Moving Toward Clean Vehicles and Fuels

A Global Overview

by Michael Walsh

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Since the end of World War II, the world's motor vehicle population has seen strong and steady growth. Over the past six decades, it has gradually spread from North America to Europe and now Asia and, to a lesser extent, Latin America. Vehicles have brought many perceived improvements to people's lives, but they have also changed many cities into sprawling conurbations, developed a huge thirst for oil, become a major source of air pollution, and now are the most rapidly growing contributor to climate change.

Trends in World Motor Vehicle Production, Fleets, and Emissions

Growth in motor vehicle production since 1945 has been dramatic, rising from approximately 5 million vehicles annually to more than 60 million. Between 1970 and 2005, approximately 1 million more vehicles have been produced each year compared to the year before, with almost 66 million vehicles produced in 2005 alone (see Figure 1).[1] While the current global recession is causing a deep production decline, it is likely to rebound and go beyond former levels within a few years.[2]

Since vehicles have been produced at a faster rate than they have been scrapped, the global vehicle fleet has steadily grown (see Figure 2). The global vehicle population exceeded 1 billion in 2002 and continues to rise. Since 1990, approximately 27 million more vehicles are on roads and highways each year compared to the previous year.

Motor vehicles emit carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NO_X), sulfur oxides (SO_X), and such toxic substances as benzene, formaldehyde, acetylaldehyde, 1,3,butadiene, particulate matter (PM_{10} and $PM_{2.5}$), and lead (where still added to gasoline). Each of these, along with secondary byproducts such as ozone and small particles (i.e., nitrates and sulfates), can cause serious adverse effects on health and the environment.

The greenhouse gases (GHGs) most closely identified with transportation are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Other vehicle-related pollutants also contribute to global warming, although their quantification is more difficult; these include CO, nonmethane hydrocarbons (NMHCs), nitrogen dioxide (NO_2), and ozone (O_3). Black carbon (soot) emitted from diesel vehicles is another emerging GHG concern.[3]

Great progress in reducing emissions from gasoline-fueled cars has occurred in the major industrialized countries and stringent requirements for diesel vehicles are starting to occur. However, the vehicle population and vehicle kilometers traveled will likely continue to grow, especially in developing countries, which could offset reductions made to date.[4]

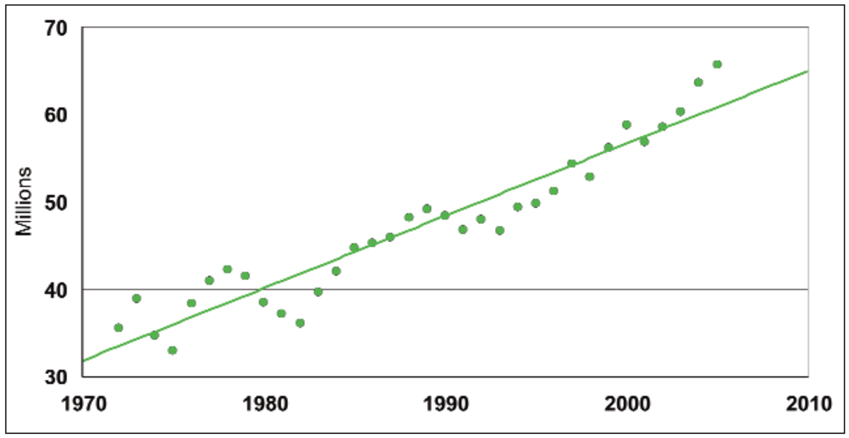

Figure 1. Annual production of cars, trucks, and buses.

