Fuel Quality in Canada

Impact on Tailpipe Emissions

Prepared for the Association of International Automobile Manufacturers of Canada

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Fuel Quality in Canada

Transportation emissions have a significant impact on the environment and the health of Canadians. Transportation emissions are influenced by the properties and type of both the vehicle and the fuel. By considering vehicles and fuels as an integrated system, with opportunities for emission reductions in both areas, greater environmental and health protection can be achieved.

This report focuses on opportunities to reduce environmental and health impacts through improvements to gasoline and diesel fuel quality standards in Canada.

Key Fuel Characteristics

For both gasoline and diesel, the research completed identified several fuel characteristics where improved fuel quality standards offer notable opportunities to reduce tailpipe emissions in Canada.

1. Sulphur in gasoline — Leading standards internationally require a limit of 10 ppm sulphur within gasoline whereas current Canadian legislation requires a yearly pool average of no more than 30 ppm and an absolute maximum of 80 ppm. By reducing sulphur levels to 10 ppm, tailpipe emissions can be significantly reduced, as shown in Figure 1, and more fuel efficient technologies can be introduced, such as lean burn engines. In fact, the Australian automotive industry agreed to further strengthening of fuel economy targets if 10 ppm sulphur gasoline became available in premium gasoline.
2. Detergency of gasoline — Fuels with high detergency levels help reduce deposits within engines, which has been shown to improve fuel efficiency and reduce tailpipe emissions as shown in Figure 2.
3. Cetane in diesel — Currently, Canada's voluntary national standard recommends a minimum cetane value of 40. This value is significantly lower than the standard in every other jurisdiction researched. Low cetane values lead to higher tailpipe emissions, as demonstrated in Table 1 for NO_X emissions, and poorer engine performance.
4. Lubricity of diesel — The lubricity of diesel impacts the amount of wear that occurs, particularly in fuel injection systems, which in turn impacts engine performance. Excessive engine wear can increase emissions and decrease fuel economy. Canada's national voluntary standard, which requires wear scars below 460 microns, is higher than the maximum of 400 microns recommended by automobile manufacturers. Improving the lubricity of Canadian diesel presents an opportunity to improve the environmental performance of all diesel vehicles in Canada.

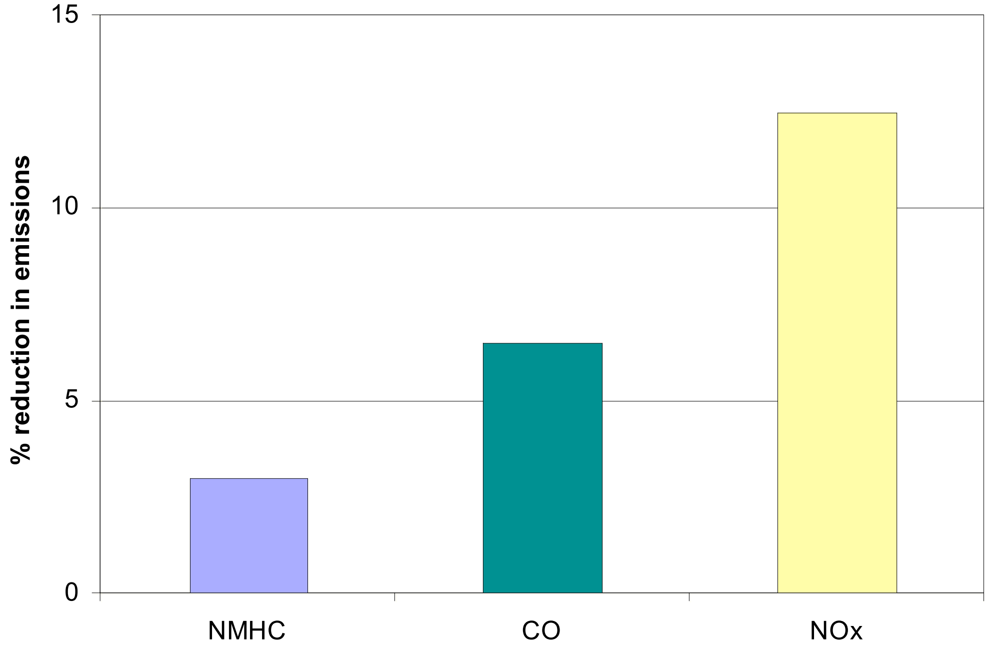

Figure 1. Impact of reducing sulphur from 30 ppm to 10 ppm

Adapted from: Clean Air Initiative for Asian Cities, *Fuel Quality Strategy Training Workshop: Module 2*, (Sydney, Australia, October 2003).

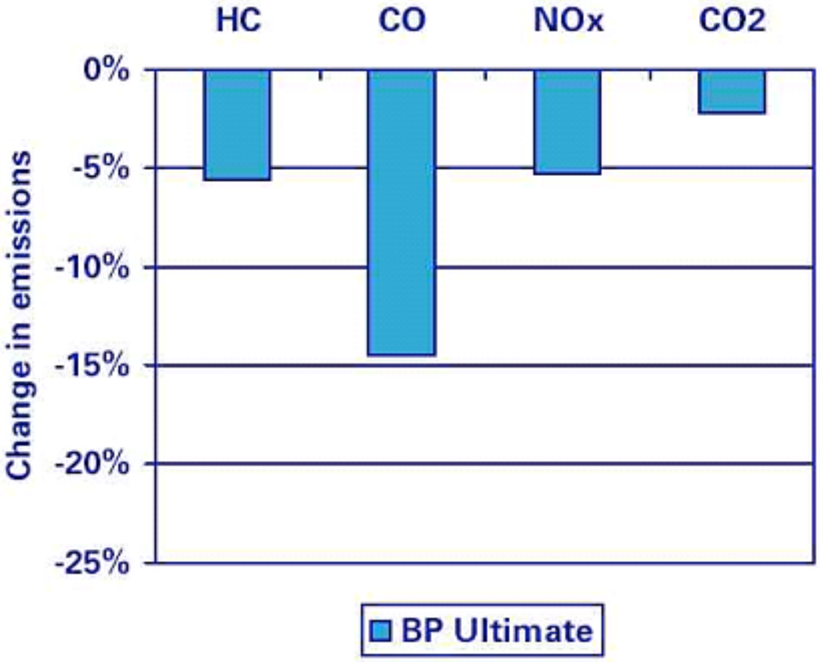

Figure 2. Effect of using a high detergency fuel (BP Ultimate) versus regular fuel

Source: Dr. John Bennett, Ford Motor Company, *Detergents and Their Role in the Emissions Performance of Vehicles — Presentation for ACEA*.

Table 1. Effect of using additives to increase cetane level in diesel (for engines without engine gas recirculation) 1

Increase in Cetane from 40 to:	Percent Reduction in NO_X Emissions
45	2.7%
50	4.5%
55	5.4%

Net Benefits

Of course, changes to fuel quality standards need to consider more than just tailpipe emissions. Any assessment of proposed changes needs to consider both the costs and the benefits throughout the entire life-cycle. As an example, analyses completed for both Australia and the EU demonstrated significant life-cycle cost and environmental benefits for reducing sulphur content in gasoline from 50 ppm to 10 ppm while improving fuel economy as well, as shown in Table 2 and Table 3.

Table 2. Net greenhouse gas and cost[2] reductions from a combination of improved fuel economy standards and reducing sulphur in premium gasoline from 50 ppm to 10 ppm[3]

Year	GHG Reduction	Cost Savings
2010	33 kt	$66 million
2020	474 kt	$244 million

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[1] Adapted from: U.S. EPA, *The Effect of Cetane Number Increase Due to Additives on NO_x Emissions from Heavy-Duty Highway Engines: Final Technical Report*, (Washington, DC: U.S. EPA, Office of Transportation and Air Quality, 2003).

[2] Costs include increased vehicle and refining costs, as well as fuel savings and reduced health costs. They do not include benefits from GHG reductions, or reductions in vehicle and refinery costs as new technologies mature and production volume increases.

[3] Coffey Geosciences Pty. Ltd., *Fuel Quality and Vehicle Emissions Standards Cost Benefit Analysis*. Prepared for MVEC Review of Vehicle Emissions and Fuel Standards Post 2006 (2003).

Table 3. Results of the cost-benefit analysis for introducing sulphur-free (<10 ppm) fuels in the European Union in 2005[4]

	2005	2012	2020
CO_2 Emissions Changes			
Change in CO_2 emissions in refineries (kt)	215.7	5,348.3	5,404.3
CO_2 change from cars (kt)	-562.8	-8,241.6	-14,960.5
Net change (– = decrease in CO_2 emissions)	**-347.1**	**-2,893.2**	**-9,556.2**
Costs and Benefits (million Euros)			
Increase in refining costs (average per year) **A**	39.0	816.9	831.4
Savings due to lower fuel consumption (average) **B**	54.1	795.5	1441.2
Benefits from better air quality **C**	0.0	221.1	3.7
Net benefits **B+C–A**	**15.1**	**199.7**	**613.5**
Net Present Value (4%) = 2.7 billion Euros			
Changes in Air Related Emissions			
NO_X (kt)	0	-28.5	-0.5
VOC (kt)	0	-10.6	-0.2
CO (kt)	0	-135.9	-4.7
PM (t)	0	-280.8	-8.0

These reports suggest that there can be both environmental and cost benefits from improvements to fuel quality in Canada. However, analysis specific to Canada that takes into account location-dependant factors such as refinery feedstocks and existing infrastructure needs to be completed.

Approach to Enforcing Fuel Quality

The research also revealed that leading jurisdictions internationally have more mandatory fuel quality requirements than Canada, as well as more stringent monitoring and enforcement practices, as shown in Table 4.

When reviewing these jurisdictions, it was noted that Canada has the fewest mandatory requirements for fuel quality and the least stringent monitoring and enforcement practices. In addition, relatively little information was readily available on the actual fuel quality of Canadian gasoline and diesel. By following the examples provided in other jurisdictions, Canada has the opportunity to improve the certainty that Canadian fuels meet agreed-upon standards and provide

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[4] Adapted from: European Commission, *The Costs and Benefits of Lowering the Sulphur Content of Petrol & Diesel to Less Than 10 ppm*. Directorate-General Environment, Sustainable Development Unit and Air and Noise Unit (2001).

confidence to both automotive manufacturers and consumers about the fuel used in their vehicles.

Table 4. Approaches to enforcing fuel quality standards

Country	Gasoline	Diesel	Primary Enforcement Mechanisms
Canada	Voluntary (CGSB 3.5) Exceptions: • Lead, sulphur, benzene and ethanol regulated federally • Ethanol and RVP regulated provincially • CGSB 3.5 is mandatory in Manitoba.	Voluntary (CGSB 3.517) Exceptions: • Sulphur regulated federally • CGSB 3.517 is mandatory in Manitoba.	Mandatory self-reporting of regulated components
United States	Regulatory (both federally and by state)	Regulatory (both federally and by state)	California: • surprise inspections of facilities producing, marketing and storing gasoline • same day analysis • RFG: 8 parameters tested • Diesel: 3 parameters tested
European Union	Regulatory	Regulatory	Varies by state
Japan	Regulatory • Sulphur, Benzene, MTBE, lead, gum content (washed), oxygen content, ethanol Voluntary • Octane, vapour pressure, density, distillation T90, copper corrosion, oxidative stability	Regulatory • Cetane, Distillation T90, sulphur Voluntary • Viscosity, density, carbon residue, flash point, pour point, cold filter plugging point	• Samples all filling stations yearly • Significant penalties in place • Testing on compulsory and non-compulsory specifications
Australia	Regulatory	Regulatory	Representative sampling and in response to complaints

Standard Setting Process

As important as the specific changes to fuel quality standards is the process by which new standards are set. Experience in other jurisdictions has clearly demonstrated the value of stakeholder involvement and buy-in within the process in order to be successful. For example, the Auto-Oil I Programme in the EU was criticized for excluding a number of industries and its recommendations were ultimately rejected. Lack of stakeholder involvement within the standard setting process for fuel quality has been noted as an area needing improvement within Canada.

Additionally, the research has indicated that most leading jurisdictions have adopted an integrated approach to transportation and air quality issues. Fuel quality, vehicle emissions and their related standards are considered as elements of an integrated fuel quality management strategy. The three pillars of such a strategy (air quality, vehicle emissions, and fuel quality) are addressed using a systems approach to maximize the benefits of fuel quality and automotive technology improvements.[5]

Implementation

Finally, it is important for decision makers to consider the broader impacts of any changes to fuel quality standards. These impacts include changes to refinery equipment and operations, downstream impacts to distribution systems (including the cross-border movement of fuels), new environmental considerations, and possible changes to monitoring and enforcement practices.

