ADVANCED INNOVATIONS ON FUEL AND EMISSION CONTROL TECHNOLOGIES

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ABSTRACT

In the global auto industry today, major developed markets such as Japan, the U.S. and Europe are unlikely to grow significantly. Automobiles are facing difficult times with challenges such as global warming, higher crude oil prices, and traffic accidents. Against this backdrop, technological developments for better fuel consumption and conservation of natural resources, as well as safety and security, are becoming increasingly important for the whole auto industry.

Automobiles in the 21st century must be in harmony with the environment, people-friendly, and enjoyable. Future development efforts must encompass diverse, sophisticated research and development based on not only downsizing and light-weight design techniques and advanced electronics control techniques, but also communications and information technologies. Mitsubishi Electric will use and integrate these to successfully develop "advanced technologies for a new modern automobile lifestyle," A report presented by the Office of Technology for developing automobiles that offer significant improvements in fuel economy and reduced emissions over the longer term. Governmental Affairs-asked OTA to examine the potential for dramatic increases in light-duty vehicle fuel economy through the use of "breakthrough" technologies, andto assess the federal role in advancing the development and commercialization of these technologies. The report presents a baseline forecast of vehicle progress in a business-as-usual environment, and then projects the costs and performance of "advanced conventional" vehicles that retain conventional drivetrains, electric vehicles, hybrid vehicles and fuel cell vehicles. Technological change in the auto industry can potentially influence not only the kinds of cars that are driven, but also the health of the economy.

Automotive emissions of hydrocarbons and nitrogen oxides are responsible for as much as 50 percent of ozone in urban areas; despite improvements in air quality forced by government regulations, 50 million Americans still live in countries with unsafe ozone levels. Recent technological improvements to engines and vehicle designs have begun to address these problems. It is clear that a major advance in automotive technology that could dramatically reduce gasoline consumption and emissions would have great national and international benefits. Such benefits would include not only the direct cost savings from reduced oil imports but also indirect savings such as health benefits of reducing urban ozone concentrationsand carbon monoxide attainment has improved dramatically.

Keywords: Advanced Technologies, Reduce Gasolineand Emissions

I. INTRODUCTION

The automobile industry first began to turn its attention to environmental issues when emissions regulations were introduced. At the time, concerns were focused primarily on the negative impact of emissions on human health. It takes the form of CO_2 and other gases that threaten to disrupt ecosystems and bring harm to life throughout our planet via global warming. Applying low-fuel-consumption, low-emissions technologies such as the CVCC engine, [(1)]Governments around the globe are committed to setting cleaner standards for their national light-duty vehicle (LDV) fleets through the implementation of increasingly stringent regulations. These emission levels and their corresponding regulatory framework vary widely among countries.

Most countries have initially adopted the European or US emission regulation levels as a starting point. Using these regulations as models, countries such as China and India have developed their national regulations according to specific local conditions. Figure 1-1 presents a general perspective for some of the countries following the European and US pathways over a 10-year span.(2)

There are great opportunities around the globe to reduce conventional pollutant emissions from LDVs, with positive effects on air quality and public health. Even though these benefits have been demonstrated and the technologies to achieve these benefits are already available, there are still large gaps between the implementation schedules for increasing the emission levels stringency. Among the reasons for delaying the implementation of stricter emission levels is the extra costs that emissions control systems add to vehicles.

The fundamental question this cost assessment seeks to answer is how much it costs vehicle manufacturers to implement the technology needed to meet more stringent emission regulations. Costs were assessed by government agencies during the rulemaking process establishing each new standard in the United States and Europe. However, the standards were established many years ago, and the substantial improvements in emission control technology since then are not reflected in the original cost estimates. The objective of this study is to assess the technology requirements costs, in current terms, derived from advancing to more stringent regulatory standards on LDVs. This report updates the cost of meeting each progressively higher emission standard so that countries considering adoption of more stringent standards can make a more informed decision.

