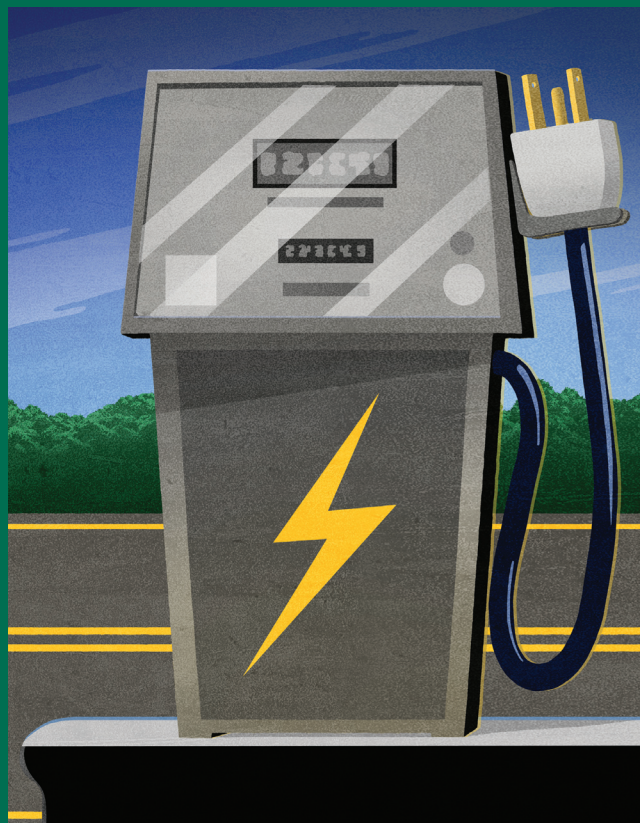


# REPORT

## Powering Autos to 2020

The Era of the Electric Car?



THE BOSTON CONSULTING GROUP

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Xavier Mosquet

Mythili Devineni

Tobias Mezger

Hadi Zablit

Andreas Dinger

Georg Sticher

Marco Gerrits

Massimo Russo

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July 2011

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For information or permission to reprint, please contact BCG at:

E-mail: [bcg-info@bcg.com](mailto:bcg-info@bcg.com)

Fax: +1 617 850 3901, attention BCG/Permissions

Mail: BCG/Permissions

The Boston Consulting Group, Inc.

One Beacon Street

Boston, MA 02108

USA



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# Executive Summary

**T**he automotive-propulsion landscape is evolving rapidly, and the questions facing OEMs as they look toward 2020 are increasingly complex. Which technologies will prevail? How will consumers react to an expanding range of choices? How is the battle for market share—conventional versus electric vehicles—likely to shake out? What are the specific go-to-market challenges facing electric vehicles?

In this report, the latest in a series on automotive propulsion, The Boston Consulting Group addresses these and other questions stakeholders will face, providing an integrated perspective on the technologies that will populate the vehicle landscape through the rest of the decade. Specifically, the report focuses on internal-combustion-engine vehicles (ICEs), including those fueled by gasoline, diesel fuel, compressed natural gas, or biofuels, as well as microhybrids; hybrid electric vehicles (HEVs), including mild and full hybrids that have both an internal-combustion engine and an electric motor but no external-charging capability; and electric vehicles (EVs), including pure battery, range-extended, and plug-in HEVs that have an electric motor and can be charged externally.

Drawing on interviews with industry experts, BCG's consumer research, and total cost of ownership (TCO) economics, the report identifies different scenarios and their implications for OEMs, suppliers, and regulators. Our high-level findings include the following:

**Conventional technologies have significant emissions-reduction potential, but OEMs will need to pull multiple levers simultaneously to meet 2020 emissions targets. It will be necessary to make modifications to combustion technologies, transmissions, vehicle mass, aerodynamics, and power management.**

- ◇ Advanced combustion technologies alone could reduce tailpipe emissions of carbon dioxide by approximately 40 percent from current average levels for new-vehicle fleets: 250 to 270 grams per kilometer (g/km) in the U.S., 150 to 170 g/km in Europe, 200 to 215 g/km in China, and 130 to 140 g/km in Japan. The cost to the consumer would be \$50 to \$60 per percentage point of reduction. This cost, roughly half what we predicted three years ago, reflects rapid recent progress in the advancement of ICE technologies.
- ◇ Of the advanced ICE technologies, engine downsizing, turbocharging, optimized cooling, low friction, start-stop systems, direct injection, and variable valve timing will likely lead the charge. We expect these to be mainstream developments across most passenger-car segments in all major markets.

**The electric car will face stiff competition from ICEs when competing solely on the basis of TCO economics and, hence, will not be the preferred option for most consumers.**

- ◇ Battery pack costs will fall sharply (approximately 64 percent from 2009 levels) to \$400 per usable kilowatt-hour (kWh) by 2020. However, to the consumer, this still represents a cost of \$9,600 per vehicle for the typical 20-kWh battery necessary for a pure battery EV.
- ◇ TCO economics for electric cars will also be significantly influenced by government incentives and fuel and electricity prices.
- ◇ High costs notwithstanding, EVs will see relatively strong uptake from some consumers. In particular,

there is evidence of a “green” consumer segment (comprising approximately 6 percent of consumers in the U.S. and 9 percent of those in Europe) willing to pay more for an EV even if the TCO economics are not compelling.

- ◇ In addition to their relatively high TCO, EVs face substantial go-to-market challenges—including questions about battery durability and the establishment of the required charging infrastructure—that will affect their rate of adoption.

**China and Europe—not the U.S., as many might think—will be the largest markets for EVs in 2020, driven by strong government support.**

- ◇ China is a major wildcard. To date, despite significant public support from the government for EVs, China has seen neither the promised breakthroughs in battery technology nor increases in the presence of EVs beyond those purchased for public fleets. The government’s efforts have, however, increased consumers’ awareness. Assuming the government remains committed to EVs, we expect that they will represent 7 percent of new-vehicle sales in 2020, supported by car buyers’ enthusiasm for the technology and China’s high gasoline taxes.

- ◇ By 2020, EVs will likely account for approximately 8 percent of new-car sales in Europe, supported by consumers’ willingness to pay for green technologies, the region’s stringent emissions standards, and high gasoline and diesel-fuel taxes.

- ◇ Combined EV and HEV sales could reach 15 percent of aggregate new-car sales in the four major markets—North America, Europe, China, and Japan—in 2020. As OEMs ramp up capacity to meet this demand, they will have to simultaneously invest in advanced ICE technologies. This will pose significant production and supply-chain challenges and likely force OEMs to increasingly globalize powertrain production.

- ◇ Market participants should closely monitor how governments choose to gauge vehicles’ environmental impact. Regulators are focusing predominantly on tailpipe emissions; if their focus should shift to the broader “well-to-wheel” metric, the environmental argument for EVs would become less compelling. Based on our current projections, EVs’ well-to-wheel emissions advantage over ICEs—estimated at 40 to 60 percent—will fall to 30 to 50 percent in 2020 as advances in ICE technologies narrow the gap and power generation from clean nonfossil fuels continues to grow slowly in most regions.





# Key Recent Changes in the Vehicle Propulsion Landscape

**B**CG's first report in this series, *The Comeback of the Electric Car? How Real, How Soon, and What Must Happen Next*, published in January 2009, considered the prospects for both electric cars and competing alternative-propulsion technologies. Our second report, *Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020*, published in January 2010, focused on the technical attributes and costs of lithium-ion batteries and battery packs for electric vehicles (EVs) and highlighted the EV market's challenges and opportunities to 2020.