Conclusions

Overall, the research completed clearly demonstrates several opportunities for potential improvement in the area of fuel quality standards in Canada. Through a review of the technical changes that can be made, as well as leading practices internationally, opportunities were identified in the areas of:

- level of standard,
- monitoring and enforcement, and
- standard setting process.

Potential environmental and health benefits of improved standards were also identified, including consideration of the upstream changes required.

Based on this research, it is recommended that the Government of Canada follow leading jurisdictions and conduct a thorough review of opportunities to reduce transportation emissions through improved fuel quality standards, including a review of total costs and benefits. The review should include broad stakeholder involvement and should consider potential changes within a Canadian context (e.g., considering Canada’s unique feedstock blend). Based on the findings of this process, a comprehensive set of mandatory fuel quality requirements should be introduced, along with enhanced monitoring, enforcement and reporting mechanisms.

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[5] Candace Vona. “Cleaner Fuel and Vehicle Policy Roadmaps” (presented at UNEP PCFV GCC Policy Development Meeting, March 12–13, 2008, in Bahrain. Original source: International Fuel Quality Center.

1. Introduction

Transportation emissions have a significant impact on the environment and the health of Canadians, and fuel quality has a direct impact on vehicle emissions. By considering vehicles and fuels as an integrated system, with opportunities for emission reductions in both areas, greater environmental and health protection can be achieved.

For gasoline and diesel vehicles, tailpipe emissions are dependent on the fuel, the engine, the emission controls and how the vehicles are driven. Fuel quality directly impacts both combustion within the engine, as well as post-combustion emission controls.

This report summarizes the opportunities to reduce environmental and health impacts through improvements to fuel quality standards in Canada for both gasoline and diesel. Section 1 provides context for the reader, including a discussion of the role of fuel and fuel standards in overall transportation emissions, and provides background information on key fuel characteristics and their relationship to environmental and health indicators. Sections 2 and 3 examine the connection between fuel quality and emissions. Section 4 explores Canadian standards and provides a comparison with leading jurisdictions internationally in order to identify potential gaps in Canadian standards and to estimate the potential benefits from improved standards and lower tailpipe emissions. Finally, Section 5 looks into the practical considerations when implementing new standards for both gasoline and diesel.

1.1 Why Does Fuel Matter?

To many, fuel is fuel. We fill our vehicles without seeing it and rarely think about the different variations of fuel that are possible and how they may impact our vehicle's environmental performance. Research tells us, however, that there is a significant difference in vehicle emissions depending on the makeup of the fuel.

The composition of gasoline and diesel in Canada impacts tailpipe emissions in three primary ways:

1. **What goes in must come out.** The amount of certain impurities within fuel, such as sulphur and benzene, corresponds with the level of emissions of these pollutants. Reducing the level of these contaminants reduces associated tailpipe emissions.
2. **Engines are designed for the expected fuel.** Engines are designed and tuned for the fuels that are expected to be used in them. Engines in a particular marketplace need to be able to run on the range of fuels available within a wide driving area. By narrowing fuel specifications within a particular marketplace, engines can be tuned to run more efficiently and with fewer harmful emissions.
3. **Fuels contribute to the degradation of vehicle components.** Vehicle components such as catalytic converters, fuel injectors and combustion cylinders can become coated with residues or degrade over time. The rate of coating or degradation is determined in part by

fuel characteristics (see Figure 3 for an example). The degradation of many of these parts leads to poorer vehicle performance and increased emissions over a vehicle's lifetime. It follows that improved fuel specifications can reduce environmental and health impacts over the entire vehicle lifetime.

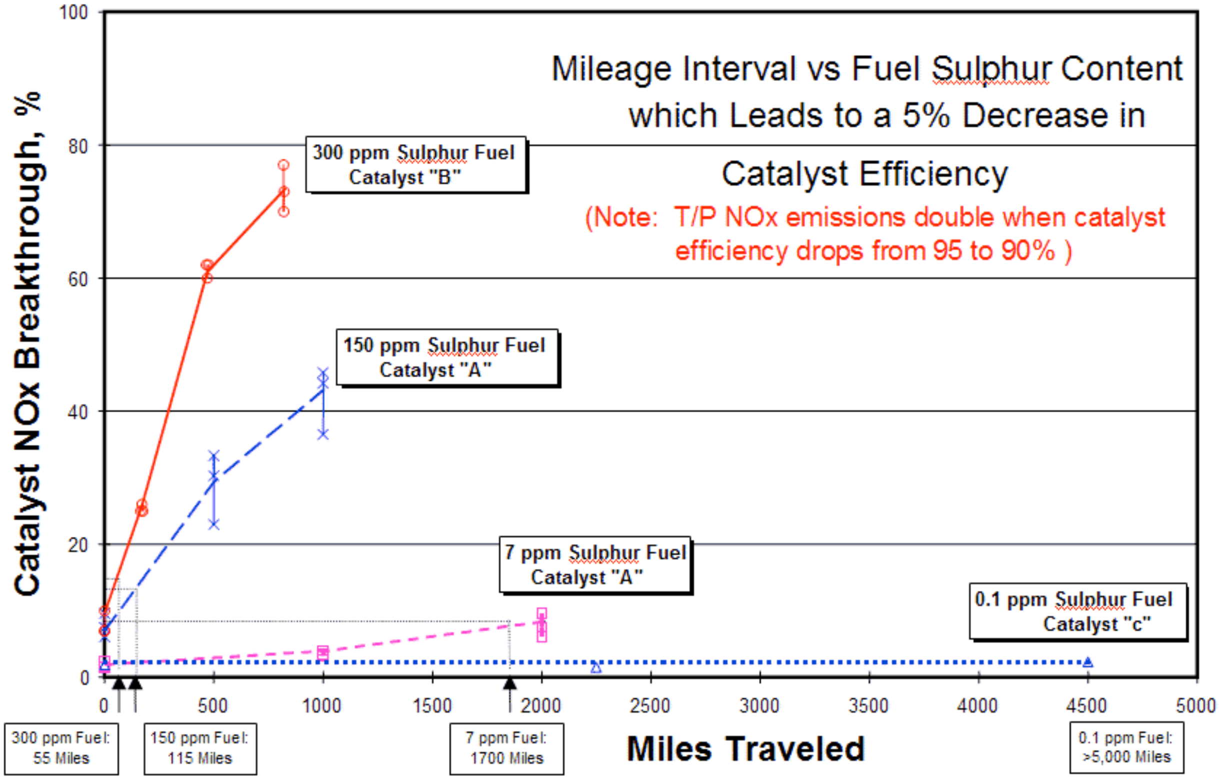

Figure 3. NO_X emissions over time for various sulphur amounts

Source: Manufacturers of Emission Controls Association. Diesel Fuel Quality and Sulfur Effects on Catalyst-Based Exhaust Emission Controls.

More information on specific fuel characteristics can be found in Section 2.

Important Note: Overall environmental and health impacts involve more than just tailpipe emissions. A full consideration of impacts needs to include the entire life-cycle of the fuel. This includes primary production, refining and transportation, as well as tailpipe emissions. This report focuses primarily on vehicle performance, and therefore the tailpipe emissions, but a full consideration of environmental and health impacts over a fuel's entire life-cycle is required. For example, reducing the sulphur content of fuels reduces tailpipe emissions, but it increases refinery emissions. Therefore, a life-cycle analysis of any potential changes to fuel quality standards is required to draw conclusions regarding the overall benefits of specific changes to fuel quality standards. Further discussion is included in Section 3.

1.2 Tailpipe Emissions

The following is a list of air emissions that are of particular concern because of their associated environmental and health impacts.

- Greenhouse gases (Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O))
  - An increase in greenhouse gases in the atmosphere reduces heat loss from the Earth's atmosphere and leads to climate change. The Intergovernmental Panel on Climate Change established by the United Nations notes that greenhouse gas emissions have led to an increase in global temperatures in the 20th century and will lead to further climate change in the 21st century.[6]
- Sulphur Oxides (SO_x)
  - SO_x are a major contributor to acid rain, which damages both terrestrial and aquatic ecosystems, human and animal respiratory systems, and buildings. SO_x can interact with other gases to form sulphate particles, which also results in acidification, or, in combination with other atmospheric compounds, can form small particulate matter (PM 2.5). Even without being transformed into other pollutants, SO_x can harm human and animal respiratory systems and damage vegetation.
- Nitrogen Oxides (NO_x)
  - Another major contributor to acid rain, NO_x contributes substantially to the acidification of bodies of water, and can also contribute to particulate matter pollution. NO_x reacting with volatile organic compounds, carbon monoxide (both described below) and sunlight produces ground level ozone, leading to the formation of photochemical smog — a combination of particulate matter and ground level ozone that presents dangers to human and ecological health.
- Carbon Monoxide (CO)
  - Carbon monoxide can have significant human health impacts, especially at high concentrations, and may contribute to respiratory problems. Even at relatively low concentrations, CO can have negative health effects for those with existing cardiovascular disease. CO also plays a role in the formation of photochemical smog.
- Particulate Matter (PM)
  - A number of studies have linked particulate pollution (including soot from diesel combustion) to respiratory and cardiac diseases such as stroke and heart attacks, and it has also been linked to lung and other cancers. Recent research also suggests that diesel exhaust containing small soot particles (particularly particles smaller than 2.5 microns, also called PM 2.5) is linked to potentially damaging changes in brain activity.[7] Vehicles also contribute to PM formation through the release of SO_x, described above, which can transform into sulphate particles that interact with other compounds to form PM 2.5.

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[6] Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC

[7] Cruts, B., et al., "Exposure to diesel exhaust induces changes in EEG in human volunteers" *Particle and Fibre Toxicology* 5:4, (2008).

- Volatile Organic Compounds (VOCs)
  - VOCs are the other major contributor to ground-level ozone, along with NO_x, and can also play a role in the formation of fine particulate matter, which may be linked to diseases like asthma and some forms of heart disease. Many VOCs, such as benzene, are known carcinogens, and may have other adverse health impacts.
    - Benzene
      - Benzene is a known carcinogen that also has mutagenic and hematological effects, including negative effects on bone marrow and red blood cell production. Benzene exposure has been linked to leukemia.

Many of these pollutants contribute to adverse health impacts, and most have a variety of other environmental effects as well.[8] Improving fuel quality helps to reduce these tailpipe emissions, which impact both air quality and climate change.

SO_x, NO_x, CO, PM and VOCs are all considered criteria air contaminants (CAC), and are often considered together along with ammonia since many of these harmful emissions share the same sources.

1.3 Fuel Characteristics

Although specific fuel parameters used may vary depending on the jurisdiction and the source of the information, fuel quality specifications address the following characteristics:

- combustion and flow properties
- concentration of impurities (e.g., sulphur)
- impact on the wear and cleanliness of the engine and related components

The Worldwide Fuel Charter (WWFC) provides a common basis for assessing fuel characteristics and standards internationally. The Charter has been developed by the major automobile manufacturers from around the world.

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[8] For effects of SO_x refer to U.S. Environmental Protection Agency. *Health and Environmental Impacts of* SO_2., www.epa.gov/oar/urbanair/so2/hlth1.html (accessed July 15, 2008).

For effects of NO_x refer to U.S. Environmental Protection Agency. *Health and Environmental Impacts of* NO_x, www.epa.gov/oar/urbanair/nox/hlth.html (accessed July 15, 2008).

For effects of CO refer to U.S. Environmental Protection Agency. *Health and Environmental Impacts of CO*, www.epa.gov/oar/urbanair/co/hlth1.html (accessed July 15, 2008).

For effects of PM refer to U.S. Environmental Protection Agency. *Particulate Matter — Health and Environment,* www.epa.gov/air/particlepollution/health.html (accessed July 15, 2008).

One of the primary of effects of VOCs is the creation of ozone (O_3). For the effects of ozone refer to U.S. Environmental Protection Agency. *Ground-Level Ozone — Health and Environment*, www.epa.gov/air/ozonepollution/health.html (accessed July 15, 2008).

The Worldwide Fuel Charter is intended to provide globally relevant recommendations on fuel quality to help reduce the environmental impact of motor vehicles, reduce customer costs by minimizing the complexity of vehicle equipment and associated maintenance issues, and increase customer satisfaction. Members of the committee publishing the charter include the European Automobile Manufacturers Association, the Alliance of Automobile Manufacturers, the Engine Manufacturers Association, and the Japan Automobile Manufacturers association. The Association of International Automobile Manufacturers of Canada and the Canadian Vehicle Manufacturers' Association are both associate members in the partnership that publishes the charter.

The WWFC is updated periodically, acting as a living document that is intended to reflect changes in market conditions, developments in engine and emissions control technologies and as a result, changes in vehicle fuel quality requirements.

