IHS ADVISORY SERVICES

FUEL QUALITY AND EMISSIONS STANDARDS IN AUSTRALIA

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Fuel Sulfur Impacts on Euro 6 Compliance

November, 2016 - Final Report

Prepared for :

Commonwealth of Australia

Department of Infrastructure and Regional Development

Contents

Background of Request

- The Australian Department of Infrastructure and Regional Development ("Customer") requires an analysis of the potential impact of fuel quality on light vehicles if Australia implements new emissions regulations.

- Specifically, the Customer is considering mandating Euro 6 noxious emissions standards and a standards regime for fuel efficiency for light vehicles.

- There is an issue of whether Australian market petrol is of an appropriate quality, in terms of sulfur content (official legal levels are 50-150 ppm), to ensure these standards would achieve their desired objectives in field. This is particularly important for the implementation of Euro 6.

Australian Fuel Quality and Emissions Standard
Key points to address

From *"ATM – Consultancy Services Reference, No:10013975 [A.A.3 – The Requirement]"*

- the possible effects of sulfur in petrol—at both average and maximum allowable levels in Australia—on the ability of vehicles to meet Euro 6 particle number requirements;
- the highest level of sulfur in petrol that could be used to operate vehicles in typical conditions without significant risk of exceeding the Euro 6 on-board diagnostic (OBD) system thresholds within the 160,000 km durability period;
- an assessment of what technologies that may be used to meet Euro 6 and/or improved fuel efficiency requirements are sulfur sensitive and what levels of sulfur in petrol would potentially exclude their use in Australia, including consideration of the scope for calibrating technologies to petrol sulfur levels;
- the possible effects of sulfur on the need for emission control systems to regenerate to comply with Euro 6 requirements, and consequential impacts on the durability of these systems.

Australian Fuel Quality and Emissions Standard
IHS Project Framework – In-house Research Experience

- IHS will use previously completed knowledge and primary research experience related to requested areas such as fuel quality, fuel efficiency, and more specifically, Euro-6 standards and sulfur related issues.
- Regarding fuel quality, IHS will provide gasoline sulfur levels and other quality specifications (existing and announced) for major countries

- IHS will conduct industrial interviews using IHS own network, which will add a value to understand a key question about using 10-150ppm range of fuels or : what level of sulfur is too much to meet Euro-6.

“Terms of Reference”

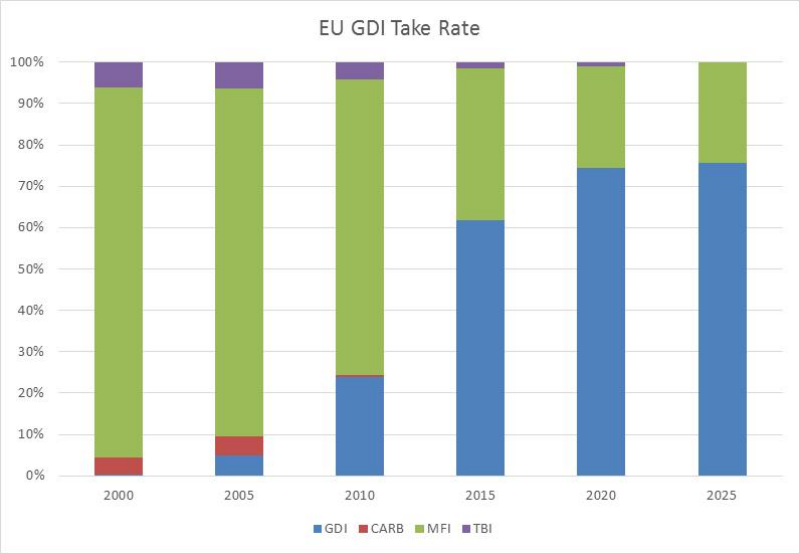
Executive Overview

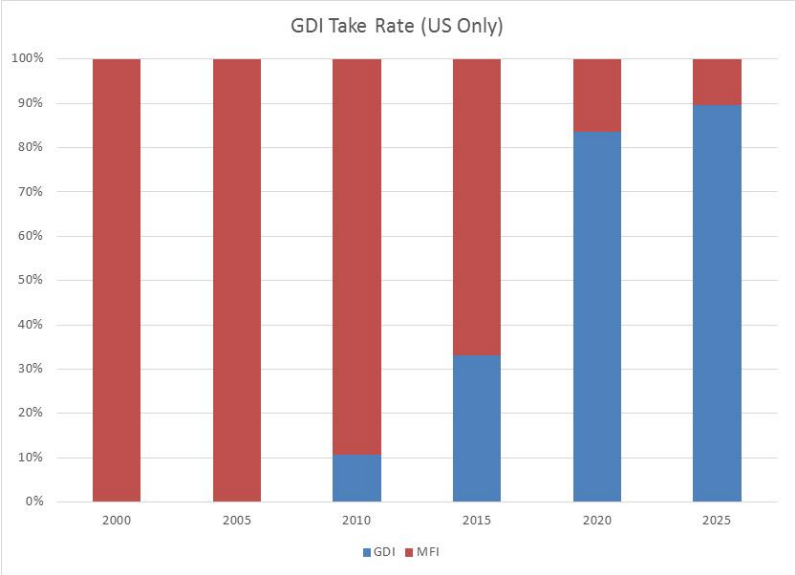
Terms of Reference

- First Question: the possible effects of sulfur in petrol—at both average and maximum allowable levels in Australia—on the ability of vehicles to meet Euro-6 particle number (PN) requirements;
  - Euro-5 was the EC's first attempt to regulate PN is light duty gasoline engines. The subsequent Euro-6 regulation maintained the Euro-5 PN specification of 6.0×10^{11}.
  - The PN specs are a response to the use of Gas Direct Injection (GDI) as the solution most automakers have implemented to meet more stringent emissions requirements
    - But GDI has a negative side impact of also increasing PN (by a factor of 10X) vs. the older port fuel injection (see MECA study from July 2013 page 23 http://www.meca.org/resources/meca_ufp_white_paper_0713_final.pdf)
    - In response car makers are adding Gas Particulate Filters (GPF) for GDI engines and NO_X traps for lean burn engines. Volkswagen announced on August 3, 2016 that starting in 2017 it will start introducing GPF that will reduce PN output by 90% (source: VW website)

Terms of Reference

- First Question (cont):
  - Note the aggressive roll out of GDI in both Europe and the United States
  - In Europe GDI was on 5% of engines produced in the region in 2005, jumping to over 10% in 2010
  - In the United States GDI was on 10% of the engines in 2010 and by 2015 it grows by over 300%
  - By 2020 GDI is on over 75% of the gasoline engines produced in both regions and is (only) not offered on some very old engine platforms