Since the publication of our first report, there have been several key developments in the regulatory environment, in technology, and in consumer behavior and sentiment that stand to have a material impact on the propulsion landscape to 2020—in particular, the adoption prospects for EVs.

## More Stringent Regulation

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On the regulatory front, standards for tailpipe emissions and fuel efficiency are becoming more stringent. (See Exhibit 1.) The targets vary by country and region for different types of emissions: the European Union's proposed 2020 target for emissions of carbon dioxide (95 grams per kilometer [g/km] for the new-vehicle-fleet average), for example, is far more aggressive than the likely targets of the U.S., China, and Japan.<sup>1</sup> The U.S., meanwhile, has set the toughest standard for emissions of nitrogen oxides (NOx). Regardless, the trend is clear: standards are rising.

In parallel, energy independence is becoming a priority in many countries, particularly in the U.S. and China. The

importance of this priority has intensified as a result of the recent geopolitical instability in the Middle East.

The combination of rising concerns over greenhouse gas emissions and a growing desire to reduce dependence on oil has underscored, in many governments' view, the need to promote EVs. Several governments already have

established significant incentives to stimulate early sales. The U.S. government, for example, offers a maximum tax credit of \$7,500 on the purchase of an EV (and some state governments, such as California's, offer up to \$5,000 in additional incentives), and more than half of EU governments offer tax reductions or exemptions. But it is unclear whether

those incentives will be sustainable when EVs approach mass adoption. Simultaneously, many of the incentives that governments had previously instituted to promote HEVs (including tax breaks, free parking, and access for single-occupant cars to high-occupancy-vehicle lanes) have been or are being phased out.

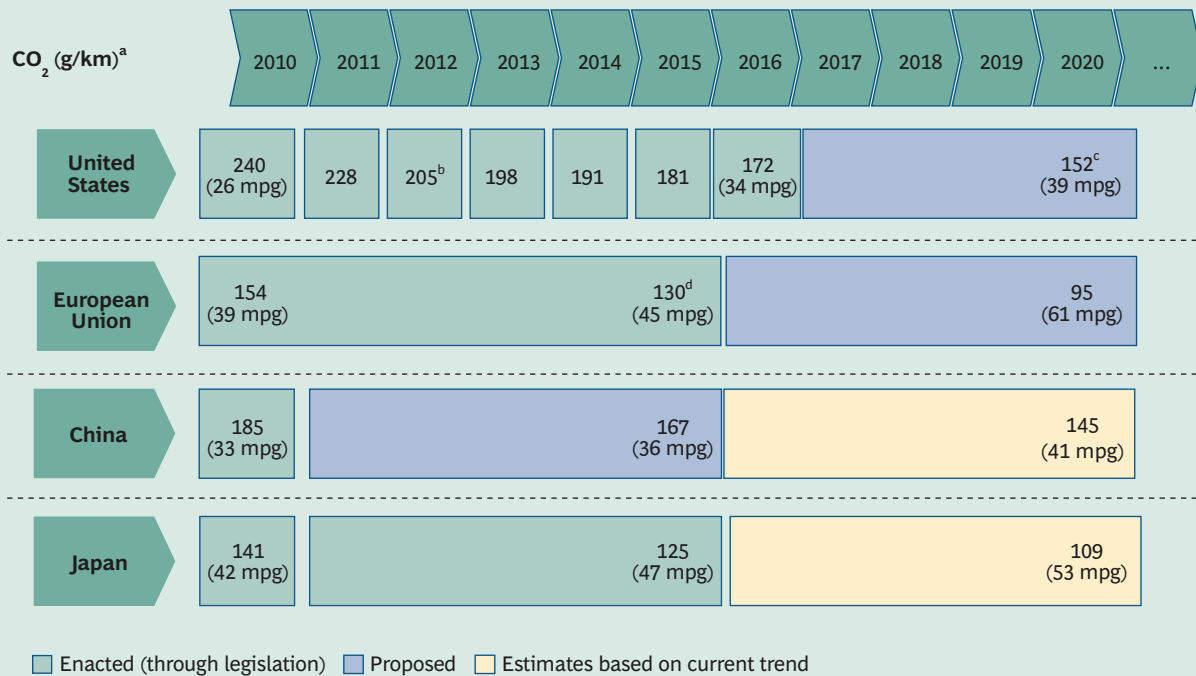
Taken together, the abovementioned factors suggest a supportive backdrop for accelerating EV adoption as the march to 2020 proceeds. Another early plus for these vehicles is that the first EVs are now on the road and consumers are becoming more familiar with the concept. So far, the results are encouraging. In the U.S., both the Volt and the Leaf have drawn more than 20,000 advance reservations, suggesting that there is demand and that both

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1. In the U.S., the Environmental Protection Agency and the National Highway Traffic Safety Administration have proposed a reduction in greenhouse gas emissions of 3 to 6 percent per year from 2017 through 2025, resulting in a fuel economy mandate of 47 to 62 miles per gallon for the new-vehicle-fleet average by 2025.

## Exhibit 1. Standards for Emissions and Fuel Efficiency Are Becoming More Stringent



**Sources:** International Council on Clean Transportation; U.S. Environmental Protection Agency; Japan Automobile Manufacturers Association, *The Motor Industry of Japan 2010*; *Asahi Shimbun*.

<sup>a</sup>All targets are expected to be phased in. CO<sub>2</sub> emissions targets are in grams per kilometer (g/km) and are based on the New European Driving Cycle (NEDC). Mileage targets are in miles per gallon (mpg) and are based on Corporate Average Fuel Economy (CAFE) standards.

<sup>b</sup>California has agreed to conform to the U.S. government's targets for 2012 through 2016. Previously, the state had enacted stricter legislation.

<sup>c</sup>This is based on the government's released scenarios of a 47- to 62-mpg target for 2025; 47 mpg is expected to be the most likely target.

<sup>d</sup>From motor vehicle technology only. The European Union plans to call for a further 10 g/km reduction in CO<sub>2</sub> emissions through other improvements (for example, to air-conditioning technology) and the use of biofuels.

General Motors and Nissan are on track to meet their respective sales targets of 10,000 EVs in 2011.

### Technological Advances

Yet significant challenges on the technology front will exert a major drag on EV adoption. The first is the high cost of batteries—a large percentage of an EV's total purchase price. EV battery technologies will continue to improve, and battery costs will continue to fall. But there is currently no technological breakthrough in sight that would lower prices enough to significantly alter the economics in favor of EVs by 2020. As our 2010 report on batteries stated and as we have recently confirmed, by 2020, battery pack costs to OEMs will likely fall sharply—to \$400 per usable kilowatt-hour (kWh), roughly 64 percent lower

than in 2009. But, for the majority of vehicle buyers, they will still be too expensive.

Falling costs for emissions reduction in internal-combustion-engine vehicles (ICEs) is the second technological hurdle for strong EV adoption by 2020. We estimate that advanced ICE technologies—the most potent lever for reducing tailpipe emissions—will allow OEMs to reduce CO<sub>2</sub> emissions at a relatively low cost to the consumer of \$50 to \$60 per percentage point of emissions reduction. This gives OEMs less incentive to aggressively push EVs to meet 2020 emissions regulations.

How these forces play out in concert remains to be seen. But on balance, recent developments suggest that from now to 2020, EVs will face more than a few bumps on the path to adoption.