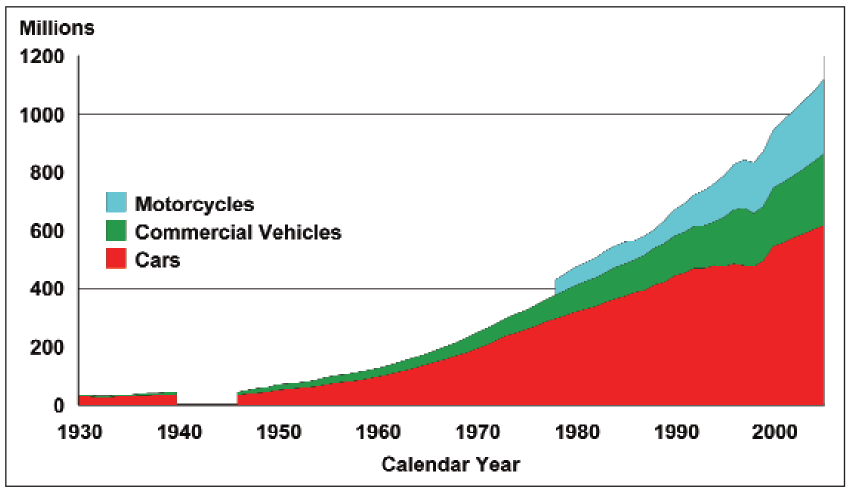

Figure 2. World motor vehicle population.

Emissions Reduction Progress

The three dominant regulatory programs in the world are the United States (including California), the European Union (EU), and Japan. The EU and U.S. standards and test procedures, or some mixture of them, have been adopted by many other countries. With regard to passenger cars, approximately 60% of the world's fleet is following the EU regulatory road map and almost 30% follow the U.S. path. The vast majority of diesel cars are following the EU path. For light trucks, more than 60% follow the U.S. standards, whereas more than 70% of heavy trucks follow the EU emissions standards. No other country outside of Japan requires the Japanese standards.

Figure 3 summarizes recent light-duty vehicle standards for NO_X and PM emissions. While U.S.

and EU compliance test procedures differ, the control technologies used are very similar and by 2015 should be almost identical. With regard to heavy-duty vehicles and engines, the United States will phase in very stringent NO_X and PM requirements in 2010 and Europe will introduce similar controls a few years later.

Diesel Vehicles and Fuels

Diesel engines emit more NO_X and PM than equivalent gasoline engines. Reducing PM tends to be the higher priority because ambient PM levels are often above recommended health levels and are responsible for hundreds of thousands of premature deaths each year. The California Air Resources Board and many other organizations consider diesel particulate (soot) to be toxic. NO_X emissions are important for causing or contributing to ambient NO_2, O_3, and nitrate PM.

