (U.S. EPA, 2015a, b). This indicates a combination of continued cost and range improvements can be expected with the next wave of electric vehicles.

Along with cost and range, electric vehicles' charging availability and recharge time present additional barriers to widespread adoption. The time it takes to recharge battery electric vehicles ranges from 4-8 hours for Level 2 charging (i.e., 240 volt, generally 3-10 kW) to 25-40 minutes for direct current quick charging (i.e., 480 volt, generally 40-90 kW) for most all-electric vehicles. Increased battery capacity and vehicle range will offer some ability to reduce the demand for public fast charging and workplace charging availability. Increased charging availability will further increase the functional daily range of vehicles and also increase driver confidence in using the expanded vehicle range. Through public financing and workplace charging initiatives, various vehicle markets around the world are seeing greatly expanded charging infrastructure networks. Based on several recent studies, consumer awareness, understanding, and responsiveness connect to the above questions about electric vehicle technical issues and infrastructure, but present additional questions. The recent research in this area is discussed in Section III.

II. INTERNATIONAL ACTIONS TO PROMOTE ELECTRIC VEHICLES

This section briefly summarizes only select high-level policies in China, Europe, Japan, and the U.S., although it is important to acknowledge there are significant local efforts in these regions and other major national efforts elsewhere as well. It builds on the background presented in preceding sections concerning zero-emission vehicle adoption, targets, projections, benefits, and barriers to discuss various regional policies for accelerating the adoption of zero-emission vehicles. This section draws from the recent literature on financial and non-financial incentives for electric vehicles (e.g., Mock & Yang, 2014; Jin et al., 2014; OECD, 2015). The financing and construction of electric vehicle charging infrastructure, as well as other electric vehicle promotion actions, are summarized from various government and research literature sources.

CHINA

China's efforts to grow the electric vehicle market include research and development, regulatory incentives, public vehicle procurement, vehicle production subsidies, consumer incentives, and public charging investments. Since the 2000s, China has spent more than \$1 billion per year at the national level in R&D loans and grants, plus an additional \$1 billion from local governments and industry (OECD, 2015). From 2009, China shifted toward a focus on incentives for manufacturer production, public procurement (e.g., fleets, taxis), and private consumer subsidies for electric vehicles, first in 10 particular cities and later 25 (Howell et al., 2014; OECD, 2015). The incentives generally have not been available to foreign-manufactured electric vehicles. Of the leading electric vehicle models in China in 2014, 15 of the top 16 are domestically produced (EV Sales, 2015). China's electric vehicle growth was slow from 2010-2013, but growth in 2014 brought China's electric passenger vehicle sales to more than 50,000 per year, behind only the United States in total national annual sales.

China's national *12th Five-Year Plan* calls for 500,000 cumulative plug-in electric vehicles on China's roads by 2015. The 2015 "Made in China 2025" plan includes goals to increase annual plug-in electric vehicle sales to more than 1 million in 2020 and more than 3 million in 2025 (MIIT, 2015). The plan also includes direction for increased fuel cell research and development, pilot fuel cell electric vehicle deployment in 2020, and expanded hydrogen infrastructure. The electric vehicle promotion activities include passenger car purchasing incentives up to 35,000-60,000 yuan (\$6,000-\$10,000) per vehicle, which have been extended through 2015. China has recently proposed to offer incentives of 32,000-55,000 yuan per passenger car for 2016-2020 (MOF, 2014). The plan also involves the construction of up to 400,000 charge points over 2011-2015 (Li, 2014). By the end of 2014, there were approximately 28,000 charge points and about 700 charging stations in China (IEA, 2015a), and many local governments are working on partnerships with local providers to increase the charging infrastructure. The government has placed further focus on pilot areas of Beijing, Shanghai, Shenzhen, Hangzhou, Hefei, Changchun, and Chongqing. These regional pilot efforts include substantial additional direct consumer incentives, sometimes doubling the national incentives; innovative partnerships with particular vehicle and battery companies; and charging infrastructure plans (Marquis et al., 2013; Howell et al., 2014).

EUROPE

There is a great diversity of electric vehicle promotion activity across Europe. Common to the European Union member states, vehicles are all promoted by the increasingly stringent carbon dioxide emission standards that aim to achieve a 95 gCO₂/km new vehicle fleet in 2021, and these regulations provide further promotion for electric vehicles with “supercredits” and the omission of upstream emissions (Mock, 2014). European countries have installed various levels of electric vehicle charging equipment in order to improve the value proposition, electric range, and range confidence of electric vehicle users. The EU-wide Clean Power for Transport directive provides targets for each member state regarding the increased deployment of plug-in charging and hydrogen refueling infrastructure (European Commission, 2014). Some European countries have also established bold targets, offered large fiscal incentives to consumers, installed vehicle charging networks, and implemented other support policies to promote electric vehicle deployment. Also, each of the European countries has had higher gasoline and diesel prices of about 1.50-1.80 euros per liter in 2013-2014 that inherently have provided greater fuel savings and a stronger relative motivation for alternative fuel vehicles (Mock & Yang, 2014).

Figure 8 provides context for the current status of the electric vehicle sales, share of new vehicles, and electric vehicle charging equipment across selected European countries (based on data from Chargemap.com, 2015; Kraus, 2015; CEM, 2015a). Norway, the Netherlands, France, the United Kingdom, and Germany lead in electric vehicles, with sales between 12,000 and 20,000 per year. The figure also shows the mix between BEVs and PHEVs. Norway’s 14% electric vehicle sales share is far higher than the rest, and Norway and the Netherlands have deployed the highest electric vehicle charging infrastructure per capita (i.e., in charge points per million population). The brief sections below provide summaries of electric vehicle promotion actions that are in play in several of the countries.

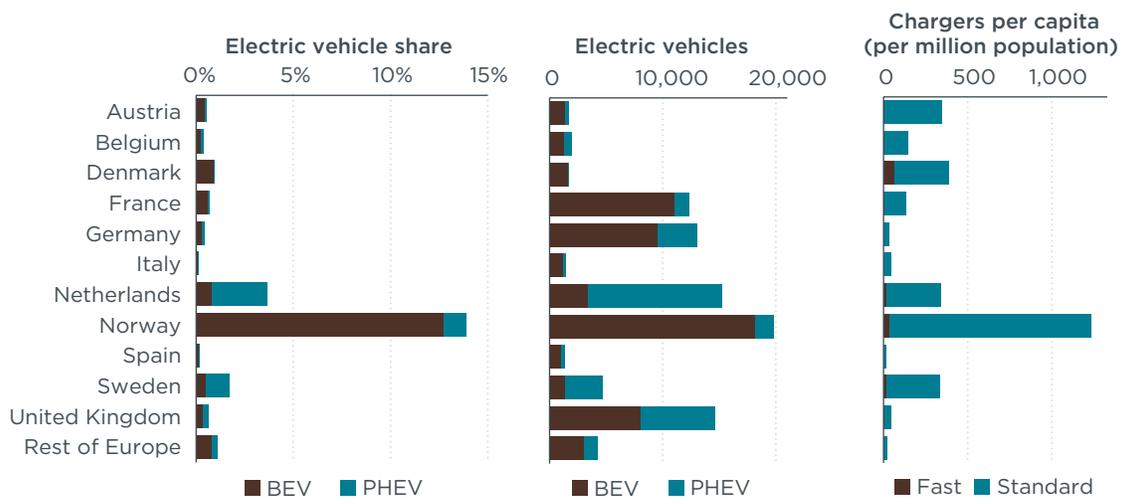


Figure 8. Electric vehicle sales share, new registrations, and charging in 2014 in Europe

Norway. As a percentage of new vehicle sales, Norway has the highest electric vehicle share, and the country also has had some of the strongest electric vehicle incentives globally. Norway already, in April 2015, had met its 2018 goal of 50,000 cumulative electric vehicles. The exemption from the normal value-added tax (VAT) and the one-time registration fee around the time of the electric vehicle purchase, as well as high fuel savings, make a battery electric vehicle less expensive to own and operate than its conventional gasoline

counterpart. Norway's electric vehicle policy framework includes free toll roads, access to bus lanes, free parking, extensive charging network, and free charging, which are also important motivating factors for electric vehicle users (Haugneland & Kvisle, 2013). In addition, Norway's relatively high gasoline and diesel prices improve the fuel-saving proposition for electric vehicle users. Norway's electric vehicle charging network is also among the most extensive in the world, on a per capita basis.

Netherlands. The Netherlands has been among the leaders in electric vehicle deployment and electric vehicle shares, and has among the more extensive national charging networks in Europe. The country has cumulative electric vehicle goals of 200,000 by 2020 and 1 million by 2025. As part of the incentive policy framework to incentivize electric vehicles, the Netherlands excludes both BEVs and PHEVs from registration and ownership taxes. Compared to comparable non-electric vehicles, the Netherlands offers per-vehicle incentives that are greater for PHEVs than for BEVs and for company (i.e., non-private) cars (Mock & Yang, 2014). The Netherlands' relatively high gasoline and diesel prices improve the fuel-saving proposition for electric vehicle users. The Netherlands also has set specific targets for the increased deployment of up to 15,000 fuel cell vehicles and 80 public hydrogen stations by 2025.