Emission control costs for diesel and gasoline vehicles are assessed separately. Gasoline engine emission control is based primarily on precise air-fuel control and catalytic aftertreatment. These emission control technologies have reached a significant level of maturity, which results in very modest incremental compliance costs for even the most stringent existingstandards. Nitrogen oxides (NOX) and particulate matter (PM) emission control from diesel engines is far more complex and requires the implementation of relatively new technologies involving air management, fuel injection control, aftertreatment and system integration. The implementation of new technologies for diesel engine emissions control has a significant impact compared withthe cost associated with gasoline engine emissions control. Emission control technologies for gasoline and diesel vehicles are presented first, and later the technology requirements for each regulatory level and its cost are estimated.

II. TECHNOLOGIES

Technologies required for control of regulated pollutants are presented below for gasoline vehicles. Emissions control technologies can be divided into two groups: in-cylinder control and aftertreatment control. A brief description of each technology, including operational principle, applicability, reduction capabilities and special conditions, is provided.

2.1 Gasoline Vehicles

Almost all gasoline, spark-ignited (SI) engines run at stoichiometric a condition, which is the point where available oxygen from the air is completely consumed, oxidizing the fuel delivered to the engine. Stoichiometric SI engines use a homogenous air-fuel mixture with early fuel introduction for good fuel vaporization. Gasoline fuel delivery systems have evolved from carbureted systems to throttle body injection (TBI), multipoint fuel injection (MPFI), and sequential MPFI. The latest evolutionary step, stoichiometric direct injection, represents a significant improvement for spark-ignited engines and when combined with turbocharging and engine downsizing makes them competitive with diesel engines in terms of fuel economy and performance.

Air-fuel control has a major impact on the formation of hydrocarbons (HC), or unburned fuel, and carbon monoxide (CO), which is partially oxidized fuel. In contrast, NOX is a byproduct of combustion, created when nitrogen and oxygen in the air combine during the combustion process. The higher the cylinder temperature, the more NOX is formed. Thus, the primary strategy to reduce the formation of NOX in the engine is to reduce combustion temperatures, using faster burn combustion chamber design and exhaust gas recirculation (EGR).

Aftertreatment emissions control for stoichiometric engines is based on the three-way catalytic converter (TWC). The TWC is capable of oxidizing HC and CO, and simultaneously reducing NOX if the air-fuel ratio is controlled very precisely at stoichiometry. Improvements in SI emission control have focused on extreme precision in air-fuel control, maintenance of stoichiometric conditions at all times, and catalyst improvements. The latest systems can simultaneously reduce all three pollutants by more than 99% after the catalyst has reached normal operating temperature. Catalyst improvements have focused on ways to quickly bring the catalyst to operating temperature and minimize emissions following cold starts, while significantly reducing the amount of precious metals required for proper operation.(3)

2.2 Environmental Impact

Honda is aware of its responsibility for the environmental impact generated by its corporate activities and use of its products, and is committed to minimizing it. To achieve this, it is essential to identify specific issues and set targetsand goals for actionin the context of our Life Cycle Assessment system, which is used to measure, assess and analyze environmental impact.

