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October 31, 2014

Henry O'Clery
Future Climate Australia

Via email:

Subject: Fuel Quality and CO_2 emission standards for Australia

Dear Henry,

Thank you for your inquiry about fuel quality and CO_2 emissions. The ICCT believes that vehicle and fuel should be treated as a system, but the present quality of fuel available for road transport across Australia does not present any impediment to reduce vehicle CO_2 emissions at rates comparable to the other regions of the world.

If Australia wishes to move towards tighter conventional pollutant emission standards such as U.S. Tier 3 emission standards, then fuel quality -- in particular sulfur content of gasoline -- should be improved. Lack of availability of ultra-low sulfur gasoline should not, however, become an excuse to delay action on light-vehicle CO_2 emission standards.

I'm including a short memo with this letter that clarifies the relationship between fuel quality and CO_2 emissions further. If you have any questions or comments, please do not hesitate to let us know.

Best regards,

Anup Bandivadekar
Passenger Vehicle Program Director
The International Council on Clean Transportation

cc:
Scott Ferraro
Eli Court

incl:
Memo on Fuel Quality and Light vehicle CO_2 emission standards for Australia

Fuel Quality and Light vehicle CO_2 emission standards for Australia

In the debate over inclusion of light-vehicle CO2 standards in Australia Energy White Paper, some stakeholders seem to have made an assertion that the lack of low sulfur and 95 RON gasoline could be an impediment in meeting any future new vehicle CO_2 standards.

Sulfur and vehicle fuel efficiency

It is likely that some of the stakeholders are confused about the fundamental differences between criteria pollutants and CO_2 emissions. Criteria pollutant (NOx, CO, HC, PM) standards, do have major linkages with gasoline-sulfur content because catalyst aftertreatment systems work better with low sulfur fuel; however, gasoline sulfur content does not present an obstacle for prominent vehicle efficiency technologies for compliance with CO_2 standards.

(1) Gasoline sulfur content does not pose a problem for increasing fuel economy.

- Source: US EPA, 2000
  - The U.S. Environmental Protection Agency implemented Tier 2 vehicle criteria pollutant standards in concert with a regulation for reformulated low-sulfur gasoline. In their regulatory research, they analyzed potential connections with these sulfur/criteria regulations and the fuel economy of vehicles.
  - Summarized that that the regulations had “no significant impacts on either fuel economy or performance of the vehicles”
- Source: Auto/Oil Air Quality Improvement Research Program (AQIRP), 1997
  - A six-year program with emission testing of over 100 vehicles by the 3 automobile and 14 oil companies, conducted to analyze reformulated fuels effect on emissions and fuel economy.
  - The project analyzed vehicle emissions from use of fuel sulfur content that ranged from 450 ppm sulfur (early 1990s levels) to 50 ppm sulfur (federal US Tier 1 levels).
  - Concluded that “Sulfur content had no effect on fuel economy”
- Source: Coordinating Research Council (CRC), 2000.
  - Testing of number of vehicles in 1999-2000 over variety of drive cycle procedures, with gasoline sulfur content of 1, 50, and 100 ppm.
  - No significant impact of sulfur content on fuel economy was found.

(2) Low sulfur fuel is crucial in enabling more stringent criteria pollutant standards for gasoline and diesel vehicles.

- Source: US EPA, 2000
  - Tier 1 and Tier 2 vehicle emission standards required lower sulfur fuel to achieve new more stringent HC, NOx, CO levels due to the problems associated with the conversion efficiency of catalytic convertors in the presence of sulfur. Sulfur also impedes the functioning of diesel particulate

filters—without ultralow sulfur diesel, Tier 2 standards would be out of reach for diesel vehicles.

(3) Low sulfur fuel might be important for long-term lean-burn combustion technologies that are in development stages.

- Traditional three-way catalysts are only effective at stoichiometry. The extra oxygen in lean-burn engines inhibits NOx reduction in the three-way catalyst. Lean-NOx catalysts are highly sensitive to sulfur and, thus, higher sulfur levels can inhibit introduction of lean-burn engines. However, even in countries with low sulfur fuel very few gasoline lean-burn engines have been produced, so this is currently only a theoretical concern.
- There are other ways to gain the efficiency advantages of running with a lean air/fuel ratio, such as using high rates of exhaust gas recirculation or using a fuel with high levels of ethanol (e.g. E30). Thus, the impact of sulfur on lean-burn engines may never become an inhibiting factor.
- Source: US EPA, 2010
    - EPA will continue to assess emissions control performance of more advanced engine efficiency technologies like lean-burn gasoline direct injection which are *not* expected to have significant deployment by 2016 even in countries with low sulfur fuel (p. 6799):

      "The EPA staff will continue to assess the emission control potential of vehicles powered by technologies such as lean-burn and/or fuel-efficient technologies, including diesel engines equipped with advanced aftertreatment systems…. In the assessment we will maintain a "systems" perspective, considering the progress of advanced vehicle technologies in the context of the role that sulfur in fuels plays in enabling the introduction of these advanced technologies."