France. France is among the electric vehicle sales leaders in Europe, and seeks to put 1-2 million electric vehicles on its roads by 2020 (ADEME, 2010). France offers extensive electric vehicle incentives of generally 4,000 euros for PHEVs and 6,300 euros for BEVs through its Bonus/Malus feebate scheme, and relatively high gasoline and diesel prices further improve the fuel-saving proposition for electric vehicle users. Policies have been adopted to increase France's public charging points to 16,000 across the country over the next several years, and to seven million charging points by 2030. In addition, France offers tax incentives for private charging equipment installation (IEA, 2015a).

United Kingdom. The United Kingdom is also among the electric vehicle sales leaders in Europe in 2014, and has a strategic goal to grow electric vehicle market share up to approximately 5% of the new automobile market by 2020 (OLEV, 2013). The government is now implementing a 500 million pound 2015-2020 plan, in addition to 400 million pounds previously, that includes research, consumer incentives, charging infrastructure, and local support elements (OLEV, 2014). The government planning and policy are technology-neutral, supporting plug-in and fuel cell electric vehicles and hydrogen fueling infrastructure, with a roadmap for 65 hydrogen fueling stations to launch the market (UK H2 Mobility, 2013). The United Kingdom plan for a network of rapid electric vehicle charging infrastructure includes growing the network to 500 rapid electric charge points by the end of 2015. Customer purchasing incentives, including a one-time incentive of up to 5,000 pounds or 25% of the car price, are applicable for new electric vehicles with less than 75 gCO₂/km, and greater tax incentives are available for company cars. Relatively high gasoline and diesel prices also improve the fuel savings for prospective electric vehicle users.

Germany. Germany was among the higher electric vehicle sales volume markets in 2014, and has previously stated goals for 1 million cumulative electric vehicles by 2020, and 5 million by 2030 (BMUB, 2014). The country has placed more focus on R&D and public-private partnerships, for example with its National Electric Mobility Platform (NPE, 2014), and less on per-vehicle consumer incentives, compared to the preceding countries. Although Germany has not used consumer purchasing tax credits or rebates to reduce the initial vehicle costs, the country has offered an exemption from the annual vehicle circulation tax, and relatively high fuel prices provide an incentive for electric vehicle

purchase and use. A 2015 law allows municipalities to offer free or dedicated parking, use of bus lanes, and access to restricted areas for electric vehicles. Germany also has four showcase regions for targeted support, visibility, and stakeholder collaboration with vehicle demonstrations, charging infrastructure, and car-sharing programs (BMVI, 2011; IEA, 2015a). Germany is also on track to achieve its goal of 50 hydrogen stations by the end of 2015, expanding to 100 by 2017 and 400 by 2023 with additional industry commitments (NOW, 2013, 2014; Daimler, 2014)

Beyond the five European countries mentioned, many similar national actions are taking place in other countries across Europe. In terms of electric charging infrastructure, for example, Estonia stands out with more than 150 quick-chargers (ABB, 2013), which is among the largest network of quick-charging stations per capita in the world. A number of cities and regions in Europe (e.g., Amsterdam, London, Oslo, and Paris) are implementing diverse and innovative local actions to promote EVs (Urban Foresight, 2014).

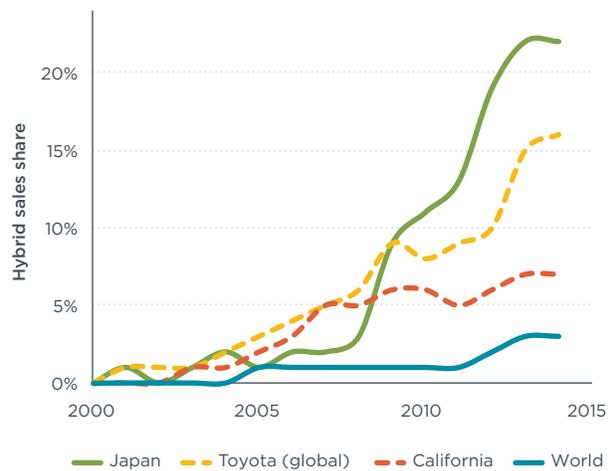
JAPAN

Japan is among the leaders in early electric vehicle growth with more than 30,000 sales in 2014. Japan has goals for plug-in electric vehicles to make up 20%-30%, and fuel cell electric vehicles 3%, of total vehicle sales by 2030 (METI, 2010). Japan's share of hybrid electric vehicles is far higher than other countries around the world; this hybrid success could provide an example of how comprehensive support policies (e.g., R&D, efficiency standards, consumer fiscal incentives) can help support the development of a market for advanced technology (see sidebar).

As part of its electric vehicle promotion efforts, Japan also has several consumer incentives and substantial electric vehicle charging infrastructure in place. Incentive programs allow for a one-time subsidy and purchasing tax exemptions for EVs and other qualified fuel-efficient vehicles since 2009. The subsidies are based on the price difference between an EV and a comparable gasoline car, with a maximum of 850,000 yen (about

JAPAN, TOYOTA, AND DEVELOPING THE HYBRID MARKET

The hybrid market in Japan provides a case study on the development of a new market for a more expensive, advanced technology. Since the late 1990s introductions of the first hybrid models, the Japan market has gone well beyond purchases by early adopters, greatly surpassing market shares elsewhere. This occurred for many reasons. Among them, Japan has had among the most aggressive efficiency standards and maintained consumer and manufacturer incentives for hybrid deployment, and Toyota in particular has made a multi-billion-dollar global bet on hybrids. The result is that, in 2014, Japan's new car market was more than 20% hybrids. In addition, Toyota is now selling more than 30 hybrid models in more than 80 countries, sells more than 1 million hybrids per year, and has reached approximately 7 million total hybrid sales. Similar hybrid support policies have pushed the share of hybrids in California to 7%. Globally, nearly every automaker has numerous hybrid models, hybrid sales are roughly 2 million per year, and the hybrid market continues to move beyond early adopters.



6,300 euros) (see CEV, 2015; Mock & Yang, 2014). These incentives generally amount to about 3,000-5,000 euros for typical BEVs and PHEVs. Japan also has reductions and exemptions for BEV and PHEV acquisition and annual tonnage taxes that can nearly double those upfront incentives for the first vehicle owner (Mock & Yang, 2014).

Japan has an extensive electric vehicle charging infrastructure plan, especially for rapid charging equipment. More than 10,000 public stations, including 3,000 fast-charge stations, have been installed in Japan (CHAdEMO, 2015; IEA, 2015a). Cities throughout Japan are exploring innovative ideas like integrated electric vehicle mobility networks and ensuring electric vehicle-ready buildings (Urban Foresight, 2014). Japan has made hydrogen a central part of its strategic energy plan, with a goal of 100 hydrogen stations in four major urban areas and corridor highways to meet the increasing deployment of fuel cell electric vehicles and a plan to showcase hydrogen and fuel cells at the 2020 Olympics (Tanaka, 2015; METI, 2014).

UNITED STATES

With more than 100,000 sales in 2014, the U.S. had the highest electric vehicle sales of any country. The U.S. set a goal of 1 million cumulative electric vehicles by 2015 and is about a third of the way to that goal. National policies to promote electric vehicles include consumer subsidies and infrastructure investments. A federal income tax credit grants from \$2,500 per PHEV (for about 10-15 mile range) up to \$7,500 for longer-range PHEV (at 16 kWh battery, or about 40-mile PHEV) and BEVs. Federal funding for an expansive national public electric vehicle charging network has helped in the rollout of more than 20,000 charge outlets at 8,000 stations (U.S. DOE, 2015). The U.S. also has a growing workplace charging network that includes more than 100 employers, 250 workplaces, and more than 4,000 chargers (U.S. DOE, 2014a,b).

California and other leading electric vehicle states. The state of California, with its Zero Emission Vehicle (ZEV) regulation, fiscal incentives (up to \$2,500 for plug-in electric and \$5,000 per fuel cell vehicles), non-monetary incentives (e.g., carpool lane access), and extensive charging infrastructure, has among the more comprehensive electric vehicle support plans (Governor's Interagency Working Group on Zero-emission Vehicles, 2013). The ZEV program is unique globally in mandating electric-drive technology with enforceable fines. Figure 9 shows electric vehicle sales, electric vehicle share of new vehicles, and chargers per million people in selected U.S. states (based on data from IHS Automotive, 2014; US DOE, 2015). California has dedicated funding through 2023 to deploy at least 100 hydrogen stations to support fuel cell electric vehicles (CARB, 2014). California, with about 11% of the U.S. car sales, makes up about 50% of overall U.S. electric vehicle sales. Other states within the U.S. provide additional extensive electric vehicle support and have greater electric vehicle shares and electric vehicle charging infrastructure in place. In particular, Washington, Oregon, Georgia, and Hawaii are providing combinations of consumer, charging, and local policy support that are driving their electric vehicle shares considerably higher than the national average (Jin et al., 2014).