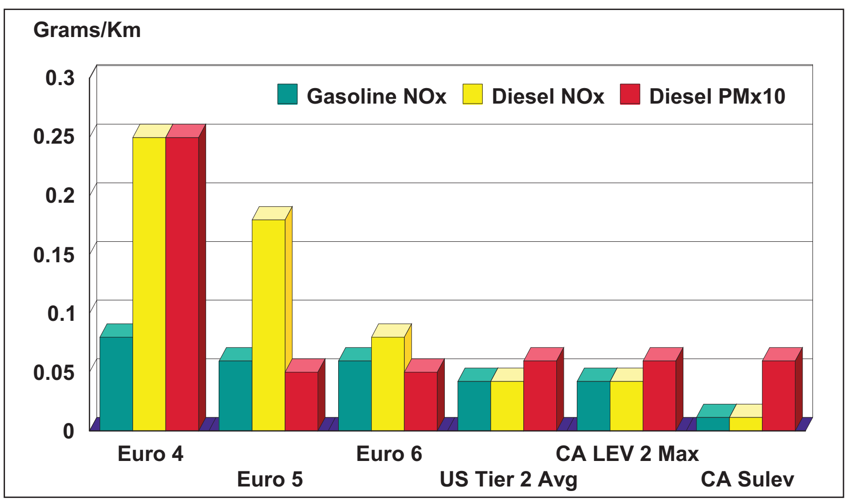

Figure 3. *EU and U.S. light-duty gasoline and diesel vehicle standards.*

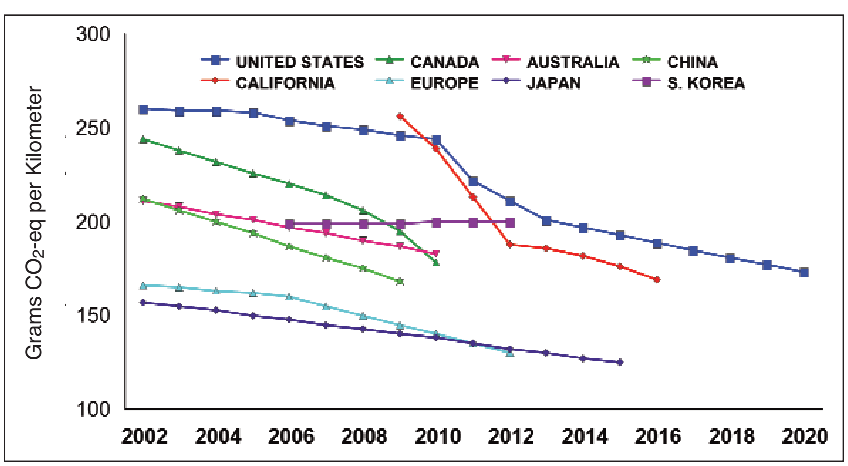

Figure 4. *Projected GHG emissions for new passenger vehicles by country/region.*

Modifying engine parameters to simultaneously reduce NO_X and PM is difficult since the optimal settings for one pollutant frequently increases emissions of the other. To attain very low levels of both NO_X and PM, therefore, requires exhaust treatment. Lean NO_X catalysts, selective catalytic reduction, NO_X storage traps, PM filter traps, and oxidation catalysts are technologies that are being phased in at differing rates in various parts of the world. A new type of diesel, the homogeneous charge compression ignition engine, provides another approach to reducing NO_X and particulates that is receiving significant attention and may be introduced on some engines within a few years.

Diesel fuel is a complex mixture of hydrocarbons with the main groups being paraffins, napthenes, and aromatics. Organic sulfur is also naturally present. Additives are generally used to influence fuel properties, such as flow, storage, and combustion characteristics. The actual diesel fuel properties depend on refining practices and the crude oil feedstock.

The quality and composition of diesel fuel can significantly influence emissions from diesel engines. The most important fuel characteristic is sulfur because it contributes directly to PM and high sulfur levels hinder applications of the most effective PM and NO_X control technologies. Filters or traps which reduce more than 90% of PM are becoming widely available. NO_X adsorbers and selective catalytic reduction systems are also being introduced, with NO_X adsorbers being especially sensitive to sulfur. Complying with the most stringent standards will require maximum sulfur levels as low as 10–15 parts per million (ppm). Higher levels impair optimal performance of the control systems, and the in-use emissions will likely exceed standards. For cleaner vehicles, depending on the technology employed, higher sulfur fuels could cause permanent damage.

Gasoline Vehicles and Fuels

The pollutants of greatest concern from gasoline-fueled vehicles are CO, NO_X, lead, and certain toxic HCs such as benzene. Each of these can be influenced by the composition of the gasoline used by the vehicle.

The use of catalyst exhaust gas treatment required the elimination of lead from gasoline. This change, which started during the 1970s and has now occurred throughout most of the world (the latest estimate is only 17 countries still allow lead), has resulted in a dramatic reduction of ambient lead levels. Other gasoline properties that can be adjusted to reduce emissions include, roughly in order of effectiveness, sulfur level, vapor pressure, distillation characteristics, light olefin content, and aromatic content (including benzene).[5]

Modern gasoline engines use computer-controlled intake port fuel injection with feedback control based on an oxygen sensor to meter precisely the quantity and timing of fuel delivered to the engine. Control of in-cylinder mixing and use of high-energy ignition promote nearly complete combustion. The three-way catalyst provides greater than 90% reduction of CO, HCs, and NO_X. Designs for rapid warm-up minimize cold-start emissions. On-board diagnostic systems sense control performance and identify component failures. Durability in excess of 160,000 km, with minimal maintenance, is now common.

Sulfur in gasoline reduces the efficiency of catalysts and adversely affects heated exhaust-gas oxygen sensors. High-sulfur gasoline is a barrier to the introduction of new lean burn technologies using $DeNO_X$ catalysts. Lowering sulfur will enable new and future conventional vehicle technologies to realize their full benefits, and existing vehicles equipped with catalysts will generally have improved emissions.