The fourth edition of the WWFC, published in September 2006, describes four different categories of fuel quality for automotive gasoline and diesel fuels. Category 1 represents markets with no or little emissions control. Categories 2 and 3 apply to markets with more stringent requirements, while Category 4 represents the highest fuel quality category, facilitating more advanced emissions control technologies and emerging vehicle technologies.

Appendix A contains a full listing of all of the fuel characteristics included in the WWFC.

2. Key Fuel Characteristics

Based on the research completed, which included literature reviews and interviews with identified experts, several fuel characteristics for both gasoline and diesel were identified that offer opportunities to reduce tailpipe emissions in Canada through improved fuel quality standards.

2.1 Gasoline Vehicles

While there are many different fuel quality parameters, the research completed consistently identified two fuel characteristics where improved standards would lead to improved environmental performance in Canada. These two characteristics are:

- sulphur content
- detergency levels

The following section summarizes the issue and opportunities in these categories.

2.1.1 Sulphur

Canada has recently reduced required gasoline sulphur levels to a yearly pool average of 30 ppm and maximum of 80 ppm. However, these improved regulations are less stringent than other jurisdictions including Japan (where a limit of 10 ppm has already been mandated), the EU (where a limit of 10 ppm is required by 2009),[9] and California (average limit of 15 ppm)[10]. Canada's new sulphur regulation also falls short of the WWFC's Category 4 recommendation of 10 ppm).

Reducing the sulphur content of gasoline leads to a direct reduction in SO_x emissions since less sulphur is present in the combustion reaction. Additionally, studies have found that sulphur reduces the performance of three-way catalysts and other after-treatment devices. By reducing sulphur content, these devices can work more effectively, leading to reductions in the emissions of VOCs, NO_x and CO. In a report summarizing the findings of several studies into the impact of sulphur on catalyst performance, the Association for Emissions Control by Catalyst (AECC)

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[9] CEPA Environmental Registry. *Questions and Answers on the federal Sulphur in Gasoline Regulations. www.ec.gc.ca/CEPARegistry/documents/regs/q_a_sul/general.cfm* (accessed July 17, 2008).

[10] California Air Resources Board. *California Gasoline Program,* www.arb.ca.gov/fuels/gasoline/gasoline.htm (accessed July 17, 2008).

concluded that reducing sulphur content led to a decrease in emissions of hydrocarbons (HCs), CO and NO_x[11].

The Clean Air Initiative for Asian Cities published a report that drew similar conclusions: reducing sulphur improved catalyst performance thereby decreasing VOC, CO and NO_x emissions. Figure 4 presents the results of this report.

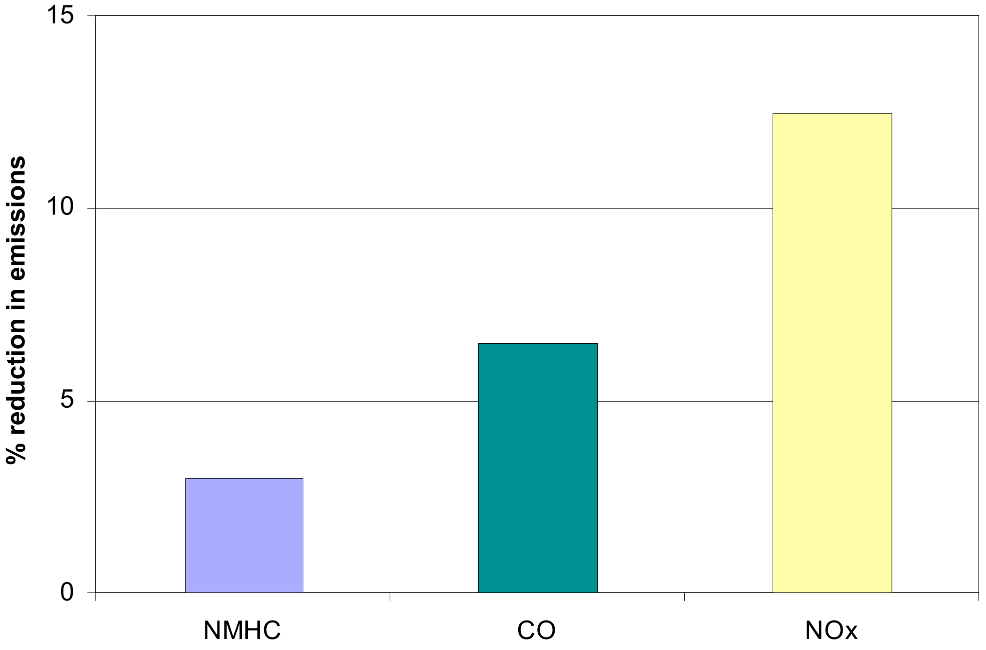

Figure 4. Impact of reducing sulphur from 30 ppm to 10 ppm

Adapted from: Clean Air Initiative for Asian Cities, *Fuel Quality Strategy Training Workshop: Module 2,* (Sydney, Australia, October 2003).

Further reducing the sulphur content of Canadian fuels is expected to decrease vehicle emissions. Aligning Canadian fuel standards with the more stringent fuel quality standards being adopted around the world will also help to ensure that Canadians have access to the most advanced vehicles and emissions control technologies.

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[11] Association for Emissions Control By Catalyst, *Response to European Commission Consultation on the need to reduce the Sulphur Content of Petrol and Diesel Fuels below 50 parts per million.* (July 2000), 9.

Lean Burn Engines

In the AECC's response to the European Commission's fuel quality directives regarding sulphur content, they note the potential for lean burn engines. In a lean burn engine, an excess of air is mixed with gasoline to ensure a more complete combustion. These engines can lead to an improvement in fuel economy by as much as 15% over conventional engines.

While lean burn engines can lead to improvements in fuel efficiency, adding excess air to gasoline leads to an increase of NO_x emissions. With current technologies and sulphur levels, European NO_x emissions requirements might not be met with lean burn engines. The AECC notes that more efficient after-treatment devices (i.e. NO_x adsorbers) would be required to reduce emissions to acceptable levels. The performance of these devices, however, is significantly limited by SO_x emissions which occupy and poison catalyst locations intended to break down NO_x emissions. Without reducing the sulphur content to 10 ppm or below, the AECC contends that such technologies can not be used given current emissions standards, despite the improvement in fuel economy they might provide.

2.1.2 Detergency

Fuel detergency is an indicator of a fuel's ability to help maintain a clean engine. Fuels with high detergency levels help reduce engine deposits. The WWFC has a number of categories tied to detergency and its effects on engines:

- Unwashed Gums
- Washed Gums
- Fuel Injector Cleanliness
- Intake Valve Cleanliness
- Fuel Chamber Deposits

At present, there are no regulations pertaining to these fuel quality parameters in Canada. However, a number of fuel refineries produce Top Tier[12] detergent gasoline — a fuel standard developed by BMW, General Motors, Honda, Toyota, Volkswagen and Audi which has detergency requirements matching WWFC requirements. Fuel meeting the Top Tier standard is available from some Canadian fuel marketers, including Chevron Canada, Shell Canada, Petro-Canada and Sunoco Canada.

Various studies have been conducted which compare fuels meeting detergency standards, such as the Top Tier program, to those which do not meet such standards. Results from these studies have all concluded that tailpipe emissions decrease as a result of improved fuel detergency.

For example, a study performed by S.A. Karpov regarding Russian fuels[13] found that improving detergency had a number of beneficial impacts including:

- improved fuel efficiency

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[12] Top Tier Detergent Gasoline requirements available at: Top Tier Gasoline. Deposit Control Standards. www.toptiergas.com/deposit_control.html (accessed July 14, 2007).

[13] Karpov, S.A. "Improving the Environmental and Performance Properties of Automotive Gasolines — Detergent Additives." *Chemistry of Fuels and Oils* 43, no. 3 (2007).

- decreased HC, CO and NO_x emissions
- reduced deposits in intake valves and carburetors (with the latter only applicable to older vehicle stock)

Similar results were obtained by a European study which compared the impacts of using BP Ultimate fuel, a fuel with high detergency, with the impacts of using a regular fuel. This study (Figure 5 below) showed 5% reductions in HC and NO_x emissions, and nearly 15% reductions of CO emissions.

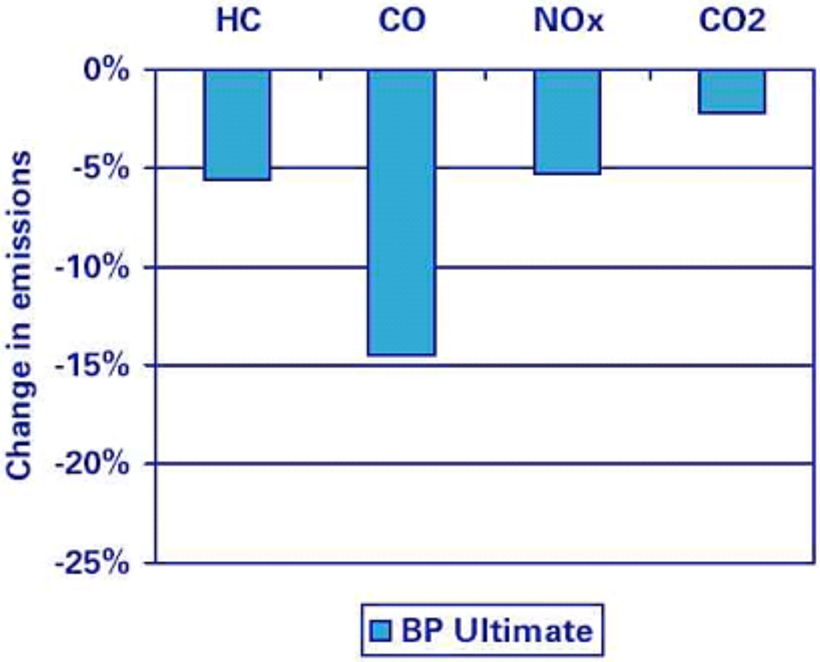

Figure 5. Effect of using BP Ultimate fuel versus regular fuel

Source: Dr. John Bennett, Ford Motor Company, Detergents and Their Role in the Emissions Performance of Vehicles — Presentation for ACEA.

With fuel meeting WWFC detergency requirements already available in Canada, it may be a good opportunity to create a national standard in this area that would help reduce emissions, improve fuel economy and help provide auto-makers with confidence in the quality of gasoline available.

2.2 Diesel Vehicles

In recent years, substantial efforts have been made in Canada and around the world to reduce sulphur in diesel fuels. With Canada's requirements for 15 ppm sulphur in diesel fuel exceeding WWFC Category 3 and approaching Category 4 requirements, this report focuses on other areas of diesel fuel quality identified as significant in the current Canadian context.

The research completed helped identify two key opportunity areas for diesel fuels in Canada:

- cetane number
- lubricity levels

The following section summarizes the issue and opportunities in each of these categories.

2.2.1 Cetane

The cetane number is a measure of the ignition quality of diesel fuel. Fuels with a higher cetane number have shorter ignition delays, allowing more time for combustion and resulting in more complete combustion.

Currently, Canada's voluntary national standard recommends a minimum cetane number of 40. This value is significantly lower than even the Category 1 recommendation of the WWFC of 48, as well as the standard in every other jurisdiction researched.

A study conducted by the U.S. Environmental Protection Agency (EPA) examining the effect of cetane on NO_x emissions of heavy-duty vehicles found that increasing cetane level leads to decreases in NO_x emissions (See Table 5).

Table 5. Effect of using additives to increase cetane level in diesel (for engines without engine gas recirculation)[14]

Increase in Cetane from 40 to:	Reduction in NO_X Emissions
45	2.7%
50	4.5%
55	5.4%

Studies conducted by the European Program on Emissions, Fuels and Engine technologies (EPEFE) confirm the EPA findings that in addition to decreasing NO_x emissions associated with increasing cetane values, emissions of CO and HCs also decrease.[15] Furthermore, the Australian Government's Department of Heritage and the Environment notes that low cetane values lead to rough operation, increased smoke and engine knocking.[16]

Cetane level is a notable area of potential improvement with respect to Canadian standards.

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[14] Adapted from: U.S. EPA, *The Effect of Cetane Number Increase Due to Additives on NO_x Emissions from Heavy-Duty Highway Engines: Final Technical Report*, (Washington, DC: U.S. EPA, Office of Transportation and Air Quality, 2003).

[15] European Program on Emissions, Fuels and Engine Technology. *European Program on Emissions, Fuels and Engine Technologies Report*, (1995). Cross referenced from:
The Department of Heritage and the Environment, Australia. *Measuring Cetane Number: Options for Diesel and Alternative Diesel Fuels*, (Australia, 2004).

[16] The Department of Heritage and the Environment, Australia. *Measuring Cetane Number: Options for Diesel and Alternative Diesel Fuels*, (Australia, 2004).