Source: IHS Powertrain Forecast

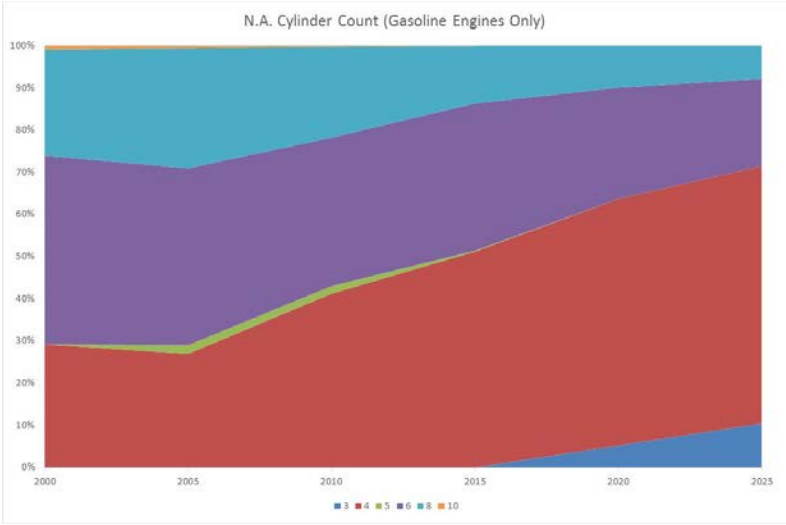
Terms of Reference

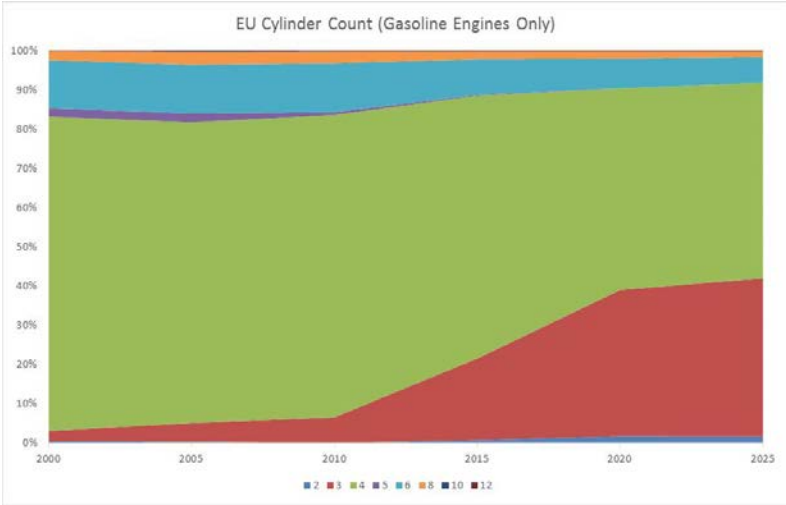
- Second Question: the highest level of sulfur in petrol that could be used to operate vehicles in typical conditions without significant risk of exceeding the Euro-6 on-board diagnostic (OBD) system thresholds within the 160,000 km durability period;
  - From the BMW section from the World Wide Fuel Charter paper (page 10 Submission to the Federal Government BMW Group Response: Vehicle Emissions Discussion Paper, BMW Group. (2016, April). https://infrastructure.gov.au/roads/environment/forum/files/BMW_Group.pdf), we know that the Oxygen sensor monitors the health of the 3-Way catalysts and the OBD system manages that process and that sulfur has a negative impact on the Oxygen sensor, which will make the engine less efficient and pollute more.
  - High sulfur levels (+50 ppm) will inhibit the Emission Control Technologies from making the 160,000 km milestone
    - In the report from the UN page 25 table 2.6 http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf

      Gasoline of <15 ppm sulfur is required
  - We do know that the USA has an average 30 ppm sulfur (moving to <10 ppm in 2017 to match what is currently available in California), and that there have not been any reported issues of early mortality in the OBD or the emission systems.

Terms of Reference

- Third Question: an assessment of what technologies that may be used to meet Euro 6 and/or improved fuel efficiency requirements which are sulfur sensitive and what levels of sulfur in petrol would potentially exclude their use in Australia, including consideration of the scope for calibrating technologies to petrol sulfur levels
  - The main thing global automakers are doing is downsizing the engines (moving away from V8 & V6 engines and replacing them with 2, 3 and 4 cylinder engines with GDI)
  - Note the dramatic change in North America where 4 cylinder engines are < 30% of the mix in 2000 and the take rate more than doubles by 2025
  - See the cylinder count in Europe where 2, 3 & 4 cylinder engines are 85% of the mix by 2020





Source: IHS Powertrain Forecast

Terms of Reference

- Third Question (cont):
- In addition to engine downsizing and GDI, carmakers are doing other things, such as
- Moving to 9 and 10 speed transmissions (no sulfur impact)
- Adding charging (super & turbo) to increase the performance of the downsized engines (there is no public data we could find regarding sulfur and these components)
- Advanced Three Way Catalysts (sensitive to +50 ppm sulfur)
- NO_X traps (sensitive to sulfur)
  - In the report from the UN page 25 table 2.6 http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf
  - page 14 "*Increasingly strict emissions standards require extremely efficient catalysts over a long lifetime. Recent regulations in Europe and the U.S. require warmed-up catalysts to have over 98% HC control, even towards the end of the vehicle's lifetime (100,000 km in Europe and 100,000 miles in the U.S.). Many inefficiencies imposed by fuel sulfur jeopardize the ability of vehicles to meet these new stringent standards, including: reductions in conversion efficiency, additional fuel-rich operation requirements, increased catalyst light-off time, and reduced ability to store oxygen".*
  - page 25 table 2.6 "*Gasoline of <15 ppm sulfur is required*"

Terms of Reference

- Fourth Question: the possible effects of sulfur on the need for emission control systems to regenerate to comply with Euro 6 requirements, and consequential impacts on the durability of these systems

(similar answer as the previous page)

- Advanced Three Way Catalysts (sensitive to sulfur)
- NO_X traps on lean burn engines (sensitive to sulfur)
  - In the report from the UN page 25 table 2.6 http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf
  - page 14 "*Increasingly strict emissions standards require extremely efficient catalysts over a long lifetime. Recent regulations in Europe and the U.S. require warmed-up catalysts to have over 98% HC control, even towards the end of the vehicle's lifetime (100,000 km in Europe and 100,000 miles in the U.S.). Many inefficiencies imposed by fuel sulfur jeopardize the ability of vehicles to meet these new stringent standards, including: reductions in conversion efficiency, additional fuel-rich operation requirements, increased catalyst light-off time, and reduced ability to store oxygen".*
  - page 25 table 2.6 "*Gasoline of <15 ppm sulfur is required*"
  - *The April 2016 BMW study states 95 RON and 10 ppm of sulfur*

Results in Past Studies
Desk Research of Reference Documents

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United Nations Environment Programme http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf

The importance of near zero sulfur fuels for motor vehicle greenhouse pollutant reductions: aosis.org/wp-content/uploads/2014/11/M-**Walsh**-**Sulfur**-**Fuels**-paper.doc

MECA paper on GPF http://www.meca.org/resources/meca_ufp_white_paper_0713_final.pdf

VEHICLE EMISSIONS DISCUSSION PAPER,
AUSTRALIAN AUTOMOBILE ASSOCIATION, April 2016

P26 (24)
https://infrastructure.gov.au/roads/environment/forum/files/Australian_Automobile_Association.pdf

- *Sulfur content in fuels can affect noxious emissions by degrading emission control systems such as catalysts and particulate filters. However, the extent to which this may be a problem for vehicles to be supplied to the Australian market is unclear.*
- *Vehicle manufacturers claim that Sulfur levels in Australian petrol would need to be reduced to support tightened noxious emission standards, whereas the petroleum industry disputes this. There does not appear to be any robust objective evidence on which to judge the merits of these claims. The AAA suggests that the Australian Government may need to undertake some testing to gather suitable data as a basis for a decision on the need for lower Sulfur levels.*

Comments submitted as reaction to Vehicle Emissions Discussion Paper (Australian Government, Feb 2016)

Feedback on the Vehicle Emissions Discussion Paper, Clarence Woo, Asian Clean Fuels Association (ACFA), 4/6/2016

- 146. Worldwide, approximately 90% of new gasoline vehicles are equipped with a three-way catalyst (TWC), which simultaneously controls emissions of CO, HC, and NO_X. Sulfur in fuel impacts TWC functioning in several ways:

- 147. Sulfur competes with these gaseous emissions for reaction space on the catalyst. It is stored by the TWC during normal driving conditions and released as SO2 during periods of fuel rich, high-temperature operation, such as high acceleration. **Reductions in Sulfur levels in gasoline—from highs of 200–600 ppm to lows of 18–50 ppm—have resulted in 9–55% reductions in HC and CO emissions and 8–77% reductions in NOX emissions, depending on vehicle technologies and driving conditions**. Greater percentage reductions have been demonstrated for low emission vehicles and high-speed driving conditions.

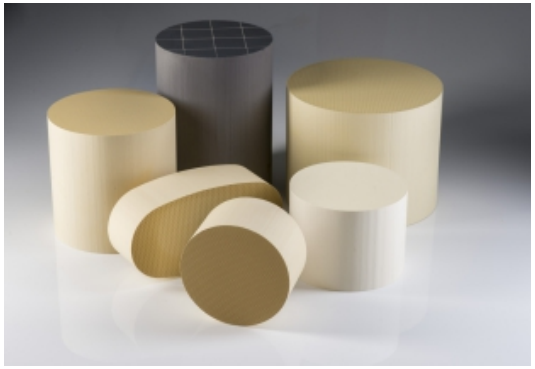


Photo source : Umicore website

Submission to the Vehicle Emissions Working Group on the Vehicle Emissions Discussion Paper, Australian Institute of Petroleum, 8 April 2016

- The question of whether the Euro 6 certified vehicle will meet the Euro 6 emission standards was largely answered by the **Orbital report2 which concluded that the Euro-6 vehicles can operate satisfactorily on PULP with a current Sulfur standard of 50ppm. The only areas of doubt were on the durability of the catalyst**. It has been shown however in recent studies that the Sulfur impacts on the catalysts are reversible, but only to an extent.

