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## The Comeback of the Electric Car?

How Real, How Soon, and What Must Happen Next



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# The Comeback of the Electric Car?

## How Real, How Soon, and What Must Happen Next

**I**n the quest to safeguard the environment and create more sustainable ways of using the earth's resources, the automotive industry has a major role to play. Many observers now see the comeback of the electric car, which was first marketed in the early 1900s and then revived unsuccessfully in the 1990s, as an important cornerstone of this effort. But what kinds of new propulsion technologies are likely to make sense, both technically and commercially? Where and when can we expect to see them entering the market? And what kinds of cars, finally, will consumers be willing to buy and drive?

### The Challenges of Sustainable Automobility

Driven both by the “sticks” of increasingly stringent government regulations, energy security concerns, and higher oil prices, and by the “carrot” of enhanced public approval of their brands, virtually all leading car-makers are exploring ways to reduce their vehicles' carbon dioxide emissions and increase their fuel efficiency. These forces are driving the development of alternative concepts for automotive propulsion as well as alternative fuels. The causal correlation between CO<sub>2</sub> emissions and global

warming is now widely accepted by a solid majority of the scientific community. The significant damage caused by global warming and the intense public awareness of this topic make the challenge of reducing CO<sub>2</sub> emissions the major force currently driving development of alternative concepts for automotive propulsion.

To meet this challenge, the automotive industry is investing large R&D budgets in a variety of new technologies for automotive propulsion. These include hybrid power trains, fuel cells, and electric cars. So far, however, the future of propulsion technology remains the subject of much speculation and debate, but one on which there is very little consensus. Even within the industry there are contradictory beliefs. For instance, one perspective holds that hybrid electric engines violate the laws of physics, whereas another holds that by 2020, companies will sell nothing but hybrids.

Meanwhile, the possible comeback of electric vehicles is getting a lot of media attention. Little wonder that the public, deluged by articles touting new kinds of vehicles, is widely confused and can hardly distinguish actual product announcements from descriptions of futuristic concept cars.

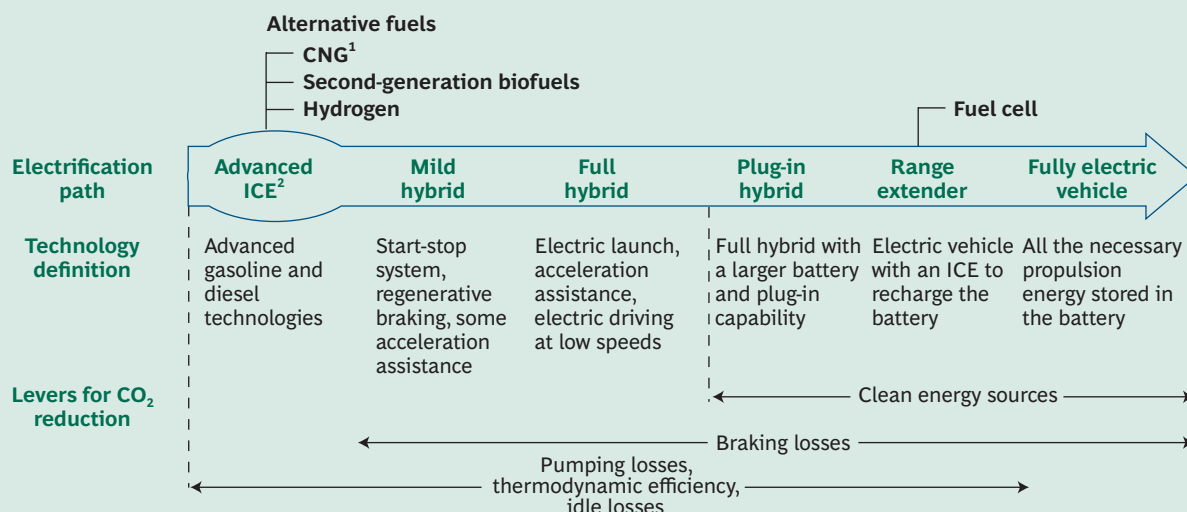
Our goal in this report is to demystify this complex topic. Toward that end, we have analyzed current scientific findings on energy consumption, oil reserves, and CO<sub>2</sub> emissions, as well as technological options for alternative propulsion concepts. We have also interviewed OEMs, suppliers, battery manufacturers, and power companies, and we have conducted consumer research.

In this report, we first evaluate the viability of leading technological options that may contribute to more sustainable automobility and then present our view of the most likely market scenario for 2020 and its implications for major stakeholders.

