ABSTRACT

There is a profound sense of urgency among leading industrialized nations: governments recognize that massive reductions in carbon emissions are required if we are to limit climate change in an era of ever-increasing global population growth and increasing affluence. They may also believe that the auto industry can deliver more carbon reduction faster at a lower absolute and political cost than other industries.

Continued investment on the part of governments and the auto industry to create a viable model for sustainable mobility and vehicle electrification in the 2010 – 2020 timeframe should help drive transport-related carbon emissions down to the 60-90 grams/kilometer level, from 130-155 grams today, and contribute to an overall 20-30 percent reduction in greenhouse-gas emissions.

When leaders of the G8 nations (the United States, Canada, Russia, the United Kingdom, Germany, France, Italy and the European Union) left the 2009 annual summit it was with a commitment to cut greenhouse-gas emissions enough to limit the rise in global temperatures in 2050 to just two degrees Celsius above pre-industrial levels.

Over the next five years, we believe that significantly higher-volume applications of existing technology, such as downsized and boosted gasoline engines, will be enough to meet current regulatory targets.

Supplier companies will find that OEMs all will draw from more or less the same technology pool, which will create business opportunities for companies that supply components and systems including turbochargers, direct-injection fuel injectors, stop-start systems and, of course, battery packs and other hybrid components.

In the run up to 2020, sources have estimated that total global spending on green initiatives will be (U.S.) $4.4 trillion, with as much as $428 billion targeted for sustainable mobility projects. Electrification of the global automotive fleet must occur, and is occurring, on multiple levels: Individual components and systems are being electrified. Mild- and full-hybrid vehicle powertrains are increasing in volume Full-electric vehicles will begin to enter production in meaningful volumes.

Executive Summary

There is a profound sense of urgency among leading industrialized nations: governments recognize that massive reductions in carbon emissions are required if we are to limit climate change in an era of ever-increasing global population growth and increasing affluence. They may also believe that the auto industry can deliver more carbon reduction faster at a lower absolute and political cost than other industries.

What this means for the automotive sector is becoming increasingly clear: The electrification of the automobile will occur on an accelerated basis, especially in 2020 and beyond.

When leaders of the G8 nations left the 2009 annual summit it was with a commitment to cut greenhouse gas emissions enough to limit the rise in global temperatures in 2050 to just two degrees Celsius above pre-industrial levels. Two degrees may not sound like much, but achieving it will require a massive 80 percent reduction in greenhouse gas emissions by 2050.

The drive to adopt the “Two-degree Solution” is fueled by some sobering population statistics. It's estimated that there are more people alive today than the total number of people who have ever lived throughout the history of the Earth, and they are consuming natural resources at an unsustainable rate. The global population is expected to grow 20 percent by 2020.
and 80 percent by 2050, according to the United Nations. That means the population of the planet will be 8.3 billion in about 10 years, and it will almost double to 12 billion people in 40 years.

The pressure this fast growing population will put on climate change goals will be significant. The population will be far more affluent, which will drive up unprecedented demand for raw materials, energy - especially for transportation -- and durable goods like automobiles. These trends are among the reasons why global greenhouse gas emissions from the transportation sector are growing faster than any other segment of the economy.

Whatever the final targets adopted by the UN, G8 and G5 are, with population, wealth and vehicles in use all growing, it is clear that transportation is going to have to play a major role in meeting the targets in every major market.

Climate change has scarcely been out of the news since the United Nation’s Framework Convention on Climate Change initially adopted the Kyoto Protocol in December 1997. Since then, we all have seen the headlines from leading news organizations like the recent one in USA Today that reported, “Arctic Temperatures Hit 2,000-year High.” Thousands of stories like this have been written about the potential impact of rising global temperatures, and these articles that have helped galvanize public and political support for legislative solutions.

In the United States, which has been slower than Europe and Japan to adopt aggressive climate change legislation, most Americans say they approve of the way President Obama is handling energy issues. That includes support for his efforts to overhaul energy policy - including the controversial cap-and-trade approach to limiting greenhouse gas emissions, according to a Washington Post-ABC News poll.

On the other side of the debate, there are think tanks, a handful of scientists, and some politicians who continue to argue that global warming caused by human activity is overstated, the risks exaggerated and the costs of “fixing” the problem too high.