P7 (7) https://infrastructure.gov.au/roads/environment/forum/files/Australian_Institute_of_Petroleum.pdf

- At its meeting of 19 March 2014, the AIP Board agreed the following position on the facts about fuel quality and operability: Long term use of higher Sulfur fuels (up to 150ppm Sulfur) will not cause significant impairment of catalysts and any effects will be largely reversible. **Reducing the Sulfur content of petrol from 150ppm to 50 ppm would only deliver limited environmental benefits in terms of reductions in tailpipe emissions.**

P10 (10)

- "The FCAI and all vehicle industry submissions argued that the 150ppm level was too high but did not provide any specific evidence to support their claim. The review is not aware of any evidence that 150ppm Sulfur level in PULP is a barrier to supplying Euro-5 compliant vehicles to the market, and the public submissions provided no evidence to the contrary. **Equally no evidence was supplied to suggest that Sulfur levels below 50 ppm were essential, except in some technologies that appear to be in very limited use. There is less certainty over the impact of 150ppm Sulfur on the durability and longevity of emission control systems in petrol vehicles (such as catalysts).** While this remains an open question there is no evidence that the current fuel standards will prevent compliance with Euro5 standards or because operational problems will prevent in-service compliance with Euro5 standards or cause operational problems, and 50ppm Sulfur petrol (95 Ron) is available to manufacturers where they have concerns about operation on 150ppm Sulfur petrol (91 RON)". ***(This quote is attributable to Euro-5 compliant vehicles not Euro-6)***

AECA, EMA & JAMA Findings September 2013

- P10 (10) , from 6 European Automobile Manufacturers Association (ACEA), Alliance of Automobile Manufacturers, Truck and Engine Manufacturers Association (EMA), Japan Automobile Manufacturers Association (JAMA), World Wide Fuel Charter, Sept. 2013, 5 th Edition, www.acea.be, p17
  - https://www.acea.be/uploads/publications/Worldwide_Fuel_Charter_5ed_2013.pdf
  - There has been extensive testing done on the impact of Sulfur on vehicle emissions. The following studies (see Table 1) indicate the emission reductions that occur with different vehicle technologies as Sulfur is reduced from the 'high' Sulfur gasoline to the 'low' (< 30 ppm):

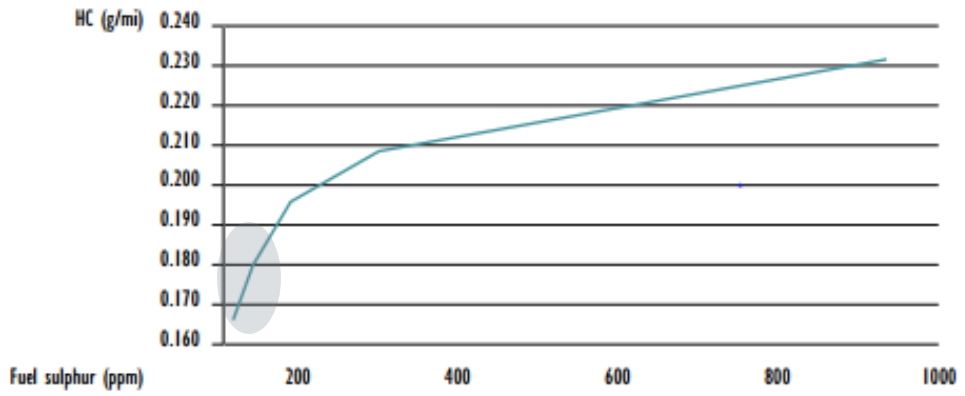
Table 1: Impact of Sulphur on Emissions

Study	Vehicle Technology	Sulphur Range (ppm)		Emission Reduction, % (high to low sulphur)		
		high	low	HC	CO	NOx
AQIRP	Tier 0	450	50	18	19	8
EPEFE	EURO 2+	382	18	9 (43*)	9 (52*)	10 (20*)
AAMA/AIAM	LEV & ULEV	600	30	32	55	48
CRC	LEV	630	30	32	46	61
JARI	1978 Regulations	197	21	55	51	77
Alliance/AIAM	LEV/ULEV	100	30	21	34	27
	LEV/ULEV	30	1	7	12	16
JCAP	DI/NOx cat.	25	2			37

* Reduction achieved during hot EUDC (extra-urban) portion of test.

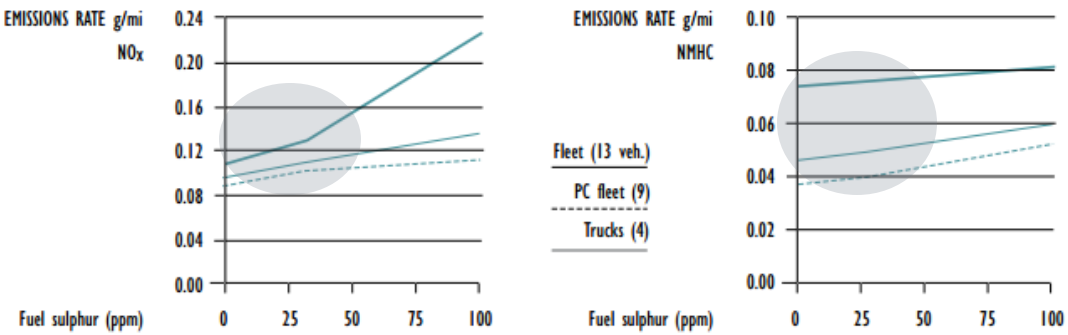
AECA, EMA & JAMA Findings September 2013

Figure 1: Sulphur Effects on Tier 0 Technology



- Figure 1, which depicts the **HC reductions** from the US AQIRP study, indicates the typical emission reduction for the different studies as the Sulfur level changes, including the significant reduction when Sulfur is reduced from about 100 ppm to 'low' Sulfur fuel. **The data illustrates the importance of a very low Sulfur (<30 ppm) limit for Euro 4 technology vehicles.** So this is a bit dated

Figure 3: Effects of Ultra-Low Sulphur Levels on Emissions of NOx and NMHC



- Figure 3 shows how the emissions of **NOx and non-methane hydrocarbons (NMHC)** continue to **decline significantly at ultra-low Sulfur (<10 ppm) levels and note the acceleration on NO_X at around the 30 ppm level.**

AECA, EMA & JAMA Findings September 2013

Figure 4: Sulphur Effect on Low Emission Vehicles – Direct Fuel Injection Engines (Japan Clean Air Program)

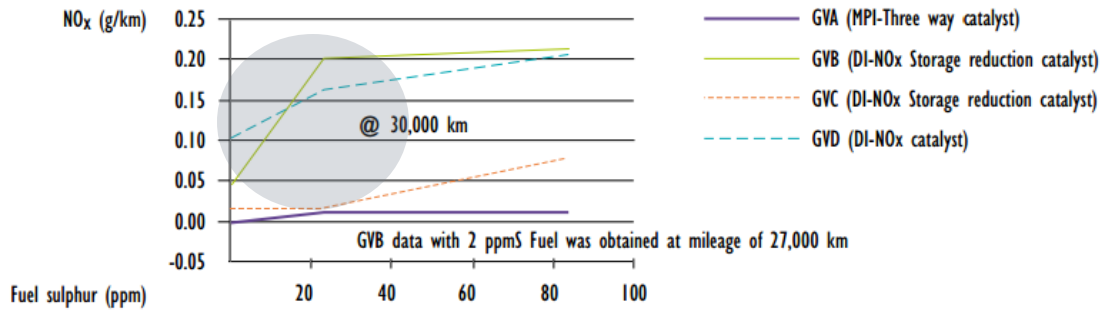
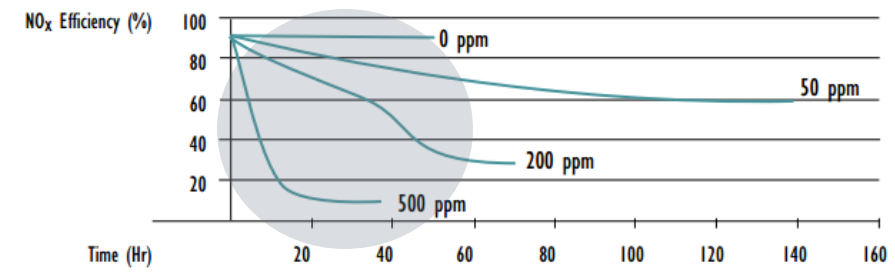


Figure 5: Effect of Fuel Sulphur on Lean NOx Traps Flow Reactor Study



- Figure 4 shows the impact of sulfur on MPI & GDI engines with various catalyst types
- Figure 5 shows the impact of sulfur on lean NO_X traps with 0 ppm, 50 ppm 200 ppm and 500 ppm sulfur. Lean NO_X traps are primarily used by premium automakers using lean burn engines.
- With increased exposure time, **the lower Sulfur gasolines allow the catalysts to retain a higher NOx conversion efficiency.**