### Technological Options

The viability of the several technological options for efficient, low-CO<sub>2</sub>-emitting power trains now in development or under consideration is far from self-evident. The options can be categorized into three groups: alternative fuels, advanced internal-combustion-engine (ICE) technologies, and electrification. These three categories are not mutually exclusive; they occupy adjacent and overlapping spaces on a broad evolutionary path toward fully electric vehicles. (See Exhibit 1.)

## Exhibit 1. The Electrification Path Determines the Major Option Space for Power Train Technologies



Source: BCG analysis.

<sup>1</sup>CNG = compressed natural gas.

<sup>2</sup>ICE = internal-combustion engine.

**Alternative Fuels.** Alternative fuels include compressed natural gas (CNG), second-generation biofuels, and hydrogen. In our view, CNG and second-generation biofuels offer significant potential for CO<sub>2</sub> reduction. CNG, for instance, can reduce CO<sub>2</sub> emissions by up to 25 percent. However, the main concern about its use is how to fund the costly investments needed for both the additional gas tank in the car and the necessary fueling infrastructure. Second-generation biofuels, such as biomass-to-liquid (BTL) for diesel and biobutanol for gasoline, will be important because they can reduce CO<sub>2</sub> emissions by up to 90 percent. They can also be used in a blend with either conventional gasoline or diesel fuel and, in this form, could gradually decrease the CO<sub>2</sub> emissions of a running fleet. Hydrogen-based propulsion is not likely to be commercially successful within the next dozen years because of its low overall efficiency and the

extremely high investments needed for infrastructure and fuel cells. Overall, the energy industry will need to make significant investments and further technological progress to achieve substantial reductions in CO<sub>2</sub> emissions by means of alternative fuels such as CNG and second-generation biofuels. Meanwhile, the automotive industry needs to focus on developing alternative power-train technologies, of which advanced ICE technologies and electrification are the most promising.

**Advanced ICE Technologies.** Advanced ICE technologies will be the most cost-effective way to reduce CO<sub>2</sub> emissions on a broad scale. These technologies, which include gasoline- or diesel-based direct injection, reduction of engine displacement by turbocharging, and reduction of internal engine resistance, cost between \$70 and \$140 for each percentage point of reduction in CO<sub>2</sub>

emissions. A combination of advanced ICE technologies can give a gasoline-based ICE a maximum 20 percent boost in fuel efficiency at a cost increase of \$2,100 per engine. For diesel-based ICEs, these technologies offer a 10 percent boost in fuel efficiency at a cost increase of around \$1,400 per engine. All such improvements in fuel efficiency translate into corresponding reductions in CO<sub>2</sub> emissions.

**Electrification.** Propulsion systems based partially or entirely on electricity can achieve even greater reductions in CO<sub>2</sub> emissions than those based on advanced ICE technologies, albeit at a higher cost: \$140 to \$280 per percentage point of reduction in CO<sub>2</sub> emissions. The main cost driver of electrified power trains will be the relatively high cost of the batteries they require, especially those based on lithium ion technology. However, the fully electric vehicle is the end-

point on an evolutionary path that contains several prior stages.

*The Mild Hybrid.* The mild hybrid is the first real step on the electrification path. It contains a small electric motor that provides a start-stop system, regenerates braking energy for recharging the battery, and offers acceleration assistance. The mild hybrid achieves modest reductions (around 10 to 15 percent) in CO<sub>2</sub> emissions, at a relatively high additional cost (around \$2,100 per vehicle). In our view, therefore, it should be seen as an intermediate development step. It will be either upgraded to a full hybrid system or downgraded to an advanced ICE with an electric start-stop system. (See Exhibit 2.)

*The Full Hybrid.* The full hybrid is the next step on the electrification path. It features both a larger battery and a larger electric motor than the mild hybrid, giving the car electric launching, electric acceleration assistance, and electric driving at low speeds. Today, a full hybrid bears extra costs of around \$7,000 as compared with a conventional ICE car. But the cost of hybrid components is expected to decrease by some 5 percent per year so that by 2020, the incremental cost of a full hybrid should fall to around \$4,000. By 2020, the full hybrid will be an economical solution compared with further optimization of the conventional ICE. It can reduce CO<sub>2</sub> emissions by 25 to 30 percent, and by 2020 the cost will have fallen to \$130 to \$160 per percentage point of reduction.

*The Plug-in Hybrid.* The plug-in hybrid is an upgrade of the full hybrid. It includes a larger battery that can be charged with electricity from the grid.