2.2.2 Lubricity

The WWFC requires a wear scar of 400 microns or less resulting from the HFRR test (high-frequency reciprocating rig) for all fuel categories. This test determines a wear scar that is indicative of the wear that can be expected on engine parts when using the fuel tested. Larger wear scars indicate poorer lubricity. Currently Canada's voluntary national standard requires a maximum wear-scar of 460 microns[17], less stringent than the WWFC standard.

Sulphur content and lubricity must be addressed together, as sulphur is a natural lubricant. A loss of lubricity resulting from sulphur reductions can be avoided through the use of additives that improve lubricity.

Lubricity itself does not have a direct impact on emissions, but low lubricity does lead to long-term wear on critical engine parts which can contribute to a degradation of engine performance over time. The California Air Resources Board (CARB)[18] suggests that emissions can be expected to rise as a result of poor lubricity due to compromised injection pump performance — CARB found that injector problems can lead to increases in PM emissions and fuel consumption.[19] CARB also states that current lubricity levels are not adequate for future low-emissions technology.

Based on these findings, lubricity is considered to be an important issue for diesel fuel quality in Canada.

2.3 Summary

With numerous categories of fuel parameters within the WWFC, it is useful to focus on those fuel characteristics with significant potential to reduce tailpipe emissions. Based on the research completed, lubricity and cetane in diesel were identified, whereas detergency and sulphur in gasoline were identified. Three of these fuel parameters are compared in Table 6 with other jurisdictions researched as well as Category 4 within the WWFC.

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[17] CGSB Standard CAN/CGSB-3.517-2007 — *Automotive (On-road) Diesel Fuel.*

[18] California Environmental Protection Agency Air Resources Board, *Proposed Amendments to the California Diesel Fuel Regulations — Staff Report: Initial Statement of Reasons,* (2003).

[19] California Environmental Protection Agency Air Resources Board, *Proposed Amendments to the California Diesel Fuel Regulations — Staff Report: Final Statement of Reasons*, (2004).

Table 6. International comparison of key fuel characteristics

	Canada	California	EU	Australia	Japan	WWFC Category 4
			Diesel			
Cetane	40	48	51	46	45	55
Lubricity*	0.460 mm	0.520 mm	0.460 mm	0.460 mm	N/A	0.400 mm
			Gasoline			
Sulphur	30 ppm	15 ppm	50 ppm (10 ppm in 2009)	50 ppm (10 ppm proposed**)	10 ppm	10 ppm

* Lubricity is calculated based on the HFFR test which generates a wear diameter; the smaller the number the better the lubricity.

**The Australian government has issued a Regulation Impact Statement indicating that they are considering reducing sulphur in premium gasoline to 10 ppm.[20]

For each of these fuel characteristics, Canada is lagging behind best practices.

Minimum cetane levels in Canadian diesel are significantly lower than levels required in any other jurisdiction researched. Higher cetane levels are expected to both reduce tailpipe emissions and improve overall engine performance.

While lubricity requirements for Canadian diesel are among the best of the jurisdictions researched, it does not match the levels set out in the WWFC for any of the fuel categories. Research indicates that improved lubricity will lead to reduced PM emissions and fuel consumption.

Internationally, sulphur content in gasoline is moving towards 10 ppm as a method of both reducing criteria air contaminant emissions and improving the fuel quality of vehicles. Japan already requires less than 10 ppm sulphur in gasoline, while the EU will require it in 2009. Reducing the sulphur in Canadian gasoline from an average of 30 ppm to less than 10 ppm will serve to reduce both CAC emissions from tailpipes, as well as enable greater fuel economy.

The fourth area highlighted as an opportunity for Canadian fuels is the detergency of gasoline. The jurisdictions researched, including Canada, do not have standards related to all of the WWFC categories that contribute to detergency, but there is clear evidence that tailpipe emissions could be reduced by requiring fuels with higher levels of detergency, such as Top Tier detergent gasoline.

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[20] Department of Transport and Regional Services of Australia. *Regulation Impact Statement for Vehicle Emissions and Fuel Quality Standards for the Post 2006 Period.* (December, 2004). www.ephc.gov.au/ltec/pdfs/FinalRISVEFSReviewDec2004.pdf (accessed August 4, 2008).

3. Net Benefits

When considering improvements to fuel quality standards, it is important to consider the net environmental and cost benefits throughout the entire life cycle. This requires examination of not only vehicle costs and emissions, but upstream impacts as well.

This section summarizes the results of two analyses that demonstrate the potential for net environmental and cost benefits from improvements to fuel quality standards.

3.1 Benefits from Proposed Fuel Quality Changes in Australia

In 2003, the Australian Motor Vehicle Environment Committee commissioned a report by Coffey Geosciences Ltd. to, in part, assess the emission and cost implications of various changes to fuel quality standards. This analysis provides a useful reference point for considering similar actions in Canada.

The Australian analysis focused on several specific options for reducing sulphur in fuels both with and without improvements to vehicle fuel economy. In the Canadian context, the most relevant result is the estimated changes in emissions and costs related to a change from a 50 ppm limit in premium unleaded petrol (PULP), with 95 Research Octane Number (RON), to a 10 ppm limit. (Reminder: the current Canadian regulations require an annual pool average of 30 ppm sulphur in all gasoline, with a maximum of 80 ppm.)

With respect to fuel economy, the potential change in sulphur levels for PULP enabled the development of a National Average Fuel Consumption Target (NAFC). The NAFC is an agreement between the Australian government and automotive industry to see the average fuel consumption reduced to 6.8 L/100 km for new passenger vehicles by 2010.[21] The Australian Automotive Industry, represented by the Federal Chamber of Automotive Industries (FCAI), have indicated that delivery of the fuel consumption target is contingent upon petrol sulphur concentration not exceeding 10 ppm.[22] The results of the Coffey analysis looked at the expected impacts of fuel quality changes both with and without new fuel economy standards.

It should be noted that Coffey Geosciences identified an uncertainty with the majority of their results of greater than 20%.

When considering both new fuel economy standards and reduced sulphur from 50 ppm to 10 ppm in PULP, it was estimated that Australia’s national greenhouse gas emissions would be reduced by 474 kilotonnes by 2020 and cost savings of up to $244 million would be achieved in

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[21] Kemp, David and Ian MacFarlane. Government of Australia. “Australian Cars will Deliver Better Efficiency and Greenhouse Savings,” news release, April 15, 2003.

[22] If 10 ppm gasoline is not available, the automotive industry would pursue a 7.4 L / 100 km target instead.

the same timeframe (see Table 7). This is primarily a result of reduced fuel consumption, which, in the case of Australia, is dependent on reduced sulphur content. Some CAC emissions are also reduced from some vehicles, explored further in Section 3.2 on benefits from fuel quality changes in the EU.

Table 7. Net greenhouse gas and cost[23] reductions from a combination of improved fuel economy standards and reducing sulphur in premium gasoline from 50 ppm to 10 ppm[24]

Year	GHG Reduction	Cost Savings
2010	33 kt	$66 million
2020	474 kt	$244 million

Without the NAFC, the change from 50 ppm sulphur to 10 ppm sulphur in PULP is expected to increase overall greenhouse gas emissions and costs, but reduce some CAC emissions for some vehicles as outlined in Table 8.

Table 8. Net greenhouse gas and cost increases from reducing sulphur in premium gasoline from 50 ppm to 10 ppm without improved fuel economy standards

Year	GHG Increase	Cost Increase
2020	238 kt	$18 million

3.2 Benefits from Fuel Quality Changes in the EU

Through its Auto Oil II process, the European Commission's Directorate-General Environment also conducted an analysis of the costs and benefits of reducing fuel sulphur. The base case for this analysis assumed that fuel from 2006 onward would contain a maximum of 50 ppm sulphur. Five scenarios were analyzed against this base case from a cost-benefit perspective. These scenarios all related to a reduction in fuel sulphur to 10 ppm or lower, with the differences between scenarios being primarily in the timeline for phasing in the changes and the types of fuel that would be required to change. Among all scenarios, sulphur reduction is associated with some CAC emissions reductions from some vehicles as indicated in Table 9. Note that Table 9 does not provide a full view of the CAC impacts of 10 ppm sulphur fuel due to the assumption of a homologation effect in the cost-benefit analysis.

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[23] Costs include increased vehicle and refining costs, as well as fuel savings and reduced health costs. They do not include benefits from GHG reductions, or reductions in vehicle and refinery costs as new technologies mature and production volume increases.

[24] Coffey Geosciences Pty. Ltd. *Fuel Quality and Vehicle Emissions Standards Cost Benefit Analysis.* Prepared for MVEC Review of Vehicle Emissions and Fuel Standards Post 2006, (2003)

Table 9. EU assumptions on vehicle emission changes for 10 ppm sulphur (reduced from 50 ppm)

Vehicle Type		CO_2	NO_x	HCs	PM
EURO IV cars	Petrol	3% (1–5%)	0%	0%	0%
	Diesel	2% (1–3%)	0%	0%	0%
EURO I,II,III cars	Petrol	0%	10%	10%	0%
	Diesel	0%	0%	0%	5%
EURO IV vans	Petrol	0%	0%	0%	0%
	Diesel	2% (1–3%)	0%	0%	0%
EURO I,II,III vans	Petrol	0%	10%	10%	0%
	Diesel	0%	0%	0%	5%

Source: European Commission. 2001. *The Costs and Benefits of Lowering the Sulphur Content of Petrol & Diesel to Less Than 10 ppm.* Directorate-General Environment, Sustainable Development Unit and Air and Noise Unit.

The “Main Scenario 2005” most closely mirrors the approach to sulphur in fuels adopted by the European Commission after the analysis took place. The scenario assumes the limited introduction of “sulphur-free” diesel and gasoline (containing 10 ppm or less sulphur) for new vehicles by 2005, with 100% of gasoline and diesel becoming sulphur-free by 2011. The analysis assumes the phased introduction of passenger cars able to take advantage of sulphur-free fuels.

Table 10 shows the net benefits of the main scenario are estimated at €2.7 billion, and an annual net reduction of CO_2 emissions of 2.9 Mt in 2012.

Table 10. Results of the cost-benefit analysis for introducing sulphur-free (<10 ppm) fuels in the European Union in 2005[25]

	2005	2012	2020
CO_2 Emissions Changes			
Change in CO_2 emissions in refineries (kt)	215.7	5,348.3	5,404.3
CO_2 change from cars (kt)	-562.8	-8,241.6	-14,960.5
Net change (– = decrease in CO_2 emissions)	**-347.1**	**-2,893.2**	**-9,556.2**
Costs and Benefits (million Euros)			
Increase in refining costs (average per year) **A**	39.0	816.9	831.4
Savings due to lower fuel consumption (average) **B**	54.1	795.5	1441.2
Benefits from better air quality **C**	0.0	221.1	3.7
Net benefits* **B+C–A**	**15.1**	**199.7**	**613.5**
Changes in Air Related Emissions			
NO_X (kt)	0	-28.5	-0.5
VOC (kt)	0	-10.6	-0.2
CO (kt)	0	-135.9	-4.7
PM (t)	0	-280.8	-8.0

* Net Present Value (@ 4% discount rate) = € 2.7 billion

Of great importance to note is the assumption in the report of a homologation effect: because the EURO IV vehicle emissions standards were already fixed prior to the change from 50 ppm sulphur fuels to 10 ppm sulphur fuels. This means that the report did not consider any effects on emissions of criteria air contaminants because no obligation would exist for manufacturers to produce vehicles that outperform the regulated emissions standard. This illustrates the importance of considering fuel quality and vehicle emissions standards in tandem; by assessing both together, it is possible to maximize the fuel economy and emissions benefits new technologies might provide through the provision of cleaner fuels.

The report also omitted some additional greenhouse gas impacts, primarily the reduced emissions of N_2O from cars using three-way catalytic converters. Capturing these impacts might further improve the argument for further reductions in fuel sulphur.

The analysis concludes that “for all scenarios considered, the accumulated benefits (financial and air quality) are higher than the costs and there is a positive effect on overall CO_2 emissions over the period considered.” It notes that with the changes fully realized, net greenhouse gas emissions reductions from the change would amount to between 1 and 2% of CO_2 emissions from road transportation.

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[25] Adapted from: European Commission, *The Costs and Benefits of Lowering the Sulphur Content of Petrol & Diesel to Less Than 10 ppm.* Directorate-General Environment, Sustainable Development Unit and Air and Noise Unit (2001).

4. Approach to Enforcing Fuel Quality

When reviewing fuel quality standards in Canada, it is important to consider the processes used to enforce the standards both within Canada and in leading jurisdictions internationally. This comparison can offer insights into the Canadian process and identify opportunities to improve current practices. Table 11 provides a brief summary of the jurisdictions regarding their approach to standardization.

