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**Accelerating pace of innovation in automotive**

Today, automotive companies from around the world are competing on a global scale to bring new brands, models, features, technologies, and processes to market first. Innovation hit the brakes briefly in the wake of the 2008 global financial crisis, but our research and experience show that the pace of innovation accelerated again through 2013, and it is continuing as we enter 2016. Indeed, the recent and prospective developments in five key areas—powertrain, lightweight materials, connectivity, active safety and autonomous driving—may well herald a new golden age of technological advancement and automotive innovation.

Driving these improvements is an intensified focus among automakers and their leading suppliers on introducing new technologies faster, continuing to improve fuel economy and reduce emissions, and developing important connectivity and active-safety features (including autonomous driving). Enabling these efforts is the transformation of the car from a collection of mechanical and hydraulic systems to a machine predominantly controlled by electronics and software. Together, these changes are altering the way cars are conceived, designed, manufactured, serviced, and driven.

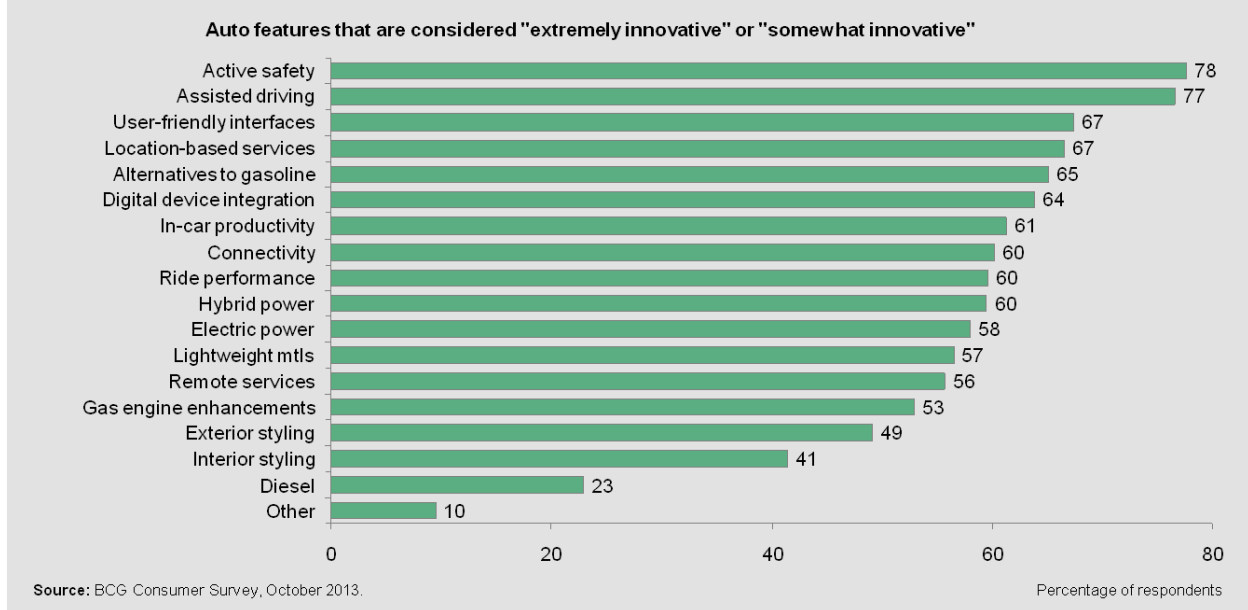
Research from The Boston Consulting Group shows that consumers cite innovation<sup>1</sup>—both generally and in key areas such as connectivity, safety, and fuel economy—as an important consideration in their purchase decision. Our analysis indicates the following:

- Consumers want to buy cars from companies that bring new technologies to market.
- Connectivity and safety are important to consumers; they want to see innovation in these areas as well as in improving fuel efficiency (see exhibit 1).
- Consumer and regulatory concerns about oil prices, oil dependency, and global warming will ensure that technologies related to fuel efficiency and emissions reduction remain at the top of OEMs' research agendas.
- OEMs and suppliers will need to expand their R&D capabilities in electronics and software. Start-ups and technology companies also now invest significantly in the industry.
- Tier one suppliers are becoming increasingly important in bringing innovations to market.
- In areas like fuel efficiency and active safety, there is a potential gap between the cost of technologies and customers' willingness to pay.