*The Range Extender.* The range extender resembles current hybrids but inverts the roles played by the electric motor and the combustion engine. The vehicle drives in electric mode. It carries a small, highly efficient combustion engine that can be

**In the next decade,  
CO<sub>2</sub> emissions from  
power generation  
will be even lower.**

used to charge the battery and extend the driving range of the vehicle. In the absence of charging infrastructure, this option can combine the benefits of the electric vehicle for city driving with the capability for longer trips.

*The Fully Electric Vehicle.* The fully electric vehicle is the last step on the electrification path. Its propulsion technology depends solely on electricity from the grid, which is stored in a large battery. Lithium ion battery technology will likely be used for automotive applications, thanks to its high-energy density and long durability. But today's lithium-ion batteries cost about \$2,000 per kilowatt-hour (kWh) because production volume is still low. Industry experts expect the cost of these batteries to drop to \$500 to \$700 per kWh by 2020. Assuming a cost of \$700 per kWh, a 20 kWh battery, which is needed for an electric-driving range of 80 miles (about 130 kilometers), would still cost \$14,000. Of course, these costs could change radically if there are further breakthroughs in battery technology.

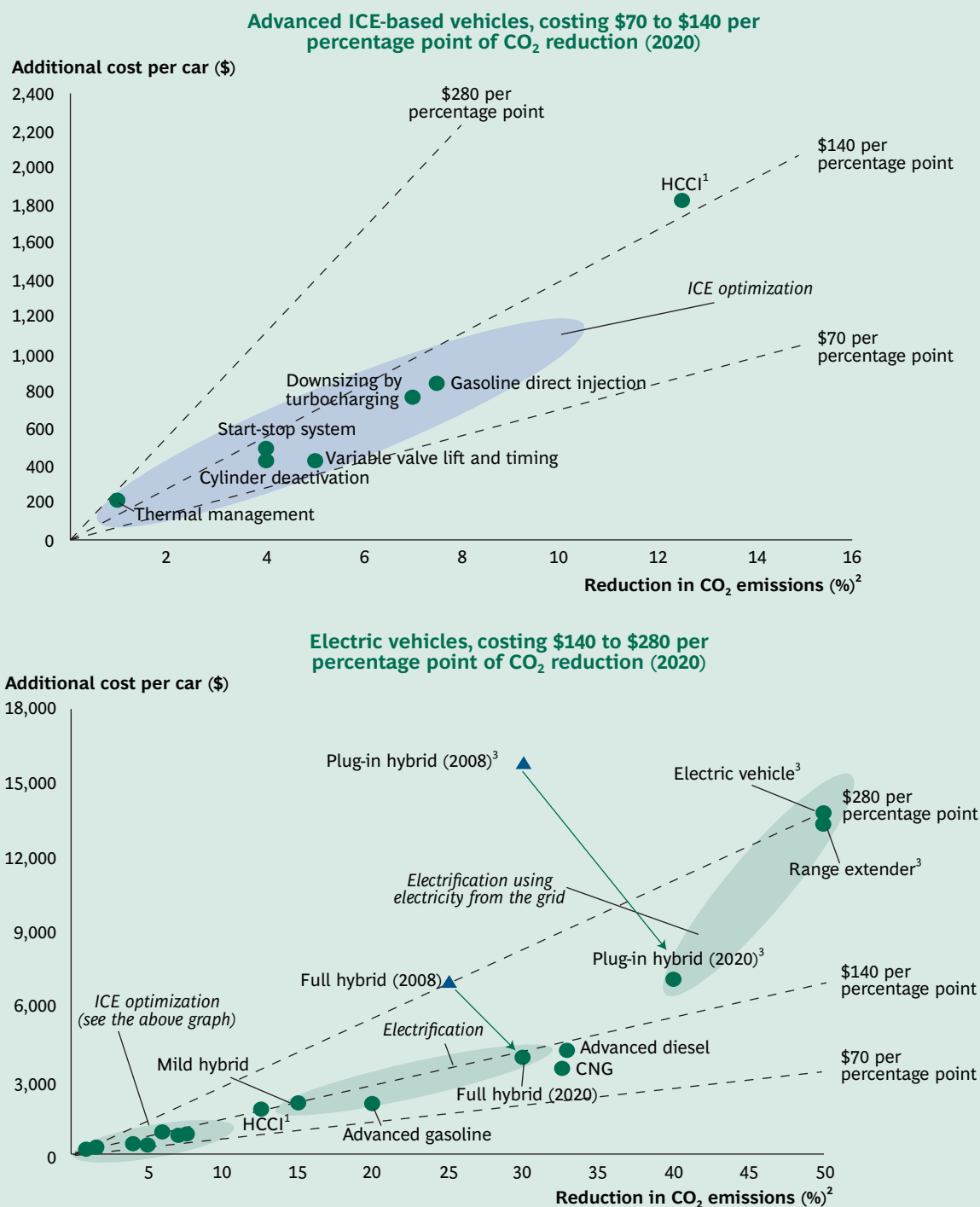
There has been some confusion about the degree to which electric