AECA, EMA & JAMA Findings September 2013

Figure 6: Influence of Sulphur Concentration in Gasoline on Vehicle Aftertreatment System Durability

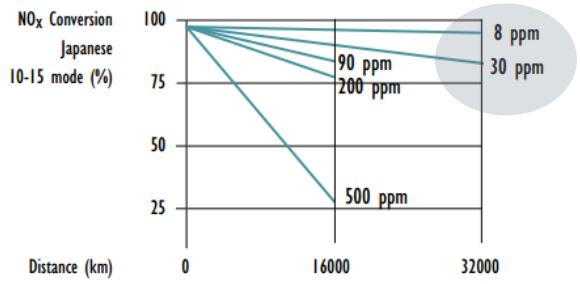
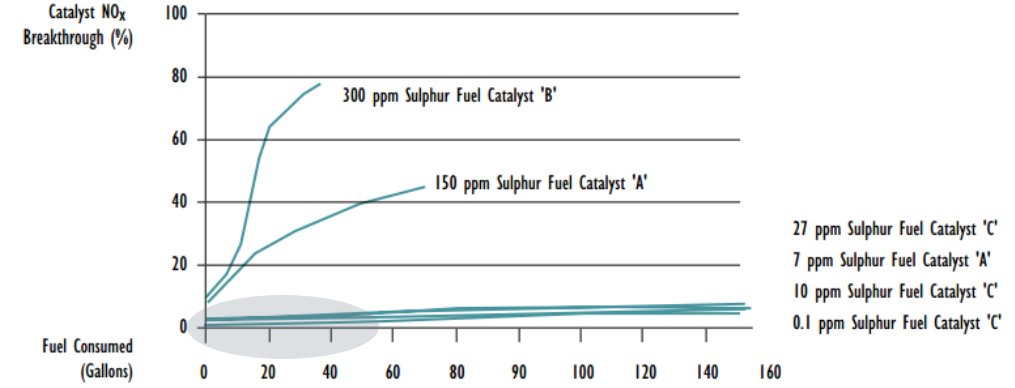
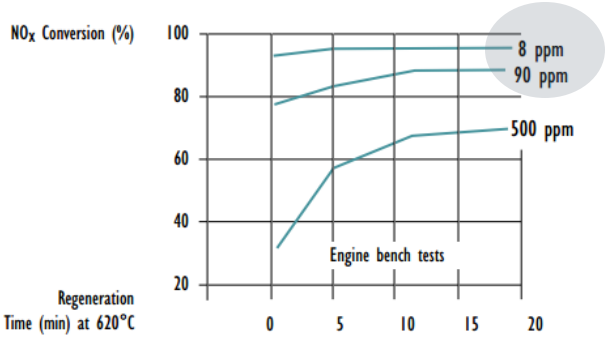


Figure 7: Lean NOx Adsorber Catalyst Data – Catalyst NOx Breakthrough vs. Fuel Consumed & Fuel Sulphur Content



- Further tests in vehicles (Figure 6 and Figure 7) confirm the **critical need for very low Sulfur (<30 ppm) gasolines. Even at 30 ppm the conversion is <80% at only 32,000 km**
- **Maintaining a high level of NOx conversion efficiency over a long period of time**—e.g., for the life of the vehicle—is another major concern due to Sulfur's cumulative impact in the field.
- Figure 8 shows how **ultra-low Sulfur (<10 ppm) gasoline can maintain much higher NOx conversion efficiencies of around 95%** over time compared with higher Sulfur levels.

Figure 8: Regeneration of Sulphur Poisoning



"Thus, ultra-low or Sulfur-free gasoline is required to achieve and maintain high NOx conversion efficiencies over years of vehicle use."

Submission to the Federal Government BMW Group Response: Vehicle Emissions Discussion Paper, BMW Group, April 2016

- https://infrastructure.gov.au/roads/environment/forum/files/BMW_Group.pdf

"BMW Group Australia believes any move to mandate Euro 6 should also include both a mandated CO_2 target, and a concomitant Australian fuel quality standard to provide **95 RON and 10ppm sulphur for all grades of fuel**. If approached as integrated package in this manner, the introduction of Euro 6 could be scheduled for market introduction in Australia from 1 January 2020"

"WWFC conclusions are drawn from expert analysis, research and detailed data. Its overview of research conducted into the effects of octane and sulphur present the following findings:

Statements on octane:

- Vehicles are designed and calibrated for a certain octane rating.
- When a customer uses gasoline with an octane rating lower than required, knocking may result. Engines equipped with knock sensors can handle lower octane ratings by retarding the spark timing, but this will increase fuel consumption, impair drivability and reduce power, and knock may still occur.
- Increasing the minimum octane rating available in the marketplace has the potential to help vehicles Significantly improve fuel economy and, consequently, reduce vehicleC02 emissions.

Statements on sulfur:

- Sulphur has a significant impact on vehicle emissions by reducing the efficiency of catalysts.
- Sulphur also adversely affects heated exhaust gas oxygen sensors.
- Reductions in sulphur will provide immediate reductions of emissions from all catalyst-equipped vehicles on the road"

Submission to the Federal Government BMW Group Response: Vehicle Emissions Discussion Paper, BMW Group, April 2016

- https://infrastructure.gov.au/roads/environment/forum/files/BMW_Group.pdf

The need for a minimum 95 RON and maximum sulphur content of 10 ppm to complement emission standards and $C0_2$ targets is widely recognised.

In its inaugural 'State of Clean Transport Policy' report, The International Council on Clean Transportation (ICCT) states:

- *"Advancing to world-class vehicle emission standards (with stringency equivalent to Euro 6/V1* or *better) paired with requirements for low sulphur fuel can dramatically reduce emissions of local air pollutants and associated health impacts, even amid growth in vehicle activity"ll*
- The European Commission maintains, *"Fuel quality is* an *important element in reducing greenhouse gas emissions from trensport"?*
- The U.S. EPA considers *"the vehicle and its fuel* as *an integrated system".*

Response from Robert Bosch (Australia) Pty Ltd, Bosch, 08 April 2016 World Wide Fuel Charter

- https://infrastructure.gov.au/roads/environment/forum/files/Bosch.pdf
- **The low Sulfur limits enable sophisticated technologies for treatment of oxides of nitrogen (NOx) and PM in the exhaust gas and ensure long term durability of three-way catalysts**, a core component of both port fuel injection (PFI) and GDI systems. “30 ppm of sulfur will only meet Euro-4 requirements”
- P3 (3)

FCAI

- https://infrastructure.gov.au/roads/environment/forum/files/Federal_Chamber_of_Automotive_Industries.pdf
- References to World Wide Fuel Charter, Sept. 2013, 5 th Edition, www.acea.be (same as BMW)

		500 ppm		150 ppm		50 ppm		10 ppm		
		Euro 2		Euro 3		Euro 4		Euro 5		Euro 6
		ADR79/00		ADR79/01		ADR79/02		ADR79/03		
								ADR79/04		ADR79/05
	Europe				Australia					
Year	Sulphur ULP&PULP	THC	CO	NOx	Sulphur ULP	Sulphur PULP	THC+NOx	THC	CO	NOx
2003	150	0.2	2.3	0.15	500	150	0.5	-	2.2	-
2004	150	0.2	2.3	0.15	500	150	0.5	-	2.2	-
2005	50	0.1	1	0.08	150	150	-	0.2	2.3	0.15
2006	50	0.1	1	0.08	150	150	-	0.2	2.3	0.15
2007	50	0.1	1	0.08	150	150	-	0.2	2.3	0.15
2008	50	0.1	1	0.06	150	50	-	0.1	1	0.08
2009	10	0.1	1	0.06	150	50	-	0.1	1	0.08
2010	10	0.1	1	0.06	150	50	-	0.1	1	0.08
2011	10	0.1	1	0.06	150	50	-	0.1	1	0.08
2012	10	0.1	1	0.06	150	50	-	0.1	1	0.08
2013	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06
2014	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06
2015	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06
2016	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06
2017	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06
2018	10	0.1	1	0.06	150*	50*	-	0.1	1	0.06

* as currently legislated and remains unchanged for the indicated period

Figure 5.3 – Australian and European Fuel Sulphur and Emissions Standards

Review of Sulfur limits in petrol, Orbital Australia, 2013

Sulfur limits in petrol, Orbital Australia, 2013

- Although the regulatory emission performance of TWCs has been extensively studied with technical data on the sensitivity of emissions to fuel sulfur, typically there has not been an extensive effort to determine which aspect of the technology is the predominate cause of any emission increase. But, much of this data is somewhat dated
- Some studies have also shown a very flat emission response to fuel sulfur, whilst others have shown a more dramatic response than the others.