Gasoline octane rating and vehicle fuel efficiency

Technically, it is accurate to state that higher gasoline octane rating enables greater compression ratios and higher levels of turbocharger boost, and hence lower fuel consumption and CO_2 emissions.

(1) Compression ratios could be increased without necessarily increasing octane rating of fuel.

- Source: U.S. Environmental Protection Agency (EPA) and Department of Transportation (DoT), 2010.
    - While stating the case for US 2012-2016 fuel economy standards, the agencies stated:
        - "Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. … Use of GDI systems with turbocharged engines and air-to-air charge air cooling also reduces

the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios."

        - The so called cooled EGR technology "reduces knock sensitivity which enables the use of more optimal spark advance or enables compression ratio to be increased for improved thermal efficiency, and increased fuel economy. Currently available turbo, charge air cooler, and EGR cooler technologies are sufficient to demonstrate the feasibility of this concept."
    - In the same document, the US agencies also state that variable valve timing can be used to alter and optimize the effective compression ratio where it is advantageous to do so.

(2) The worldwide fuel charter RON 95 is a wish, not a requirement.

- The worldwide fuel charter (WWFC) makes several excellent points about fuel quality including the need to have lead and manganese free gasoline, as well as low-sulfur fuels. The charter also states that "95 RON will enable manufacturers to optimize powertrain hardware and calibrations for thermal efficiency and CO2 emissions".
- Note that the U.S. gasoline pool has an effective RON rating of about 92, and this has not affected the introduction of high-efficiency downsized turbocharged/gasoline direct injection engines. For example, Mazda's SKYACTIVE-G 2.5-liter direct injection gasoline engine has a compression ratio of 13.0:1, and runs on regular unleaded gasoline.

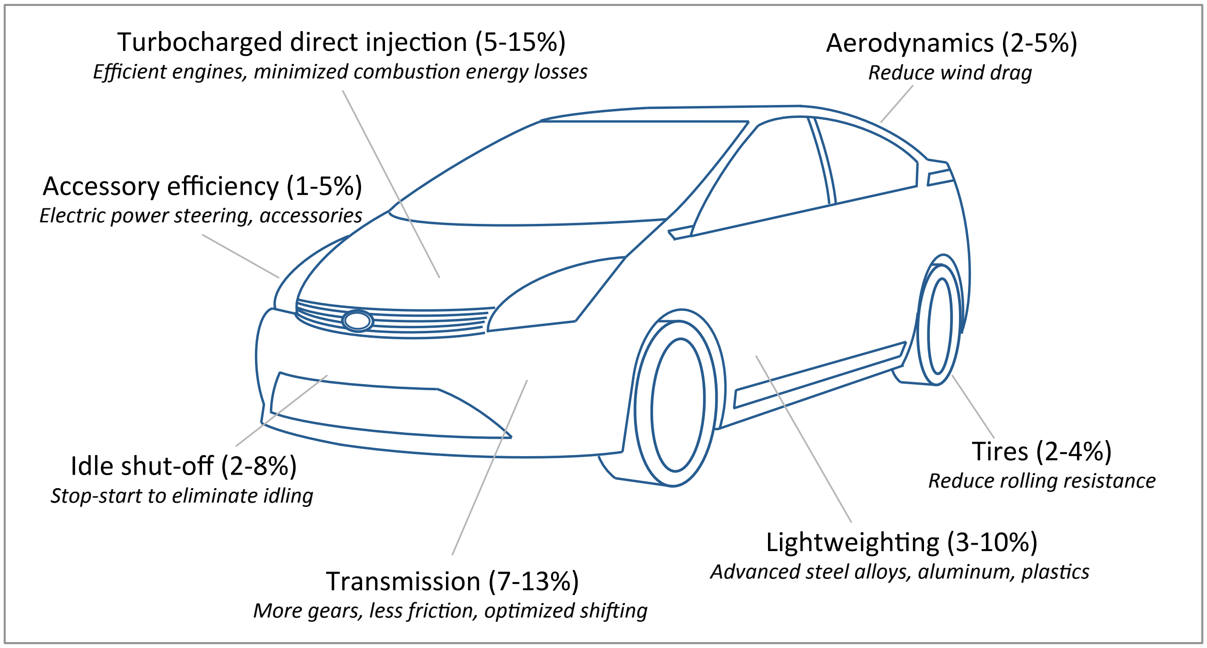
(3) The impact of octane on vehicle fuel economy is not large

- Source: Speth et al (2014)
    - The ratio of compression ratio to octane number is 0.17% to 0.25%, i.e. compression ratio can be raised by one with an octane increase of 4 to 6 RON.
    - The impact of compression ratio on efficiency varies with the baseline compression ratio. For example a unit increase in compression ratio with a 10.0:1 baseline will yield a 2.2% increase in efficiency and with a 11.5:1 baseline will yield a 1.4% increase.
    - The higher compression ratio will also increase performance. Simulations using Argonne National Laboratory's Autonomie model yield an additional 32% increase (x1.32) in efficiency for engine downsizing associated with the performance increase.
    - Speth et al modeling of a 6 RON increase yielded a net fuel consumption reduction of 3.0-4.5% for a naturally aspirated engine and 4.9-7.1% for a turbocharged engine.
    - Thus, increasing octane for regular grade fuel in Australia from 91 to 95 RON would reduce fuel consumption of current generation naturally aspirated engines by 2.0-3.0% and 3.3-4.7% for turbocharged engines.
        - Note that this improvement will decrease in the future as baseline compression ratios rise.