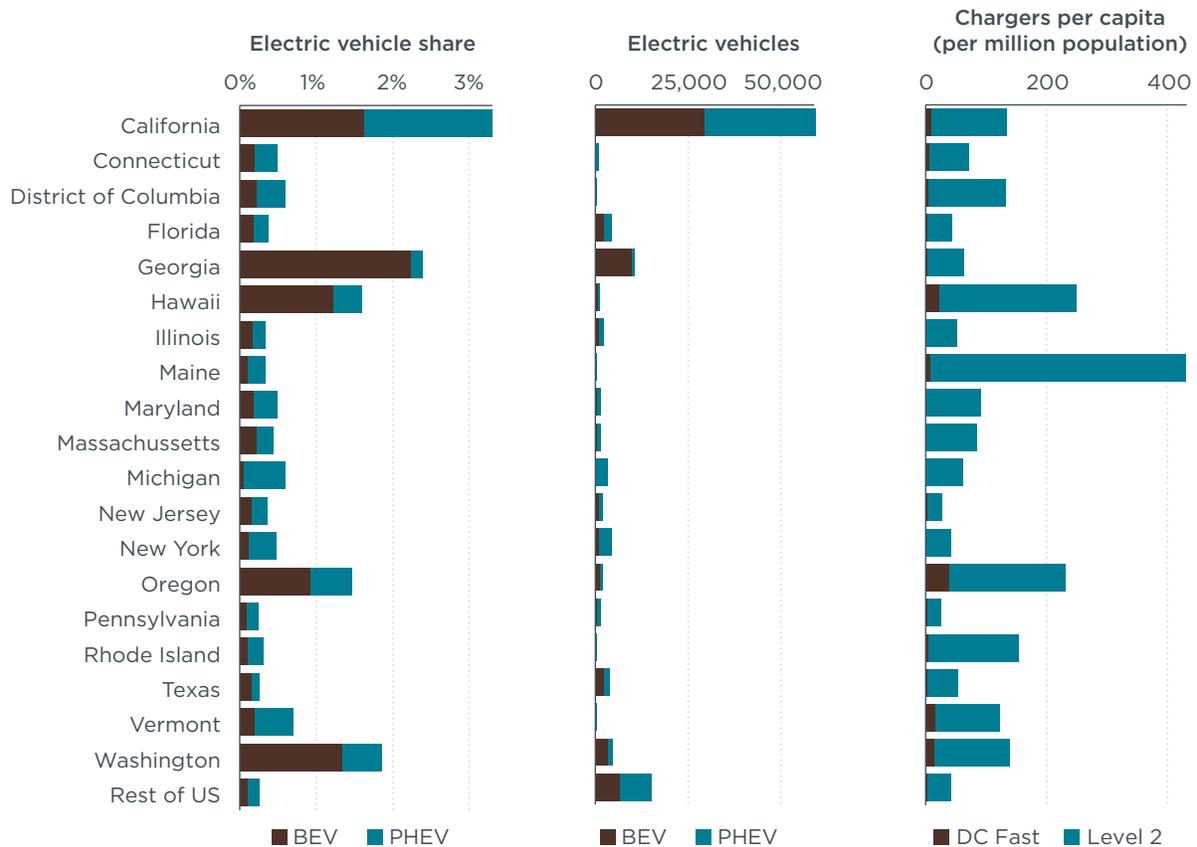


Figure 9. Electric vehicle share, new registrations, and public charging infrastructure in 2014 in various U.S. states

OVERVIEW OF ACTIONS

Table 2 summarizes which electric vehicle promotion actions are in place in several major automobile markets. The table highlights the breadth of activity that is underway in many of the leading governments seeking to promote electric vehicles, including vehicle manufacturing, consumer purchasing incentives, and infrastructure-focused actions. Along the top two rows in the table, the various regions' vehicle sales and production of all passenger vehicles are shown to provide context of the scale of the market in each place. The markets in the table represent more than 90% of global electric vehicle sales in 2014. As shown, some of the electric vehicle promotion actions (e.g., efficiency standards, investment in charging infrastructure, and public outreach activity) are in place in many of the jurisdictions. However, other actions are only adopted in several places. It is noted that although all the jurisdictions are seeing electric vehicle charging infrastructure rollout, there is great variation in the charging infrastructure per capita (e.g., see Figure 8 and 9). Although most governments have adopted many of the listed electric vehicle promotion activities, more promotion actions are in place in Norway, the Netherlands, and California than in the other areas. The table is, of course, not comprehensive of the full span of activities underway in the various areas and also does not convey the varying levels of the activity (e.g., the amount of consumer incentives and infrastructure).

Table 2. Summary of government electric vehicle promotion actions in selected areas

Area	Action	China	France	Germany	Japan	Netherlands	Norway	United Kingdom	United States (excl. California)	California
Global market share	Vehicle sales in 2014 (million vehicles)	22	2.2	3.3	4	0.5	0.2	2.6	14	1.7
	Vehicle manufacturing in 2014 (million vehicles)	22	1.7	5.7	10	<0.1	<0.1	1.6	11	<0.1
	Percent of 2014 global electric vehicle sales	17%	4%	4%	10%	5%	6%	5%	19%	19%
Vehicle manufacturer	Research and development support	X	X	X	X	X	X	X	X	X
	Long-term efficiency standards	X	X	X	X	X	X	X	X	X
	Incentive provisions within efficiency regulations	X	X	X		X	X	X	X	
	Cumulative sales goal	X	X	X		X	X	X	X	X
	Vehicle deployment requirements									X
	Vehicle production subsidy	X								
Consumer purchase	Vehicle purchase subsidy (tax credit)								X	
	Vehicle purchase subsidy (rebate)	X			X			X		X
	Vehicle purchase tax exemption					X	X		/	
	Vehicle fee-bate scheme		X					X		
	Government fleet vehicle purchasing preferences		X		X			X	X	X
	High fuel price and greater fuel savings		X	X		X	X	X		
Consumer use	Annual vehicle fee exemption			X	X	X	X	/	/	
	Discounted/free electric charging				X	X	X	/	/	X
	Preferential lane (e.g., bus, HOV lane) access			/		X	X		/	X
	Reduced roadway tax or tolls			X	X	X	X	X		
	Preferential parking access		/	/		/	/	/	/	/
Fuel provider, infrastructure	Carbon pricing scheme	X	X	X	X	X	X	X	/	X
	Low carbon fuel incentive for electricity providers							/		X
	Public charging network funding	X	X	X	X	X	X	X	X	X
	Home charging equipment tax incentives		X						/	/
Consumer awareness	Public outreach activities to educate on consumer benefits	X	X	X	X	X	X	X	X	X

Based on IEA, 2015a; Jin et al., 2014; Mock & Yang, 2014; NRC, 2015; OECD, 2015; OICA, 2015a,b; "X" denotes national program; "/" signifies smaller local or regional program

INTERGOVERNMENTAL ELECTRIC VEHICLE INITIATIVES

Beyond national, state, and local actions, many government agencies in various areas are forging collaborations with agencies in other countries to leverage their efforts to promote electric vehicles. Among the international activities is the Clean Energy Ministerial's Electric Vehicle Initiative (EVI), which involves 17 member countries. The EVI seeks to facilitate the global deployment of 20 million EVs by 2020 by encouraging national goals and best practices; leading the sharing of city experiences; sharing information; engaging private-sector stakeholders to better align expectations; discussing the respective roles of industry and government; and focusing on the benefits of continued investment in EV technology innovation and EV procurement for fleets (CEM, 2015b).

Another international initiative is the International Energy Agency Hybrid and Electric Vehicle Implementing Agreement, which consists of 18 member countries and includes working groups collaborating on various electric vehicle technology questions (IEA, 2015b). Another initiative, the Urban Electric Mobility Initiative (UEMI), involving UN-Habitat, cities, industry, and development banks, seeks to increase the global market share of electric vehicles in cities to at least 30% in 2030 (UN-Habitat, 2015). The United Nations Economic Commission for Europe's Electric Vehicle and the Environment (EVE) working group exchanges information on, and seeks to minimize differences in, electric vehicle regulations across countries (UN ECE, 2014). Finally, the C40 Cities Climate Leadership Group's Low Emission Vehicle Network coordinates city-level actions by facilitating knowledge sharing on topics like electric vehicle charging and fleet projects among the 24 participating cities (C40 Cities, 2014).

There are many high profile bilateral international electric vehicle initiatives; two prominent ones involve China and Germany and China with the U.S. Under the Sino-German Electric Vehicle Strategic Partnership Framework, China and Germany signed various ministry-level memoranda of understanding between the ministries in the two countries on electric vehicles, leading to collaboration in many areas (China, 2014). The activities include research into the technology and market development of EVs, pilot demonstration programs, charging infrastructure and regulations, policies, and standardization. Another initiative includes three pairs of collaborative cities and includes the investigation of new business models and innovative transportation solutions (such as electric car sharing); non-fiscal incentives such as parking policies and dedicated lanes, battery safety, testing, EV application to certain logistics fleets; and some hydrogen research. Other components include in-depth collaboration between German and Chinese universities on energy storage, electric drive and electric systems research and development, and environmental impacts of electric vehicles. Finally, another collaboration led to a July 2014 agreement between China and Germany to harmonize charging interface protocols for electric vehicles in the two countries.