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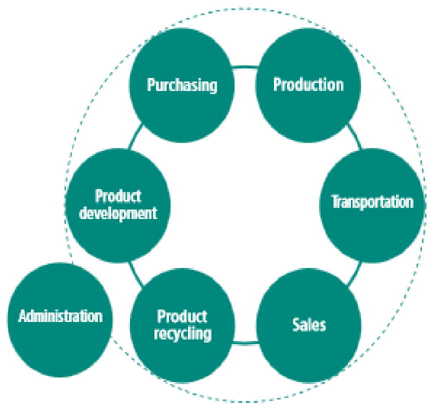
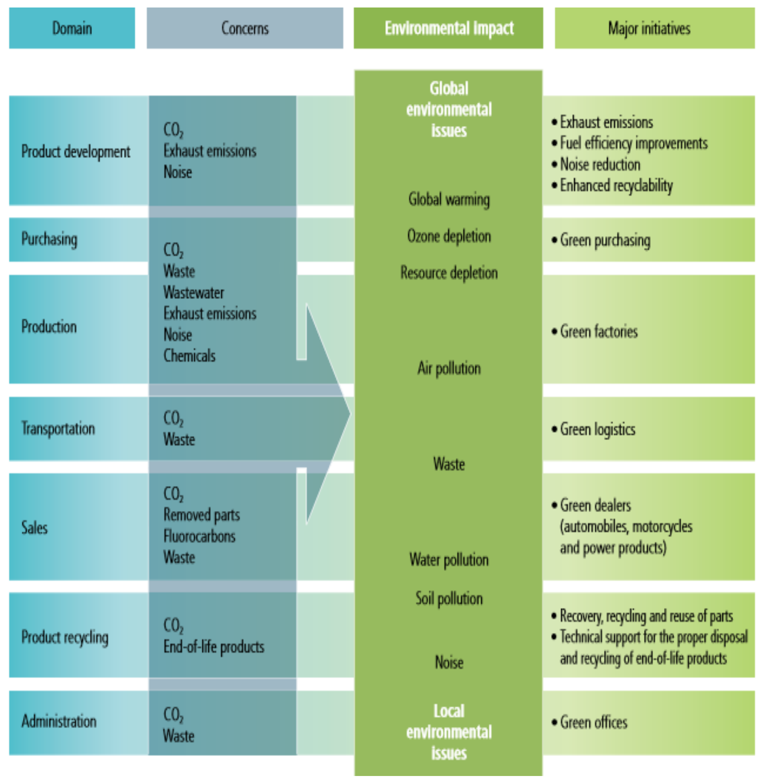
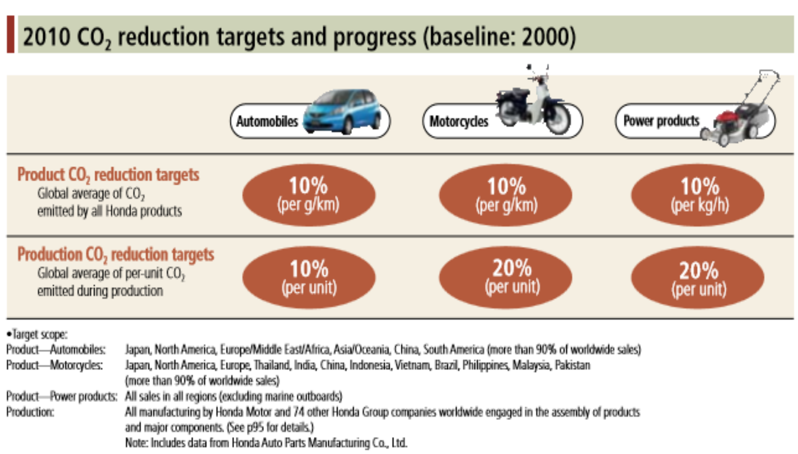


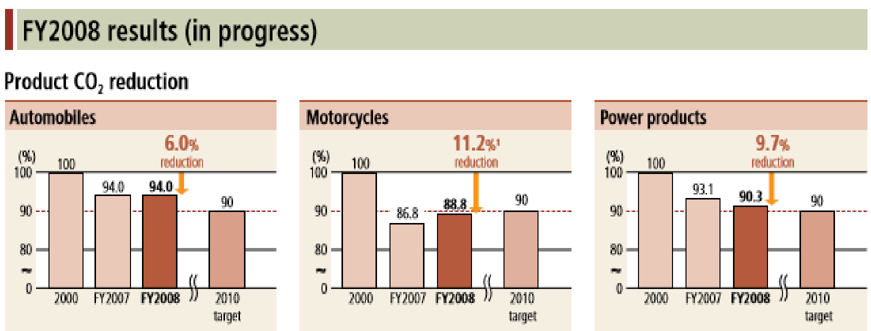
In 2006 Honda became the world's first automaker to announce global CO_2 reduction goals for its products and production activities. It also presented an aggressive and unprecedented strategy to help stabilize climate change. We consider such initiatives to be the responsibility of a global corporation, and we will continue to lead the way in environmental protection. To help combat global climate change, Honda is leading the way, setting global targets for CO_2 reduction and progressingsteadily toward the achievement of those targets.