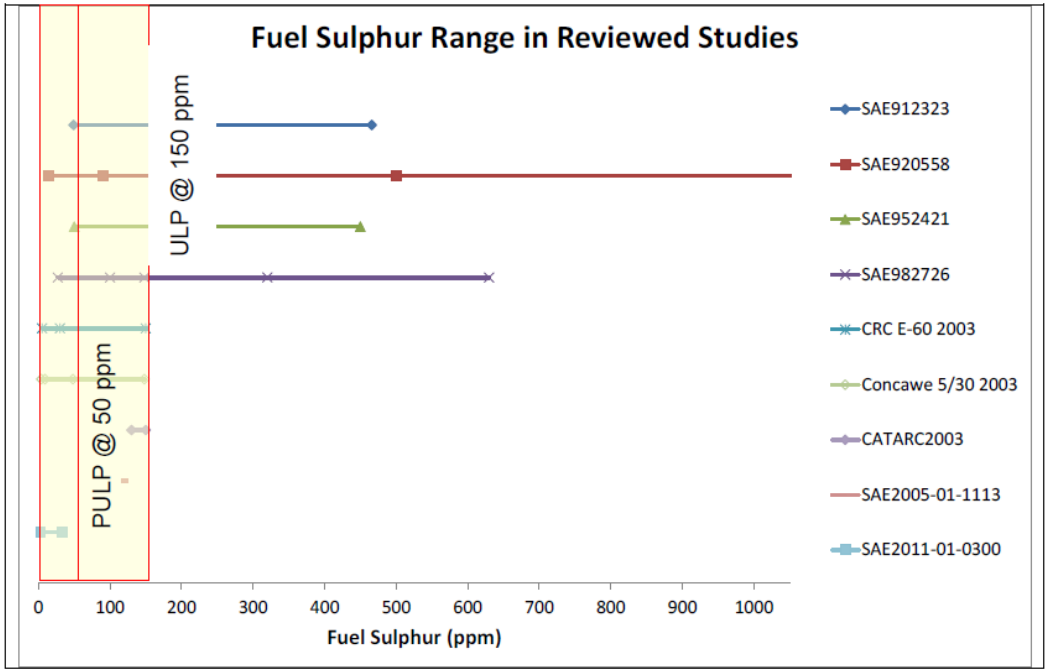


Figure 7.22 – Fuel Sulphur Studies Reviewed Tailpipe Emissions and Range of Sulphur Covered

Sulfur limits in petrol, Orbital Australia, 2013

- Link in word: http://www.environment.gov.au/protection/publications/review-Sulfur-limits-petrol
- http://www.environment.gov.au/system/files/resources/dd12186b-956a-47a0-9add-6e8009f00a50/files/review-fuel-Sulfur-limits-petrol.pdf

P59-60:

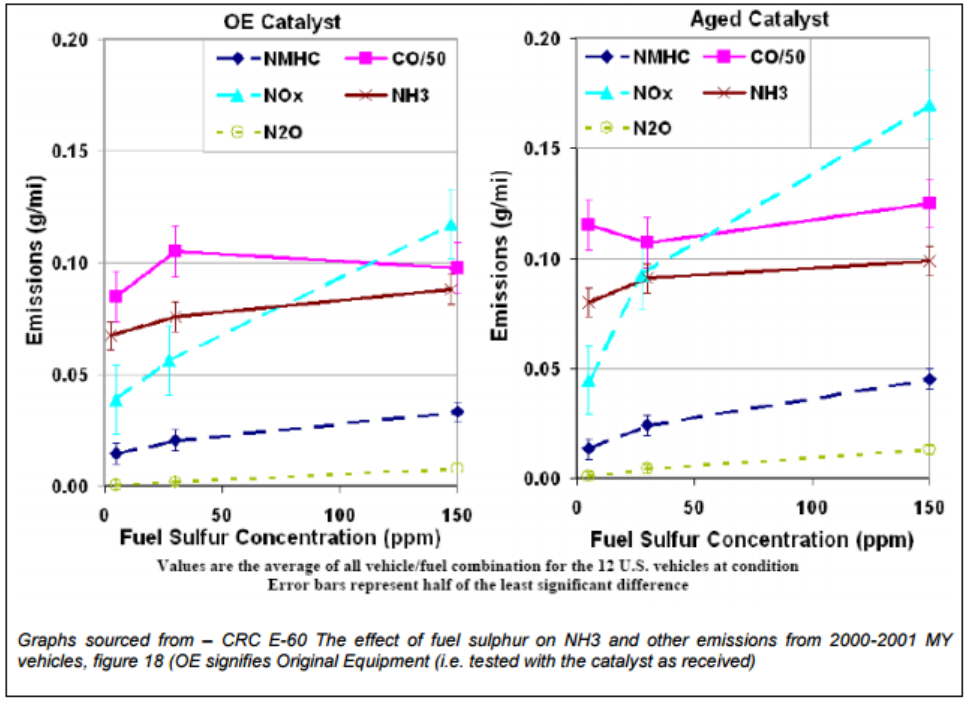
- Fleet emission response to fuel Sulfur over the FTP cycle showed increasing NOx and CO emissions with increasing Sulfur concentration, although the gradient was shallow.
- Fleet emission response to fuel Sulfur over the FTP cycle showed no change in NMHC with increasing Sulfur concentration.
- Data for emission responses for fuel Sulfur from 30 to 150 ppm is of most interest and considered reliable for consideration in this review. The 5 ppm test data was considered inconsistent.

P61:

- Over the **NEDC cycle fleet emissions showed no significant emission response to fuel Sulfur levels** (see charts in P62-5)

Sulfur limits in petrol, Orbital Australia, 2013

- Please note this data is nearly 16 years old
- But there are some good insights to be gained from this chart
- The OE catalyst represents a brand new catalyst from the factory and the aged catalyst represents the vehicle after it has been in use (time is not represented)
- For the most part emissions levels have a steep rise from interpolated sulfur levels of about 10 ppm, then have a sharp rise up to 25 ppm, and in the case of NO_X on the aged catalyst have a much more aggressive decrease in the catalyst's ability to maintain original factory levels of performance with the higher sulfur levels of 150 ppm the legal maximum in Australia



Graphs sourced from – CRC E-60 The effect of fuel sulphur on NH3 and other emissions from 2000-2001 MY vehicles, figure 18 (OE signifies Original Equipment (i.e. tested with the catalyst as received)

Figure 7.11 – CRC E-60: US06 Fleet Average Emissions Response Sulphur

Sulfur limits in petrol, Orbital Australia, 2013

- P67: 7.1.10 SAE 2011-01-0300: Effects of fuel Sulfur on FTP NOx emissions from a PZEV 4 cylinder application □The paper demonstrated that **NOx emissions were 40% higher with 33 ppm Sulfur fuel than with 3 ppm Sulfur fuel**. □Reversibility was possible, but temperatures in excess of 600oC were required.
- P68: Figure 7.20 – Mobile6 EPA 2001: Sulfur Effects for LEV & ULEV Vehicles

Initial Emission Effects from Varying Sulfur for LEV & ULEV Normal Emitting LDVs

Pollutant	Emissions Mode	% Increase in Emissions when Sulfur is Increased from 30 ppm to:			
		75	150	330	600
HC	Composite	16.7	31.1	49.8	65.6
NMHC	Composite	13.7	25.3	39.9	52.1
CO	Composite	24.3	46.5	76.7	103.6
NOx	Composite	38.3	76.8	133.6	188.7
HC	Running	48.0	99.2	179.1	260.5
NMHC	Running	57.5	122.0	228.2	341.4
CO	Running	56.1	118.7	220.9	329.2
NOx	Running	68.7	150.6	293.1	453.0
HC	Start	4.75	8.50	12.9	16.4
NMHC	Start	5.22	9.35	14.2	18.1
CO	Start	4.54	8.11	12.3	15.6
NOx	Start	10.8	19.8	30.9	40.0

* Note, these are not the final effects used in MOBILE6.