Certain other additives put in gasoline can also affect vehicle emissions. Additives such as methyl-cyclopentadienyl manganese tricarbonyl and ferrocene when added to gasoline will increase manganese-oxide and iron-oxide emissions, respectively, from all categories of vehicles. Because of health concerns, an international workshop

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recently concluded, "The addition of organic manganese compounds to gasoline should be halted immediately in all nations."[6]

Vehicle manufacturers have expressed concerns regarding catalyst plugging and oxygen sensor damage because of these additives, which could lead to higher in-use vehicle emissions especially at higher mileage. The impact seems greatest with vehicles meeting tight emissions standards and using high cell density catalyst substrates.

Global Climate Change

With regard to GHGs, the prognosis is less promising than with urban air pollution. CO_2-equivalent emissions from the transportation sector grew significantly in developed countries between 1990 and 2004.[7] In fact, the growth in the transportation sector (24%) was by far the largest of any during this period. There are several technology-based approaches to reducing GHGs from the transportation sector, three of which are mentioned below.

Vehicle Standards

California has mandated GHG emissions standards and is awaiting the U.S. Environmental Protection Agency's reconsideration of its waiver request to implement them. Nationally in the United States, mandatory Corporate Average Fuel Economy (CAFE) requirements have been in place since the mid-1970s with no significant tightening until 2007. CAFE can lower CO_2 emissions, but does not address the other GHG emissions.

The EU negotiated a voluntary agreement with the European vehicle industry to achieve CO_2 targets (there were also similar agreements with Japanese and Korean manufacturers), but this agreement broke down in early 2007 in recognition that the target of 140 g/km by 2008 would not be met. As a result, the EU imposed a mandatory limit of 130 g/km to be phased in between 2012 and 2015 and will likely further tighten limits to 95 g/km by 2020.

Japan's approach has also focused on fuel consumption using the best in class at a point in time to stimulate industry wide progress; it has also introduced the first requirements in the world for heavy trucks. Figure 4 shows a summary of planned or adopted vehicle requirements.[8]

Low-Carbon Fuels

California recently proposed carbon-based fuels requirements and the EU is pursuing low-carbon fuel standards (LCFS).[9] The goal of LCFS is to promote investment and use of low-carbon fuels (e.g., sustainable ethanol and biodiesel, compressed natural gas, renewable electrons/hydrogen) and dampen demand for high-carbon fuels (e.g., tar sands, shale oil, coal to liquids). However, to assure that low-carbon fuels actually have global benefits, a full life-cycle analysis that includes direct and indirect land-use effects is needed. When such factors are taken into account, identifying low-carbon fuels that actually achieve significant benefits becomes a very difficult proposition.

The current U.S. Renewable Fuels Standard (RFS) takes a step toward LCFS by requiring life-cycle GHG standards for three categories of biofuels: baseline renewable biofuels (20% below gasoline), advanced biofuels (50% improvement), and cellulosic biofuels (60% improvement). The RFS, however, only applies to biofuels and thus does not dampen demand for high-carbon fuels.

Advanced Vehicle Technologies

Plug-in hybrid electric vehicles are receiving a great deal of attention, and with further development and cost reductions could become commercially available in a few years. Full performance battery electric vehicles—defined as fully capable of high-speed U.S. urban/suburban freeway driving—are expected to grow more slowly due to limited range and long recharge time. Neighborhood electric vehicles—defined as capable of top speeds between 20 and 25 mph; limited to roads with posted speeds of 35 mph or less—are commercially viable now and will continue to grow, but slowly due to limited functionality. City electric vehicles—defined as having limited acceleration and top speed (e.g., 50/60 mph)—are expected to become commercially viable in Japan and Europe soon. The intense effort on fuel-cell electric vehicles may result in technically capable vehicles by the 2015 to 2020 time frame, but successful commercialization depends on meeting challenging cost goals and creating an adequate hydrogen infrastructure.

Summary

Increasing vehicle production and ownership creates continuing pressure to maintain and improve air quality in cities across the world. Compounding the adverse health effects of poor air quality is climate change, another global problem to which motor vehicles are major contributors. Necessary to address these challenges are new emissions control systems and vehicle propulsion advances beyond the conventional internal combustion engine. Another critically important lesson learned to date is that clean vehicles and high-quality fuels go hand in hand; they must be treated as a system. While success is by no means guaranteed, vehicle technologies and fuels must advance in order to improve upon progress made to date. **em**

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