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<sup>1</sup>The Boston Consulting Group. *Accelerating innovation: new challenges for automakers*. Detroit, MI: BCG Report (2014). Retrieved from [https://www.bcgperspectives.com/content/articles/automotive\\_innovation\\_accelerating\\_innovation\\_new\\_challenges\\_automakers/](https://www.bcgperspectives.com/content/articles/automotive_innovation_accelerating_innovation_new_challenges_automakers/)

## Exhibit 1 | Active Safety and Assisted Driving Top the List of Innovative Features



R&D spending by OEMs has accelerated, increasing at a rate of 3 percent a year from 2001 through 2012 and at an annual rate of 8 percent since 2009. At tier one suppliers, R&D spending has risen by 4 percent a year since 2001 and by 5 percent a year since 2009. Another measure of innovation, the number of patent filings, also reflects an increase. The patent activity of tier one suppliers has outpaced that of OEMs for the past 15 years, with the number of filings increasing by 6 percent a year from 1995 through 2011, compared with a rise of 3 percent a year for OEMs.

### Key Areas of Innovation

Three principal forces are driving innovation in the auto industry today: regulatory mandates with respect to fuel efficiency, emissions, and safety; consumer demand and expectations; and technological advances that enable the development of new features and reduce their cost. The result is that companies are concentrating their product-development efforts in five areas: powertrain, lightweight materials, connectivity, active safety and autonomous driving.

Our analysis of recent patent activity supports this view. Patent filings by the top OEMs on BCG's list of the most innovative companies, as well as by the biggest tier-one suppliers, show double-digit growth from 1995 through 2011 in powertrain, lightweight materials, and connectivity, compared with an average growth rate for all patent filings by these companies of only 4 percent. The number of patent applications in the area of active safety grew by 6 percent annually.

### Powertrain and Electrification

Current fuel efficiency standards mandate an average fuel economy of 54.5 miles per gallon (mpg) in the United States for the 2025 model year; the European Union is targeting 64.8 mpg by 2020; and China's goal is 50.1 mpg by 2020. Automakers have stepped up the development of electric and hybrid vehicles and increased their efforts to improve the mileage of mass-market models through advancements such as more efficient powertrains and lighter car bodies. Some 50 automotive models offer hybrid engines today, up from only 2 in 2001.

Conventional Internal Combustion Engine (ICE) technology is going through an evolution, providing significant potential for increased efficiency, improved fuel economy and reduced emissions. Ongoing research and development in fundamental engine processes (e.g. air handling, fuel injection, combustion, etc.), advanced computing capabilities, sensor technology and adoption of advanced manufacturing processes help accelerate the path toward mass commercialization of highly efficient ICEs for passenger and commercial vehicles.

Ongoing developments in ICE technology will help OEMs improve fuel economy of gasoline-fueled vehicles by up to 35 to 50 percent (30 to 35 percent for diesel fueled vehicles) between 2009 and 2020<sup>2</sup> at a cost of \$2,000 to \$2,500 to consumer per vehicle. These improvements will ultimately help OEMs meet emission targets.