vehicles actually reduce CO<sub>2</sub> emissions. The answer is more complex than for other technologies. Although the electric systems in these vehicles don't themselves emit any CO<sub>2</sub>, the generation of the electricity that charges their batteries does. An analysis of the worldwide power-generation market shows that, for example, in China and India, the substitution of electric vehicles for ICE vehicles would hardly reduce CO<sub>2</sub> emissions, either today or in 2020. The power mix in those countries is so carbon intensive that the operation of electric cars entails, on a "well-to-wheel" basis, the emission of almost as much CO<sub>2</sub> as does the operation of conventional cars.

On the other hand, in Europe, where the power generation mix is much cleaner, thanks to the use of renewable and nuclear energy, an electric vehicle generates 55 to 60 percent less in CO<sub>2</sub> emissions than a conventional ICE car. In the next decade, CO<sub>2</sub> emissions from electricity generation will be reduced even further as a higher percentage of electricity is generated from renewable generation capacity (such as power from windmills) and as new technologies (such as carbon capture and storage [CCS], which will automatically reduce the electric vehicle's well-to-wheel CO<sub>2</sub> emissions) come into increasing use.

**Impact on the Total Cost of Ownership.** How attractive are these propulsion concepts likely to be to consumers? Recent surveys confirm that a key criterion influencing consumers' buying decisions is the total cost of ownership (TCO). So we looked at the likely five-year TCO for these competing technologies, for cars bought in Germany today and in

## Exhibit 2. The Electrification Path Substantially Cuts CO<sub>2</sub> Emissions, but the Cost Is High



Source: BCG analysis.

Note: Each label in italic type represents a set of technologies.

<sup>1</sup>HCCI = Homogeneous charge compression ignition.

<sup>2</sup>All CO<sub>2</sub>-improvement numbers refer to a base gasoline engine.

<sup>3</sup>Values are calculated assuming 586 grams per kilowatt-hour (g/kWh) of carbon intensity from power generation.



2020, as a function of the price of oil. We assumed an average mileage of 9,000 miles (about 14,500 kilometers) per year and no change in current taxation schemes. Our calculation includes analysis of vehicle depreciation, the cost of fuel and electricity consumption, battery costs, value-added taxes, and CO<sub>2</sub>-related taxes; we did not include insurance or maintenance costs. (See Exhibit 3.)

By our calculation, the advanced diesel vehicle will remain a very attractive proposition. Its five-year TCO in 2020 is lower than that of the advanced gasoline vehicle at all oil prices. The hybrid vehicle, for its part, starts having a lower TCO than the gasoline-based vehicle when the price of oil reaches about \$70 per

barrel; it outperforms the advanced diesel on TCO when that price reaches about \$170 per barrel.

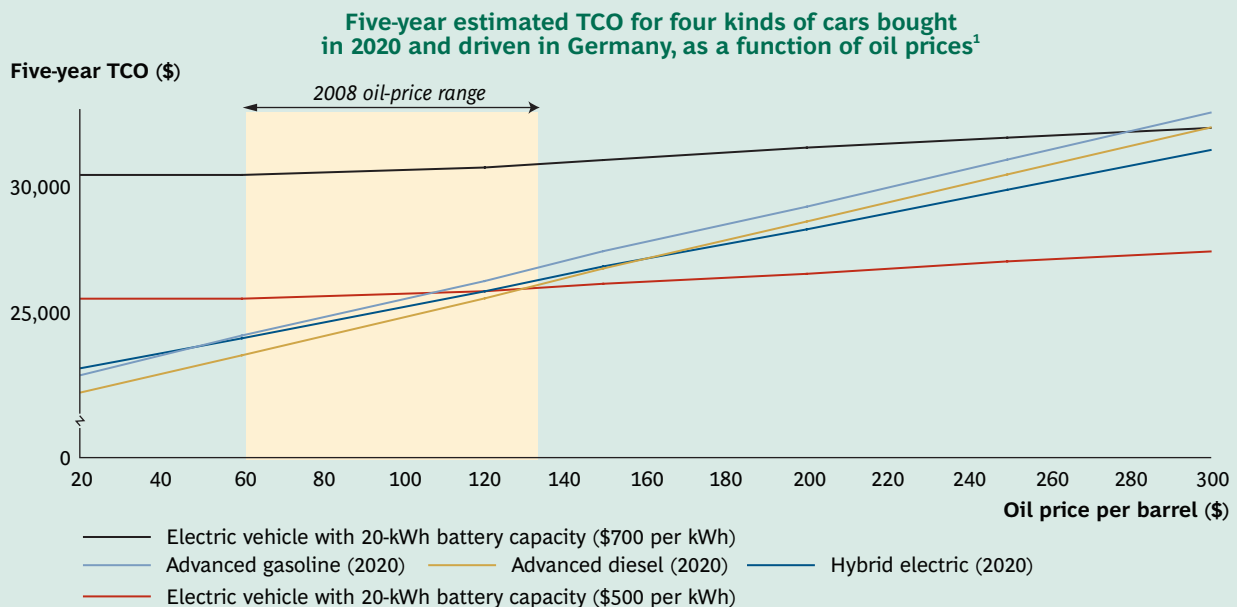
However, from a TCO perspective, the electric vehicle is expected to remain relatively unattractive to consumers in 2020, unless its cost is subsidized. At the expected battery cost of \$700 per kWh, the electric car costs more than advanced ICE vehicles and hybrids when oil prices are below \$280 per barrel. Only if the battery cost drops very low, to \$500 per kWh, will the electric vehicle become attractive at an oil price between \$100 and \$120 per barrel. We found similar results, with some variations due to different price levels and fuel-taxation schemes, in China, Japan, and the United States.