Two China-U.S. collaborations focus on similar areas related to electric vehicles. First, the U.S.-China Clean Energy Research Center was established in 2009, and, in 2014, President Obama and President Xi renewed the commitment to the center. One of the four main components of the Center is the Clean Energy Vehicle Consortium, which has included more than \$50 million in funding for research on advanced batteries, vehicle electrification research, and vehicle-grid integration (Peng & Minggao, 2013). The Center also has hosted joint conferences, technical meetings, and collaborative meetings; authored technical journal and conference papers; and filed international

patents. The second, more recent, collaboration is the China-U.S. ZEV Policy Lab, which involves collaboration on policy activity to increase the use of zero-emission vehicles (UC Davis, 2014).

Within North America, a number of prominent initiatives help support the deployment of electric vehicles. Ten states have adopted the California Zero Emission Vehicle program. Eight U.S. states, representing more than half the U.S. electric vehicle market, have signed a memorandum of understanding to support the associated deployment of electric vehicles and collaborated on a Multi-State ZEV Action Plan to prioritize and enact many complementary actions to support electric vehicle deployment and use (NESCAUM, 2013, 2014). Four Pacific Coast Collaborative jurisdictions are coordinating to support electric vehicles by implementing low carbon fuel standards, supporting fleet electric vehicle deployment, and investing in infrastructure (PCC, 2014). Collaboration between Québec and California includes a working group to work together on zero-emission vehicle promotion activities, policies, and incentives (Quebec, 2015). Also, the U.S. DOE Clean Cities program helps coordinate 80 major U.S. metropolitan areas' efforts to reduce their fleets' petroleum use by establishing local public-private coalitions, identifying funding opportunities, facilitating information sharing, and providing technical assistance regarding the deployment of alternative fuel vehicles (U.S. DOE, 2015b).

A brief summary of such intergovernmental electric vehicle initiatives is provided in Table 3. The initiatives summarized above, taken as a whole, have resulted in far greater coordination, exchange of research information, and sharing of policy experience than would have occurred otherwise. In particular, the IEA Implementing Agreement and the CEM EVI have resulted in the convening of many ministry staff officials to exchange notes several times a year, and have produced a number of reports that have synthesized information from multiple jurisdictions (e.g., see CEM, 2015b; IEA, 2013a). The other initiatives have brought more targeted collaborations in particular research areas.

Table 3. Summary of intergovernmental electric vehicle initiatives

Initiative	Participants	Elements
Clean Energy Ministerial Electric Vehicle Initiative	17 countries: Canada, China, Denmark, Finland, Germany, India, Italy, Japan, Netherlands, Norway, Portugal, South Africa, South Korea, Spain, Sweden, UK, U.S.	<ul style="list-style-type: none"> • Convene twice a year • Share information, experiences • Conduct several projects per year (e.g., EV Outlook, City EV Casebook)
International Energy Agency Hybrid and Electric Vehicle Implementing Agreement	18 countries: Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, South Korea, Spain, Sweden, Switzerland, Turkey, U.K., U.S.	<ul style="list-style-type: none"> • Convene twice a year • Share information, experiences • Working groups on various technical research areas
Urban Electric Mobility Initiative (UEMI)	UN-Habitat, Mahindra Reva, BYD, Wuppertal Institute, Michelin, Siemens, CEM EVI, IEA	<ul style="list-style-type: none"> • Commitments from cities, industry for 30% electric vehicle share in 2030 • Provide forum for knowledge transfer
United Nations Economic Commission for Europe (UN ECE) Electric Vehicle and the Environment (EVE) working group	Led by Canada, China, Japan, and U.S., with participation from many countries, battery and vehicle manufacturers, non-governmental organizations	<ul style="list-style-type: none"> • Exchange information on, and seek to minimize differences in, regulatory requirements for electric vehicles • Develop electric vehicle regulatory reference guide
C40 City Leadership Low Emission Vehicle	More than 20 major world cities, including Bogota, London, Los Angeles, Madrid, Mexico City, San Francisco, Santiago de Chile, Warsaw, Yokohama	<ul style="list-style-type: none"> • Share information and best practices in implementing vehicle charging, car-sharing, fleet, taxi projects
Sino-German Electric Vehicle Strategic Partnership Framework	China (Ministry of Industry and Information Technology [MIIT], Ministry of Science and Technology [MoST], National Development and Reform Commission [NDRC], China Automotive Technology & Research Center [CATARC]); Germany (Federal Ministry of Economic Affairs and Energy [BMWi]; Ministry of Transport and Digital Infrastructure [BMVI]; Ministry of Education and Science [BMBF]; Federal Ministry of Environment Protection [BMU]; Federal Enterprise for International Cooperation [GIZ])	<ul style="list-style-type: none"> • Technology and market development, pilot demonstration programs, charging infrastructure and regulations, policies and standardization • Study electric car sharing, non-fiscal incentives, and other local electric vehicle support policies in three pairs of cities • Research collaboration on battery research and environmental impact of EVs • Harmonization of charging interface protocols
U.S.-China Clean Energy Research Center	China (Ministry of Science and Technology [MoST], National Bureau of Energy, research groups [including China Academy of Science, Tsinghua University, Beijing Institute of Technology]); United States (U.S. Department of Energy, research [including University of Michigan, Massachusetts Institute of Technology, Oak Ridge National Laboratory], industry [including vehicle, oil, and battery companies])	<ul style="list-style-type: none"> • \$50 million in funding for Clean Energy Vehicle Consortium, including focus on advanced battery, vehicle electrification research, vehicle-grid integration • Host joint conferences, technical meetings, collaborative meetings • File international patents
China-U.S. Zero Emission Vehicle Policy Lab	China (National Development and Reform Commission [NDRC]; China Automotive Technology and Research Center [CATARC]); California (Air Resources Board; UC-Davis)	<ul style="list-style-type: none"> • Collaborate on policy activity to increase the usage of zero-emission vehicles
Green eMotion	42 partners including European Union, Bosch, IBM, SAP, Siemens, BMW, Daimler, City of Copenhagen, City of Rome, research organizations, TÜV Nord	<ul style="list-style-type: none"> • Define EU-wide standards for electric mobility • Showcase 12 regions to demonstrate technical and business solutions for electric vehicles (ended in February 2015)
Governors eight U.S. states' Memorandum of Understanding	California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont	<ul style="list-style-type: none"> • Coordinate on Multi-State ZEV Action Plan to support deployment of 3.3 million electric vehicles by 2025
Zero Emission Vehicle program	Ten U.S. states: California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont	<ul style="list-style-type: none"> • Adopt and co-implement the California zero-emission vehicle requirement for new vehicles through 2025
Pacific Coast Collaborative	Three U.S. states: California, Oregon, Washington One Canadian province: British Columbia	<ul style="list-style-type: none"> • Coordinate on fuel standards, fleet procurement, and infrastructure investment for electric vehicles
Québec-California collaboration	California (Environmental Protection Agency), Québec (Ministry of Sustainable Development)	<ul style="list-style-type: none"> • Working group to collaborate on zero-emission vehicle promotion, policies, and incentives
U.S. DOE Clean Cities Coalition	84 major U.S. metropolitan areas	<ul style="list-style-type: none"> • Establish local coalitions, identify funding, facilitate info sharing on alternative fuel vehicles

III. ELECTRIC VEHICLE POLICY EFFECTIVENESS

RESEARCH TO DATE

Research into electric vehicle policies and electric vehicle deployment continues to examine various government policies' relative effectiveness. Assessments that have been conducted on particular U.S., European, China, and international bases are each providing early insights into the relative importance of various types of policies, public and private investments, and other non-policy electric vehicle promotion actions.

Table 4 summarizes recent studies that have investigated the importance of various electric vehicle promotion policies. Generally, these studies are clearly indicating that many different actions by governments at various levels (national, regional, state) and by industry stakeholders (vehicle manufacturers, charging infrastructure providers) will be necessary over the 2015-2025 time frame to grow the electric vehicle market.

Although regulatory standards for vehicle efficiency are found to be important to promote electric vehicle deployment, they are shown to be insufficient to drive the electric vehicle technology into the marketplace without complementary policies and incentives. This has led to additional regulatory incentives in the U.S., the EU, China, and elsewhere within the efficiency standards for 2020-2025 new vehicles. The consensus from the emerging studies clearly indicates the importance of consumer electric vehicle purchasing incentives and electric vehicle charging infrastructure, as well as education and awareness actions in driving electric vehicle purchasing and use; however, the studies appear to put additional importance on various types of measures.