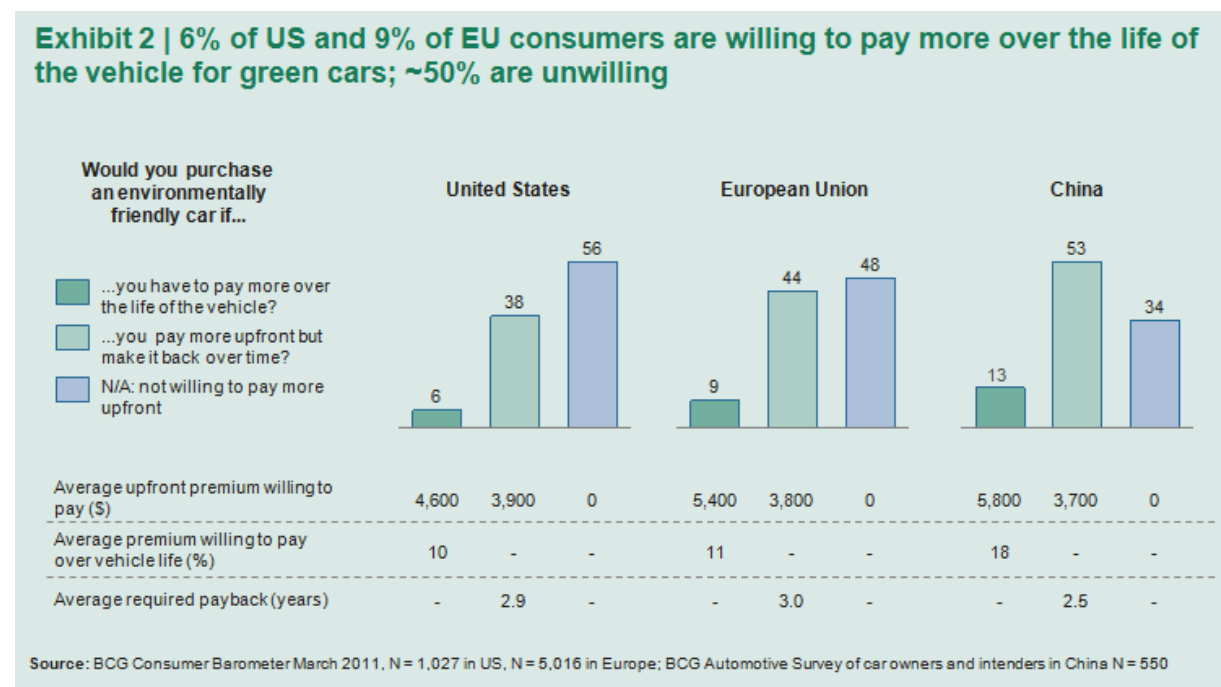
Among the recent developments in ICE technologies, low-temperature combustion (LTC) is noteworthy due to very high thermal efficiencies and significant emissions reduction potential through optimization of fuel injection, fuel mix and combustion reaction properties.

In addition to LTC, there is a wide range of advancements in ICE system level technologies for gasoline-fueled ICEs including optimized cooling, low friction materials, air handling (e.g., optimized air intake and exhaust, variable valve timing, turbo chargers), advanced combustion (e.g., high compression ratio, GDI, EGR) advanced fuel injection, start/stop systems, engine downsizing and solid state energy conversion (e.g., conversion of exhaust energy into electricity).

Some of these developments, such as optimized cooling, low friction, start-stop systems, and engine downsizing combined with mild turbo charging, stand to see widespread adoption across many vehicle segments due to their relatively low cost. Other developments such as LTC require further R&D and technology maturation before they can be mass commercialized. Strong collaboration among industry, academia, research institutions and governmental and regulatory bodies will help overcome technical barriers and accelerate deployment of these technologies in commercial production.

Given these improvements, Internal Combustion Engines will continue to dominate for the foreseeable future. According to recent market forecasts, ~90% (~99% including hybrid and plug-in- hybrid) of global vehicle production in 2020 will still utilize some form of ICE (e.g. gas, diesel, LPG, CNG) as its source of power generation.

The penetration for hybrid and electric vehicles in the U.S. has been consistently growing in the past ten years and peaked at 3.8% of vehicle sales in 2013. In the past two years, it has declined to 2.9%, due to the cheaper price of gasoline. This is due to the fact that only 6.0% of U.S. customers are willing to pay more (\$4,600/car on average) for a more environmentally friendly car without payback. Another 38% of customers are willing to pay on average \$3,900/car<sup>2</sup>, but they require a payback of less than three years on their investment. As prices of gasoline decline, the payback period of hybrid vehicles becomes too long. We note that another 56% of customers will not spend any more on their car for fuel efficiency or lower emissions (see exhibit 2).