Table 11. Approaches to enforcing fuel quality standards

Country	Gasoline	Diesel	Primary Enforcement Mechanisms
Canada	Voluntary (CGSB 3.5) Exceptions: • Lead, sulphur, benzene and ethanol regulated federally • Ethanol and RVP regulated provincially • CGSB 3.5 is mandatory in Manitoba	Voluntary (CGSB 3.517) Exceptions: • Sulphur regulated federally • CGSB 3.517 is mandatory in Manitoba	Mandatory self-reporting of regulated components
United States	Regulatory (both federally and by state)	Regulatory (both federally and by state)	California: • surprise inspections of facilities producing, marketing and storing gasoline • same day analysis • RFG: 8 parameters tested • Diesel: 3 parameters tested
European Union	Regulatory	Regulatory	Varies by state
Japan	Regulatory • Sulphur, Benzene, MTBE, lead, gum content (washed), oxygen content, ethanol Voluntary • Octane, vapour pressure, density, distillation T90, copper corrosion, oxidative stability	Regulatory • Cetane, Distillation T90, sulphur Voluntary • Viscosity, density, carbon residue, flash point, pour point, cold filter plugging point	• Samples all filling stations yearly • Significant penalties in place • Testing on compulsory and non-compulsory specifications
Australia	Regulatory	Regulatory	Representative sampling and in response to complaints

4.1 Fuel Quality Standards in Canada

In Canada, fuel quality regulation is generally within provincial jurisdiction, with the exception of some federal jurisdiction over environment-related fuel characteristics — sulphur, benzene, lead, and now the ability to require certain amounts of renewable fuels such as ethanol and biodiesel. Few provinces regulate many aspects of fuels, with the exception of biofuel content and Reid vapour pressure. The exception to this is Manitoba, which requires sellers of gasoline and diesel to adhere to the established industry voluntary standard.[26]

In Canada, many product and materials standards are determined by the Canadian General Standards Board (CGSB), a component of Canada's Department of Public Works and Government Services. CGSB standards include voluntary standards for gasoline and diesel fuel (CAN/CGSB 3.5 and CAN/CGSB 3.517). These standards are determined and overseen by the CGSB, and are derived through a volunteer-based expert stakeholder process. For a detailed enumeration of these standards and the requirements of the regulations discussed below, see Appendix B.

Existing CGSB standards for gasoline and diesel in Canada are voluntary unless specified as a compulsory point of reference in legislation. Unfortunately, only limited information on actual compliance with the voluntary standards was readily available.

Compliance with federal and provincial regulations is mandatory. In the case of federal regulations, stipulations for enforcement are laid out in Environment Canada's Compliance and Enforcement Policy for CEPA 1999.[27] Different compliance, monitoring and enforcement regimes exist for various fuel quality regulations at different levels of jurisdiction, but at the federal level, most regimes focus on mandatory self-reporting, such as the system specified in the *Sulphur in Diesel Fuel Regulations.*[28]

4.2 Fuel Quality Standards in the United States

Because of differences in state-by-state treatment of fuel quality regulation, discussion of regulatory context for fuel quality in the United Sates is limited to best-in-class (or the most stringent) approaches to fuel regulation. Specifically, this section focuses on reformulated gasoline (RFG) requirements, particularly in California.

RFG was first federally legislated in the United States by the EPA. RFG has been required to be used since 1995 in metropolitan areas with the most severe air pollution and in other non-attainment areas that requested the cleaner burning gasoline. Today, about 30 percent of the gas

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[26] *Storage and Handling of Petroleum Products and Allied Products Regulation*, Man. Reg. 188/2001

[27] CEPA Environmental Registry. *Compliance and Enforcement Policy for the Canadian Environmental Protection Act*, 1999. www.ec.gc.ca/CEPARegistry/documents/policies/candepolicy/toc.cfm (accessed July 14, 2008).

[28] CEPA Environmental Registry. *Sulphur in Diesel Fuels.* www.ec.gc.ca/ceparegistry/regulations/DetailReg.cfm?intReg=63 (accessed July 14, 2008),

used in the United States is RFG.[29] RFG is described by the EPA as gasoline formulated "to reduce emissions of ozone-forming and toxic air pollutants." Specifically, RFG is less likely to evaporate in summer months than conventional gasoline, and it typically contains higher levels of oxygenates and lower levels of benzene, olefins, and aromatics.[30]

California's RFG requirements

The California Environmental Protection Agency (Cal/EPA) has revised the Clean Air Act of the 1970s several times and has given the California Air Resources Board (CARB) the responsibility to improve air quality through more stringent fuel standards. CARB's stated mission is to "promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering the effects on the economy of the state".[31]

California has created its own RFG standards since federal legislation created the RFG program in 1995. The California standard is more stringent than its federal predecessor and, as a result, is the focus of this research. For a detailed enumeration of these standards, see Appendix B.

The CARB is responsible for the inspection of gasoline and diesel fuel in California. CARB fuels inspectors conduct surprise inspections of facilities producing, marketing and storing gasoline and diesel fuel, including refineries and service stations. Samples of fuel are analyzed in a Mobile Fuels Laboratory, allowing inspectors to conduct same-day analysis of collected samples and quicker implementation of enforcement measures in the case of non-compliance.

California RFG samples are tested on eight different fuel parameters: Reid vapor pressure, T50 and T90 distillation temperatures, total aromatics, olefins, oxygen, benzene, and sulphur contents.

California Diesel samples are tested on three different fuel parameters: sulphur, aromatic hydrocarbon content, and polynuclear aromatic hydrocarbon content.[32]

If violations are documented by inspectors, further investigation is conducted. CARB staff evaluate the data, determine the cause and severity of the violation, and prepare the case. Most cases are resolved through CARB's mutual settlement program, or referred for settlement or litigation.

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[29] United States Environmental Protection Agency, *Regulatory Announcement: Removal of Reformulated Gasoline Oxygen Content Requirement,* (2006). www.epa.gov/otaq/regs/fuels/rfg/420f06035.htm, (accessed May 29, 2008).

[30] United States Environmental Protection Agency, *Is Reformulated Gasoline a "New" Gasoline?* (1995). www.epa.gov/otaq//rfgnew.htm (accessed May 29, 2008).

[31] California Environmental Protection Agency, Air Resources Board, *ARB Mission, Goals and Strategic Plan* (2008) www.arb.ca.gov/html/mission.htm (accessed October 20, 2008).

[32] Additionally, alternative diesel fuel formulations are tested for nitrogen content, cetane and additives. [Source: Dickman Lum, California Air Resources Board, personal communication; www.arb.ca.gov/enf/fuels/inspections.htm]

How does actual fuel quality in California align with standards?

California's actual fuel quality aligns closely with the state's RFG and diesel standards in the fuel characteristics tested by CARB. In 2007, fewer than 1% of gasoline samples were non-compliant with standards, with the majority of these resulting from seasonal RVP requirement non-compliance due to the changeover of fuels between seasons, and most of the remainder resulted from violations in racing fuel. Only one test out of 2664 detected non-compliance with another fuel characteristic (levels of benzene that exceeded requirements). For diesel fuel, less than 1% of fuels sampled were not compliant with requirements, with 5 out of 703 diesel samples containing levels of sulphur that exceeded state limits.[33]

4.3 Fuel Quality Standards in the European Union

Fuel quality standards in the European Union are stated in two documents:

- Directive 98/70/EC
- Directive 2003/17/EC

Directive 98/70/EC sets minimum or maximum limits on physical properties for petrol and diesel. The limits are designed in order for internal combustion engines to function efficiently (which will impact on emissions of both air quality pollutants and greenhouse gases) and to limit harmful emissions, such as hydrocarbons, sulphur and lead content.

Directive 98/70/EC includes a general ban on the marketing of leaded gasoline from 2000 and also limited sulphur levels to 150 ppm for gasoline and 350 ppm for diesel from 2000. Since 2005, the mandatory sulphur limit has been 50 ppm for both fuels.

Directive 2003/17/EC was developed following EC consultations with stakeholders on whether the 2005 sulphur limit should be reduced further. Directive 98/70/EC resulted in a requirement for introduction of sulphur-free fuel (<10 ppm sulphur) to be made available "on an appropriately balanced geographical basis" from January 2005 (with annual reporting on availability).[34] Full mandatory conversion to sulphur-free gasoline is to be achieved by 2009 (this timeline for diesel is under current review). The EC directive notes that by 2009 the composition of vehicle fleets able to take full advantage of the lower sulphur content should be sufficient to offset any disadvantages due to additional refining of the fuel. The availability of sulphur-free petrol (<10 ppm) would lead to an improvement in the fuel economy of future gasoline direct injection cars by 1–5%, compared to similar vehicles using fuel containing a maximum of 50 ppm sulphur.[35] It would also lead to lower emissions of conventional pollutants from the existing fleet of petrol vehicles

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[33] Information provided by Frederick Schmidt, California Air Resources Board Fuels Inspection Program.

[34] Commission Recommendation 2005/27/EC provides guidance on what constitutes availability of fuels "on an appropriately balanced geographical basis."

[35] European Environmental Press, "Final agreement on sulphur-free petrol and diesel fuels," *European Environmental Press Newsletter* 37 (December 17, 2007). www.eep.org/newsletters/newsletter021217.htm (accessed July 14, 2008).

The Directives are formally proposed by the European Commission, usually following extensive research (such as by the Joint Research Centre)[36] and stakeholder input. The European Parliament and European Council discuss, amend (as needed), then choose whether to pass the Directives. It is then the responsibility of the European Commission to ensure implementation of the legislation through the member states. [37]

Enforcement of fuel quality is the responsibility of member states. The European Commission is focused on enforcement of fuel quality monitoring systems and reporting. Directive 2003/17/EC requires that member states develop fuel quality monitoring systems in accordance with European Standard. Commission Decision 2002/159/EC and European Standard EN 14274:2003 provide requirements and common data templates for reporting fuel quality by member states. Directive 2003/17/EC requires that member states report on the availability of sulphur-free (10 ppm or less) fuels each year. There is an option in Directive 2003/17/EC, in which "the use of an alternative fuel quality monitoring system may be permitted provided that such a system ensures results of equivalent confidence."

In January 2007, the European Commission proposed new standards for transport fuels with the goal of reducing their contribution to climate change and air pollution, including through greater use of biofuels. Similar to British Columbia's low-carbon fuels requirement, "the revised directive will introduce an obligation for fuel suppliers to reduce the greenhouse gas emissions that their fuels cause over their life-cycle, i.e., when they are refined, transported and used. From 2011, suppliers will have to reduce emissions per unit of energy by 1% a year from 2010 levels. This will result in a 10% cut by 2020." [38]

One result of this change that may have significant implications for fuel quality is the creation of a separate gasoline blend that will be permitted to have a higher oxygenate content than previously (with up to 10% ethanol permitted).

The EU is still negotiating over acceptable biofuel standards.

4.4 Fuel Quality Standards in Japan

Gasoline and diesel quality are both regulated under the *Law on the Quality Control of Gasoline and Other Fuels* ("Quality Assurance Law"), among other regulations. Additional voluntary standards, JIS K2202 and K2204, are maintained by the Japanese Industrial Standards Committee and Japanese Standards Association. For further details of these standards and the requirements of the Japanese regulations on fuel quality, see Appendix B.

The Quality Assurance Law requires sampling of all filling stations on a yearly basis. This includes more than 240,000 samples processed per year, with significant penalties for station

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[36] European Commission Joint Research Centre, ec.europa.eu/dgs/jrc/index.cfm (accessed May 29, 2008).

[37] European Commission. 2003. *How the European Union Works: A Citizen's Guide to the EU Institutions.* ec.europa.eu/publications/booklets/eu_documentation/06/en.pdf (accessed May 29, 2008).

[38] McDermott, Will & Emery, "Stricter Fuel Standards to Reduce Air Pollution," *Brussels Brief* (February 2, 2007). www.mwe.com/index.cfm/fuseaction/publications.nldetail/object_id/fc8069ab-a2b6-4ed2-b3f4-fd12a2e8f98e.cfm (accessed July 9, 2008).

owners found to be out of compliance with mandatory parameters.[39] Stations meeting all requirements receive and display a government mark of approval (“SQ” mark). The enforcement and standards system is government funded. The National Petroleum Association carries out the testing using government grants. Laboratory testing is conducted on all specifications (including non-compulsory specifications).

Japan has demonstrated a growing interest in low-carbon fuels, particularly biofuels. The petroleum industry is anticipating a blend of 7% ETBE (using ethanol as a feedstock) in 20% of all Japanese gasoline beginning in 2010.

How does actual fuel quality in Japan align with standards?

Gasoline

In 2005, 116,368 tests were carried out for premium and regular gasoline, with 101 samples in non-compliance with standards, with the majority of compliance incidents resulting from octane number deficiencies. Non-compliant samples represent less than 0.1% of tested samples.