# ICEs and Emissions Targets

**T**ightening emissions standards pose a key challenge for OEMs—a challenge that will undoubtedly influence how quickly and aggressively they move (or are forced to move) down the path of vehicle electrification through the rest of the decade. Ultimately, we believe that most OEMs should be able to meet 2020 emissions targets through a combination of modifications to ICE technologies and other levers (for example, reductions to vehicle mass) and should be able to do so in a cost-effective manner. (See Exhibit 2.) Our current projections are that, through these measures, OEMs will be able to reduce CO<sub>2</sub> emissions of gasoline-fueled vehicles by 15 to 49 percent, at a cost to the consumer of 2 to 16 percent per vehicle. Reducing diesel-fueled vehicles' CO<sub>2</sub> emissions by 3 to 36 percent will result in a cost to the consumer of 4 to 12 percent per vehicle. Hence, from a 2020 emissions standpoint, there is minimal need for OEMs to pursue EVs even though EVs will undoubtedly play a major role in meeting 2035 and 2050 ambitions.

## Engine-Based Levers

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Among the emissions-reducing levers at OEMs' disposal, ICE technology improvements are the most effective, offering the potential to lower emissions by as much as 40 percent: 250 to 270 g/km in the U.S., 150 to 170 g/km in Europe, 200 to 215 g/km in China, and 130 to 140 g/km in Japan. These levers are, however, also the most expensive, adding approximately \$2,000 to the price of a vehicle. (See Exhibit 3.) There is a range of such levers for gasoline-fueled ICEs, spanning air intake and exhaust,

engine architecture, engine control, fuel injection, and ignition. Some of these, such as optimized cooling, low friction, start-stop systems, and engine downsizing combined with mild turbocharging, stand to see widespread adoption across many vehicle segments due to their relatively low cost. Larger, more expensive vehicles will feature strong turbochargers to maintain superior performance.

From a 2020 emissions standpoint, there is minimal need for OEMs to pursue EVs.




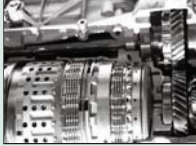

Fewer levers are available for diesel-fueled ICEs, which are already optimized. The most promising levers are turbocharging, which is well developed, and the still-nascent homogeneous charge combustion ignition (HCCI). Turbocharging and HCCI could reduce CO<sub>2</sub> emissions by 5 to 10 percent and 10 to 15 percent, respectively. The high cost of posttreatment for meeting NO<sub>x</sub> emissions standards poses a significant hurdle for the growth of diesel-fueled vehicles. We expect that in Europe, a traditional diesel stronghold, by 2020, sales of these vehicles will have declined from the current 46 percent of new-vehicle sales to approximately 30 percent. (We included diesel hybrids in our HEV projections.) Lacking government incentives promoting diesel-fueled vehicles, the other big markets (the U.S., China, and Japan) are unlikely to see a commensurate pickup in demand. Diesel could, however, continue to play a significant role in India and other emerging markets, where the TCO economics are more favorable.

## Other Levers

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To meet emissions targets for both gasoline- and diesel-fueled vehicles, OEMs will be forced to use a range of other levers beyond those focused on engines. The avail-

## Exhibit 2. Conventional Technologies Have Significant Emissions-Reduction Potential

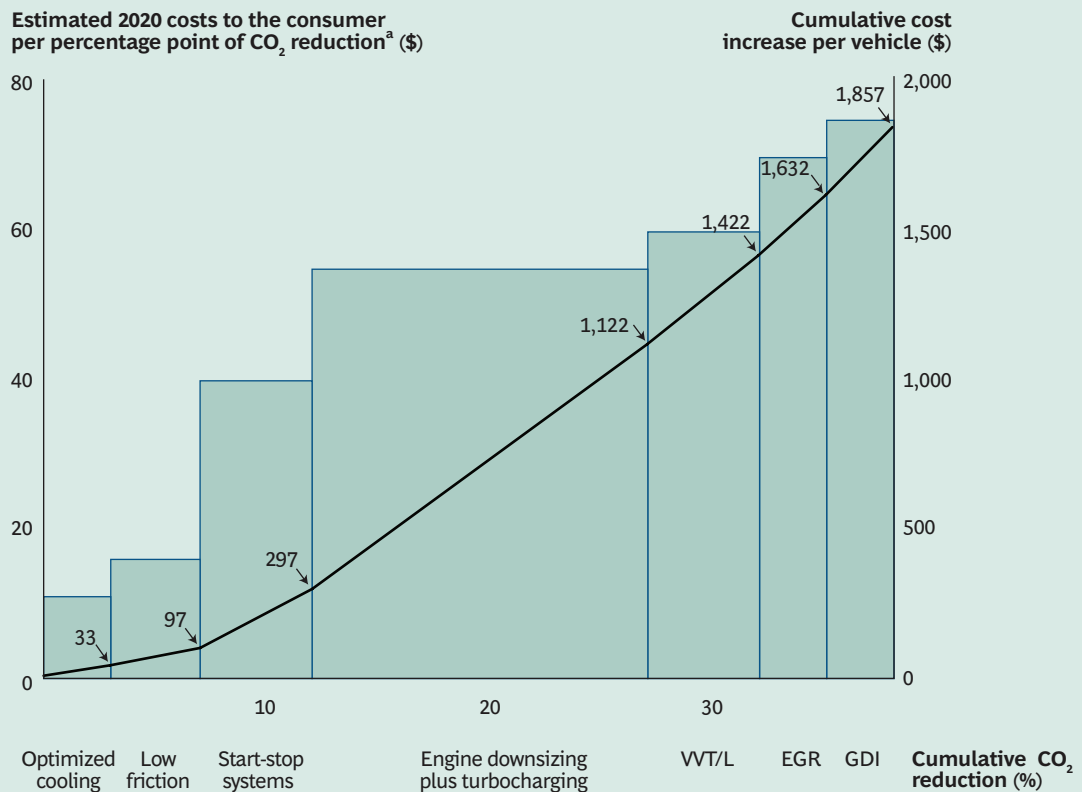
	Aerodynamics	Vehicle mass	ICE technology	Transmissions	Power management
					
<b>Levers</b>	<ul style="list-style-type: none"> <li>Optimized design (drag coefficient and frontal area)</li> <li>Optimized tires</li> </ul>	<ul style="list-style-type: none"> <li>Lightweight materials</li> <li>New manufacturing technologies</li> <li>Content optimization</li> <li>Downsizing</li> </ul>	<ul style="list-style-type: none"> <li>Vaporization and combustion optimization</li> <li>Reductions in energy losses due to pumping, friction, and heat</li> <li>Weight reduction</li> </ul>	<ul style="list-style-type: none"> <li>Improved control of automatic transmissions</li> <li>Continuously variable transmissions</li> <li>Dual clutch</li> </ul>	<ul style="list-style-type: none"> <li>Switching from mechanical to electronic accessories</li> <li>Optimization of accessories' electricity consumption</li> </ul>
<b>Impact on CO<sub>2</sub> emissions</b>	1% reduction per ~0.01 reduction in the drag coefficient	3%–4% reduction per 10% mass reduction	1%–20% reduction per technology	1%–7% reduction per technology	1%–2% reduction per technology
<b>Approximate maximum potential CO<sub>2</sub> reduction by 2020</b>	5%	5%–6%	40% <sup>a</sup>	5%–10%	3%–5%
<b>Approximate cost to consumer per car<sup>b</sup></b>	\$100 (\$20 per percentage point of CO <sub>2</sub> reduction)	\$500 <sup>c</sup> (\$100 per percentage point of CO <sub>2</sub> reduction <sup>d</sup> )	\$2,000–\$2,500 (\$50–\$60 per percentage point of CO <sub>2</sub> reduction <sup>e</sup> )	\$100–\$200 (\$20–\$40 per percentage point of CO <sub>2</sub> reduction <sup>f</sup> )	\$150–\$250 (\$50 per percentage point of CO <sub>2</sub> reduction)
<b>Sources:</b>	Expert interviews; BCG analysis.				
	<sup>a</sup> For diesel, the potential reduction is 30 to 35 percent.				
	<sup>b</sup> Vehicle price increase before VAT.				
	<sup>c</sup> The cost for an average weight reduction of 250 pounds.				
	<sup>d</sup> New materials show the potential for weight reductions of up to 37 percent at a cost of \$2,100, or approximately \$160 per percentage point of CO <sub>2</sub> reduction.				
	<sup>e</sup> The average for gasoline and diesel: individual technologies vary from \$20 to more than \$100 per percentage point of CO <sub>2</sub> reduction.				
	<sup>f</sup> Replacement of a five-speed automatic gearbox with a dual-clutch transmission in a compact car.				