The political posturing already has begun. According to a recent New York Times report, the Democratic Party of Japan (DPJ), which won recent parliamentary elections last year by a landslide, has pledged to slash Japan’s greenhouse-gas emissions 25 percent below 2005 levels in the coming decade, compared to the 15 percent cut promised by the incumbent Liberal Democratic Party.

As the BP oil debacle clean up continues and gas prices rise along with the global economic recovery, expect a vigorous public debate on green energy. But don't lose site of the fact that from the standpoint of the global auto industry, it no longer matters if global warming and its associated risks are real or not. Government policies around the world are aligning to promote sustainable mobility and curtail carbon emissions.

Unlike in 1997, there is a profound sense of urgency among leading industrialized nations. Governments recognize that massive reductions in carbon emissions are required if we are to limit climate change in an era of ever-increasing global population growth and increasing affluence. What this means for the automotive sector is becoming increasingly clear: The electrification of the automobile will occur on an accelerated basis, especially in 2020 and beyond.

The Two Degree Solution

When leaders of the G8 nations (the United States, Canada, Russia, the United Kingdom, Germany, France, Italy and the European Union) left the 2009 annual summit it was with a commitment to cut greenhouse-gas emissions enough to limit the rise in global temperatures in 2050 to just two degrees Celsius above pre-industrial levels.

Two degrees may not sound like much, but achieving it will require a massive 80 percent reduction in greenhouse gas emissions by 2050. To help get there, the United States, Japan and the European Union have pledged to reduce emissions in the near term by 15 - 20 percent.

The U.S. contribution alone will require massive shifts in vehicle usage and powertrain technology, given the country’s outsized carbon emissions - about 1.6 billion tons each year or nearly 20 percent of the global total, according to Oak Ridge National Laboratory.

![Atmospheric Carbon Dioxide Concentrations to 2050](image)

1Centre de Mathématiques Appliquées, Assessing carbon values to achieve strong post-Kyoto CO2 reduction targets for France, 31st IAEE International Conference, June 2008.


3Nettel, A., Historical CO2 record from the Siple Station Ice Core, Physics Institute, University of Bern, Switzerland, September 1994.

4 CSM Worldwide analysis
Meanwhile, the developing world's G5 nations (Brazil, China, India, Mexico and South Africa) have called on the G8 to stretch even further and achieve a 40 percent reduction by 2020 to allow for small contributions from lesser-developed nations.

India has said it will reject any new treaty to limit global warming that makes the country reduce greenhouse-gas emissions because it would undermine its energy consumption, transportation and food-security strategies. Developing countries like India point to the fact that many of their citizens live without access to clean water, reliable electricity and other underpinnings of industrialized societies, and thus need cheap energy. They also make a strong argument that approximately 80 percent of the CO₂ buildup in the atmosphere to date has been contributed by industrialized nations like the United States.

While the G5 ultimately must cooperate with the G8 if the 2050 goals are to be achieved, it's not unreasonable to expect that governments in the West and Japan will at least to some extent compensate for the greenhouse-gas emissions of less-developed countries.

The drive to adopt the “Two-degree Solution” is fueled by some sobering population statistics. It's estimated that there are more people alive today than the total number of people who have ever lived throughout the history of the Earth, and they are consuming natural resources at an unsustainable rate. The global population is expected to grow 20 percent by 2020 and 80 percent by 2050, according to the United Nations. That means the population of the planet will be 8.3 billion in about 10 years, and it will almost double to 12 billion people in 40 years.

According to IHS economic forecasts, average global wealth will increase by an estimated 75 percent by 2030, with China and India expected to see wealth increase by 300 percent. The pressure this rapidly-growing population will put on climate-change goals will be significant. Economic growth in the developing world, coupled with increasing wealth in major economies will lead to unprecedented demand for raw materials, energy - especially for transportation - and durable goods like automobiles. These trends are among the reasons why global greenhouse-gas emissions from the transportation sector are growing more quickly than any other segment of the economy.

Indeed, at forecasted levels of prosperity for India, the potential exists to support roughly 166 vehicles for every 1,000 people within the next two decades. In China, per capita GDP is expected to rise 400% by 2030 which could result in a penetration rate of 250 vehicles per 1000 people. Combined, these two countries alone could require a car parc of 500 million vehicles by 2030, twice the size of today's U.S. vehicle population.

Whatever the final targets adopted by the U.N., G8 and G5, it's clear that with population, wealth and vehicles in use all growing, transportation is going to have to play a major role in meeting the targets in every major market.