Table 4. Summary of major findings related to electric vehicle policy effectiveness

Finding	Study
<ul style="list-style-type: none"> Consumer incentives, the presence of local manufacturing, and especially charging infrastructure are significantly connected to increased electric vehicle adoption Consumer incentives and charging infrastructure do not ensure high electric vehicle adoption 	Sierzchula et al., 2014
<ul style="list-style-type: none"> Fiscal incentives are reducing electric vehicles' total cost of ownership in line with conventional vehicles and helping spur electric vehicle sales, e.g., the Netherlands, Norway, California The relative importance of non-fiscal, local, and infrastructure actions warrants further study 	Mock & Yang, 2014
<ul style="list-style-type: none"> Electric vehicle promotion policies vary greatly by type and by magnitude across all OECD countries 	OECD, 2015
<ul style="list-style-type: none"> Standardization and increased deployment of charging infrastructure, fleet deployment, and other local measures are most important to stimulate electric vehicle mobility in cities 	Bakker & Trip, 2013
<ul style="list-style-type: none"> Vehicle efficiency and CO₂ standards through 2020 in the EU can be met with gasoline and diesel technologies and are therefore insufficient to drive electric vehicles into the market 	Meszler et al., 2013
<ul style="list-style-type: none"> Free toll roads, vehicle sales tax exemption, fuel savings, access to bus lanes, free parking are most important electric vehicle incentives for Norwegian consumers 	Haugeland & Kvisle, 2013
<ul style="list-style-type: none"> Fiscal incentives, preferential access (lanes, parking) are important drivers of electric vehicle sales States with consumer incentives (California, Georgia, Hawaii, Oregon, Washington) have 2-4 times greater than average electric vehicle uptake 	Jin et al., 2014
<ul style="list-style-type: none"> Consumer subsidies, infrastructure, and local policies are critical in driving electric vehicle uptake, and are causing large variation in electric vehicle uptake across 25 major U.S. cities Cities with greater consumer incentives, charging infrastructure have 2-5 times greater electric vehicle uptake 	Lutsey et al., 2015
<ul style="list-style-type: none"> Vehicle efficiency and CO₂ standards through 2025 in the U.S. would only require that approximately 2% of new 2025 vehicles are electric 	U.S. EPA and NHTSA, 2012
<ul style="list-style-type: none"> Regulatory incentives within vehicle efficiency standards (e.g., 0 g/mile accounting, super credits) make the deployment of electric vehicles cost effective as compliance approach 	Lutsey & Sperling, 2012
<ul style="list-style-type: none"> Consumers tend to underestimate fuel savings from electric vehicles Consumers are generally unaware of state and local incentives for electric vehicles 	Krause et al., 2013
<ul style="list-style-type: none"> Public announcements and marketing that raise awareness about the available consumer incentives and fuel savings are especially important 	Krupa et al., 2013
<ul style="list-style-type: none"> Charging and incentives are both important, infrastructure may be more important 	Li et al., 2015
<ul style="list-style-type: none"> Compared with workplace and public recharging, home recharging infrastructure improvements appear to have a greater impact on BEV-PHEV sales. The impact of improved charging infrastructure is amplified by a faster reduction in battery cost 	Lin & Greene, 2011
<ul style="list-style-type: none"> Plug-in electric vehicles put greater demands on, and may require new approaches from, vehicle dealers to market and sell them 	Cahill et al., 2014
<ul style="list-style-type: none"> Regional weather differences can increase annual energy use by 15% Differing marginal electricity sources can double the carbon emissions of electric vehicles 	Yuksei & Michalek, 2015
<ul style="list-style-type: none"> Long-term policies (e.g., ZEV program, incentives) are essential in the transition to electric drive fleet Hydrogen refuelling infrastructure deployment must precede fuel cell electric vehicle market launch Plug-in electric and fuel cell vehicles will both be important in the long term Transition to an electric fleet will take decades and benefits are likely to be at least 10 times greater than the costs (technology, incentives, infrastructure) 	Greene et al., 2014a, b
<ul style="list-style-type: none"> Difficult to overcome electric vehicle price premiums by fuel savings alone State and local electric vehicle purchasing incentives, preferential access would be important to encourage electric vehicle ownership and use 	NRC, 2013a
<ul style="list-style-type: none"> Lower operating costs (reduced fuel and maintenance costs) reduce the total cost of operating plug-in electric vehicles to make it lower than conventional vehicles 	Davis et al., 2013
<ul style="list-style-type: none"> Electric vehicle charging is predominately at home at 75%-80% across 16 US cities and regions Plug-in hybrid electric vehicles with 38-mile range are accruing approximately similar annual electric miles as 84-mile range all-electric vehicles 	INEL, 2014
<ul style="list-style-type: none"> Public charging infrastructure, environmentalism, fuel price, electricity price, education, VMT per capita, HOV lane access, and incentives significantly correlated with electric vehicle sales 	Vergis & Chen, 2014
<ul style="list-style-type: none"> Market formation incentives, legitimation from sales targets, and positive externalities may be contributing to higher shares of PEV market shares 	Vergis et al., 2014
<ul style="list-style-type: none"> Home charger access could be more important than public charging infrastructure for electric vehicle interest 	Baillie et al., 2015

EMERGING BEST-PRACTICE PRINCIPLES

Based on the results of various government actions promoting electric vehicles and recent research on effective policies, some basic principles are emerging regarding electric vehicle policy. The policies would ideally be targeted at helping overcome known potential barriers to prospective electric vehicle users, including incremental vehicle cost, vehicle range, vehicle recharge time, and consumer awareness regarding electric vehicle ownership benefits. Many countries are seeking to overcome these barriers and promote electric vehicle technology, mobility, and sales.

Several basic design principles appear important in policy implementation. To promote vehicle sales to consumers, it appears to be important to make purchasing incentives significant in magnitude (e.g., above 15% of the purchase price) and available at the initial point of vehicle sale. Among the various forms of incentives, the use of vehicle purchasing tax exemptions and making the rebates applicable at the point of sale can be especially attractive. These forms of incentives ensure that consumers are not dissuaded by the delay in receiving the tax benefit or the uncertainty about its applicability due to their tax liability. Making the incentives applicable for vehicle leasing also helps mitigate consumer uncertainty about battery life and resale value. Another important factor involves committing to consumer purchasing incentives for a relatively long-term period (e.g., through 2020, not only renewed one year at a time) to send a clear signal to automakers to invest in and deploy the technology.

In addition, non-fiscal incentives of various types are also important for many consumers. For example, preferential parking access, preferential highway access, and free toll road access can be monetized and have the effective value to average consumers of well over \$1,000 per vehicle in particular urban conditions, specifically when parking is relatively scarce and when driving is relatively congested. However, a key consideration is that such benefits must be well analyzed in advance to avoid over-use and minimize any potential public resistance.

Fully engaging electric power utilities with policies that encourage their active participation in promoting electric vehicles has only been partially explored, but is likely to be an important area in leading electric vehicle markets. Allowing and encouraging electricity providers to set preferential lower electricity rates for home, workplace, and public electric vehicle charging can be an important principle, and having “time-of-use” electric utility rates that link vehicle charging to off-peak rates tends to have advantages for both power utilities and consumers. Other beneficial policies, for example related to power utilities’ role in public charging infrastructure, vehicle-to-grid activities, and low carbon fuel policies’ ability to help finance charging infrastructure, are also emerging.

There are a number of policy design principles that would help overcome the barrier of electric vehicles’ limited range. Deploying a more extensive public and workplace charging network, including strategic coverage for early adoption communities and high-traffic corridors, is a key focus area for many jurisdictions. These growing networks expand the effective range of electric vehicles, as well as increase the confidence of electric vehicle users. As previously illustrated in Figure 8 and 9, various markets are seeing greatly varying electric vehicle charging equipment (e.g., an order of magnitude difference in public chargers, and quick chargers, per capita). In addition to increasing the availability of public chargers, more widespread use of workplace charging is an area of emphasis that can effectively double the daily range for prospective electric vehicle

commuters. Governments that are offering incentives for employers to install workplace charging infrastructure, as well as directly installing charging equipment for their own employees, are helping to mitigate electric vehicle range limitations.

Another way to mitigate the range limitation is the increased placement of electric vehicles in car-sharing fleets; this increases the use of electric vehicle activity, but allows consumers the option to select electric or non-electric vehicles depending on the necessary trip length. Another potential way to adjust policy design to better motivate increased vehicle range is to shift government consumer purchasing incentives to longer-range electric vehicles (e.g., greater subsidy for electric vehicle range of 200 or 250 kilometers). Making all consumer incentives that apply to plug-in electric vehicles equally applicable for hydrogen fuel cell vehicles, which tend to have significantly longer driving range, would also help avoid this potential barrier.

Several potential policy design principles could help overcome the barrier of electric vehicles' slow recharge time, compared with the refueling time of gasoline or diesel vehicles. Increased deployment of public fast charging is clearly in evidence in some jurisdictions (e.g., Norway, Oregon, and Japan), and this provides greater opportunities for 15-40 minutes of charging to work within more prospective electric vehicle users' average travel patterns. Governments can encourage such rapid charging stations with tax incentives for workplace or third party installations, or by directly funding or directly deploying the infrastructure through federal, state, or city government agencies. Implementing incentive policies that are inclusive of hydrogen fuel cell vehicles ensures that this technology, which does not have the charging time limitation, is also promoted.