able choices will have a smaller impact on CO<sub>2</sub> emissions, but they will also cost less. They include improved aerodynamics and drag reduction, which could reduce emissions by up to 5 percent at an added cost of \$100 per vehicle; transmission levers (for example, improved automatic-transmission control), which could reduce emissions by 5 to 10 percent at an added cost of \$100 to \$200 per vehicle; and power management levers (for example, switching from mechanical to electronic accessories), which could reduce emissions by 3 to 5 percent at a cost of \$150 to \$250 per vehicle. Another potentially overlooked lever is reduced vehicle weight achieved through the use of lightweight materials and optimization of con-

tent. Weight-reducing measures could reduce CO<sub>2</sub> emissions by 5 to 6 percent at an approximate cost of \$500 per vehicle. How automakers balance the use of these levers to meet emissions targets will vary.

Although OEMs in aggregate should comfortably meet 2020 emissions standards, the effort and expense necessary for individual companies to hit those targets will depend on each company's starting point. German OEMs, including BMW, Daimler, and Volkswagen, lead the industry in innovations for diesel- and gasoline-fueled ICES. France's PSA Peugeot Citroën has a similarly strong position in diesel. But U.S. and Japanese OEMs are catching

## Exhibit 3. ICE Technologies Alone Can Reduce Emissions by Approximately 40 Percent



Average incremental cost per percentage point of CO <sub>2</sub> reduction	0%–10%	10%–20%	20%–30%	30%–40%
	\$23	\$44	\$58	\$70

Source: BCG analysis.

Note: VVT/L = variable valve timing divided by lift; EGR = exhaust gas recirculation; GDI = gasoline direct injection.

<sup>a</sup>The estimated 2020 price to the consumer before VAT assumes a 1 percent decrease in manufacturing costs from 2010 to 2020 and OEM markups ranging from 50 to 100 percent. Estimates are for North American D-segment vehicles. Vehicles of other segments will likely show minor variances.

up, and their progress is reflected in their increased patent activity from 2000 through 2010. And a range of OEMs and suppliers have been pushing the envelope in building intellectual property in key emissions-reduction technologies such as turbocharging and supercharging (for diesel and gasoline), exhaust gas recirculation, valves, and weight reduction.

### Alternative Fuels

Alternative fuels constitute another potentially promising emissions-reduction lever—especially in considerations

of emissions on a “well-to-wheel” basis. Advances in the development of second-generation biofuels, in particular, hold promise, although it will take some time before plants can produce these fuels at the necessary scale: the approximately 46 billion gallons of second-generation biofuels expected to be available in 2020 will be sufficient for only a small portion of the world’s passenger cars. Compressed natural gas (CNG) has similarly attractive emissions-reduction potential, especially in certain regions (notably the U.S., given its recent discoveries of natural gas) and for specific vehicle segments, particularly certain fleets. (See the sidebar “Compressed Natural Gas: A Potential Bridge Technology?”)

## Compressed Natural Gas

### A Potential Bridge Technology?

As OEMs wrestle with advanced ICEs and EVs, they will have to remain aware of the opportunities and challenges presented by a compelling alternative-fuel source—compressed natural gas (CNG).

CNG has several key advantages. One is its large reserves, which give CNG a cost advantage at the pump over gasoline and make it appealing from an energy independence perspective. A second major advantage of CNG is its favorable emissions profile. Well-to-wheel CO<sub>2</sub> emissions of CNG-fueled vehicles are 15 to 25 percent lower than those of gasoline-fueled vehicles.

But CNG also poses challenges for OEMs that are similar to the challenges associated with EVs—for example, high up-front vehicle costs. A CNG passenger car costs \$4,000 more than its gasoline equivalent, even when CNG cars are manufactured at scale. The biggest hurdle to widespread CNG adoption, however, will be establishing the required fueling infrastructure. Despite a tax credit of \$0.50 per gasoline gallon equivalent (GGE) in the U.S., the business case for investments in CNG fueling stations is not clear for utilities and infrastructure providers.

Overall, CNG offers emissions reduction potential similar to that of hybrids at similar cost. Hybrids face less of an uphill battle, however, as they are more widely accepted by consumers and do not require additional infrastructure. Although CNG may struggle to reach widespread adoption among individual consumers, it is the ideal choice for certain vehicle fleets. For investors, there can be significant scale advantage in CNG fueling stations—a high-throughput station (that is, one that dispenses more than 30,000 GGE per month) requires a \$1.5 million investment but has an attractive ROI. And for fleet owners,

as mileage rises due to CNG's low cost, CNG becomes an increasingly attractive alternative to hybrids. For these reasons, CNG could expand beyond its current strongholds with transit buses and airport shuttles and see growing adoption by delivery vehicles, government fleets, and taxis—all vehicles that, because they build up high mileage, make frequent short trips, and employ centralized refueling, are ideally suited to CNG deployment. By targeting selected fleet segments, CNG could garner 0.5 to 1.0 percent of passenger car and light-truck sales in the U.S. and China, with potentially higher penetration for buses and midsize trucks. In Europe, where the appeal of CNG could extend beyond the fleet segment, penetration could reach 2 percent of passenger car sales. Italy already has a significant fleet of CNG-powered vehicles and a good fueling infrastructure in place—the result of a concerted effort by the government, Fiat, and Eni (Italy's national energy company) since 1999.

Governments can spur CNG adoption by mandating its use by fleet vehicles and by establishing inner-city emissions targets. The governments of India and Pakistan, for instance, have been able to mandate such adoption for public transportation, including buses and taxis, in major metropolitan areas. Similar legislation in the U.S. could drive CNG adoption there, leading to emissions reduction at a lower cost to consumers and the government than that associated with EVs.



# The Role of the Consumer

Our market research shows that consumers in the U.S., Europe, and China are interested in alternatives to the traditional gasoline-fueled ICE powertrain. (See the sidebar “Consumer Research.”) Among the alternatives we considered, hybrid electric vehicles (HEVs) and EVs resonated most strongly with consumers. (See Exhibit 4.) In each of the markets we looked at, HEVs and EVs garnered the most interest. U.S. and European consumers viewed HEVs most positively; Chinese consumers preferred EVs. Biofuels and CNG, in contrast, appear to face an uphill battle to widespread consumer adoption: approximately 30 percent of consumers in both the U.S. and Europe indicated that they are not interested in these technologies. Clean diesel is still viewed favorably in Europe, with 68 percent of consumers expressing interest. But it has less appeal in the U.S. Approximately 40 percent of U.S. consumers indicated a lack of interest.