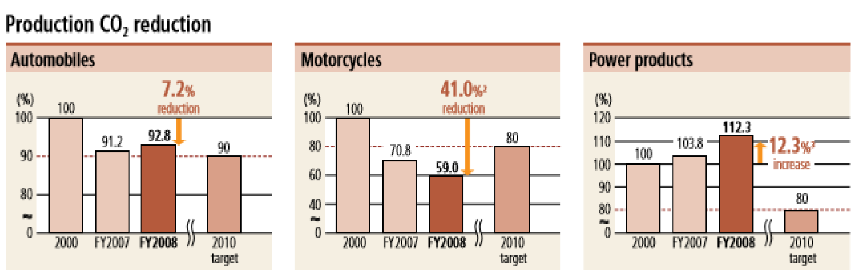
2.3 Product Efficiency

Setting goals for higher fuel-efficiency averages for all products worldwide Since the internal combustion engine is expected to continue to provide the principal means of mobility until at least 2020, Honda is working to improve its efficiency and fuel economy. Stringent regulations such as Corporate Average Fuel Economy (CAFE) standards have been introduced in the U.S.,Europe and other regions to mandate fuel-efficiency improvements for automobile fleets. Recognizing the need for global initiatives, Honda is moving from measuring regional fuel-efficiency averages to measuring global fuel-efficiency averages, and from fuel-efficiency averages based on vehicle categories to average targets for its entire worldwide vehicle lineup.



2.4 Production efficiency

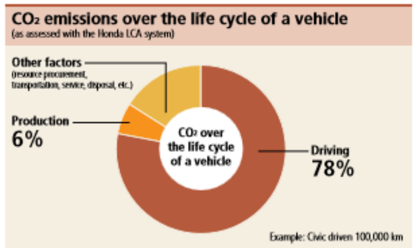
Reducing per-vehicle CO_2 emissions in manufacturing worldwide Honda is also committed to further improving the efficiency of its worldwide manufacturing processes and reducing CO_2 emissions. To this end, in 2006 we established global targets for average per-unit CO_2 emissions in manufacturing and are working steadily to reach these targets.

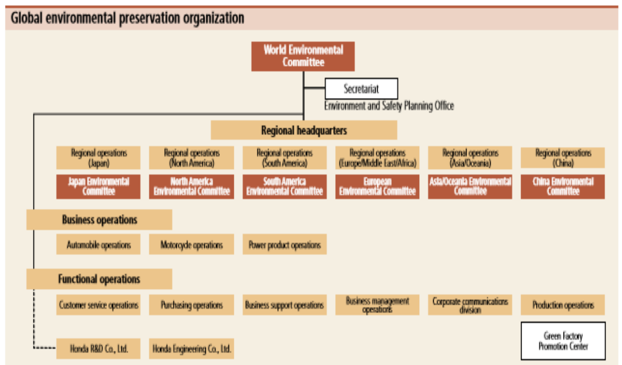


1 An 11.2% reduction from 2000 has already been attained, and we are working steadily to achieve further reduction.
2 Although the target has already been attained, an expansion of production is foreseen in this region, where CO_2 emissions are relatively high. We are striving to maintain the reduction target level and achieve even greater reduction by 2010.
3 Higher, per-unit emissions in power products manufacturing can be attributed to changes in production and more feature-rich new products.

2.5 Targets that address the automobile life cycle

According to assessments made on the basis of the Honda Life Cycle Assessment (LCA) system, approximately 78% of emissions are generated by the operation of vehicles and about 6% in their manufacture. Thus Honda's CO_2 targets, which focus both on its products and its production processes, cover more than 80% of the CO_2 emissions generated throughout the life cycle of its automobiles.