Clearly, subsidies will play a major role in bringing the TCO for electric vehicles down to an attractive level for the consumer. Such subsidies are already available in some countries. For example, in France, the government currently pays a subsidy of \$7,000 to the owner of an electric vehicle, which makes the vehicle's TCO attractive even at the current oil price of \$60 to \$80 per barrel. Similar subsidies are in place in Denmark and Israel.

## Scenarios for 2020

The alternative propulsion technologies discussed above will strongly affect the automotive industry in 2020. The Boston Consulting Group's propulsion-market model looks at the

### Exhibit 3. When Oil Prices Are Moderate, the Market Attractiveness of Electric Vehicles Is Low



Source: BCG analysis.

**Note:** Base car: Volkswagen Golf 1.6 Comfortline. Advanced gasoline vehicle: base car with downsizing by turbocharging and direct injection. Advanced diesel vehicle: base car with high-pressure common-rail injection (pressure > 2,000 bar) and advanced exhaust after-treatment system against nitrogen-oxide emissions. Hybrid electric vehicle: base car with a power-split hybrid electric-propulsion system. Electric vehicle: base car with an 80- to 93-mile (130- to 150-kilometer) range and performance that is equivalent to that of the base and hybrid vehicles. The assumed average annual mileage for all vehicles is 9,000 miles (about 14,500 kilometers).

<sup>1</sup>TCO = total cost of ownership.

world's four largest automotive markets—Western Europe, North America, Japan, and China—from 2008 to 2020, incorporating regional differences in average mileage, CO<sub>2</sub> regulations, taxes, and likely acceptance of technologies.

The major drivers of future propulsion markets are “push” from governments and “pull” from consumers. Push from governments takes the form of supply-side regulation of OEMs, such as Corporate Average Fuel Economy (CAFE) standards in the United States and mandatory CO<sub>2</sub>-emissions targets in Europe. Governments can also contribute positive incentives to both OEMs and consumers. For example, in July 2008, as part of a set of measures to reduce energy consumption, the Spanish government announced an objective of having 1 million electric and hybrid vehicles operating in Spain by 2014. The government is currently holding negotiations with OEMs about ways to encourage the development, production, and sales of these vehicles.

To assess the effect of supply-side regulations, we calculated the current CO<sub>2</sub> emissions for each vehicle segment and automotive market and compared those values to the corresponding target values for the same segments and markets for the year 2020. To assess the effect of pull from consumers, we looked primarily at TCO. We calculated the TCO for the base ICE car, as well as for vehicles that employ alternative propulsion technologies. We then used the differences in TCO to determine likely market acceptance.

Separately from these calculations, we developed three scenarios that

describe the year 2020 mainly from the environmental point of view, based on three distinct answers to one question: How fast has public concern about climate change and CO<sub>2</sub> been rising?

### **In all four regions we modeled, ICEs will remain dominant in 2020.**

**Scenario 1: Slowdown.** The price of oil has fallen to \$60 per barrel. (This is the approximate price of oil as this report goes to press, down from the peak price of \$150 per barrel in mid-2008.) In this scenario, energy security concerns have abated, public concern about climate change has diminished, and there is no longer intense scrutiny of the automotive industry as a root cause of global warming.