## Motivation to Purchase

For most consumers, environmental concerns and the potential for savings through better fuel economy are the main motivators for considering alternatives to traditional ICE technologies. But there are some notable differences among consumers by region. U.S. consumers attach significant importance to energy independence. Chinese consumers are more interested in EVs than in any other technology, motivated primarily by the vehicles’ cutting-edge appeal. In our experience, Chinese consumers generally tend to state higher interest levels than their U.S. and European counterparts, so it is more revealing to compare the rankings of the different technologies than the percentages of consumers interested in each.

## Willingness to Pay a Premium

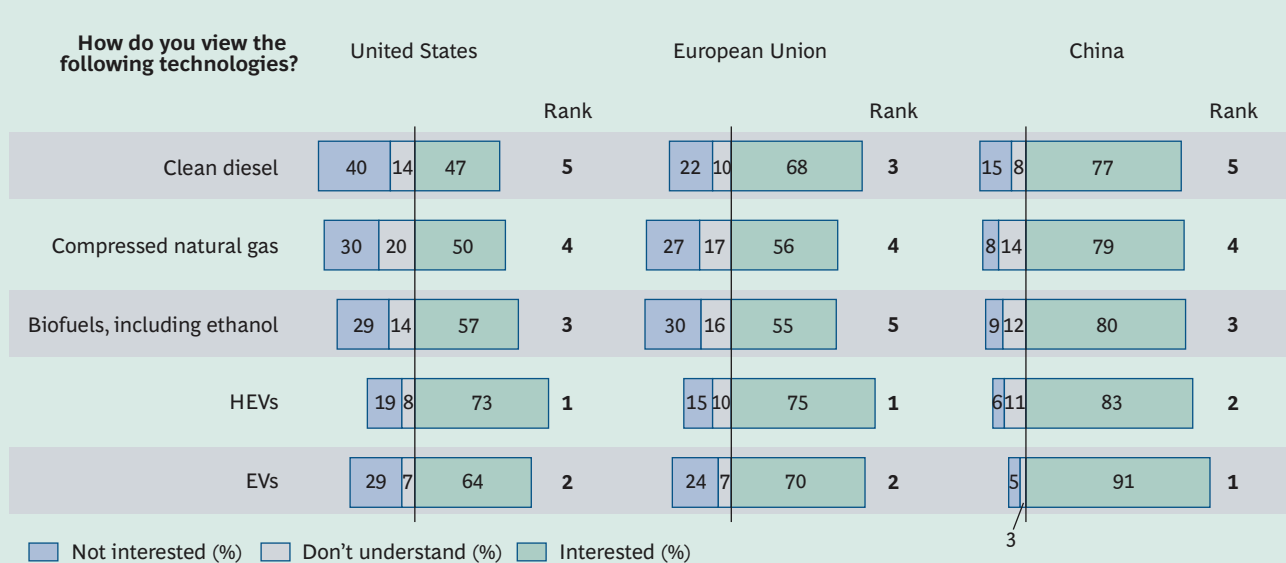
A major question mark for the adoption of alternative powertrains is consumers’ willingness to pay more for new technology. Our research shows that there is a segment of “green” consumers—consumers willing to pay more for an environment-friendly car even if the TCO economics are unfavorable—who represent about 6 percent of car buyers in the U.S. and 9 percent of those in Europe (See Exhibit 5.) These buyers are willing to pay an average premium of \$4,500 to \$6,000 to purchase a green vehicle. They do not expect their up-front invest-

### Consumer Research

In the spring of 2011, BCG conducted online surveys in the U.S. Europe, and China, asking consumers about their views on specific alternative powertrain technologies—clean diesel, biofuel, CNG, hybrid, and EV—as well as their willingness to pay for those technologies. We surveyed 5,016 European consumers drawn from the region’s five largest markets by 2010 sales (Germany, France, the U.K., Italy, and Spain); 1,027 U.S. consumers; and 550 Chinese vehicle owners and first-time buyers drawn from the country’s 20 most populous cities.

We asked two sets of questions. The first sought to gauge interest in and knowledge about the different technologies. The second dealt with consumers’ willingness to pay for those technologies. The questions were designed to minimize consumers’ inherent tendency to overstate their willingness to pay. We calibrated the results through comparisons with observed HEV penetration in the U.S. market.

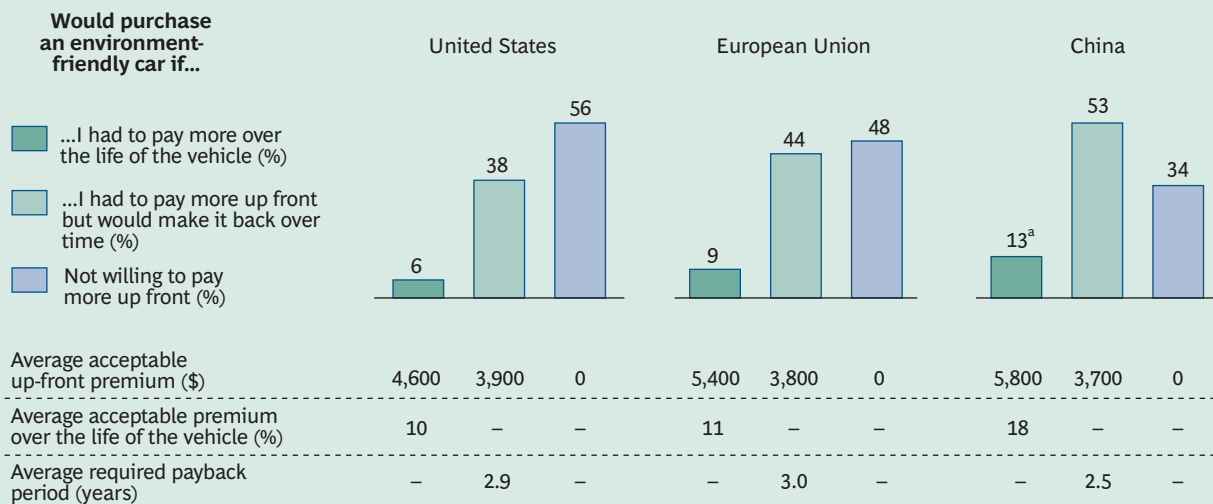
## Exhibit 4. Of the Alternative Technologies, HEVs and EVs Interest Car Buyers Most



**Sources:** BCG Consumer Barometer, March 2011 (n = 1,027 in the U.S. and n = 5,016 in Europe); BCG automotive survey of car owners and intenders in China (n = 550).

**Note:** Because of rounding, totals may not equal 100. EU data are weighted based on 2010 vehicle sales (France, 24 percent; Germany, 28 percent; Italy, 19 percent; Spain, 10 percent; and the U.K., 20 percent). HEVs = hybrid electric vehicles. EVs = electric vehicles, plug-in and battery.

## Exhibit 5. Buyers' Sensitivity to Green-Car Costs Varies by Market



**Sources:** BCG Consumer Barometer, March 2011 (n = 1,027 in the U.S. and n = 5,016 in Europe); BCG automotive survey of car owners and intenders in China (n = 550).

**Note:** Because of rounding, totals may not equal 100. EU data are weighted based on 2010 vehicle sales (France, 24 percent; Germany, 28 percent; Italy, 19 percent; Spain, 10 percent; and the U.K., 20 percent).

<sup>a</sup>Weighted average of vehicle owners and first-time car buyers. Reweighted based on city size.



ment to be amortized over time through lower operating costs, and they are willing to pay about 10 to 20 percent more in terms of TCO over the life of the vehicle. OEMs will likely find their first EV buyers in this segment: 15 percent of consumers in this group are willing to pay a premium of \$10,000 or more up front—enough to cover the price difference between a gasoline-fueled car and an EV. Other consumers in this group say that they could be convinced to purchase an EV if the up-front price differential were spread over several years through a leasing offer, giving this mode of financing an edge over straight purchase—an interesting option for OEMs looking to drive adoption.