Diesel

In 2005, 58,001 tests were carried out for automotive diesel fuel, with 413 samples in non-compliance. The majority of compliance incidents stemmed from failure to meet sulphur requirements, flash point standards, and coumarin (benzopyrone) content limits. Non-compliant samples represent approximately 0.7% of tested samples.

4.5 Fuel Quality Standards in Australia

Some mandatory requirements for fuel have been established nationwide, while others (perhaps most significantly Reid vapour pressure limitations) have been implemented at the state level. For a detailed enumeration of the requirements of the Australian regulations on fuel quality, see Appendix B.

A few state standards are more stringent than the national (Commonwealth Government) standards. State and territory requirements operate concurrently with the Commonwealth regulations, and the more stringent standard is applied when regulated in both jurisdictions. In one example of state-level regulations, Western Australia put into force its Environmental Protection (Diesel and Petrol) Regulations 1999 beginning January 1, 2000, with certain more stringent requirements ahead of the national-level requirements which were phased in through 2005. Although some state requirements are more stringent than national standards, the majority of state-level standards have been superseded by the Commonwealth-level standards.

Voluntary standards from Standards Australia have mostly been superseded by the Commonwealth fuel requirements. AS 3570-1998, the standard for automotive diesel fuel, provides some additional guidance on minimum requirements to ensure optimal cold-weather

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[39] Kiyoyuki Minato, *Fuel Quality Regulations in Japan.* Japan Automobile Research Institute. www.jari.jp/pdf/rt0806/07minato.pdf (accessed August 4, 2008).

performance. Previously in place for gasoline (petrol) was AS 1876-1990, which has now been withdrawn.

Commonwealth regulations applying to all jurisdictions within Australia include the Fuel Quality Standards Act 2000, Fuel Quality Standards Regulations 2001, Fuel Standard (Petrol) Determination 2001 and Fuel Standard (Diesel) Determination 2001. These pieces of legislation allow for broad regulation and enforcement of fuel quality requirements. Penalties for non-compliance are as high as $550,000.00 under the Fuel Quality Standards Act, which also lays out a process for the appointment of inspectors and details on monitoring and compliance enforcement.

Fuel sampling in Australia attempts to provide a representative sample of fuels in the country while also responding to consumer complaints. Sampling is carried out primarily at distribution terminals and points of sale (gas stations).[40] Fuel quality inspectors employed by a fuel sampling program run by the Australian government carry out sampling at hundreds of sites each year, including at gas stations.

Standards for biofuels are planned, including for ethanol and biodiesel fuel blends.

How does actual fuel quality in Australia align with standards?

Compliance levels are quite high in Australia. In 2007, 145 compliance incidents were reported out of 2,321 samples. A similar compliance level was noted for the 2005–2006 period. Most of the non-compliance incidents are a result of gasoline failing to meet minimum octane requirements. The samples total and compliance incidents include not only gasoline and diesel, but also biodiesel and liquefied petroleum gas.

4.6 Jurisdictional Comparison of Fuel Quality Standards

Approaches to fuel quality regulation and standards vary somewhat from jurisdiction to jurisdiction. A regulatory approach to fuel quality is most common in the jurisdictions studied, combined with voluntary mechanisms in some instances.

Although Canada does have some national-level requirements for gasoline and diesel fuel (sulphur, lead, benzene and ethanol), Australia and the EU had generally more stringent requirements, or a higher number of minimum requirements for a broader range of fuel characteristics at the national level. Canada’s fuel quality standards are a mix of compulsory requirements legislated at the federal and provincial level, and voluntary standards developed through the CGSB.

Australia offers more strict guidance on fuel quality at the federal level than Canada, and provides an example of a more comprehensive national-level standards setting process that has

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[40] Department of the Environment and Water Resources. 2007. *Annual Report 2006–2007*. www.environment.gov.au/about/publications/annual-report/06-07/legislation-fuel-quality.html (accessed May 26, 2008).

occurred in the past decade. Beginning in 2000, Australia embarked on a national-level standards-setting process for fuel quality.

While Australia's federal standards are far from comprehensive, they provide guidance at the federal level on a number of areas of fuel quality for diesel, gasoline, biofuels and liquefied petroleum gas (autogas). Standards for gasoline take into account a variety of fuel characteristics, from octane number (both research and motor) to distillation, sulphur content and aromatics, covering those minimum characteristics required in Canada along with several not addressed by Canada at the federal level. Similar to Australia, the EU has developed a regional approach with a focused fuel quality program with strict requirements for member nations, with certain characteristics varying depending on geography.

The Australian approach is representative of a more unified effort at the national level to address fuel quality issues, as opposed to the Canadian combination of voluntary standards and federal regulations around fuel quality. Although Japan's approach to fuel quality is also a combination of regulatory and voluntary measures, their results in achieving higher fuel quality have been more pronounced than in Canada, with world-leading requirements in certain fuel characteristics. Sampling and monitoring of fuel is also much more stringent, as is the case with all of the other jurisdictions researched.

One significant difference in the approaches of the other jurisdictions studied and Canadian efforts has been the recognition in other jurisdictions of fuel quality as a pillar of an emissions control strategy. Australia's impetus for creating national fuel quality standards is closely related to an identification of fuel quality as a critical element of a comprehensive automobile emissions strategy. For other leading jurisdictions, including the EU, differences with the Canadian approach are more pronounced at the level of the standard-setting process described in Section 5. In the case of the EU, recognition of the critical importance of fuel quality in relation to automobile emissions is captured in the Auto-Oil II process described later in this report.

It should be noted that in most jurisdictions investigated, volatility of fuel (primarily regulated through Reid vapour pressure requirements) is dealt with at the state or regional level and often varies between cities or regions. This is primarily due to geographical and climatic factors impacting the behaviour of fuel with different volatility characteristics; requirements typically also change by season to account for climatic variability.

5. Standard Setting Process

The International Petroleum Industry Environmental Conservation Association notes that "a cost-effective air quality management system requires local and national authorities to simultaneously address fuel quality, vehicle technology, vehicle maintenance and road/traffic conditions."[41]

When considering standard setting processes in Canada, it is useful to look at experiences of other jurisdictions. The European Union, Japan and Australia provide good examples of comprehensive approaches to establishing fuel quality standards.

5.1 European Union

Initially heralded as a model for environmental policy development, the European Commission's Auto-Oil I (AOI) Programme represented a change from the incremental tightening of emissions that previously occurred in the EU. The program was developed through a three way dialogue between the European Commission (EC) and the automobile and oil industries, with a goal of achieving environmental quality objectives with least-cost regulations. However, the European Parliament and Environmental Council ultimately rejected this approach and adopted a far more stringent fuel quality control approach than was recommended in the program.[42]

Many of the problems arose because the Auto-Oil I process mostly excluded stakeholders outside of the EC and the automobile and petroleum industries. An article on AOI in the Journal of European Public Policy notes that "[t]he main procedural deficiency was the exclusion of member state governments, environmental and consumer NGOs, and the supplier industry."[43] In addition, there already existed a Motor Vehicles Emissions Group within the Commission, but it was rarely briefed on the occurrences of the AOI process, and was far from an active participant in the process itself.

A number of observers have pointed to four main problems with AOI. First, the program considered only human health issues and mostly excluded other environmental issues (including climate change). The second problem was a failure to focus on the most severe local health

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[41] International Petroleum Industry Environmental Conservation Association. *Fuel Sulphur: Strategies and options for enabling clean fuels and vehicles* (International Petroleum Industry Environmental Conservation Association, 2006).

[42] Friedrich, Axel and Matthias Tappe. "A new approach to EU environmental policy-making? The Auto-Oil I Programme," *Journal of European Public Policy* 7, no. 4 (2000): 593–612.

[43] Ibid.

issues (such as congested urban areas). A target date of 2010 downplayed immediate beneficial effects of changes to emissions standards and fuel quality and ignored the importance of fuel quality changes for the development of future emissions control technology. The last major issue was the narrow approach to cost-effectiveness which did not account for social costs (e.g. the increase in health problems and premature death from air quality issues) and damage to ecosystems.[44, 45]

Following the Auto-Oil I process, the European Union had proposed further standards to be implemented by 2005 for both fuels and cars through the Auto-Oil II program. The Auto-Oil II program has a wider range of participants than the first program including all relevant industries (not only oil and motor vehicles), member states, non-governmental organizations, and research institutes.[46]

As a result of the AOII process, Directive 98/70, the directive that dictates fuel quality requirements, was amended in 2003. This amendment required the introduction of fuel containing a maximum 10 ppm sulphur by January 1, 2005, with a transition to 10 ppm maximum sulphur for all fuels by December, 2009. It also required that gasoline contain a maximum of 35% aromatics by volume.

These changes did not face the notable barriers in the European Parliament and Environmental Council that the proposed changes from the AOI process encountered. The design of AOII demonstrates European decision makers preference for broad stakeholder involvement in developing new regulations.

5.2 Japan

Japan Clean Air Program I (JCAP I) and Japan Clean Air Program II (JCAP II):

The purpose of the Japan Clean Air Programs was to assess fuel technologies and automobile technologies aimed at creating zero emissions and improvements in fuel economy in order to evaluate the potential for the adoption of low emission vehicles.

JCAP I ran for five years from 1997 to 2001. It involved collaborative study by the automobile industry and petroleum industry and was supported primarily by funding from the Ministry of Economy, Trade and Industry, the Petroleum Association of Japan and the Japan Automobile Manufacturers Association.

JCAP II ran from 2002 to 2007 with a budget of approximately $60 million CDN, most of which was provided by the Ministry of Economy, Trade and Industry. The Japan Petroleum Energy

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[44] Friedrich, Axel and Matthias Tappe. “The Auto-Oil Programme: a critical interim assessment,” *European Environmental Law Review* 7, no. 4 (1998): 104–11.

[45] European Parliament. 1997. *Report on the Directive Relating to Measures to be Taken Against Air Pollution*. Rapporteur: Bernd Lange, A4-0116/97 of 24 March.

[46] Energy Information Administration. 2000. *International Energy Outlook 2000*. (Washington, D.C.: U.S. Department of Energy): 140–141. www.eia.doe.gov/oiaf/archive/ieo00/boxtext.html (accessed August 4, 2008).

Center supervised JCAP II while automobile manufacturers and petroleum companies offered research and technology support.

Japan Auto Oil Program (JATOP)

A new project called the Japan Auto-Oil Program (JATOP) has been launched as an enhanced form of JCAP I / II beginning in 2007. With an eye to addressing climate change concerns and ensuring energy security as premises for conservation and improvement of air quality, the five-year program aims to establish fuel and vehicle technologies that might be best suited to solve three issues in parallel: reduced carbon dioxide emissions, fuel diversification and reduced vehicle emissions.

5.3 Australia

The document "Improving the Quality of Australian Transport Fuels"[47] by the Australian Government provides a good summary of the standard setting process in Australia:

> **The Goal**
>
> To reduce air pollution and greenhouse gas emissions resulting from transport in Australia and overseas by improving fuel quality standards.
>
> […]
>
> **How did we make it happen?**
>
> Fuel standards have been developed in Australia through technical research and industry/stakeholder consultation, leading to new legislation. In 2002 the *Fuel Quality Standards Act 2000* introduced fuel quality standards for petrol and automotive diesel. A downstream compliance regime was also established.
>
> A Consultative Committee was established to provide advice and expertise in the process of fuel standard development. The Committee includes representatives from the Australian Government, States and Territories, fuel producers, environment bodies, consumer interest groups, the automotive manufacturing industry, independent fuel importers and suppliers, the alternative and renewable fuels industry and the trucking industry.
>
> […]
>
> **How far have we come?**
>
> There have been a number of developments in improving fuel quality in Australia and overseas, including:

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[47] Department of the Environment and Heritage. *Improving the Quality of Australian Transport Fuels.* www.un.org/esa/sustdev/csd/casestudies/e4_australia.pdf (accessed July 18, 2008).

> - Fuel quality standards for petrol and automotive diesel came into force in 2002 with the *Fuel Quality Standards Act 2002*, which progressively harmonises Australian fuel quality with international standards.
> - Fuel quality standards for biodiesel and autogas came into force in 2003, and a standard for fuel ethanol is under development. These standards generally tighten over time, for example, sulphur in diesel was capped at 500 mg/kg in 2002 compared to 50 mg/kg in 2006 (with a further drop to 10 mg/kg in 2009). With the resulting improvement in air quality in Australia's urban environments, an estimated $AU3.4 billion will be saved in health costs by 2020.
> - Incentives for early production and import of lower sulphur petrol and diesel have been introduced, resulting in massive investment to upgrade the quality of fuel refined in Australia, whilst bringing forward environmental benefits.
>
> […]
>
> **What have we learnt?**
>
> The success of Australia's fuel standard initiatives is based on strong policy settings and awareness of technological development. Consultation was vital in developing and implementing fuel standards — without an understanding of the importance of the issue, it is difficult to gain public and industry support. As the impacts of transport pollution and emissions are global in nature, it is essential to assist other countries and harness available resources and expertise in order to achieve the goals of reducing air pollution and greenhouse gas emissions.