**Scenario 2: Steady Pace.** Fears of climate change have intensified, and people are increasingly concerned about their cars' CO<sub>2</sub> emissions. Oil prices have risen to around \$150 per barrel and energy security concerns abound. Governments enforce existing laws and regulations to reduce CO<sub>2</sub> emissions, and set tax incentives for buyers of “green” cars.

**Scenario 3: Acceleration.** All stakeholders—including governments, private-sector organizations, and the public—now feel an urgent need to reduce CO<sub>2</sub> emissions. Governments introduce even stricter regulation of CO<sub>2</sub> emissions and award high tax subsidies to people who drive vehicles with alternative propulsion technologies. Oil prices in the neighbor-

hood of \$300 per barrel create strong incentives to switch to fuel-efficient vehicles.

## **The Outlook for 2020**

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Under all three scenarios and in all four regions we modeled, internal-combustion engines will remain the dominant technology in 2020. Cars equipped with alternative propulsion technologies—including hybrids, range extenders, and electric vehicles—will together achieve market penetration somewhere between 12 percent (for the slowdown scenario) and 45 percent (for the acceleration scenario). In our view, the outcome most likely to be realized in 2020 is the steady-pace scenario, whereby alternative propulsion technologies will win an overall market share of 28 percent. (See Exhibit 4.)

In terms of market segments, fully electric vehicles are most likely to be introduced in the city car segment, where they will take the form of small city cars (such as the Daimler Smart) used mainly for commuting within the city. We expect that about 18 percent of city cars across our four regions will be fully electric vehicles in 2020 under the steady-pace scenario. The small-car segment (as exemplified by the Volkswagen Golf), in contrast, probably will contain the broadest spectrum of available technologies: hybrids will have significant penetration at above 20 percent, along with range extenders at around 7 percent. Range extenders could offer the benefits of electric cars without their driving-range limitations, at the cost of the necessary ICE. Fully electric vehicles potentially will play a lesser role within the small-car segment, as they are subject to range limitations



and constrained to city driving in the absence of interurban charging infrastructure. Among the larger-car segments, there will probably be few fully electric vehicles or range extenders, whereas hybrids may gain a relatively high market share of 18 to 26 percent.

Counted in units, in China, Japan, North America, and Western Europe, 1.5 million fully electric vehicles will be sold in 2020, reflecting some 2.7 percent of the total automotive market in these regions. Range extender electric vehicles will represent another 1.5 million units, or some 2.7 percent of the overall market. Hybrid electric vehicles, including mild and full hybrids, will reach some 20 percent penetration—the largest share of all alternative power-train con-

cepts. Adding CNG-fueled vehicles to the above models, altogether some 28 percent of the cars sold in these markets in 2020 could be powered by alternative power-train technologies. (See Exhibit 5.)

## Implications for Stakeholders

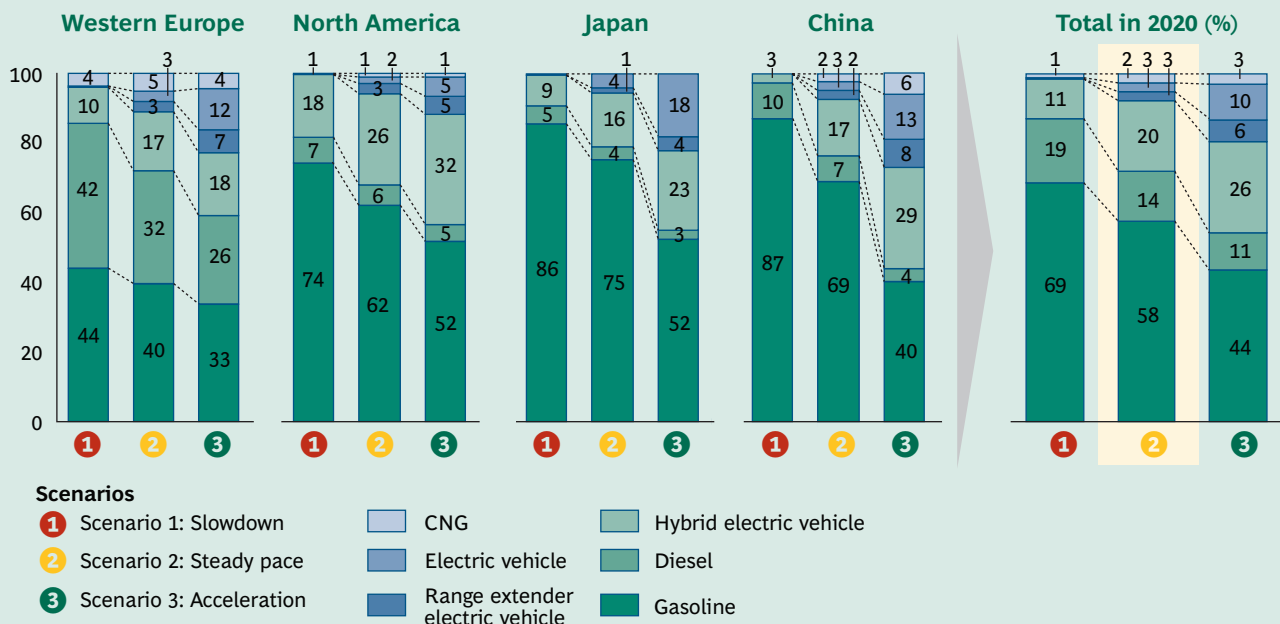
Who will pay for the electric car? The planned reductions in CO<sub>2</sub> emissions will come at a high price. For example, in Europe alone, BCG calculates that in 2020, under the steady-pace scenario, the embedded extra product costs for the new propulsion-technology mix will come to a staggering \$49 billion. Investments totaling an additional \$21 billion will be needed by then for battery-charging infrastructure (stations near homes, ho-