<sup>2</sup>The Boston Consulting Group. *Powering autos to 2020: the era of the electric car?* Detroit, MI: BCG Report (2011). Retrieved from [https://www.bcgperspectives.com/content/articles/automotive\\_energy\\_environment\\_powering\\_autos\\_2020\\_era\\_electric\\_car/](https://www.bcgperspectives.com/content/articles/automotive_energy_environment_powering_autos_2020_era_electric_car/)

This constitutes a challenge for electric vehicles. Overall battery costs have declined significantly, due to technology and manufacturing improvements as cost at the cell-level have plummeted from roughly \$700/kilowatt hour<sup>3</sup> in 2009 to \$150/kWh today<sup>4</sup>. This translates to roughly \$250/kWh at the pack-level. To provide a 200 mile range, which seems to be what customers are asking for to take care of range anxiety, battery powered electric vehicles (BEV) will need at least 50 kWh, representing an additional cost of \$12,500/car today at the pack-level, and possibly \$9,000/car in 2020, before any markup from the car manufacturers. Given this expectation, it is important that tax incentives or other forms of incentives remain in place to sustain this emerging market. Non-financial incentives like reserved parking spaces at charging stations or access to priority lanes are also strong purchase motivators in urban environments. Even with these extended ranges, fast-charging infrastructure on highways will remain necessary for battery powered EVs to support all driving needs.

In addition, small-scale series manufacturing of fuel cell electric vehicles (FCEV) has already started (e.g. Hyundai Tucson iX35, Toyota Mirai) and several other OEMs (e.g. GM, Honda, Ford, Nissan) have already announced their plans to launch FCEV by 2020. Recent studies forecast that FCEV production volumes will be in the range of 1,000–10,000 units p.a. per OEM in the next 5–10 years.

Current and forecasted technological progress coupled with experience curve and scale effects, are expected to reduce Fuel Cell System cost by 3%p.a. in the next five years. Fuel cell system costs are currently at \$475/kW for a 50kW system (at 1,000 units production volume) and ~50% of system costs are driven by the Fuel Stack, which uses Platinum (Pt) as the reaction catalyst, exposing system costs to fluctuations in Pt prices. Our market models show that increasing scale and associated experience will further push system costs down (e.g. \$295/kW at 10,000 units and \$110/kW at 150,000 units of production) and by 2030 FCEV could reach similar levels of cost competitiveness (TCO) as BEV, if necessary investments are put in place to increase production capacity and hydrogen fueling infrastructure to support the development of the market.

The future of FCEV market is still subject to several tipping points that might limit the market to niche application. Alternative technology breakthroughs in BEV that can overcome current range/charging time limitations, insufficient hydrogen fueling infrastructure development (due to lack of long term commercial attractiveness) and unfavorable developments in cost structure can hamper projected growth trajectory. We believe the support of policy makers, regulatory authorities, together with a strong collaboration among industry and academia, is key to spur the development, of the future FCEV market.

## Lightweighting

Lightweighting can be a major contributor to meet future vehicle efficiency requirements. It is generally accepted that a 10% reduction in vehicle mass can enable a 6-8% improvement in fuel economy of a vehicle with conventional Internal Combustion Engine.

Reducing mass also has a “compounding” beneficial effect. Firstly, reduced mass of the body structure can allow the use of smaller and lighter engines and smaller, lighter chassis components such as suspensions and brakes. Secondly, the decreased weight and resultant increased fuel efficiency can enable the vehicle to get the same range with less gas, thereby allowing the vehicle to haul less fuel and use smaller (lighter) fuel tanks. Finally, reducing weight of components can also allow manufacturers to offset weight gains that are the result of revised safety requirements or the addition of popular comfort and convenience features demanded by today’s consumers.

The shift to lightweighting has several challenges around costs, manufacturability and serviceability. The material and processing costs of light weight materials (e.g. Aluminum, Advanced High Strength Steel (AHSS), Magnesium, Carbon Fiber Composites, etc.) are generally higher than that of current incumbent/conventional materials. In primary applications, the relative costs of lightweight materials are 1.2 to 5 times more than that of conventional materials. The ability to robustly manufacture (e.g. form and join) advanced materials is also another challenge in using lightweight materials. Simple techniques (e.g., welding, bolting, bending, stamping) cannot be used to join these new materials without compromising their strength, dimensional stability and durability.