        - Note that this reduction in fuel consumption would only occur if engines in Australia were redesigned to take advantage of the higher octane.
- Source: Leone et al 2014
    - Over the EPA test cycles, a turbocharged engine optimized for 11.9:1 compression ratio yielded a 4.8-5.1% improvement in fuel economy compared with a baseline 10.0:1 compression ratio.
    - This increase (4.8-5.1%) is roughly the same as the 4.9% improvement found by Speth et al for turbocharged engines. However, the compression ratio increase is much larger -- 1.9 versus 1.0 for Speth. This suggests that the fuel consumption decreases found by Speth et al may be overstated.

(4) Improving engine compression ratio is just one technology among a multitude of technology pathways available to reduce vehicle CO_2 emissions. The following tables and accompanying figure shows a variety of engine, transmission as well as vehicle level technologies that can be brought to bear on reducing vehicle fuel consumption and CO_2 emissions. Nearly all of these technologies have larger impacts on fuel consumption than raising octane from 91 to 95 RON.

Area	Technology	Fuel economy improvement	Example new vehicle models and technology marketing names
Engine	Advanced variable valvetrains	4-6%	Audi “Valvelift”; Honda “VTEC”; BMW “VANOS”
	Turbochargers	2-5%	Ford “EcoBoost” (Fusion, Escape, Edge F150);
	Gasoline direct injection (GDI)	5-15%	GM “Ecotec”; Mazda “SkyActiv”; Ford “EcoBoost” (Fusion, Escape, F150); VW “TSI”
	Cylinder deactivation	5-6%	Honda “Variable Cylinder Management”; GM “Cylinder on Demand”
	Diesel engines	15-25%	Mercedes “Bluetec”; VW “TDI”
Transmission	6+ speed transmissions	2-8%	Chrysler 200 (8-speed); Audi A3 (7-speed)
	Dual-clutch transmission	9-13%	Ford “PowerShift” (Focus); VW “Direct-Shift Gearbox” (Jetta, Golf)
	Continuously variable transmission (CVT)	8-11%	All Toyota, Nissan, Honda hybrids; Jeep Patriot, Compass; Subaru Impreza
	Stop-start	2-8%	Hyundai “Blue-Drive”; Ford “Auto Stop-Start”
Overall vehicle	Accessory and auxiliary efficiency (e.g., electric power steering, efficient air-conditioning)	1-5%	(all manufacturers)
	Low rolling resistance tires	2-4%	(all manufacturers)
	Aerodynamic features (lower clearance, underbody panels)	2-5%	(all manufacturers)
	Lightweight advanced materials (aluminum, plastic, carbon fiber)	3-10%	(all manufacturers)
	Hybrid gasoline-electric vehicle	5-50%	Toyota Prius; Honda Civic hybrid
	Plug-in electric vehicle	50-100%	GM Volt; Nissan LEAF;



Note also the following examples of actual vehicles sold in the U.S. market that have improved efficiency by using many of the technologies mentioned above:

Vehicle model	Vehicle class	Original fuel economy (km/L)	New fuel economy (km/L)	Change	Low-carbon/efficiency technologies
Ford Focus	Compact car	11.9	13.6	14%	Direct injection, 6-speed dual-clutch transmission, electric power steering
Subaru Impreza	Station wagon	9.4	12.8	36%	Continuously variable transmission, 160-lb mass reduction, lower rolling-resistance tires, electric power steering
Hyundai Sonata	Midsize sedan	9.4	11.1	18%	Variable valve timing, direct injection, 6-speed, aerodynamics, mass reduction
Nissan Altima	Midsize sedan	11.1	13.2	19%	Intake/exhaust valve timing, continuously variable transmission, taller gear ratio, mass reduction, aerodynamics
Mazda CX-5	Small sport utility vehicle	9.8	11.9	22%	Direct injection, 6-speed transmission, mass reduction, aerodynamics, friction reduction, high compression Atkinson engine
Ford Explorer	Large sport utility vehicle	6.8	9.8	44%	Turbocharging, direct injection, 6-speed transmission, mass reduction, aerodynamics
Ford F150	Large pickup truck	6.0	7.7	29%	Turbocharging, direct injection, 6-speed transmission, mass reduction, aerodynamics

In conclusion, there is no direct relationship between fuel sulfur content and vehicle CO_2 emissions, and Australia's current fuel quality does not present any impediment to delivering CO2 emission reduction at rates comparable with other regions of the world.

References:

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