China stands out for the size of its green segment, which was represented by 13 percent of the car owners and first-time buyers we surveyed. This cohort is a blend of two very different groups. The first group comprises current vehicle owners, who are generally younger, more affluent, and more likely to live in a city than the country's overall population and, therefore, are more willing to pay for green technologies. Many of these consumers are attracted by the buzz that has been generated around EVs in China and the cutting-edge status that ownership conveys. The second group is made up of first-time buyers focused on basic functionality. These consumers are not willing to pay more for an alternative powertrain unless

China stands out for the size of its green segment—represented by 13 percent of those we surveyed.

the vehicle has a payback period of three years or less. It should be noted that approximately 35 to 40 percent of cars sold in China cost less than 70,000 yuan (\$11,000); it is unlikely that buyers of these vehicles could afford an EV or HEV without significant government incentives.

About 40 percent of car buyers in the U.S. and Europe and 50 percent in China are willing to pay more up front (approximately \$4,000 more on average) for a green car if this investment is paid back through lower operating costs. Most consumers in this group expect a payback within three years. A significant minority (15 to 20 percent), however, are willing to accept payback of five years or longer, which is close to the estimated payback horizon for HEVs in 2020. Swaying this group toward EVs will take either lower-than-expected battery costs or government actions, such as purchase incentives or fuel taxes, to shorten payback periods. Governments could also sweeten the deal by offering significant nonfinancial incentives, such as preferred parking or the use of high-occupancy-vehicle lanes in urban areas.

Finally, 56 percent of car buyers in the U.S., 48 percent in Europe, and 34 percent in China, say that they are not willing to pay more up front for alternative powertrain technologies. For the time being, this segment will likely stay with conventional gasoline-fueled ICES.



# The Potential for EVs and HEVs

**E**lectrification, which offers greater potential for emissions reduction than conventional ICE-based technologies, will undoubtedly play a significant and growing role in many countries' energy and environmental efforts in the coming decades. But the potential for EVs to capture share of the global vehicle market to 2020 will remain capped by the relatively high cost of batteries.

## EVs

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Our estimate of the cost to OEMs—\$400 per usable kWh in 2020—translates to a cost of approximately \$9,600 for a 20-kWh battery pack for consumers (assuming a 20 percent OEM markup). This cost will keep the economics of EV ownership unattractive for the majority of the world's car buyers. Governments are offering generous purchase incentives (that can total as much as \$12,500 in California) to spur initial demand. But because this degree of support is unlikely to be financially sustainable over the long term, EVs will probably have to compete on their own pure economics by 2020. (Our base-case scenario assumes that purchase incentives will expire before 2020.)

EVs will also be held back by technological limitations. Even in 2020, despite ongoing improvements in the underlying technology, electrification probably will not be feasible for the largest SUVs and pickups, whose mass is simply too great. Similarly, owing to their batteries' ongoing range limitations, EVs will have less appeal for drivers who regularly take long-distance trips.

The U.S. and Japan are currently the world's largest HEV markets, representing a combined 80 percent of global sales. Given the degree of government support and OEMs'

sales targets, those countries are expected to take a comparable lead in EV sales. But China and Europe will likely become the biggest EV markets as the decade progresses and initial government incentives are phased out. Purely from a TCO perspective, EVs' share of total vehicle sales in China and Europe could be as high as 7 percent and 8 percent, respectively, in 2020, assuming an oil price of \$130 per barrel. (See the sidebar "The China Wildcard.") Sales of EVs in the U.S. and Japan, meanwhile, will rise steadily until 2020 but remain lower than those in China and Europe. We expect EVs to account for 2 percent of vehicle sales in North America and 5 percent in Japan in 2020.<sup>2</sup> (See Exhibit 6.)

It is too early to tell which technology—pure battery EV, range extender, or plug-in hybrid—will prevail within the EV space. Currently, plug-in hybrids and range extenders—both of which have a battery and an internal-combustion engine and can therefore accommodate both short- and long-distance driving—look most promising, given consumers' concerns about range limitations. Most consumers are indifferent to the distinction between the two, but OEMs face difficult technology and cost tradeoffs in deciding whether to develop a plug-in hybrid or range extender as their long-range EV offering: a conventional powertrain architecture can be leveraged for a plug-in hybrid, whereas a new architecture has to be developed for a range extender. Toyota, building on its leadership in hybrids, is introducing a

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2. Our current estimate for penetration of the U.S. market is lower than what we projected in 2009. This is due to a change in our assumptions regarding oil prices (we now expect a price of \$130 per barrel instead of \$150) and incentives (we now expect no incentives instead of \$2,000 per vehicle), a refined understanding of consumer behavior, and our finding that ICE performance improvements will come at a lower cost.

## The China Wildcard

China is the biggest wildcard in any global EV-growth projection. The government, driven by the desire to leapfrog traditional OEMs in this new technology, reduce dependence on foreign oil, and cut pollution, has ambitious plans to drive adoption of EVs. China's goal is to have 500,000 EVs—passenger cars, trucks, and buses—on the road by 2015 and 5 million by 2020. It is supporting that goal by setting up an EV alliance of companies across the full value chain, funding it with a war chest of 100 billion yuan, and providing incentives to consumers and automotive-industry players. In parallel, the government has directed State Grid Corporation of China to develop the supporting infrastructure for EVs. SGCC is making large investments and plans to build 2,300 charging stations and 220,000 charging poles from 2011 through 2015.

But local OEMs that introduced EVs early have so far met a cold reception from Chinese consumers. Only around 2,000 electric passenger cars were sold in 2010 (primarily to public-sector fleets) despite central-government incentives as high as 60,000 yuan (approximately \$9,000). Simultaneously, global OEMs are stepping up their efforts to penetrate the Chinese market.

We see three key market opportunities for EVs in China: fleets, wealthy environment-oriented consumers, and mass-market urban vehicles. EVs' penetration of fleets could increase rapidly, depending on the direction given by the national and local governments. The high-end market is already showing a trend toward HEVs, which are considered to be in vogue; EVs could have similar success. But neither segment is large enough to create a breakthrough. To achieve a breakthrough, OEMs must do three things: they must offer attractive mass-market vehicles, address the vehicles' potential downsides (including their relatively high price and limited driving range), and promote a better understanding of the advantages of EVs among consumers.

At the moment, each comes with a different set of challenges. First, mass-market consumers, especially first-time car buyers, are still motivated primarily by vehicle size, brand, and price. Even a small price premium for an EV prompts most would-be buyers to choose an alternative. Second, in the near term, there may not be a sufficient choice of vehicles offered to satisfy consumers. Currently, most planned EV launches are niche models. (So far, only 4 of the country's 20 best-selling passenger cars are expected to have an EV derivative by 2012.) In addition, government support to date has focused on state-owned enterprises, which have a limited presence in the vehicle segments that best fit EVs. Third, initial global trials have shown that consumers prefer to charge their vehicles overnight. This will be a challenge for the large number of urban vehicle owners in China who do not have dedicated parking.

The government's stated commitment to EVs, coupled with its willingness to take a long-term perspective (20 to 30 years), should not be discounted: China has successfully nurtured other nascent industries and technologies. To secure a higher adoption of EVs, the government may resort to measures beyond the current incentives (for example, driving restrictions). This makes the Chinese market a wildcard. EV stakeholders should therefore prepare for multiple volume and penetration scenarios. At the same time, stakeholders should identify new business opportunities that could emerge if the aforementioned barriers can be overcome.

plug-in hybrid. And European OEMs are considering creating a range extender add-on that consumers can purchase for pure battery EVs.