There are several other potential government actions that could help overcome the barrier of prospective consumers' knowledge and awareness about electric vehicles. It is evident from the research that most prospective consumers are not well informed about the existing policy incentives or the potential fuel savings from replacing their conventional vehicles with electric vehicles. Education and awareness activities would ideally involve state and local governments, as well as utilities, providing information about relevant purchasing and charging incentives at dealerships, on websites, and through advertising campaigns.

Providing information to prospective electric vehicle consumers on vehicle ownership fuel-saving benefits on websites and consumer labels is an important basic step. Public events (e.g., ride-and-drive with public officials) and increased placement of electric vehicles in government fleets increase awareness regarding the new technology. Finally, the placement of vehicles in company, rental, and car-sharing fleets can also help to overcome the basic foundational lack of awareness and comfort regarding available electric vehicle models.

Table 5 summarizes actions to overcome potential barriers to greater electric vehicle uptake and use. The actions would aim to increase awareness among consumers about electric vehicles, reduce the effective electric vehicle ownership and operational cost, and help support increased vehicle range and reduced recharging times. Example areas where such policy actions are in place are listed in the final column.

Table 5. Electric vehicle adoption barriers and policy actions

Potential barrier	Potential actions to help overcome barrier	Examples of regions with action
Vehicle ownership cost	Provide fiscal incentives to defray incremental upfront cost	France, Norway, Netherlands, U.K., U.S.
	Extend electric vehicle fiscal incentives to 2020 or later	California, China
	Offer non-fiscal incentives (e.g., preferential road, parking, lane access) to provide effective monetary benefits to vehicle users	California, China, Norway
Vehicle range	Deploy extensive plug-in vehicle charging network , including strategic coverage for early adoption communities and high-traffic corridors	Japan, Norway, U.K.
	Deploy extensive hydrogen refuelling network , including strategic coverage for early adoption communities and high-traffic corridors	California, Germany, Japan, Netherlands, U.K.
	Encourage and create incentives for workplace charging infrastructure	U.S.
	Placement of vehicles in car-sharing fleets	France, Germany
	Introduce minimum range requirements to shift public fiscal and non-fiscal incentives to greater incentivize longer-range electric vehicles	
Vehicle recharge time	Provide charging infrastructure incentives for private deployment of more and faster at-home, workplace, public charging stations	
	Deploy extensive public quick charging network	Japan, Norway
Consumer knowledge and awareness	Provide information regarding state, local, and utility incentives widely, at dealerships, on websites, through advertising in broad awareness campaign	California, U.K.
	Provide cost evaluation tools and information to prospective electric vehicle consumers on vehicle ownership fuel-saving benefits (websites, consumer labels)	
	Conduct public events (e.g., ride-and-drive with public officials) to increase awareness and encourage first electric vehicle experiences	
	Place electric vehicles in government, company, and car-sharing fleets	China, Québec

RECOMMENDED RESEARCH

There are of many missing pieces in the movement to better understand what it will take to accelerate the deployment of electric vehicles in the marketplace in the decades ahead. The research summarized above, as well as the prevailing policy questions in each of the major automobile markets, hint at many of the areas that warrant deeper investigation including fiscal, regulatory, technical, and infrastructure aspects of electric vehicles.

Among the potential questions of high interest for electric vehicle policy are the following:

- » *Getting the right mix of incentives and promotion actions:* With all the competing new research on electric vehicle promotion actions, are best-practice recommendations for governments emerging? For example, research could continue to inform whether vehicle purchasing subsidies of particular types, charging infrastructure rollout of a particular type or distribution, particular local policies, and particular awareness activities are proving to be most effective in influencing electric vehicle uptake. A rigorous review of the literature, including

the studies listed in Table 4, could help distill lessons about critical and non-critical policy actions.

- » *Matching future purchasing incentives with technology improvement:* How long might electric vehicle consumer purchasing incentives be needed? How might electric vehicle consumer purchasing incentives be incrementally reduced over time? In particular, a related question is whether electric vehicle incentives can be reduced, corresponding to technology improvements in the 2015-2025 time frame, while sustaining market growth. For example, if the next-generation PHEV and BEV technologies see reduced battery costs by given amounts (e.g., to less than \$250/kWh), then subsidies might be reduced by a given amount. As a result, research into how the given cost-per-kilowatt reductions could allow some combination of greater range, less expensive cars, and a tapering off of incentives might help give policymakers and automaker perspective on the public investment for the subsidies. In addition, subsidies could evolve to provide greater incentives for second-generation technology. For example, electric vehicle subsidies could evolve to be applicable only to next-generation vehicles with greater range (e.g., only 200+ mile electric vehicles), which therefore better meet more widespread consumer constraints.
- » *Focusing on the ideal types of consumer incentives:* What are the ideal types of subsidies to motivate prospective electric vehicle consumers? Variations include the mechanism (e.g., rebate, sales tax exemptions, annual tax exemptions), the timing of the incentive for consumers (e.g., point of sale), the applicable technologies (e.g., inclusion of plug-in hybrids, threshold battery capacity), and the time frame of the incentives (e.g., through 2020). A study of the rationale and effectiveness of subsidy types would also help inform how best to evolve existing subsidies as the next-generation of electric vehicles are commercialized and how they could best meet a broader customer base, from early adopters, to first followers, to mainstream consumers. An analysis that includes different national, regional, and local incentives, and how they affect the market would help in informing which types of incentives are most important.
- » *The role of utilities in accelerating electric vehicle deployment:* How could electric power utilities gain from increased deployment of electric vehicles, and how might utilities provide direct incentives to electric vehicle owners to encourage greater use, lower carbon emissions, and reduced operating costs? At the same time, what are the issues for utilities regarding electric vehicles that must be solved? It is increasingly clear that there are synergies with lower-cost electricity for consumers and benefits for utilities and other fuel providers supplying the electricity (e.g., Ryan & Lavin, 2015). There also might be a great opportunity to capture and store renewable electricity generation that is otherwise not well matched to electricity demand, in electric vehicles. Distilling which governments around the world have had important lessons learned, have found particular problems, and are aligning utility and consumer interest could be helpful in prioritizing future policy.
- » *Deploying charging infrastructure with increased electric vehicle sales:* Is there an ideal amount, type, and rate of electric vehicle charging infrastructure (home, workplace, public fast charging per capita) that best encourages electric vehicle purchasing and use? The electric vehicle charging equipment across cities, states, and countries varies greatly and is a key factor for the range and utility of electric vehicles. Improved tracking and analysis about the use of public and workplace charging would help direct future policy and infrastructure investments. Linking

various types of charging equipment (per capita or per vehicle) with increased electric vehicle deployment in future years could help increase the attractiveness and use of electric vehicles. With more rigorous analyses of the diversity of charging deployment to date, it is plausible that some clear lessons could emerge that might be generally applicable for future government investments between consumer subsidies and charging infrastructure.

- » *Electric vehicle model availability:* What is the role of the number of electric vehicle models available in given markets in the sale of the vehicles? As nearly every major automaker introduces electric vehicle models into the marketplace, electric vehicle awareness and sales continue to increase. However, some countries are seeing far more models and far more extensive attempts by companies to sell the models across various regions. Most electric vehicle models are sold in just a few automobile markets, and within those markets sales are greatly concentrated in just several areas. Some markets with relatively high consumer incentives appear not to have much electric vehicle uptake, with one plausible explanation being that these markets are not among the early focus areas for automaker launches of the new models. On the other hand, there are markets where relatively few electric vehicle models are available, but early sales uptake has been relatively high. A study that analyzed electric vehicle availability would help inform on the importance of electric vehicle model availability in driving the early electric vehicle market.
- » *Long-term synergy between electric and autonomous vehicles:* With the recent excitement over autonomous or self-driving vehicles, are there potential synergies between the two technologies in the 2020-2030 time frame that might offer greater potential benefits in electric vehicle deployment and environmental benefits? Conversely, perhaps there could be issues or risks of the technologies simultaneously entering the market. For example, automobile companies' technology budgets or unique company strategies could slow the rollout of either autonomous or electric technologies. Or the two technologies could put different or increasing demands on infrastructure, consumers, energy use, and emissions.
- » *Importance of green supply chains:* Electric vehicles continue to be subject to some amount of skepticism and backlash from both a consumer and political perspective due to questions about how clean the upstream power source is. In some cases this is related to legitimate questions about environmental benefits but often is related to misinformation in reporting of various life cycle emissions analyses. What are the full life cycle emissions of electric vehicles across the major auto markets? How important are the life cycle carbon and energy footprint to potential consumers? A synthesis of existing research into the impact of the primary electricity energy sources, vehicle manufacturing emissions, and these impacts' trends in the future could help elucidate when, where, and how electric vehicles are most beneficial to climate. Such a study could also report on findings related to best practice policies, utility practices, and information programs.