III. EMISSION REDUCTION TECHNOLOGY COSTS

After identifying the set of technologies required for each regulatory level, an indirect cost assessment was performed. It is an indirect assessment, because the technology cost is only known by auto manufacturers, who are understandably unwilling to share cost information because of competitive concerns. Beyond that, there are only a few scattered sources of information. Thus, our main sources of cost information are official estimates from regulatory agencies. Unfortunately, the cost information in those reports, especially for the earlier standards, is old and does not reflect recent improvements in emission control technology. The cost values for emission control technologies found in those reports were corrected by inflation and complemented with in-house developed estimates of the cost of the most recent technology. For technologies that are being introduced in passenger vehicles, such as PM and NOx aftertreatment systems for diesel cars, the costs were reduced by a factor accounting for learning reduction costs. Experts from the manufacturer and supplier sector reviewed the final cost estimates in this report. While they were not able to provide specific dollar estimates, they identified places where the original cost estimates were too high or too low. This final expert check provides some assurance that the costs estimates in this report are reasonable.

Tables ES-1 and ES-2 present the incremental cost for meeting the next more stringent emission standard for Europe and the United States, respectively. The tables present the cost of technology for different engine size and for each regulatory level. Included in the table are variable costs (hardware) and fixed cost (R&D, tooling, certification).

Table ES-1 Incremental costs for LDVs meeting European standards (2010 dollars)

ENGINE TYPE	VEHICLE CLASS	EURO 1 (BASELINE)	EURO 1 TO EURO 2	EURO 2 TO EURO 3	EURO 3 TO EURO 4	EURO 4 TO EURO 5	EURO 5 TO EURO 6	NO CONTROL TO EURO 6
Gasoline	4 cylinders Vd= 1.5 L	$142	$63	$122	$25	$10	--	$362
Gasoline	4 cylinders Vd = 2.5 L	$232	$3	$137	$15	$30	--	$417
Diesel	4 cylinders Vd = 1.5 L	$56	$84	$337	$145	$306	$471	$1,399
Diesel	4 cylinders Vd = 2.5 L	$56	$89	$419	$164	$508	$626	$1,862

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The cumulative cost of emission reduction technologies is presented in Figure ES-2 for gasoline and diesel vehicles assuming a 2.0L engine. It is clear that the incremental emission control costs for gasoline vehicles are much more favorable than those for diesel vehicles. Control of gasoline vehicle pollutants is based on improving air-fuel control using faster oxygen sensors and better control logic, combined with improvements in TWC technology. The TWC technology has undergone extensive R&D work and improvements, substantially reducing the manufacturing cost. Therefore, the cost impact of emission control technologies in gasoline vehicles is minimal.

On the other hand, diesel vehicles, due to their inherently lean combustion process and direct fuel injection, require much deeper system modifications to achieve the emission targets. Diesel vehicles require the implementation of high-pressure fuel injection systems (common-rail), more responsive turbocharging systems (VGT), and more complex cooled-EGR systems (larger heat exchange surface) and sophisticated aftertreatment devices developed in parallel with in-cylinder control through engine tuning.

In previous sections, the estimated cost and the incremental cost of emission control technologies were presented for engine sizes that are typical of each region. In this section, a cost comparison between regions and technologies is done assuming a common engine size. For sake of simplicity, a 2.0L engine was selected. Figure 5-1 presents the cost of emission control technologies, for gasoline and diesel vehicles under the EU and the US regulations. It is clear that the cost for gasoline LDVs is much more favorable than for diesel LDVs.

Gasoline vehicles require incremental air-fuel and aftertreatment system modifications to meet more stringent emission standards. The control of pollutants is based on improving air-fuel control using faster oxygen sensors and better control logic, combined with adjustments in PGM loading, washcoat formulation, and catalyst volume. Therefore, the incremental cost impact of emission control technologies in gasoline vehicles is less strong once the vehicles are fitted with MPFI and TWC.

Diesel vehicles, due to their inherently lean combustion process with direct fuel injection, require much deeper system modifications to achieve the emission targets. Diesel vehicles require the development and implementation of new fuel injection systems (common-rail), more responsive turbocharging systems (VGT), more complex EGR systems (double loop and larger heat exchange surfaces) and sophisticated aftertreatment devices (DOC, DPF, LNT, SCR), developed in parallel with in-cylinder control through engine calibration.