By dealing with fuel quality as part of a systems approach to emissions management, Australia has demonstrated that it is possible to maximize the benefits of fuel quality changes and vehicle emissions standards by treating them as two sides of the same issue. Although Australia has not yet moved to introduce 10 ppm or lower sulphur fuels through regulation, the government's Land Transport Environment Committee has recommended a shift to a limit of 10 ppm sulphur for premium gasoline. As a result of this integrated approach, the Australian automobile manufacturing industry has signaled that it is willing to accept more stringent fuel economy requirements — 6.8L / 100 km as opposed to 7.4L / 100 km –if this improvement takes place to enable more advanced vehicle technologies.

6. Implementation

The implementation of improved fuel quality standards requires consideration of the broad set of impacts that any changes have on both industry and government (e.g., changes to refinery practices or enforcement mechanisms). This section of the paper discusses several considerations that have been identified and documented through previous changes to fuel quality standards. The considerations listed here may or may not apply to specific changes to fuel quality standards.

6.1 Potential Changes to Refineries

Through previous changes to fuel quality standards, such as reduction in sulphur levels for both gasoline and diesel, a number of potential changes to refinery equipment and practices have been identified.

- change of feedstock, e.g. switching to a lower sulphur feedstock.[48]
- installation of new equipment or modification of existing equipment, such as the fluid catalytic converter, a hydrotreater or a hydrocracker.[49]
- changes to other processes, e.g. desulphurization reduces the octane of gasoline, and thus would require increased aromatics, oxygenates or alkylation to be used, with each option having different impacts for both the refinery and the final product.[50]

6.2 Downstream Considerations

A change to fuel quality also requires consideration of the impacts downstream from the refinery. These include:

- Cross contamination between fuels during handling and transportation

  This is primarily an issue for pipelines. For example, low sulphur fuel can become contaminated with sulphur from other fuels that have been previously transported through the pipeline.[51]
- Changes to environmental impacts

  For example, increased oxygenates may be added to compensate for reducing sulphur. This may increase the risk of groundwater contamination in the event of a spill.[52]

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[48] International Petroleum Industry Environmental Conservation Association. *Fuel Sulphur: Strategies and options for enabling clean fuels and vehicles* (International Petroleum Industry Environmental Conservation Association, 2006).

[49] Ibid.

[50] Ibid.

[51] Ibid.

- Additional distribution requirements

  In some cases, in other jurisdictions, fuel with new specifications has been added to the market without removing any existing fuels. This may require additional, dedicated equipment to transport, store and dispense the new fuel.[53]
- Affect on cross-border movement of fuels and vehicles

  Changes to fuel standards in Canada will have an impact on the ability to move fuels into and out of the country, particularly with the United States — Canada's largest trading partner. For example, improvements to Canadian standards may improve the ability to export fuels to jurisdictions with tighter regulations; whereas improvements to Canadian standards may also limit the ability to import fuels from jurisdictions with lower regulatory limits.

6.3 Monitoring and Enforcement

New fuel quality standards also introduce new monitoring and enforcement processes. These new processes could replace or complement existing processes, or they could be designed to introduce a new approach to monitoring and enforcement. New approaches to monitoring and enforcement could be designed to either increase or decrease the resources required by government and industry, as well as the level of compliance and transparency within the system.

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[52] Ibid.

[53] Ibid.

7. Conclusions

The quality of fuel in Canadian vehicles has a direct impact on vehicle tailpipe emissions — not only in how the fuels are burned in existing vehicles, but also in the introduction of new vehicle technologies. A comprehensive approach to addressing vehicle emissions has been used in many jurisdictions internationally and has led to improved fuel quality standards in those regions. Canada could benefit from a similar approach.

Through the research completed, several specific opportunity areas in which Canadian fuel standards can be improved were identified. These include sulphur and detergency in gasoline, and cetane and lubricity in diesel. The research identified examples of more stringent fuel quality standards in each of these areas as well as research demonstrating the opportunity for reduced tailpipe emissions. It was also noted that internationally, leading jurisdictions have more mandatory fuel quality requirements than Canada, as well as more stringent monitoring and enforcement practices.

Of course, changes to fuel quality standards need to consider more than just tailpipe emissions. Any assessment of proposed changes needs to consider both the costs and the benefits throughout the entire life cycle. Analyses completed for both Australia and the EU demonstrated significant life-cycle cost and environmental benefits for reducing sulphur content in gasoline from 50 ppm to 10 ppm while improving fuel economy as well. These reports suggest that there can be both environmental and cost benefits from improvements to fuel quality in Canada. However, Canadian-specific analyses need to be completed in order to take into account location-dependant factors such as refinery feedstocks and existing infrastructure.

Equally important to the specific changes to fuel quality standards is the process by which they are set. Experience in other jurisdictions has clearly demonstrated the value of stakeholder involvement and buy-in within the process in order to be successful. This has been noted as an area needing improvement within Canada.

Finally, it is important for decision makers to consider the broader impacts of any changes to fuel quality standards. These impacts include changes to refinery equipment and operations, downstream impacts to distribution systems (including the cross-border movement of fuels), new environmental considerations and possible changes to monitoring and enforcement practices.

Based on this research, it is recommended that the Government of Canada follow leading jurisdictions and conduct a thorough review of opportunities to reduce transportation emissions through improved fuel quality standards, including a review of total costs and benefits. The review should include broad stakeholder involvement and should consider potential changes within a Canadian context (e.g., considering Canada's unique feedstock blend). Based on the findings of this process, a comprehensive set of mandatory fuel quality requirements should be introduced, along with enhanced monitoring, enforcement and reporting mechanisms.

Appendix A: World Wide Fuel Charter Categories

Tables A1, A2, and A3 summarize the four categories within the World Wide Fuel Charter.

Gasoline

Canada has already achieved Category 2 gasoline as specified in the Charter; therefore, the research has focused on comparisons to Category 3 and Category 4 fuels.

In general, a number of indicators do not change from category to category between Categories 2, 3 and 4. The indicators which change the most have been presented in bold italics. The most significant decreases lie in the sulphur content of gasoline — it decreases five-fold from Category 2 to 3 and is cut in three between Categories 3 and 4. Significant changes also occur in benzene content, unwashed gum and the cleanliness of engine components. Based on our research into other fuel standards, we have found that Reid vapour pressure (i.e. volatility) also various notably between standards.

Table A 1. Gasoline fuel quality categories within the World Wide Fuel Charter

Measurement	Category 1	Category 2	Category 3	Category 4	Unit	min/max
91 RON	91	91	91	91	Research Octane Number	min
	82	82.5	82.5	82.5	Motor Octane Number	min
95 RON	95	95	95	95	Research Octane Number	min
	85	85	85	85	Motor Octane Number	min
98 RON	98	98	98	98	Research Octane Number	min
	88	88	88	88	Motor Octane Number	min
Oxidation Stability	360	480	480	480	minutes	min
Sulphur Content	***1000***	***150***	***30***	***10***	***mg/kg***	***max***
Metal Content (Fe, Mn Pb, others)	non-detectable	non-detectable	non-detectable	non-detectable	mg/l	max
Phosphorus Content	N/A	non-detectable	non-detectable	non-detectable	mg/l	max
Silicon Content	N/A	non-detectable	non-detectable	non-detectable	mg/kg	max

Oxygen Content	2.7	2.7	2.7	2.7	%m/m	max
Olefins Content	***N/A***	***18***	***10***	***10***	***%v/v***	***max***
Aromatic Content	***50***	***40***	***35***	***35***	***%v/vg***	***max***
Benzene Content	***5***	***2.5***	***1***	***1***	***%v/v***	***max***
Volatility	See Table A 2 below					
Sediment	N/A	1	1	1	mg/l	max
Unwashed Gums	***70***	***70***	***30***	***30***	***mg/100ml***	***max***
Washed Gums	5	5	5	5	mg/100ml	max
Density	715–780	715–770	715–770	715–770	kg/m^3	range
Copper Corrosion	Class I	Class I	Class I	Class I	merit	
Appearance	Clear and bright; no free water or particulates					
Carburetor Cleanliness	8	N/A	N/A	N/A	merit	
Fuel Injector Cleanliness (Method 1)	10	5	5	5	% flow loss	max
Fuel Injector Cleanliness (Method 2)	10	10	10	10	% flow loss	max
Particulate Contamination, Size Distribution	***N/A***	***N/A***	***18/16/13 per ISO 4406***	***18/16/13 per ISO 4406***		
Intake Valve Cleanliness	9	N/A	N/A	N/A	merit	
Intake Valve Sticking	—	pass	pass	pass		
Intake Valve Cleanliness II						
Method 1 (CEC F-05-a-93) or	***N/A***	***50***	***30***	***30***	***avg. mg/valve***	***max***
Method 2 (ASTM D 5500) or	***N/A***	***100***	***50***	***50***	***avg. mg/valve***	***max***
Method 3 (ASTM D 6201)	***N/A***	***90***	***50***	***50***	***avg. mg/valve***	***max***
Combustion Chamber Deposits						
Method 1 (ASTM D 6201) or	***N/A***	***140***	***140***	***140***	***% of base fuel***	***max***
Method 2 (CEC-20-F-A-98) or	***N/A***	***3500***	***2500***	***2500***	***mg/engine***	***max***
Method 3 (TGA-FLTM BZ154-01)	***N/A***	***20***	***20***	***20***	***% mass. @ 450°C***	***max***

Table A 2. Gasoline volatility categories within the World Wide Fuel Charter

CATEGORY 1					
Class *	**A**	**B**	**C**	**D**	**E**
Ambient Temp. Range, °C	> 15	5 to 15	-5 to +5	-5 to -15	< -15
Vapour Pressure, kPa	45 - 60	55 - 70	65 - 80	75 - 90	85 - 105
T10, °C, max	70	70	65	60	55
T50, °C	77 - 110	77 - 110	77 - 110	77 - 110	77 - 110
T90, °C	130 - 190	130 - 190	130 - 190	130 - 190	130 - 190
EP, °C max.	215	215	215	215	215
E70, %	15 - 45	15 - 45	25 - 45	25 - 47	25 - 47
E100, %	50 - 60	50 - 65	50 - 65	55 - 70	55 - 70
E180, % min	85	85	85	85	85
* ‘Class’ is based on the minimum expected ambient temperatures of the market and will vary by season.					

CATEGORY 2, 3 and 4					
Class *	**A**	**B**	**C**	**D**	**E**
Ambient Temp. Range, °C	> 15	5 to 15	-5 to +5	-5 to -15	< -15
Vapour Pressure, kPa	45 - 60	55 - 70	65 - 80	75 - 90	85 - 105
T10, °C, max	65	60	55	50	45
T50, °C	77 - 100	77 - 100	77 - 100	77 - 100	77 - 100
T90, °C	130 - 175	130 - 175	130 - 175	130 - 175	130 - 175
EP, °C max.	195	195	195	195	195
E70, %	20 - 45	20 - 45	25 - 45	25 - 47	25 - 47
E100, %	50 - 65	50 - 65	50 - 65	55 - 70	55 - 70
E180, % min	90	90	90	90	90
D.I., max	570	565	560	555	550
* ‘Class’ is based on the minimum expected ambient temperatures of the market and will vary by season.					

Diesel

The diesel requirements from the WWFC are summarized in Table A3. Since Canada has already achieved Category 2 diesel, the research focused on comparisons to Category 3 and Category 4 fuels.

Many recommendations for particular fuel characteristics do not change from category to category between Categories 2, 3 and 4. The indicators which change the most have been presented in bold italics in Table A 2. The most significant decreases lie in the sulphur content of diesel — it decreases six-fold from Category 2 to 3 and is cut to one fifth between Categories 3 and 4.