tels, and shopping centers). This cost needs to be distributed among the main stakeholders in the automotive industry. To understand the dynamics of the propulsion market from now through 2020, it is useful to examine what drives each set of stakeholders and what their likely reactions will be.

**Governmental Authorities.** Even the most benevolent government faces the limitations of the system in which it operates. Its members must make long-term political and economic commitments while operating within short-term time frames driven by election cycles or appointment terms. In the case of the power train market, regulatory authorities have made the laudable decision to reduce CO<sub>2</sub> emissions and oil consump-

**Exhibit 4. All Three Scenarios for 2020 Show ICE Technology Still Dominating Key Automotive Markets**

Share of new-car sales in four markets in 2020 (%)



Source: BCG's propulsion-market model.

## Exhibit 5. Markets in 2020 May See Sales of Some 11 Million Hybrids and 3 Million Electric Vehicles and Range Extenders

Estimated passenger-car sales in 2020 under the steady-pace scenario (millions of units)

	Western Europe	North America	Japan	China	Total
CNG	0.8	0.2	0	0.3	1.3
Electric	0.6	0.4	0.2	0.3	1.5
Range extender	0.5	0.6	0.1	0.3	1.5
Hybrid	2.9	5.4	0.7	2.0	11.0
Diesel	5.5	1.2	0.2	0.9	7.8
Gasoline	6.7	12.9	3.4	8.4	31.4
<b>Total</b>	<b>17.0</b>	<b>20.7</b>	<b>4.6</b>	<b>12.2</b>	<b>54.5</b>

Source: BCG's propulsion-market model.

tion. In doing so, they have placed a large burden on automotive stakeholders but have failed to specify who will bear this cost or how. The important next step for regulating authorities is to recognize this added obligation and provide the appropriate incentives to all stakeholders: not only to OEMs to reduce their fleets' CO<sub>2</sub> emissions but also to consumers to buy alternative propulsion systems and to the power industry or third parties to invest in infrastructure.

**OEMs.** In our view, OEMs need to focus on three things: ensuring access and building solid know-how across effective supply networks, offering consumers attractive value propositions, and managing the high complexity of their R&D portfolios. Ensuring access to raw materials, production capacity, and battery technology will be critically important. In the latter case, OEMs should be pursuing partnerships with battery suppliers. Several cooperative arrangements are already in place, including, for example, those between Toyota and Panasonic, Volks-

wagen and Sanyo, Bosch and Samsung, and Renault-Nissan and NEC.

The second challenge for OEMs is to ensure that their value propositions succeed in the marketplace. For that to happen, there needs to be adequate infrastructure in place for buyers to operate electric vehicles; and both the purchase price and the TCO need to be competitive with those of conventional cars.

To provide the required infrastructure and create new business models, some OEMs have already built partnerships with third-party investors or directly with power companies. For example, Toyota partnered with EDF, the large French electric company, to test its plug-in hybrid in the EDF fleet and create an innovative charging and billing system. And Better Place, a U.S. start-up partnering with Renault, is dedicated to building a global charging infrastructure for electric vehicles, starting in Denmark and Israel in 2011. Better Place plans to offer drivers the possibility of either recharging at charging

stations or going to exchange stations to swap a depleted battery pack for a fully charged one. This latter option would allow drivers to travel greater distances without lengthy stops for recharging (which currently takes four to eight hours).