One thing is certain: the competition among OEMs and their respective favorite EV technologies will be fierce, especially in the C-segment. For OEMs, there may also be a sizable premium attached to getting to market early. Lessons from the growth of the HEV market suggest a significant first-mover advantage—evidenced by

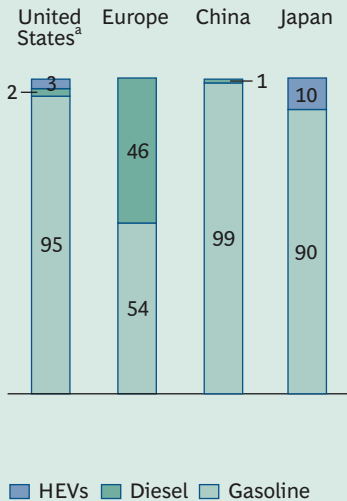
the performance of Toyota, Honda, and Ford—which could support the early-market-entry strategies of Nissan and GM.

## HEVs

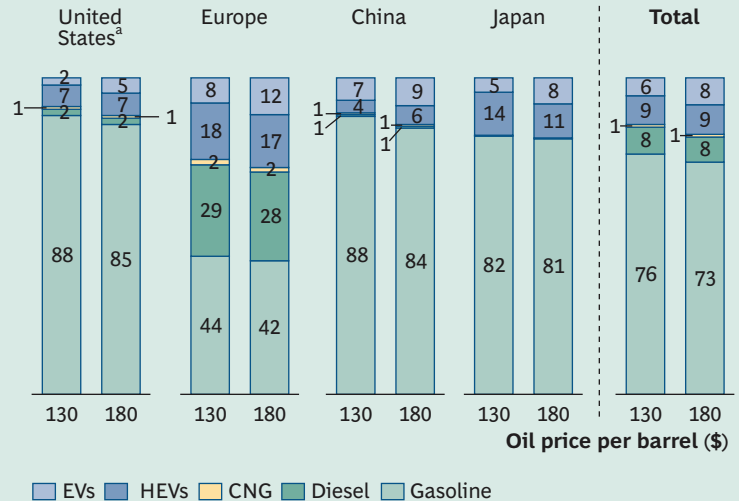
Sales of HEVs, meanwhile, will be significant across all markets to 2020. Growth will be fastest in Europe, where we expect HEVs' share of overall vehicle sales to rise to

## Exhibit 6. ICEs Will Continue to Dominate the Market Until 2020 . . .but EVs Will Make Inroads

Percentage of passenger car sales in 2010



Projected percentage of passenger car sales in 2020



Sources: Edmunds; European Automobile Manufacturers' Association (ACEA); Autoneus; The Daily Yomiuri; BCG analysis.

Note: Because of rounding, totals may not equal 100. EVs = electric vehicles, which include plug-in hybrids and range extenders; HEVs = hybrid electric vehicles, which include mild, full, and diesel hybrids; CNG = compressed natural gas; gasoline includes microhybrids and flexible fuels.

<sup>a</sup>We are using the U.S. as a proxy for North America.

18 percent in 2020. Japan will remain a strong market for HEVs, whose share of total vehicle sales is expected to rise to 14 percent in 2020 from a 10 percent share in 2010. In the U.S., HEVs' share of the market will rise to 7 percent from the current 3 percent; in China, HEVs will claim 4 percent of the market, rising from a current near-zero share. HEVs will remain the most attractive green option for buyers of larger vehicles (D-segment cars, large SUVs, and pickups): their weight requires larger (and more costly) batteries, making EVs a less attractive choice in these segments.

Hydrogen-fuel-cell-powered EVs are expected to remain nascent through 2020. The technology's costs are not expected to fall below three times the cost of comparable ICE powertrains, and developing the required fueling infrastructure by then poses significant challenges.

### Factors That Could Materially Affect Adoption Rates

The forecast EV and HEV penetration rates are very sensitive to a few key factors. The price of oil is the most prominent: in a scenario in which oil is priced at \$180 per barrel (instead of the \$130 we assume in our base case), EV penetration would increase to 5 percent in the U.S., to 12 percent in Europe, to 9 percent in China, and to 8 percent in Japan. Battery pack costs, as we noted earlier, are another key driver. Reducing usable battery-pack costs (to the OEM) to \$300 per kWh or sustaining purchase incentives of \$2,000 per EV would increase EV penetration by an average of 2 percentage points in each of the four major markets. Much of this increase would be at the expense of HEVs, which are targeting a similar consumer segment.



# Go-to-Market Challenges for EVs

**O**EMs face a basic dilemma as they bring EVs to market: should they target high volumes in order to move further down the experience curve for batteries while incurring substantial up-front losses, or should they sell small volumes at a price closer to breakeven? Under both models, the most immediate upside to OEMs will come from the PR halo effect of the new technology, which will help build a green brand image and increase showroom traffic.

## Geographic Sequencing

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Geographic sequencing—determining which markets to focus on first—is another important concern facing OEMs. The key consideration here is the strength of local-government support for EVs. Government support will have a strong impact on both the price OEMs offer and the degree and speed of customer adoption.

## Financing

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Next, OEMs will have to define attractive financial terms for customers. Currently, a variety of sales models are being discussed: the Volt and the Leaf are sold under a traditional sales or leasing model, while with other vehicles, such as Renault's Fluence, OEMs are experimenting with new approaches, such as battery rental or pay per use. Leasing and rental models could help mitigate the initial sticker shock that comes with an EV's 60 to 80 percent price premium relative to a similar vehicle with an ICE powertrain.

## Consumers' Worries over Battery Life and Charging

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In addition to addressing consumers' price concerns, OEMs will also need to respond to consumers' anxiety about battery life. Consumers have no experience with this new technology and thus need to be educated (as do many OEMs and their sales forces) about the ways in which driving and charging behavior can affect driving range and battery life. Consumers need to know, for instance, that fast charging can have a negative effect on battery life. They also need to understand the effects on batteries of low winter temperatures and recharging after driving short distances. OEMs will also

have to design warranty and service contracts to assure consumers that they will get support should their battery fail. Some OEMs are already addressing this: both the Leaf and the Volt come with an eight-year, 100,000-mile warranty and additional service offerings, such as roadside assistance and courtesy vehicles. Battery warranties, however, pose a substantial risk to OEMs, so they will have to decide how to handle failed and end-of-life batteries. OEMs may need to find effective ways to repair or remanufacture failed batteries.

Charging is another concern. Initially, for most consumers, home charging will be the preferred way of charging their vehicles. A home charging station, however, will add roughly \$1,500 to the consumer's cost, and the installation can be complex. At a minimum, OEMs will have to guide consumers through this process and may even want to consider offering an integrated solution. OEMs also face a paradox. The best candidates for EV adoption are urban drivers who commute short distances. But these

OEMs may need to find effective ways to repair or remanufacture failed batteries.

same consumers tend to live in multifamily housing, which poses a challenge to the installation of personal home charging stations.

To further woo customers, OEMs should think about additional services that would increase the convenience of owning an EV. Services such as remote battery-status monitoring, remote preconditioning (warming or cooling the vehicle while it is still connected to a charging point),

and remote diagnostics could help address consumers' concerns about reach, vehicle availability, and the reliability of the technology. Finally, OEMs will have to define the boundaries of their business model, deciding whether and to what extent they want to get involved in public charging infrastructure and electricity contracts for their customers.