Table A 3. Diesel fuel quality categories within the World Wide Fuel Charter

Measurement	Category 1	Category 2	Category 3	Category 4	Unit	min/max
Cetane Number	***48***	***51***	***53***	***55***		***min***
Cetane Index[54]	***48.0 (45.0)***	***51.0 (48.0)***	***53.0 (50.0)***	***55.0 (52.0)***		***min***
Density @ 15°C	820	820	820	820	kg/m^3	min
Viscosity @ 40°C	2	2	2	2	mm^2/s	min
Sulphur Content	***2000***	***300***	***50***	***10***	***mg/kg***	***max***
Metal Content (Zn, Cu, Mn, Ca, Na, Other)	N/A	non-detectable	non-detectable	non-detectable	g/l	max
Total Aromatics Content	***N/A***	***25***	***20***	***15***	***%m/m***	***max***
PAH Content (di+, tri+)	***N/A***	***5***	***3***	***2***	***%m/m***	***max***
T90	***N/A***	***340***	***320***	***320***	***C***	***max***
T95	***370***	***355***	***340***	***340***	***C***	***max***
Final Boiling Point	***N/A***	***365***	***350***	***350***	***C***	***max***
Flash Point	55	55	55	55	C	min
Carbon Residue	***0.3***	***0.3***	***0.2***	***0.2***	***%m/m***	***max***
CFPP or LTFT or CP	Max must be equal to or lower than the lowest expected ambient temperature					
Water Content	500	200	200	200	mg/kg	max

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[54] Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parentheses.

Oxidation Stability - Method 1	25	25	25	25	g/m^3	max
Foam Volume	***N/A***	***N/A***	***100***	***100***	***ml***	***max***
Foam Vanishing Time	***N/A***	***N/A***	***15***	***15***	***sec***	***max***
Biological Growth	N/A	'Zero' content	'Zero' content	'Zero' content		max
FAME Content	***5***	***5***	***5***	***non-detectable***	***%v/v***	***max***
Ethanol/Methanol Content	non-detectable	non-detectable	non-detectable	non-detectable	%v/v	max
Total Acid Content	N/A	0.08	0.08	0.08	mg KOH/g	max
Ferrous Corrosion	N/A	Light rusting	Light rusting	Light rusting		max
Copper Corrosion	Class I	Class I	Class I	Class I	merit	max
Ash Content	***0.01***	***0.01***	***0.01***	***0.001***	***%m/m***	***max***
Particulate Contamination, Total	10	10	10	10	mg/kg	max
Particulate Contamination, Size Distribution	N/A	18/16/13 per ISO 4406	18/16/13 per ISO 4406	18/16/13 per ISO 4406	code rating	max
Appearance	Clear and bright; no free water or particulates					
Injector cleanliness	N/A	85	85	85	% air flow loss	max
Lubricity (HFRR wear scar diameter @ 60°C)	400	400	400	400	micron	max

Appendix B: Jurisdictional Standards

The tables below provide information on fuel quality standards and regulations in jurisdictions reviewed for this report. Both gasoline and diesel standards are profiled.

Canada

Table B 1. CGSB 3.5 Automotive Gasoline

Parameter	Amount	Unit
Octane (Motor)	82	MON minimum
Antiknock Index	87–93	(RON+MON) /2 (minimum)
Distillation T90	185–190	°C, maximum
Vapour Pressure	38–107 (seasonal and regional)	kPa
Sulphur	30 ppm	Pool average; 80 ppm cap limit
Manganese	18	mg/l maximum
Benzene	1.00	% volume
Lead	Undetectable	mg/l maximum
Gum Content (washed)	5	mg/100 ml maximum
Conductivity	25	pS/m
Carbon Residue	0.2	Ramsbottom %mass, maximum
Copper Corrosion	no.1	D130 test method
Oxidation Stability (min induction period)	240	D525 test method
Copper Corrosion	No. 1	maximum
Phosphorus	1.3	mg/l maximum

Table B 2. CGSB 3.517 Automotive Low-Sulphur Diesel

Parameter	Amount	Unit
Cetane Number and Index	40	minimum
Distillation T90	360	°C
Viscosity	1.7–4.1	CST, at 40°C
Conductivity	25	pS/m
Carbon Residue	0.2	Ramsbottom % mass, maximum
Copper Corrosion	no.1	D130 test method
Sulphur	15	ppm
Water and Sediment	0.05	% volume
Flash Point	40	°C, minimum

European Union

Table B 3. Directive 98/70/EC and Directive 2003/17/EC — Gasoline

Parameter	Amount		Unit	Notes
	Min	Max		
Octane (Research and Motor)				
Research Octane Number (RON)	95		—	
(for RON 91fuel only)	91		—	
Motor Octane Number (MON)	85		—	
(for RON 91fuel only)	81		—	
Sulphur				
Low sulphur		50	mg/kg	Limit as of 2005
Sulphur-free		10	mg/kg	Directive 2003/17/EC amends Directive 98/70/EC: In each Member State from 1 January 2005, sulphur-free (<10 ppm) fuels were required to be made available “on an appropriately balanced geographical basis”. From 1 January 2009 only sulphur-free fuels will be available.
Vapour Pressure, DVPE				
Summer Pressure (normal)		60	kPa	
Summer Pressure (arctic or severe weather conditions)		70	kPa	
Benzene		3	% (v/v)	
Control Aromatics (including MTBE, DIPE, TBA) and Olefins				
Olefins		18	% (v/v)	
Olefins (RON 91 fuel only)		21	% (v/v)	
Aromatics		35	%(v/v)	Limit as of 2005
Lead		0.005	g/l	
Distillation				
- evaporated at 100°C	46		% (v/v)	
- evaporated at 150°C	75		% (v/v)	
Oxygen content		2.7	% (m/m)	
Oxygenates				
Methanol		3.0	% (v/v)	

Ethanol		4.0	% (v/v)	
Iso-propyl alcohol		10.0	% (v/v)	
Tert-butyl alcohol		7.0	% (v/v)	
Iso-butyl alcohol		10.0	% (v/v)	
Ethers with 5 or more carbon atoms per molecule		15.0	% (v/v)	
Other oxygenates		10.0	% (v/v)	

Table B 4. Directive 98/70/EC and Directive 2003/17/EC — Diesel

Parameter	Amount		Unit	Notes
	Min	Max		
Cetane Number and Index	51			
Density at 15°C		845	kg/m^3	
Distillation — 95% point		360	°C	
Sulphur				
Low sulphur		50	mg/kg	Limit as of 2005
Sulphur-free		10	mg/kg	Directive 2003/17/EC amends Directive 98/70/EC: In each Member State from 1 January 2005, sulphur-free (<10 ppm) fuels were required to be made available “on an appropriately balanced geographical basis”. From 1 January 2009 only sulphur-free fuels will be available.
Polycyclic aromatic hydrocarbons		11	% (m/m)	

Japan

Table B 5. JIS K2202 — Gasoline

Parameter	Amount	Unit	Notes
Octane (Research)	89 (96 for Grade 1 / premium)	RON	
Sulphur	10	ppm	effective Jan. 1, 2008
Vapour Pressure	44 to 78	kPa	93 max in winter allowed for cold climates, 65 max in summer
Benzene	1	% volume	5% before 2000
MTBE	7.00	% volume	
Density	0.783	g/cm^3 at 15°C	
Lead	Undetectable	g/L	
Gum Content (existent gum — washed)	5	mg/ 100 ml	
Distillation T90	180	°C, maximum	90% max
Oxygen Content	1.30	% mass maximum	
Ethanol	3	% volume maximum	
Copper Corrosion (3 hrs @ 50ºC)	1	maximum	
Oxidative Stability	240	minutes	

Table B 6. JIS K2204-No.2 Diesel Fuel (also includes regulated Quality Assurance Law requirements)

Parameter	Amount	Unit	Notes
Cetane Number and Index	45	minimum	
Distillation T90	360	°C	maximum (90% recovered min)
Viscosity	3.5	CST, at 30°C	Alternative test method: Kinematic Viscosity @ 30ºC, mm^2/s, min (30°C), 1.7
Density	0.86	g/cm^3 at 15°C	
Carbon Residue	0.1	Ramsbottom % mass, maximum	10% residue, Mass %, max
Sulphur	10	ppm	Effective 2007; previously 50 ppm
Flash Point	45	°C, minimum	
Pour Point	–7.5	°C, maximum	–20°C maximum for No. 3
Cold Filter Plugging Point	–5	°C, maximum	–12°C maximum for No. 3

Australia

Table B 7. Gasoline Standards in Australia

Parameter	Amount	Unit	Notes
Octane (Research)	Regular: 91 Premium: 95	minimum	
Octane (Motor)	Regular: 81 Premium: 85	minimum	
Sulphur	50	ppm, maximum	
Benzene	1	% volume, maximum	
Olefins	18	% volume, maximum	
MTBE	1.0	% volume, maximum	
DIPE	1.0	% volume, maximum	
TBA	0.5	% volume, maximum	
Lead	0.005	g/L, maximum	
Gum content (existent gum - washed)	50	mg/L, maximum	
Distillation	210	°C, maximum final boiling point	
Oxygen content	without ethanol: 2.9 with ethanol: 3.9	% mass, maximum	
Induction period	360	minutes, minimum	
Ethanol	10	% volume, maximum	
Copper corrosion (3 hrs @ 50ºC)	Class 1	maximum	ASTM D130 test method
Phosphorous	0.0013	g/L, maximum	
Aromatics	42% over 6 months Cap of 45%	pool average	

Table B 8. Diesel Standards in Australia

Parameter	Amount	Unit	Notes
Cetane Number and Index	46	minimum	
Viscosity	2.0-4.5	cSt	@ 40 degrees C
Distillation T95	360	°C, maximum	
Density	820-850	kg/m3	
Conductivity	50	pS/m	@ ambient temp
Lubricity	0.46	maximum	
Carbon residue	0.2	% mass, maximum	@ 10% distillation residue
Copper corrosion	1	Class, maximum	
Sulphur	50	ppm, maximum	Reduced to 10 ppm maximum in January 2009
Ash and Suspended Solids	100	ppm, maximum	
Water and Sediment	0.05	% volume, maximum	
PAH’s	11	% mass, maximum	
Oxidation stability	25	mg/L, maximum	
Flash point	61.5	°C minimum	
Filter blocking tendency	2.0	maximum	

California

Table B 9. California RFG Phase 3 — Gasoline

Parameter	Flat limit	Unit	Averaging Limit	Unit	Cap limit	Unit	Notes
Sulphur	20	ppm	15	ppm	30	ppm	Cap will be reduced to 20 ppm Dec. 31, 2011
Vapour Pressure	7.00 or 6.90	psi	N/A		6.40–7.20	psi	re: 6.90 applies when evap element of predictive model is used; RVP cap limit = 7.20.
	(48.3 or 47.6)	(kPa)			(44.1–49.6)	(kPa)	
Benzene	0.8	Vol %	0.7	Vol %	1.1	Vol %	
Control Aromatics (including MTBE, DIPE, TBA)	25	Vol %	22	Vol %	35	Vol %	
MTBE	0.05	Vol %	N/A		0.5	Vol %	As of July 2007
Olefins Content	6	Vol %	4	Vol %	10	Vol %	
Lead	0.05	gm/gal	N/A		0.05	gm/gal	
	(0.0132)	(gm/L)			(0.0132)	(gm/L)	
Phosphorus Content	0.005	gm/gal	N/A		0.005	gm/gal	
	(0.00132)	(gm/L)			(0.00132)	(gm/L)	
Oxygen Content	1.8–2.2	Weight %	N/A	Weight %	0–3.5	Weight %	1.8% winter minimum applies Nov. 1 to Feb. 29 in the South Coast Area and Imperial County. Cap limit is 3.7 (instead of 3.5) w% if oxygen is > 3.5 w% and ethanol content is <10 v%.
Distillation, T50	213	°F	203	°F	220	°F	
	(100.6)	(°C)	(95.0)	(°C)	(104.4)	(°C)	
Distillation, T90	305	°F	295	°F	330	°F	
	(151.7)	(°C)	(146.1)	(°C)	(165.6)	(°C)	
Ethanol Content	10	Vol %	N/A		10	Vol %	

Table B 10. California Code of Regulations, Title 13, Division 3, Chapter 5 (Standards for Motor Vehicle Fuels) Article 2. Standards for Diesel Fuel

Parameter	Specification	Unit	Designated Equivalent Limits	Unit	Notes
Cetane Number and Index	48	min			47 for small refiners, 53 for alternative diesel
Viscosity at 40°C	2–4.1	cSt			
Distillation IBP	340–420 (171–215)	°F (°C)			
10% REC.	400–490 (204–254)	°F (°C)			
50% REC.	470–560 (243–293)	°F (°C)			
90% REC.	550–610 (288–321)	°F (°C)			
EP	580–660 (304–349)	°F (°C)			
Lubricity	520	microns	520	microns	
Sulphur	15	ppm	15	ppm	
PAH's			3.5	% by wt.	only for alternative diesel
Flash Point	130 54.4	°F (min) (°C min)			
Aromatic Hydrocarbon Content	10	% by vol	21	% by w	20 v% for small refiners
Gravity	33–39	API			
Polycyclic Aromatic Hydrocarbon	1.4	% max			4% for small refiners
Nitrogen Content	10	ppm max			90 for small refiners, 500 for alternative diesel
API Gravity	N/A		36.9	minimum	