Table sourced from – Fuel sulphur effects on exhaust emissions – Recommendations for MOBILE6 EPA 2001, table 12

Sulfur limits in petrol, Orbital Australia, 2013 Conclusion - Figure 12.1

- P116:
- This project has reviewed and evaluated an extensive amount of technical literature. Much of the literature details studies undertaken more than a decade ago when both the European and US regulators were evaluating the drivers for lowering fuel sulfur levels in their jurisdictions. The focus of the older literature was the performance of conventional TWC equipped vehicles.
- Figure 12.1 (next page) provides a summary of literature elements identified and the implications that **fuel sulfur at levels of 50 and 150 ppm would have on satisfying Euro 5 (core) and Euro 5/6 objectives**. Three overall grades are assigned in this summary table:

  - **Unsatisfactory:** The assessment of higher than 10 ppm fuel Sulfur showed evidence of negative impacts which could potentially result in unacceptable system behaviour or non-compliance.
  - **Doubtful:** The assessment of higher than 10 ppm fuel Sulfur showed some level of degradation, but the concerns were not sufficient to warrant an unsatisfactory rating.
  - **Satisfactory:** No issues sufficient to warrant concern were identified.

Sulfur limits in petrol, Orbital Australia, 2013 Conclusion - Figure 12.1

Issue	Refer Section	10 ppm Sulphur Fuel	50 ppm Sulphur Fuel		150 ppm Sulphur Fuel	
			Euro 5 (core)	Euro 5 / 6	Euro 5 (core)	Euro 5 / 6
Certification at Low Mileage	7.2.3.1, 7.2.4 8.3, 8.4, 8.5	European member countries have 10 ppm sulphur fuel where Euro 5 and 6 emission regulations are applicable.	✓	✓	✓	✓
In-service compliance testing at High Mileage	7.2.3.1, 7.2.4 8.3, 8.4, 8.5		✓	✓	✓	✓
Emissions at low mileage THC and CO	7.1, 8.1		✓	✓	?	?
Emissions at low mileage NOx	7.1, 8.1		✓	✓	✗	✗
Emissions at high mileage THC and CO	7.1, 8.1		?	?	✗	✗
Emissions at high mileage NOx	7.1, 8.1		?	?	✗	✗
Particle Emissions PM and PN	7.3		Refer report detail - insufficient data to complete the assessment. Data identified is mostly for MPI vehicle, and not for latest generation GDI engine technology.			
Fuel Consumption and GHG	7.4		No evidence identified to directly link combustion of fuel sulphur to changes in engine fuel consumption. Indirectly, high fuel sulphur is incompatible with lean burn exhaust catalysts.			
Reversability at low mileage	7.2.3		✓	✓	?	?
Reversability at high mileage	7.2.3		?	?	?	?
Three Way Catalyst Palladium Susceptibility	7.2.2		?	?	?	?
Lean NOx Catalysts (NSR / Traps)	6.1, 6.2 7.1, 8.3.1		✗	✗	✗	✗
Oxygen sensor	7.6		✓	✓	✓	✓
OBD II Catalyst Monitoring THC	7.5, 8.2		✓	✓	✓	✓
OBD II Catalyst Monitoring NOx	7.5, 8.2		✓	?	?	✗

Key Points:

- Catalyst reversibility at low mileage is likely
- Catalyst reversibility at high mileage is doubtful

Legend	
✓	All aspects satisfactory
?	Some aspects doubtful
✗	Some aspects unsatisfactory

Regulatory Impact Analysis (RIA) of Tier 3 Motor Vehicle Emissions and Fuel Standards Final Rule, EPA, March 2014

Sulfur limits in petrol, Orbital Australia, 2013: Refuting Information

The Manufacturers of Emission Controls Association (MECA) study dated April of 2016 provides some updated information beyond the Orbital study which has data in it which is nearly 16 years old (that is 2 design cycles in the automotive industry)

- In the light-duty gasoline vehicle sector Euro 6/U.S. Tier 2/U.S. Tier 3 noxious emission standards build on the extensive experience and success with advanced three-way catalysts. Euro 6 gasoline exhaust standards are roughly equivalent to U.S. Tier 2 exhaust standards, but less stringent than U.S. Tier 3 exhaust standards.
- A recent Society of Automotive Engineer's technical paper (SAE paper no. 2011-01-0301) demonstrates how advanced three-way catalysts utilizing high cell density substrates can be combined to achieve the lowest available U.S. Tier 3 exhaust emission limits (Tier 3, Bin 20 or Bin 30 limits of approximately 20 or 30 mg/mile NMOG+NOx emissions over the U.S. FTP test cycle [or approximately 30-50 mg/km NMOG+NOx]) on a four-cylinder, light-duty gasoline vehicle
- Ultra-low sulfur (i.e. <10 ppm) gasoline levels are a pre-requisite to deliver meaningful reductions in noxious emissions from both existing and future gasoline vehicles in Australia.

Other References

International fuel quality standards and their implications for Australian standards, Hart Energy, 2014.

- https://www.environment.gov.au/system/files/resources/f83ff2dc-87a7-4cf9-ab24-6c25f2713f9e/files/international-feul-quality-standards.pdf
- P31 (14): In 2000, the European Commission, DG Environment published a report on consultation on the need to reduce Sulfur content of gasoline and diesel fuels to below 50 ppm in a policy makers summary. It assessed the opinion of vehicle and fuel industries, and different institutions, about reducing Sulfur below 50 ppm in automotive fuels. The policy summary informed that:
  - ❑ **Direct effects of reducing Sulfur to 10 ppm in gasoline are reduction in sulfate-based particulate matter (PM and total SO2 emissions). However, CONCAWE noted that the emission fall from 50 ppm to 10 ppm is less considerable compared to Sulfur reduction from 3,000 ppm to 150 ppm and then to 50 ppm.**
  - ❑ **Transition to 10 ppm fuels indirectly would aid performance of three-way catalysts, especially those sensitive to Sulfur.**
  - ❑ **10 ppm Sulfur gasoline presents the possibility of reducing NOx emissions by 21% and non-methane hydrocarbons (NMHC) emissions by 13% compared to low-Sulfur (>30 ppm) fuels.**
  - ❑ **ACEA and AECC informed that 10 ppm Sulfur gasoline would reduce the rate of deterioration of the lambda sensor and improve efficiency of the three-way catalyst.**
  - ❑ **In the opinion of ACEA, 10 ppm Sulfur gasoline would reduce N2O and methane emissions.**
  - ❑ **Lowering Sulfur in gasoline to 10 ppm would bring air quality benefits if the reduction would be mandatory for fuel suppliers EU-wide.**
- P119 (102): JCAPI **studied lean-burn engines** and discovered the poor functionality of three-way catalysts (catalytic converters) in dealing with NOx, resulting in the use of **NOx eliminating catalysts that are highly susceptible to Sulfur** content in the fuel. This resulted in the automobile industry **calling for ultra-low-Sulfur (<10 ppm) gasoline to be supplied**.

How To Interpret The Divergent Studies

- There are three distinctive groups of studies from the publically available research: information from the petroleum industry, information from the automakers, information from automotive suppliers and their consortiums and information from public policy organizations.
- In the opinion of IHS there is no clear and concrete answer from the public studies. You can interpolate that 16 to 28 ppm of sulfur will not destroy modern emission systems (levels claimed by the Australian Institute of Petroleum for premium gasoline in Melbourne & Sydney). IHS has no independent data about the rest of the country and have to assume that 50-150 ppm fuel will find its way into Euro-6 vehicles. Also, the vast majority of vehicles certified to meet Euro-6 run on regular gasoline. Carmakers would have to put premium only requirements on the vehicles (which consumers might likely disregard).
- And there is a secondary issue, Euro-6 vehicles are calibrated to 10 ppm fuel. Higher sulfur levels will equate to real world emissions that would be higher than what the sticker says on the new car, and this is on top of the added issue of RDE being higher than the laboratory test results (NEDC).

Additional Information

Who We Interviewed

- IHS Automotive has a client base that includes 99% of the carmaker's and key component suppliers globally.
- We used these relationships to talk to :
  - Car makers based in Europe, Japan & the United States who are producing and testing modern Ultra Low Emissions Vehicles (ULEV) compliant to Euro 6 specifications
  - Global automotive component suppliers producing Gas Direct Injection (GDI) systems, turbo chargers, gasoline particulate filters (GPF) and three way catalyst systems (TWC).
    - GDI, GPF & TWC are essential subsystems in downsized ULEV engines
    - Turbochargers are used to improve vehicle performance in modern downsized engines, but have no impact on pollution control systems
  - These companies would not provide data that could be released publically, but it did provide a path on where we should focus our efforts

Findings

- The Robert Bosch & BMW studies emphasize that to achieve Euro-6 emissions standards ultra low sulfur fuel of 10 ppm or less is required to make the Euro-6 calibrated emissions systems perform their job and survive the warranty period.
- New regulatory requirements in Europe (Euro 5&6), Asia (JC08) and the USA (FTP 75 Tier-3) have created demand for new engine technologies and related fuel changes like 10 ppm Sulfur. Many of the referenced studies state that are BOTH 10 ppm fuel and the powertrain technologies need to work together to provide the emissions reductions in the Euro-6 regulations.
- The automakers have introduced (ing) new 2, 3, 4 and 6 cylinder engines with Direct Injection, Variable Valve Timing/Variable Valve Lift (VVT/VVL), Turbo Charging and Super Charging, Three Way Catalytic Converters (TWC), lean NO_X traps, Gas Particulate Filters (GPF) and advanced Exhaust Gas Recirculation (EGR) systems. To make the vehicles compliant to Euro-6.
- These new engines need both these technologies and 10 ppm Sulfur to meet Euro-6 targets for emissions according to the findings in the following studies: Robert Bosch, United Nations Environment Programme, AECC, MECA, and icct.