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<sup>3</sup>The Boston Consulting Group. *Batteries for electric cars: challenges, opportunities, and the outlook to 2020*. Boston, MA: BCG Report (2010). Retrieved from <https://www.bcg.com/documents/file36615.pdf>

<sup>4</sup> General Motors Corporation.. *Global business conference - October 2015*. Detroit, MI:

Lightweighting materials with all the desired properties do not yet exist and must be developed. For instance, to reduce the cost of Carbon Fiber Composites, lower cost precursor materials are being explored and OEMs and steel suppliers are pursuing a new, 3<sup>rd</sup> generation of AHSS, that is affordable, with high strength and ductility.

Due to the aforementioned limitations and challenges around costs, manufacturability and availability, OEMs and their suppliers embrace a philosophy of picking the right material for the right place so that a number of different lightweighting materials are used for different applications. For example, Aluminum castings are ubiquitous in powertrain applications, such as engines and transmissions. Aluminum is also being used in structural members (e.g., Ford F150) of automobiles since the body structure holds the potential for the greatest mass reduction. Carbon Fiber Composites are also utilized for very demanding applications or where performance justifies its use, such as in high performance cars (e.g. Chevrolet Corvette, BMW i8).

The development of lightweight materials that break compromise of cost and resistance, as well as new bonding technologies and their related manufacturing investments, will justify the support of public policy.

## **Connectivity and Cyber Security**

Automotive market is witnessing an unprecedented rise in connectivity. Most car manufacturers now offer embedded connectivity solution (such as GM OnStar) on most vehicles, 4G LTE hotspots as well as support brought in connectivity from smart phones (CarPlay, Android Auto). Over the next 10 years, penetration of embedded as well as brought-in connectivity support in new vehicles sold in the US is expected to reach close to 100%. In addition to rise in connectivity through embedded and brought in devices, increasing number of vehicles will connect to Wi-Fi networks to allow remote update of automotive software when needed. The benefits to the consumers and car manufacturers are high: accident or theft alert, remote unlocking, over-the-air updates of software, and better management of recalls and maintenance are among them.

In addition to being connected to the cloud, vehicles will connect with other vehicles, infrastructure and pedestrians through Dedicated Short Range Communication (DSRC) or V2X mainly to improve the range of vision of the car in order to increase safety, paving also the way for autonomous cars.

Increasing connectedness of cars to other devices and internet might make vehicles vulnerable to hacking attacks. Recent attempts by ethical hackers to expose vulnerabilities and extent of vehicle control that can be taken over by hackers has highlighted the need for strengthening cyber security in connected vehicles. We see cyber security as a key area automotive industry will remain focused on for next 5-10 years.

## **Active Safety**

In 2014, the number of accidents on U.S. roads amounted to 6 million, causing 3.9 million injuries and 33 thousand fatalities. The cost to society of these accidents has been evaluated to \$910 billion each year in the U.S. In addition to the pure safety dimension, every accident is usually the cause of traffic congestion, leading to increased fuel consumption.

Available Advanced Driver Assistance Systems (ADAS) that can be purchased today could help reduce the number of accidents on U.S. roads by 30%<sup>5</sup>. Those features include systems like forward collision warning and automated emergency braking, blind spot detection, and support to night vision. However the penetration of those features is low today, typically in the single digit percentage, and growing very slowly. Penetration is limited by the fact that customer willingness to pay is on average 50% of the current price of these features on the market. Given the value of scale in these technologies, their costs could be half of what they are today, with 50% penetration.