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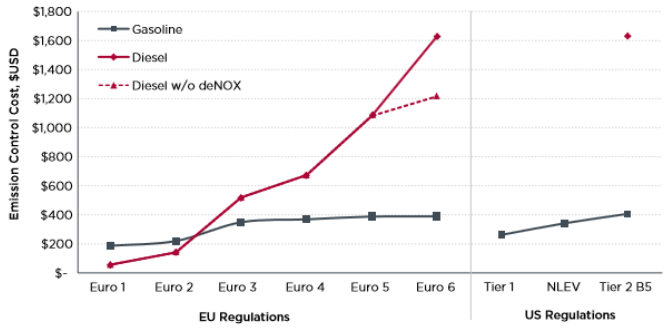

Figure 5-1. Estimated cumulative emission control technology cost for gasoline and diesel light-duty vehicles assuming a 2.0 L engine

IV. SUMMARY

The fundamental problem addressed by this cost assessment is the cost of technology required in light-duty vehicles for compliance of emission regulations. After gathering the required set of technology and assessing the cost per technology for a limited number of engines a cost summation was calculated for each engine technology (gasoline and diesel) under each regulatory body.(4)

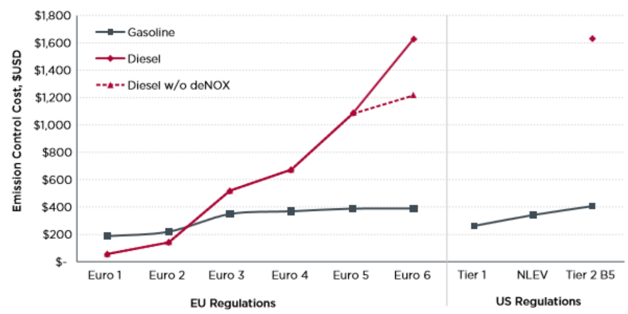

Figure ES-2 Estimated cumulative emission control technology cost for gasoline and diesel light-duty vehicles assuming a 2.0 L engine

V. CONCLUSIONS

Gasoline and diesel vehicle technology requirements for emission control in each regulatory level were identified, and their cost estimated, according to European and US standards. The main findings of this study are presented below:

5.1 Gasoline Vehicles

- Gasoline vehicles require, as the basic setup, the installation of port fuel injection technologies (sequential MPFI is preferred), three-way catalysts, and oxygen sensors. Once these basic components are installed, compliance with subsequent emission levels is accomplished through a series of incremental improvements in the system. (5)
- For gasoline vehicles, the most significant improvement over the basic emission control setup is the use of close-coupled catalyst, OBD requirements, EGR, and engine control updates.

- CC catalysts are used for cold-start HC emission control in NLEV, Tier 2 and Euro 3 and later vehicles.
- OBD requirements impose the use of a secondary set of oxygen sensor to track catalyst performance over time. This technology is required from Tier 1 and Euro 3 vehicles.
- Engine control unit processing capacity and sensor response are expected to increase as new emission and performance requirements are met.

5.2 Diesel Vehicles

- Diesel vehicles, due to their direct-injection lean-combustion process with late fuel injection, require much deeper system modifications than gasoline vehicles to achieve the emission targets.
- Euro 1 and Euro 2 diesel vehicles require only in-cylinder control, based on improvements in fuel injection pressure, provided by a rotary pump, and an EGR valve. Increasing fuel injection pressure was used for PM control, while the EGR valve was used to control NOX. (6)
- More stringent standards starting from Euro 3 require the use of fuel injection systems capable of variable fuel injection timing and metering, at high injection pressures. Common-rail injection systems became the de facto solution for high fuel injection pressure and fuel injection timing and metering flexibility. This type of fuel injection systems allows for almost simultaneous in-cylinder PM and NOX control. Euro 3 and subsequent regulations demand cooled EGR systems for NOX control. Turbocharging was added to most Euro 4 vehicles to help with air-fuel management. Aftertreatment in the form of a DOC for HC and PM control is also required in most passenger vehicles starting with Euro 3.

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