**Steps Toward a Low Carbon Future: 2010 - 2020**

For the US, Japan and EU the legislative roadmap to achieve meaningful reductions in carbon emissions is already laid out before us, at least through 2015. The recipe is strict limits on CO₂ emissions, higher fuel-economy standards and dramatically higher fuel prices in the United States.
From the standpoint of efficiency, this aligned global policy framework will see the U.S. vehicle fleet match the fuel economy and greenhouse-gas emissions of today's home-market European and Japanese fleets by 2015, according to IHS forecasts. That equates to emissions of about 135-155 grams of CO\textsubscript{2} per kilometer, or less than half of the U.S. fleet's 2003 performance. Achieving this goal will be a major accomplishment given the significant differences that exist in driving habits, fuel prices and consumer preferences.

Over the next several years, IHS Automotive expects that the gap between the fuel economy and emissions performance of the three major regions' fleets will diminish, almost to the point of convergence by 2020.

**2016 US Fuel Economy Targets By Manufacturer**

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<th>Manufacturer</th>
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Over the next five years, we believe that significantly higher-volume applications of existing technology, such as downsized and boosted gasoline engines, will be enough to meet current regulatory targets. In the United States, the fuel-economy standard will be 34.1-mpg fleet average in model year 2016 - which will be regulated by the National Highway Traffic Safety Administration (NHTSA) - and the equivalent of 155.4 grams/kilometer of CO\textsubscript{2} - which will be regulated by the Environmental Protection Agency (EPA). Each vehicle manufacturer will have individual targets based on the size, volume and composition of their respective portfolio, but on balance, passenger-car fuel economy will have to increase by an average of 4.7 mpg, with light trucks increasing by 5 mpg compared with 2010.

Of course, averages are deceiving. Some automakers need to improve much more than the average. To understand how the changes would apply to a large-volume manufacturer like General Motors, IHS Automotive conducted a portfolio gap analysis to determine how GM could achieve a 6.9-mpg improvement in North America to improve from its combined, unadjusted car and truck base of 25.4 mpg to 32.3 mpg.

Key findings include:

Nearly GM's entire fleet will have to be fitted with variable valve timing.

Six-speed transmissions will have to be deployed across 85 percent of its fleet.

Direct-injection and E85 capability will have to stretch across 70 percent and 65 percent of its offerings, respectively.

About one-third of GM vehicles will need to offer cylinder deactivation technology.
All of these technologies are readily available and affordable, and deploying them in high volumes will reduce the need to launch costly hybrids in high volume, at least in the near term. However, Hybrids and Electric Vehicles (EVs) will remain a key part of nearly every automakers strategy because of the multiplier effect they have on fuel-economy credits. For that reason, GM will require a 4 percent hybrid penetration rate spread across at least 13 nameplates.

This portfolio gap analysis tends to support the federal government's contention that the new fuel-economy rules adopted by the Bush and Obama administrations will add an average of $1,129 per vehicle in costs. In aggregate, NHTSA's analysis shows that among the seven largest OEMs operating in the United States, the Ford, GM, Hyundai and Nissan car portfolios will have the highest compliance costs. On the truck side, GM, Chrysler Hyundai and Nissan will face the biggest hurdles.

Supplier companies will find that OEMs all will draw from more or less the same technology pool, which will create business opportunities for companies that supply components and systems including turbochargers, direct-injection fuel injectors, stop-start systems and, of course, battery packs and other hybrid components.

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Electrified Propulsion Systems to 2020

Making Green Pay

As the General Motors gap analysis shows, electrified vehicles will play an important role in the industry’s CO₂ compliance strategies, especially in the United States, because of the credit-multiplier effect of EVs, hybrids and plug-in hybrids. And as regulations get stricter, volumes will grow smartly. By 2020, we expect that nearly 800 vehicle models around the world will include some form of vehicle electrification technology - defined as stop-start systems, mild- and full-hybrids and battery-electric vehicles - up from just over 100 today.

At the retail level, we expect to see a handful of “pure play” green vehicles like the Chevrolet Volt. But segment-specific green targets, as well as marketing demands, could result in some 45 percent of all vehicle nameplates offering some form of electrification.

The actual technology mix that gets deployed, however, will vary quite a bit by region. In Europe, about 15 million units will be electrified to one degree or another by 2020, with stop-start systems accounting for the vast majority of the volume. This reflects the relatively green status of the fleet today due to the popularity of small displacement gas engines and high-efficiency diesels.