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<sup>5</sup>Motor and Equipment Manufacturers Association & The Boston Consulting Group. *A roadmap to safer driving through advanced driver assistance systems*. Detroit, MI and Washington D.C.: BCG Report (2015). Retrieved from <https://www.bcgperspectives.com/content/articles/automotive-roadmap-to-safer-driving-through-advanced-driver-assistance-systems/>

The savings that are associated with the increased safety could be as high as \$16k per car over the 20-year lifetime of the vehicles. There is therefore significant benefit to society, both in terms of safety and fuel-efficiency, to support the increased penetration of active safety features. This can be done through increased customer education, advancements in regulation as NHTSA recently announced, and potential incentives either from insurance companies or possibly tax incentives. The increase in penetration of ADAS is even more important as several of its sensor technologies, like cameras and LIDAR, can be the basis for future autonomous vehicles.

## **Autonomous Cars**

Autonomous cars have the promise of significant benefits in terms of safety, convenience, fuel-efficiency, as well as lower emissions. Their evolution will likely come in stages, starting with partial autonomy, such as single-lane highway driving, adding features such as automated valet parking, and traffic jam autopilot. At some point, cars should be able to evolve at low speed in urban traffic, and then become fully autonomous in most driving conditions and speeds. Our analyses show the cost of these features to range from \$4k for one feature to \$10k for full autonomy at the time of market introduction.

Overall, customer demand for autonomous features and vehicles is very high, with 55% of U.S. drivers likely to consider buying a partially autonomous vehicle, and 44% a fully autonomous one<sup>6</sup>. 20% of these drivers are also willing to pay an extra \$5k or more for autonomous driving features, showing the high value that customers place in the promise for increased safety, the convenience, and also the customer view that it could reduce their insurance and fuel expenses.

The safety impact when fully deployed should be significant, with a 90% reduction in the number of accidents, and therefore an increase in traffic fluidity and fuel efficiency. It is also noted that smoother driving improves fuel-efficiency, and better information on availability and location of parking spaces will further improve efficiency. In dense urban environments, up to 30% of time in a vehicle can be spent looking for a parking space.

In addition, our calculations show that with a shared fleet of robo-taxis, cities like New York could replace a fleet of 900k private vehicles by 80-100k shared cars, with the potential upside of more fluid traffic and significant fuel efficiency benefits. At the same time, these cars are less involved in accidents or do it at a much reduced speed, therefore it would be possible to reduce the weight of the vehicles with further improvement in fuel efficiency and reduced emissions.

Car sharing and connectivity can together increase the possibility of efficient carpooling, with a much higher mileage than privately owned cars, shared cars can significantly reduce the payback period of fuel efficient technologies and electric vehicles. A recent survey conducted by BCG and the World Economic Forum showed that 66% of customers in large cities would expect autonomous vehicles to be either hybrid or electric.

## **Supporting future market development**

The automotive industry is experiencing a period of increased innovation, with significant potential impact on energy savings, health, safety and convenience for consumers. Many of these technologies will also add cost to current vehicles, at least in the short-term while technology and cost are being improved. In technologies related to fuel efficiency and safety, customers' current willingness to pay is often below the cost of bringing these technologies to market. During this period, there are several levers that legislation and regulation can pull to support the market development:

- Supporting the cost of technology development in the form of grants or experimentation. This is particularly true for powertrain improvements, electric vehicles, lightweighting and autonomous vehicles.
- Customer education, together with possible incentives, notably in the case of active safety, where the benefits are high and customer willingness to pay is limited.

- Sustained incentives will be required to continue the development of electric vehicles, be it battery powered or fuel cells. These incentives might follow a number of different directions:
  - Evolve toward incentives based on industry wide volumes, as opposed to OEM specific volumes, in order to continue supporting the efforts of early innovators
  - Support of charging, or hydrogen distribution infrastructure, broadly speaking or for select experimentation
  - Support non-financial incentives for electric vehicles with reserved parking spaces or access to priority lanes
  - Support customers in upgrading their home-charging to 220V, which will be required for the next generation of electric vehicles with extended ranges
  - Potentially offer more credit to OEMs for electric cars used in a car sharing environment, where they are likely to have higher utilization
- Overall, the legislation will have to think about the adequate balance between fuel efficiency and safety in consumer and government spending. And define the appropriate balance of investment in improving conventional powertrain technologies compared to supporting zero emission vehicles.