New analysis, and synthesis of existing experiences among leading electric vehicle stakeholders, namely government and industry, could help answer these questions. As introduced above, a number of studies have begun to answer these questions, but only in isolated circumstances, with limited 2011-2014 data, and generally looking within just one major automobile market. Now, as data on differing policy approaches proliferate across different markets, far deeper analyses are possible and could be helpful in charting out more informed electric vehicle policy in the 2015-2016 time frame.

IV. SUMMARY FINDINGS REGARDING GLOBAL COLLABORATION

This section summarizes several key findings on the 2014 state of the global electric vehicle market, postulates several potential zero-emission vehicle targets that could help set policy to drive electric vehicle promotion policies in leading governments, and provides summary thoughts on the potential importance of increased global collaboration.

IMPLICATIONS FOR FUTURE ZERO-EMISSION VEHICLE GOALS

The findings of this report indicate that global electric vehicle sales are increasing, especially in several particular automobile markets. Figure 2 summarizes electric vehicle sales by the major regions of China, Europe, Japan, and the U.S. Global annual electric vehicle sales reached approximately 100,000 in 2012, 200,000 in 2013, and 300,000 in 2014. In 2014, Europe and China in particular saw greater increases in electric vehicle sales. Leading markets in sales volume within Europe are the Netherlands, France, Norway, and the UK. Based on this assessment, these regions are all implementing diverse electric vehicle promotion actions, but their policy incentives and infrastructure differ considerably, and they are seeing varying electric vehicle deployment shares.

Looking forward to the future market penetration of zero-emission vehicles, research studies have led to greatly divergent future projections. Analyses of particular markets, under varying assumptions for technical advancement and increased policy support (e.g., R&D, infrastructure, regulation) found 20% to more than 50% electric vehicle shares, including plug-in and fuel cell electric, were possible in leading electric-drive vehicle markets in the 2025-2030 time frame; however, lesser technology and policy assumptions generally pointed toward 5%-10% electric vehicle share in the same time frame. These analytical scenarios provide potential bounds for possible electric vehicle deployment in leading electric vehicle markets around the world.

A number of governments have sought to put forward particular electric vehicle deployment goals to provide milestones and aspirational visions for how far and how fast they would like to see the market grow. Such targets are shown in Table 1. The various national goals, if simply summed, amount to at least 15 million cumulative electric vehicle sales globally by 2020, and more than 25 million electric vehicles in the 2025-2030 time frame. In compiling these targets in 2013, the Clean Energy Ministerial indicated that the nations' targets would result in approximately 6 million electric vehicle sales per year in 2020 and include 20 million cumulative electric vehicles by 2020.

Some governments have acknowledged that the original electric vehicle goals are not likely to be met (e.g., Shephardson, 2015). Because 2010-2014 sales have been modest compared to the original goals (i.e., 300,000 global sales per year in 2014), global growth in electric vehicles sales would have to increase rapidly to reach those goals. Global electric vehicle annual sales growth would need to average greater than 65% per year to get back on track for the 6 million per year sales goal, and 75% per year to be on track for 20 million cumulative global electric vehicle goal by 2020. Another way to put the international 20-million-electric-vehicle goal in perspective is to compare it to the hybrid vehicle growth by the leading hybrid manufacturer. Toyota went from about 300,000 annual global hybrid sales in 2006 to roughly 1.4 million per year in 2014, selling more than 6 million hybrids in that period. To achieve 20 million electric vehicles by 2020, three companies would have to simultaneously accomplish the same growth

in electric vehicle sales from 2014-2020 that Toyota demonstrated in hybrid sales from 2006-2014.

As various leading countries expand their electric vehicle activities and contemplate longer-term transportation, energy, and climate policy, new electric vehicle deployment goals for 2025-2035 could be considered. Now, in 2015, governments have a far better understanding of electric vehicle deployment constraints, have begun adopting more comprehensive promotion policies, and are more focused on long-term climate targets. Based on plausible electric-drive market growth trajectories, as well as putting the transport sector on a path toward long-term climate stabilization goals, new mid-term targets are postulated here.

Table 6 summarizes potential metrics for zero-emission vehicle goals, citing examples of such goals that have been announced in various circumstances and postulating several potential plausible goals for zero-emission vehicles in the 2025-2035 time frame. Such goals could provide approximate extensions to previously announced goals, and they could do so with levels of deployment that are plausible and ambitious for interested governments to help guide future zero-emission vehicle policy. The potential targets and their relative merits are discussed below.

Table 6. Metrics, examples, and potential zero-emission vehicle goals for leading governments

Target metric	Existing examples	Potential 2025-2035 targets
Cumulative sales target	<ul style="list-style-type: none"> At least 3.3 million cumulative electric vehicle sales by 2025 (<i>U.S. eight-state agreement</i>) At least 20 million cumulative electric vehicle sales by 2020 (<i>Clean Energy Ministerial EVI goal</i>) At least 5 million hybrid and plug-in electric vehicles (<i>China New Energy Vehicle goal</i>) 	<ul style="list-style-type: none"> At least 30 million cumulative zero-emission vehicles are sold by 2025 At least 90 million cumulative zero-emission vehicles are sold by 2030
Annual sales	<ul style="list-style-type: none"> At least 6 million electric vehicle sales per year by 2020 (<i>Clean Energy Ministerial EVI goal</i>) 	<ul style="list-style-type: none"> At least 30 million zero-emission vehicle sales per year by 2035
Sales share	<ul style="list-style-type: none"> At least 10% of new sales are battery electric vehicles by 2020 (<i>Renault-Nissan CEO Carlos Ghosn</i>) At least 20% of new sales are plug-in hybrid and battery electric vehicles by 2020 (<i>Mitsubishi</i>) At least 15%-22% of new vehicle sales are plug-in and fuel cell electric vehicles by 2025 (<i>California Zero Emission Vehicle program</i>) 	<ul style="list-style-type: none"> At least 20%-30% of new vehicle sales are zero-emission vehicles by 2030 At least 35% of new vehicle sales are zero-emission vehicles by 2035
Electric mobility share	<ul style="list-style-type: none"> At least 30% of passenger vehicle activity is via electric vehicles by 2030 (<i>UN-Habitat Urban Electric Mobility Initiative</i>) 	<ul style="list-style-type: none"> At least 15% of national passenger vehicle activity is via zero-emission vehicles by 2035

The four example goals in the right-most column in Table 6 reflect future year sales, cumulative deployment, sales share, and zero-emission vehicle deployment that are approximately consistent with one another, depending on assumptions for relative vehicle sales growth across the countries. These goals relate to the leading 2015 electric vehicle markets (i.e., China, Europe, Japan, and the U.S.) seeing an average compounded annual increase in zero-emission vehicle sales of approximately 25% for 2015-2035 (greater in earlier years, lower in the later years). For this illustrative assessment of future goals, the remainder of the world vehicle market is assumed to lag the four major leading markets in zero-emission vehicle sales share by five years. The numbers presented here assume that Europe, Japan, and the U.S. experience

overall vehicle market growth of 1% per year, and China and other nations experience annual overall vehicle market growth of 4% per year through 2035. To provide a sense of the relative optimism of this global electric drive scenario, it requires that the leading markets of Europe, China, Japan, and the U.S. (as a whole) lag the California market's ZEV requirements by about three years (i.e., 15% in 2028 compared to California's 2025). The rest of the world is assumed to lag the California ZEV program timeline by about 10 years.

Several considerations, assumptions, and relative merits related to the various zero-emission vehicle goals are postulated in Table 6. The top two example metrics listed in the table, for cumulative sales (90 million by 2030) and annual sales (30 million zero-emission vehicle sales per year by 2035) both relate to overall global goals. Any such long-term cumulative or annual sales goals could provide milestones on the path toward long-term electrification and give a benchmark related to the industry's movement toward larger economies of scale. Global vehicle sales could greatly increase from 2014 to 2030, and a fixed zero-emission vehicle sales target in 2030 could mean a far higher or lower zero-emission vehicle sales share. Depending on how quickly the overall automobile market grows — for example, up to 100 million or 150 million vehicles per year — then 30 million annual zero-emission sales could amount to 20% up to 30% of the total sales share. A volume-based global sales target could potentially function better as broader group target (e.g., for China, Europe, Japan, and the U.S.) because it takes out country-to-country fluctuations and collectively commits countries to a common global goal.

The two share-based zero-emission vehicle deployment goals, the bottom two rows in Table 6, also have relative merits and considerations. Contrary to volume-based zero-emission vehicle deployment goals, share-based goals could have greater meaning on an individual country basis. Zero-emission vehicle share and electric mobility goals might provide clearer links to long-term transportation climate stabilization goals, namely because governments could be interested in demonstrating progress toward near 100% zero-emission vehicle deployment in the 2040-2050 time frame. In addition, share-based goals allow each country to track the increase in its zero-emission vehicle share toward a future goal (e.g., 35% zero-emission vehicle share by 2035), as well as compare against other markets around the world. As a result, a percent-vehicle-share, more so than a cumulative-million-vehicle, goal provides a direct indication of the shift from conventional to electricity- or hydrogen-based energy sources. The electric mobility, or electric vehicle usage, share goal would similarly allow each country to better track its progress in electrifying the transport sector. However, zero-emission vehicle usage goals would have an associated difficulty in being able to track the actual vehicle activity over time, and such a goal is also more uncertain based on vehicle retirement assumptions.