The viability of these and other novel business models remains to be seen. Certainly, these examples suggest that the commercialization of electric vehicles may benefit from unconventional market models.

The management of an OEM's current R&D portfolio, which is likely to focus on alternative power-train technologies and a broader model line-up, becomes particularly crucial under the current circumstances of widespread financial crisis. R&D management must, of course, pay close attention to economic parameters, including costs and profitability; but they should also place strong emphasis on the potential CO<sub>2</sub>-reduction capacities of technologies under development.

Even with strong partnerships, innovative new business models, and an optimized R&D portfolio, OEMs are unlikely to be able to create compelling value propositions for electric vehicles on their own. They will need to make it clear to regulators that governments must provide incentives to other stakeholders—principally power companies and consumers—to help create the necessary infrastructure and viable business models.

**Battery Manufacturers and Suppliers.** Battery manufacturers and suppliers focusing on lithium ion technology will see tremendous growth opportunities in the coming decade

because the industry needs to develop cheap, reliable, and safe batteries that provide increased energy density to make hybrid and electric vehicles a true alternative. To realize those growth opportunities, battery manufacturers will need to evolve from cell manufacturers into system suppliers. Toward that end, they need to develop a deep understanding of the electric vehicle's overall market environment and requirements. Building close relationships with tier-one suppliers or OEMs is a crucial step. Such partnerships can also help justify the suppliers' investment of R&D resources by backing them with production commitments.

At the same time, battery makers should be exploring backward integration and partnerships to secure a supply of raw materials and battery components (such as membranes), which are likely to be in short supply when the electric-vehicle market starts taking off. Securing the upstream value chain will be crucial to meeting production commitments at contractual prices.

**Power Companies.** If electric cars are to reach a broad market, rather than just serving as second cars for city dwellers with large garages, it will be essential to create a public electric-charging infrastructure. Unless the length of the charging process can be shortened significantly from the current four to eight hours, each market will need a pervasive charging infrastructure to ensure that drivers can charge their cars at or near their residences, at hotels if they are traveling, or at locations such as cinemas and shopping centers.

However, it's hard to make a business case for a public electric-charg-

ing infrastructure. The added revenue to service providers is limited, the investments are high, and the risk is substantial. For example, even if 10 percent of all the cars in Germany (or 5.5 million cars) were electric, the country's total demand for elec-

### A TCO advantage is a prerequisite for the widespread adoption of electric vehicles.

tricity would increase by only 1.7 percent. If electric-power companies were to pay for the new infrastructure needed to support those cars and amortize its cost over 15 years, they would have to more than double the price of electricity for charging electric vehicles—making them unattractive to consumers. Moreover, if technology subsequently were to evolve to allow fast charging (in 15 minutes or less), then it could take place at gas stations, rendering obsolete the costly installed infrastructure near residences and elsewhere. Under these conditions, it is unlikely that power companies will invest in the needed charging infrastructure without powerful government incentives and a clear technology road map from OEMs.

**Consumers.** Recent global surveys of consumers revealed that most are not willing to pay substantial price premiums for electric vehicles unless those vehicles yield an economic advantage in terms of TCO. But of course, people's buying decisions are rarely based entirely on logic. Emotional factors, such as distress over high oil prices or concern about environmental degradation, may move some consumers to buy electric vehi-

cles even at a relatively high TCO. Such decisions are likely in some niche segments; consumers in these segments can function as early technology adopters. But for the mainstream market, a TCO advantage is a prerequisite for the widespread adoption of the electric vehicle.

Clearly, consumers who care keenly about the environment and want to contribute to the sustainable use of the earth's resources can look forward to having some interesting automotive options in the next dozen years. Meanwhile, they can add their voices to the chorus of those lobbying their governments to ensure that the necessary infrastructure is built and the necessary incentives—and disincentives—are in place to make electric vehicles viable.

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To attain the goal of reducing CO<sub>2</sub> emissions through increased vehicle efficiency, all automotive OEMs need to include electric vehicles as an integral part of their portfolios. But OEMs cannot create this sustainable new approach to automotive mobility by themselves. Countries such as Denmark, France, and Israel, which are now establishing attractive incentive schemes for electric vehicles, could potentially generate a huge competitive edge for their domestic automotive and power industries. But unless other governments act promptly to provide adequate incentives for consumers to purchase these cars and for power companies and private investors to provide the necessary infrastructure at affordable prices, the electric vehicle may be off to another false start.



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