In Japan and Korea, stop-start systems will be applied to about one million units, but the volume of mild- and parallel hybrids will be about twice as large. As in Europe, this reflects the relative greenness of the existing fleet, and Japan’s leadership in battery technology.

In the NAFTA region, mild- and parallel hybrids also will dominate, but the volumes will be much lower at just under one million units. Vehicle manufacturers here will drive most of their gains through the volume application of high-efficiency conventional powertrains, and by building smaller, lighter vehicles.

How enthusiastically the market will embrace these vehicles will be a function of the cost - benefit ratio. History has shown that a technology that pays for itself in less than five years will achieve a high market penetration. Those that take longer to pay back achieve niche status at best.

That brings us to the fuel-price discussion. Gasoline prices in the U.S. need to rise from today’s relative low levels in order for consumers to consider paying for better fuel economy technology. In the United States, the $1,000 technology cost of a gas-turbo, direct-injection engine pays back in about 5.4 years, based on $3 per gallon gasoline, while in the United Kingdom, where prices are closer to $8 per gallon, the same technology pays for itself in only two years.

Similarly, a hybrid vehicle with a technology cost of $3,000 would take 8.2 years to payback in the United States. But in Japan and the European Union, where pump prices are closer to $8 per gallon, the payback is only 4.1 years.

The pure battery-vehicle equation is even more challenging with low fuel prices. With a technical cost of $20,000, the payback is 14.7 years at $3 per gallon gas, 6.2 years at $6 per gallon and 4.5 years at $8 per gallon.

Even assuming technology costs fall at an annual average rate of 15 percent, it’s clear from this analysis that the most expensive technology options, which also are the “greenest,” only make economic sense when fuel prices are high.

Governments, including the U.S. Congress, recognize this, and despite the difficulty of raising taxes in recession, it’s critical that industrial policy and environmental policy line up to make CO₂ reduction a viable business strategy. After all, automakers are in business to build cars for profit, not practice.

Taking Autos Out Of the Climate Debate

Continued investment on the part of governments and the auto industry to create a viable model for sustainable mobility and vehicle electrification in the 2010 - 2020 timeframe should help drive transport-related carbon emissions down to
After 2020, however, is when all the investments in batteries and fuel cells will begin to pay off. To achieve the U.N.'s “Two-degree Solution” requires that over the succeeding 30 years overall consumption of fossil fuels must drop by 75 percent.

The 5-5-5 Product Development Design Cycle

That's an operating environment that is difficult to imagine from where we stand today. However, it's not so far out in the future that it can be dismissed as science fiction by the industry.

SUMMARY/CONCLUSIONS

The most practical approach for suppliers and automakers alike will be to compete aggressively for a share of the public monies available for green technology research. Indeed, those companies that can deploy the best mix of conventional technology to help the industry profitably achieve required fuel economy and CO$_2$ targets in the near term, while tapping government funds to supplement their own full-electric vehicle research and development programs, will likely be in the best position for long-term success.

It is becoming increasingly clear that the need to meet increasingly stringent global CO$_2$ emissions rules will drive unprecedented shifts in the way vehicles are powered. Looking regionally and globally, our 10-year technology outlook and assessment of the regulatory framework in North America, Europe and Asia suggests that diesel and gas internal-combustion engines have untapped efficiency potential - enough to meet fuel economy and clean-air rules when combined with strategies like vehicle downsizing and weight reduction.

Within that same time horizon, electrification must occur, and is occurring, on multiple levels:

Individual components and systems are being electrified.

Mild- and full-hybrid vehicle powertrains are increasing in volume.

Full-electric vehicles will begin to enter production in meaningful volumes.

For automakers, fine-tuning can still be done to ensure that the most fuel-economy and emissions-compliance goals are met as quickly and efficiently as possible. The technology mix that each OEM must offer will be highly variable, depending on its fleet mix, geographic mix, compliance gap and R&D budget. For established suppliers, technology companies and start-ups, plenty of opportunity still exists to tailor a product plan, and a sales and marketing strategy, to meet these needs.

However, the emissions reductions envisioned by world leaders beyond the 10-year forecast horizon cannot be met with today's vehicle, technology and powertrain strategies. The future will belong to those companies that can build a business case for high-volume production of vehicles that use next to no petroleum products for propulsion.

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