Figure 10 illustrates a trajectory of zero-emission vehicle deployment that approximately matches the four goals postulated in Table 6. To summarize the key assumptions, this level of zero-emission vehicle deployment assumes an average 25% compounded global annual zero-emission vehicle sales growth from 2015-2030. This includes faster growth in the earlier years in China, Europe, Japan, and the U.S., and zero-emission vehicle shares in the rest of the world experience a five-year delay from those leading markets. The trajectory shown in the figure results in more than 30 million zero-emission vehicles sales in the four leading markets in 2035 (more than 35 million including the rest of the world), more than 90 million cumulative zero-emission vehicle sales by 2030, and 35% zero-emission vehicle sales share globally in 2035. These goals would roughly translate

to 15% of national automobile usage being from zero-emission vehicles in the four leading zero-emission vehicle markets by 2035.

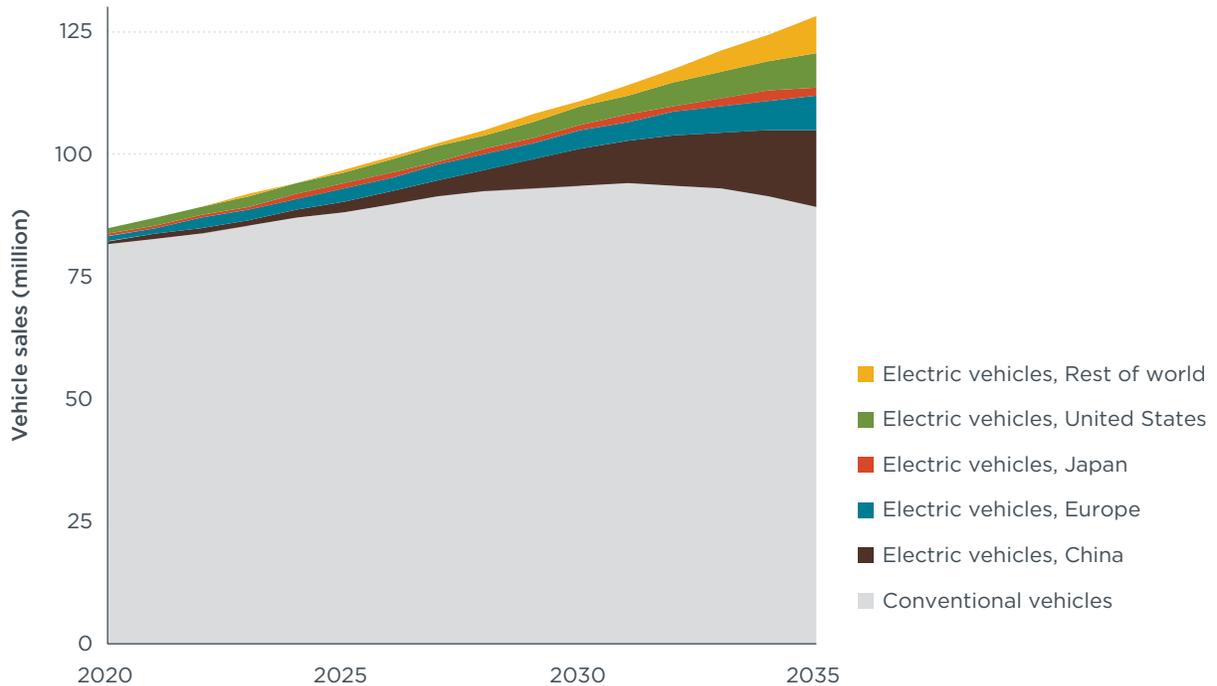


Figure 10. Illustrative scenario for increased 2020-2035 zero-emission vehicle deployment goals

CONCLUDING DISCUSSION

A key objective of this report is to investigate current and potential future government actions that can be taken to help drive the next-generation electric-drive technologies into the marketplace. Indirectly, then, the goal is to help accelerate zero-emission vehicle sales to drive up economies of scale, and thus help bring forward lower cost electric-drive technologies as much as possible in the 2015-2035 time frame. In the context of this report, the goal is broader than surmounting the individual market barriers; it is creating sustainable markets for automakers to make larger investments to roll out global electric vehicle platforms and launch new models in multiple markets. Simultaneously using public policy to help scale up supply chains, charging infrastructure, and consumer awareness about electric vehicles will be critical in building the full electric-drive ecosystem.

With this goal in mind, Table 5 provides example actions, and a template, for governments to continue to adopt similar such policies. Looking beyond the immediate time frame, the more successful each individual market is, the more it could lead to greater global success in commercializing electric vehicles.

Spurring automobile manufacturing companies toward higher-volume deployment of zero-emission vehicle technology is a global challenge. The policies described above, if more fully adopted, could help provide durable and consistent incentives, for manufacturers and consumers alike, across leading auto markets globally. Vehicle manufacturing companies choose the early launch regions where models are made available and where the first tens and hundreds of thousands of vehicles are being

deployed. They also dictate how extensive and widespread their efforts are with dealer training, company sales incentives, and marketing. Examples of the sort of electric vehicle deployment approaches that result from increased global policy activity are seen in recent announcements by Renault-Nissan, General Motors, and Tesla. These companies are proceeding to roll out electric vehicle models with increased vehicle range, reduced cost, and higher volume in their second- and third-generation electric vehicle models. Global multiple-market launches for greater economies of scale at higher manufacturing volume are likely to be even more important for electric vehicles than conventional vehicles. Systematic policy promotion of electric vehicles by leading governments around the world facilitates more of these big moves by automakers to be made more quickly.

Overtaking the incumbent internal combustion technology will require global battery and fuel cell technology improvements, global manufacturing scale, cost reduction, and global electric vehicle platforms. The decades-long transition to an electric-drive fleet will also require global cooperation on what policies, incentives, infrastructure, and support activities create the right recipe to sustain growth in the new technology. Based on the findings, we draw the following three conclusions:

Policy action by leading governments is spurring electric vehicle deployment.

The most comprehensive electric vehicle promotion actions globally are in Norway, the Netherlands, and California, and these actions are resulting in electric vehicle deployment that is more than 10 times the international electric vehicle uptake. More broadly, the actions of the governments of China, France, Germany, Japan, the Netherlands, Norway, the U.K., and the U.S. are leading with policy incentives and infrastructure investments, and these countries make up more than 90% of the world's electric vehicle market.

Best practices in electric vehicle promotion policies are emerging. From the early electric vehicle promotion activity, best practices to accelerate electric vehicle deployment are beginning to emerge. Increasingly stringent efficiency standards, electric vehicle research and development support, and national electric vehicle planning appear to be necessary but insufficient actions to grow the electric vehicle market. Consumer incentives that reduce the cost of ownership are important to improve the consumer proposition on the new advanced electric technologies. Increasing the availability of home, workplace, and public electric charging infrastructure is also of high importance, and several leading automobile markets (e.g., Japan, Norway, and parts of the U.S.) have far more extensive charging infrastructure per capita than others. It is increasingly becoming clear that a comprehensive portfolio of national, state, and local actions is critical for the increased deployment and use of electric vehicles.

Greater international collaboration could better leverage existing efforts to promote zero-emission vehicles. This assessment points to several possible ways that governments can better collaborate and coordinate. The establishment of a zero-emission vehicle deployment target (e.g., 35% of automobile sales being zero-emission vehicles and 30 million annual global zero-emission vehicle sales) and an electric mobility target (e.g., at least 15% of vehicle use being electric) for 2035 would help in establishing a common long-term global electric-drive vision. Such goals would send clear signals about the pace of development and amount of resources that will be needed. Further coordinated research on policy effectiveness

would further help prioritize government actions that are most important in increasing zero-emission vehicle uptake and use.

The transition of the automobile sector to electric drive will require not only sustained policy incentives but also increased communications about progress and policy learning. In these early years in the transition, there is much to learn from every region's experience in the rollout of zero-emission vehicles. Developing the new zero-emission vehicle market will require global scale, in the tens of millions of vehicles, to achieve lower cost and long-term success. Automakers are learning from their first- and second-generation electric vehicles and increasingly developing global electric-drive vehicle platforms and launching them in multiple markets. Meeting long-term climate goals will also likely include diffusion of hydrogen fuel cell vehicle technology into the fleet, as well as electric-drive technologies into heavy-duty vehicles, so the technology and policy advancement into these areas will also be important over time. Similarly, governments ideally will have to continue to learn from initial policy experiences and embrace common international best policy practices in many markets across the globe. International collaboration will be a critical step toward greater volume and a long-term market transformation to a zero-emission vehicle fleet.

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