Findings

- You can use 30ppm to 50ppm fuel in cars calibrated for Euro-6, but the emissions output of those vehicles will not likely meet Euro-6 levels
- Vehicles designed to meet Euro-6 must have gasoline of 10 ppm or less to provide the desired emissions levels required by the Euro-6 requirements.
- Additionally, if you drive a Euro-6 compliant vehicle using Australia's current regular unleaded fuel that can have up to 150 ppm sulfur the catalysts will not do the job they were designed for. In fact the vehicle will ultimately consume more fuel and emit more emissions every time it tries to go into regeneration mode.
- Implementing a Euro-6 regulation will not achieve the desired emissions reductions if the fuel standard is not changed.

Key Learnings From Our Research

- Manufacturers of Emission Control Association (MECA) document dated June 2013

The MECA findings are:

- *Sulfur in gasoline inhibits the emission control performance of catalyst technology. A variety of factors influence the degree of this impact and the extent to which it is reversible. These factors include the sulfur level in the gasoline, the catalyst composition, the catalyst design, the catalyst location, the type and control of fuel metering, the engine calibration, and the manner in which the vehicle is operated*.
- *In a Toyota study, the reversibility of NOx conversion efficiency of catalysts was investigated. Four catalysts that were aged up to 16,000 km with 8 ppm, 30 ppm, 90ppm and 500 ppm sulfur fuels were prepared. NOx conversion efficiency of each catalyst was measured on an engine dynamometer before and after regeneration of sulfur poisoning. The condition of sulfur regeneration was at 620°C catalyst bed temperature and at an air fuel ratio of 14.0 (rich of stoichiometric). The study showed the catalyst that was aged with higher sulfur fuel shows lower reversibility. The NOx conversion level of the catalyst aged with 8 ppm sulfur fuel recovered nearly to the fresh condition level after a short regeneration period. However, the NOx conversion efficiency of the NSR catalyst aged with 30 ppm sulfur fuel could not be regenerated to the fresh level after 25 minutes of regeneration*

Key Learnings From Our Research

- It is clear that Sulfur is a catalyst poison and our industry interviews confirmed that point
- There are some studies cite research saying that the catalysts can recover from exposure to higher Sulfur levels
  - The majority of research in this area is around going from 10 ppm to 33 ppm, not 50 to 150 ppm
  - Sulfur “poisoning” can regress, but not totally and not in normal driving condition’s
    - You would need to drive 3-5 tanks of gas on high speed highways. Stop and Go city driving will not create high enough catalyst temperatures to provide the necessary regression
    - Catalyst suppliers say the new TWC’s using high density substrates would not perform well in a +50 ppm Sulfur environment. The rate of degraded performance would be a function of how the vehicle is driven; highway driving has better results than city driving, and using lower sulfur fuels for regeneration also has a positive impact.

Conclusions

- The world is moving to 10 ppm sulfur gasoline. By 2020 it will be commonplace and readily available in the APAC region.
- EURO 6 calibrated vehicles
  - <10 ppm sulfur is the test fuel for Euro-6 calibrated vehicles
  - <30 ppm works in other markets like the USA, and we can infer from available data that Euro-6 vehicles can survive the 160,000 km warranty period if sulfur at these levels is used.
  - >50-150 ppm there are some doubts about emissions systems surviving the 160,000 km warranty period

    Will have problems with the TWC's and the new GPF's that are now coming online in Europe
  - Stronger conclusions cannot be drawn from the publically available sources

Appendix

Appendix

WRITTEN COMMENTS OF THE *MANUFACTURERS OF EMISSION CONTROLS ASSOCIATION* ON THE AUSTRALIAN GOVERNMENT'S VEHICLE EMISSIONS DISCUSSION PAPER, Manufacturers of Emission Controls Association, April 5 2016

- https://infrastructure.gov.au/roads/environment/forum/files/Manufacturers_of_Emission_Controls_Association_MECA.pdf
- Similar to the diesel case, ultra-low Sulfur gasoline levels are a pre-requisite to deliver meaningful reductions in noxious emissions from both existing and future gasoline vehicles in Australia. Australia should follow the lead of Europe and the U.S. in reducing gasoline fuel Sulfur levels to around the 10 ppm level as part of any future tightening of light-duty gasoline vehicle emission standards. The negative impacts of gasoline Sulfur levels on the performance and durability of three-way catalysts is well documented and was included in MECA's written comments on the U.S. EPA's proposed Tier 3 light-duty emission standards (see MECA's July 1, 2013 and August 22, 2013 written comments on EPA's proposed Tier 3 light-duty vehicle emissions and fuel standards available at: http://www.meca.org/news/testimony. **Improved three-way catalyst performance and durability is observed even in reducing gasoline fuel Sulfur levels from 30 ppm to 10 ppm**. MECA's June 2013 report on "The Impact of Gasoline Fuel Sulfur on Catalytic Emission Control Systems," available at: http://www.meca.org/resources/reports (under Fuels) reviews the wealth of information published on the negative interactions between gasoline Sulfur and precious metal-containing three-way catalysts. Due to the largely reversible impacts of gasoline fuel Sulfur, reducing gasoline fuel Sulfur levels to the ultra-low levels recommended here, can provide significant and nearly immediate emissions benefits to the existing fleet of Australian light-duty gasoline vehicles
- P3-4 (3-4)
  - http://www.meca.org/attachments/2156/MECA_written_comments_on_EPA_Tier_3_proposed_rule_070113.pdf
  - **EPA has released** a thorough and well-designed Sulfur effects study on 81 in-use Tier 2 light-duty gasoline vehicles that clearly **showed significant reductions in criteria pollutants in comparing emissions performance on gasoline with 28 ppm Sulfur versus 5 ppm Sulfur.** Work published in a **2011 SAE technical paper (SAE paper no. 2011-01-0300)** shows similar, **significant emission benefits on a 2009 model year PZEV vehicle operated with 3 ppm Sulfur gasoline versus 33 ppm Sulfur gasoline**. In this gasoline Sulfur effects study, on a 2009 PZEV passenger car, the results clearly show that the underfloor converter used on the close-coupled + underfloor PZEV catalytic converter system was susceptible to Sulfur-related performance degradation due to its cooler operating temperatures during the FTP test cycle using a 33 ppm Sulfur-containing gasoline. The loss in NOx performance of this underfloor PZEV converter in successive FTP tests could be recovered to some extent, or avoided to a large degree, by either purging stored Sulfur off the underfloor converter with the use of a higher speed and load test cycle (i.e., the US06 test cycle) sandwiched between FTP tests, or using a gasoline with significantly lower Sulfur levels (i.e., a 3 ppm Sulfur-containing gasoline).

Appendix

WRITTEN COMMENTS OF THE MANUFACTURERS OF EMISSION CONTROLS ASSOCIATION ON THE AUSTRALIAN GOVERNMENT'S VEHICLE EMISSIONS DISCUSSION PAPER, Manufacturers of Emission Controls Association, April 5 2016

- http://www.meca.org/attachments/2227/MECA_EPA_Tier_3_supplemental_comments_082213.pdf
- **In their published test results both hydrocarbon and NOx FTP emissions increased significantly when the gasoline fuel Sulfur level was increased from 8 ppm to 33 ppm** (additional large increases in hydrocarbon and NOx FTP emissions were observed when the fuel Sulfur level was increased to 150 ppm).