# Implications for OEMs, Suppliers, and Regulators

**T**he automotive landscape is evolving. The changes are posing significant challenges to key stakeholders: OEMs, suppliers, and regulators.

## OEMs

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OEMs will be forced to manage a larger, more complex technology portfolio and will have to strike a balance between optimizing for today's requirements and positioning themselves for tomorrow's opportunities. Given the high costs associated with a wider technology portfolio, companies' key tasks will include reducing the variance in mature technologies (for example, reducing the number of engine architectures) and developing a partnering strategy, as Renault-Nissan and Daimler have started to do. OEMs will have to decide when and where to invest in manufacturing capacity: should they, for instance, move into making electric motors or batteries? OEMs will also have to decide where to locate new powertrain plants, whether in Europe—which, despite being one of the largest markets for green vehicles in 2020, is also characterized by slow overall growth—or elsewhere. In any case, the complexity of powertrain supply chains will increase, and OEMs will have to adjust.

OEMs will also have to ensure that their downstream operations, including sales and after-sales service, are ready to meet demand for EVs. Dealerships, for example, will need to be upgraded with appropriate tooling and trained mechanics who can handle EVs—even in areas where EVs have low penetration. And new financing products will have to be developed specifically for EVs. Finally, OEMs will need to determine which of the opportunities

that emerge as the landscape evolves—for example, the launch of EV specialist dealers—are worth pursuing.

Finally, OEMs and other industry participants should closely monitor how governments choose to gauge vehicles' environmental impact. Regulators are focusing predominantly on tailpipe emissions; if their focus should shift to the broader well-to-wheel metric, the environmental argument for EVs would become less compelling. Based on our current projections, EVs' well-to-wheel emissions advantage over ICEs—estimated at 40 to 60 percent—will fall to 30 to 50 percent in 2020 as advances in ICE technologies narrow the gap and power generation from clean nonfossil fuels continues to grow slowly in most regions.

## Suppliers

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Suppliers, for their part, will need to position themselves for new growth areas in both advanced ICE technologies and the EV space. This will require suppliers to conduct a thorough review of their technology portfolios, assessing the likely extent of the demand for components in the different realms and evaluating their internal capabilities. Suppliers (as well as OEMs) will need to closely monitor changes in technology and regulation as the trajectory of technological development becomes more uncertain. Furthermore, suppliers will have to redefine their unique value proposition in a field that includes startups and other newly involved players such as chemical companies.

## Regulators

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Regulators face a host of challenges, both strategic and tactical. They must weigh the goals of climate preserva-



tion, energy independence, and positioning their country as a center for new technologies. They must continue to pursue the reduction of tailpipe emissions but, at the same time, work on the greening of energy generation. And they must determine the most efficient method of regulating—for example, purchase incentives versus fuel taxes, and a technology-neutral stance versus one tied to specific technologies.

Regulators must also take the necessary steps to support fledgling markets. They should set and support market volumes for EVs and other new technologies until market forces allow those technologies to achieve economic viability independently. In parallel, regulators should foster necessary infrastructure development for charging stations (and, potentially, CNG and hydrogen-fuel-cell fueling stations). They should also try to convey a consistent long-term regulatory perspective that will encourage investment among OEMs and suppliers.

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**S**ignificant uncertainty continues to surround the four key factors—regulation, oil prices, technology, and consumer preferences—that will determine the developmental path of vehicle propulsion to 2020 and beyond. We can imagine at least three very distinct paths:

◇ *The Pragmatist Path.* Governments focus on energy independence and oil conservation. They also place growing emphasis on well-to-wheel emissions. In this

environment, small, efficient ICEs and HEVs are increasingly viewed as optimal solutions. The focus on well-to-wheel emissions and energy independence also benefits advanced biofuels. EVs maintain a relatively modest share of the overall market and are viewed primarily as a hedge against spiking oil prices.

◇ *The Technology Breakthrough Path.* New technology drives battery costs below \$250 per kWh, making EVs a more widely attractive option for consumers. EVs ultimately take a significant share of the market (from 10 to 30 percent by 2020), barring unexpectedly low gasoline prices.

◇ *The Green Path.* Oil prices surge above \$250 per barrel, and governments invest in clean sources of electricity. Investing to support the development of EVs becomes a win-win economic and environmental solution for all players: consumers, OEMs, and governments. A mix of small-model EVs and larger-model HEVs could capture up to a third of the market by 2020. Given its abundant supply, CNG could take a more significant share of ICE powertrains if its price continues to decouple from the price of oil.

The challenge for OEMs and suppliers as the decade unfolds will be to prepare for and retain the flexibility to switch among the different paths the industry could take. The challenge for governments will be to define policies that accommodate all three paths until there is greater clarity on energy prices, environmental considerations, and technological capabilities.





# For Further Reading

The Boston Consulting Group has published other reports on automotive propulsion:

**Batteries for Electric Cars:  
Challenges, Opportunities, and the  
Outlook to 2020**

A Focus by The Boston Consulting Group,  
January 2010

**The Comeback of the Electric Car?  
How Real, How Soon, and What  
Must Happen Next**

A Focus by The Boston Consulting Group,  
January 2009



# Note to the Reader

## About the Authors

**Xavier Mosquet** is a senior partner and managing director in the Detroit office of The Boston Consulting Group and coleader of the firm's global Automotive practice. **Mythili Devineni** is a principal in BCG's Chicago office. **Tobias Mezger** is a project leader in the firm's Detroit office. **Hadi Zablit** is a partner and managing director in BCG's Paris office. **Andreas Dinger** is a partner and managing director in the firm's Munich office. **Georg Sticher** is a senior partner and managing director in BCG's Munich office and coleader of the firm's global Automotive practice. **Marco Gerrits** is a partner and managing director in BCG's Beijing office. **Massimo Russo** is a senior partner and managing director in the firm's Boston office.

## Acknowledgments

The authors would like to thank our BCG colleagues who contributed to this report, especially Fernando Apaez, Aoi Iwana, Rolf Kilian, Tejus Kothari, Stefan Reiter, Justin Rose, Laurent Rossi, and Alexander Wachtmeister. They would also like to thank Gary Callahan, Elyse Friedman, Kim Friedman, Gerry Hill, and Kirsten Leshko for their contributions to the writing, editing, design, and production of this report.

## For Further Contact

If you would like to discuss our findings in greater detail, please contact one of the authors:

### Xavier Mosquet

*Senior Partner and Managing Director*  
BCG Detroit  
+1 248 688 3500  
mosquet.xavier@bcg.com

### Mythili Devineni

*Principal*  
BCG Chicago  
+1 312 993 3300  
devineni.mythili@bcg.com

### Tobias Mezger

*Project Leader*  
BCG Detroit  
+1 248 688 3500  
mezger.tobias@bcg.com

### Hadi Zablit

*Partner and Managing Director*  
BCG Paris  
+33 1 40 17 10 10  
zablit.hadi@bcg.com

### Andreas Dinger

*Partner and Managing Director*  
BCG Munich  
+49 89 23 17 40  
dinger.andreas@bcg.com

### Georg Sticher

*Senior Partner and Managing Director*  
BCG Munich  
+49 89 231 7 40  
sticher.georg@bcg.com

### Marco Gerrits

*Partner and Managing Director*  
BCG Beijing  
+86 10 8527 9000  
gerrits.marco@bcg.com

### Massimo Russo

*Senior Partner and Managing Director*  
BCG Boston  
+1 617 973 1200  
russo.massimo@bcg.com

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