- http://www.meca.org/Gasoline_Fuel_Sulfur_2013Final.pdf
- It has been reported that Sulfur inhibition is worse with vehicle systems calibrated to meet the California LEV standards (8, 9, 10). Gorse (8) reported data showing that Sulfur inhibition increases the emission levels of a LEV vehicle to that of a Tier 0 vehicle. Benson (10) reported data showing a 60% increase in HC, 65% increase in CO, and 180% increase in NOx when going from 40 to 1000 ppm Sulfur fuel.
- P11-12 (11-12)

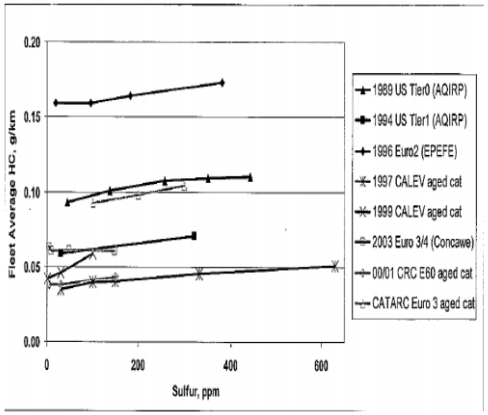


Figure 2: Sulfur Effect on Emissions from Older Vehicles

Source: CRC Project E-84

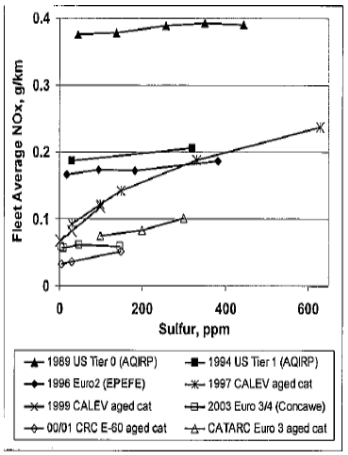


Figure 3: Sulfur Effect on Emissions from Older Vehicles

Source: CRC Project E-84

- Bottom of P15
- P23: The full EPA Tier 2 gasoline Sulfur study is available at: http://www.epa.gov/otaq/models/moves/t2Sulfur.htm. Highlights from this important gasoline Sulfur effects study are included below.

Review of the Fuel Quality Standards Act 2000, Marsden Jacob Associates, 2016

- http://duqm0dwvyjbvv.cloudfront.net/wp-content/uploads/2016/05/Review-of-the-Fuel-Quality-Standards-Act-2000_Final-Report.pdf
- P104 (89): A number of previous studies have also examined the impact of higher than certified levels of Sulfur on the life of 3-way catalysts. As noted in section 4.3.2, the durability issue is important in the context of Euro 5/6 as these standards require manufacturers to demonstrate compliance with the emissions standards at 160,000 km (compared to 100,000 km in Euro 4). Drawing on research cited in Orbital 2013 and USEPA 2014, the number of vehicles affected by catalyst durability has been conservatively estimated at 1% of vehicles from 2019 onwards, five years (or 100,000 km after the introduction of Euro 6). The numbers of vehicles affected is determined by the fuel quality scenario adopted and the timing of the introduction of ultra-low Sulfur levels under that scenario. The cost of reduced catalyst durability for each affected vehicle is estimate at $375 per vehicle, based on the depreciated value of an $800 catalyst. A summary of the total number of vehicles affected and the cost impacts of the loss of catalyst durability is provided in Table 39.

Table 39: Estimated impacts of using higher than certified sulfur on catalyst durability

	2016	2020	2025	2030
Scenario A				
No. affected vehicles (000's)	0	18.0	0	0
Estimated cost impact ($m)	0	6.7	0	0
Scenario B/C				
No. affected vehicles (000's)	0	18.0	19.3	20.5
Estimated cost impact ($m)	0	6.7	7.2	7.7
Scenario D				
No. affected vehicles (000's)	0	18.0	19.3	0
Estimated cost impact ($m)	0	6.7	7.2	0

Appendix

http://www.unep.org/Transport/New/PCFV/pdf/Maps_Matrices/AP/matrix/AP_Matrix_June2015.pdf

Updated June 2015

Status of Fuel Quality and Vehicle Emission Standards in Asia-Pacific

		Current and Planned Sulphur Levels in Fuel (max, ppm) (nationwide unless otherwise stated)				Vehicle Emission Standards and Enforcement		
COUNTRY	Lead Status	Diesel (ppm)	Petrol (ppm)	50ppm Target Date	Comments	Emission Standards (Current)	Use of Catalytic Converters	Comments
Afghanistan	Unleaded	10,000	No info	No date	• Euro 3 equivalent gasoline and petrol imported • Most of the information on lead in gasoline indicates that the country is now unleaded	None	No info	No comments
Bangladesh	Unleaded (since 2001)	5,000	1,000	No date	• 500ppm - July 2014 (Dhaka and Chittagong)	Euro 1	No info	• Euro 2 – July 2014 (Nationwide) • Euro 3 – July 2014 (Dhaka and Chittagong) • Euro 3 – July 2019 (Nationwide) • Euro 4 – July 2019 (Dhaka and Chittagong)
Bhutan	Unleaded	500	No info	No info	No comments	No info	No info	No comments
Brunei Darussalam	Unleaded (since 2003)	500	1,000	2016	No comments	Euro 1 – Diesel Euro 2 – Petrol	No info	• Euro 4 – 2016
Cambodia	Unleaded (since 2007)	1,500	1,000	No date	No comments	No info	No info	No comments
China (nationwide)	Unleaded (since 2001)	50	50		• Many cities have had 50ppm in fuels like Beijing since 2008; Shanghai since 2009; and Guangdong Province since 2010 • 10ppm in fuels by 2017	China IV (~Euro 4/IV)	Required for all China II (Euro 2) cars and above	• China V (Euro 5) – 2013 (Beijing) • Euro 6 – 2016 (Beijing) including 10ppm sulphur in fuels • China V nationwide by 2017
China (Hong Kong SAR)	Unleaded (since 1999)	10	50	-	No comments	Euro 5	Required	No comments
China (Macao SAR)	Unleaded (since 2001)	50	50	-	No comments	Euro 4 equivalent	Required	No comments
Chinese Taipei	Unleaded (since 2000)	10	50	-	• 50ppm petrol since 2007 and since 2007 in diesel		Required	No comments
Cook Islands	Unleaded	No info	No info	No info	No comments	No info	No info	No comments
Democratic People's Republic of Korea	Unleaded	No info	No info	No info	• Most of the information on lead in gasoline indicates that the country is now unleaded	No info	No info	No comments
Fiji	Unleaded (since 2006)	500	No info	No info	No comments		No info	No comments
India	Unleaded (since 2000)	350	150	No date	• 50ppm sulphur in fuels available in 11 major cities	Euro 3	No info	• Euro 4 in eleven major cities • Ongoing Auto-Fuel Policy Committee to 2020
Indonesia	Unleaded (since 2006)	3,500 (avg.) / 500ppm	500	No date	• Sale of lower grade, high sulphur diesel is still is still rampant	Euro 2	No info	• Discussions ongoing for implementation of Euro 4
Japan	Unleaded (since 1999)	10	10	-	No comments	Equivalent to Euro 5/6 and V/VI standards for light-duty and heavy-duty vehicles	Required	No comments
Kiribati	Unleaded (since 2006)	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments
Lao People's Democratic Republic	Unleaded	2,500	500	No date	No comments	No info	No info	No comments
Malaysia	Unleaded	500	500	2016	No comments	Euro 2	No info	• Plans implementation of Euro 4 by January

Appendix

http://www.unep.org/Transport/New/PCFV/pdf/Maps_Matrices/AP/matrix/AP_Matrix_June2015.pdf

Updated June 2015

Status of Fuel Quality and Vehicle Emission Standards in Asia-Pacific

		Current and Planned Sulphur Levels in Fuel (max, ppm) (nationwide unless otherwise stated)				Vehicle Emission Standards and Enforcement		
COUNTRY	Lead Status	Diesel (ppm)	Petrol (ppm)	50ppm Target Date	Comments	Emission Standards (Current)	Use of Catalytic Converters	Comments
	(since 1999)							2016
Maldives	Unleaded (since 2000)	No info	No info	No info	No comments	No info	No info	No comments
Marshall Islands	Unleaded (since 2006)	50	150	No date	• Imports all oil and petroleum products	No info	No info	• Discussions on-going for establishment of Euro based vehicle emission standards
Micronesia, Fed. States of	Unleaded (2006)	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments
Mongolia	Unleaded	5,000	No info	No date	• Available fuels are mostly Euro 2 and Euro 3 compliant but there are no clear national standards for fuel quality	No info	No info	No comments
Myanmar	Unleaded	2,000	No info	No info	• Most of the information on lead in gasoline indicates that the country is now unleaded	None	No info	No comments
Nauru	Unleaded (2006)	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments
Nepal	Unleaded (2003)	350	150	No date	• Imports all fuel from India which is currently at Bharat III standards nationwide, i.e. 350ppm for diesel and 150ppm for gasoline	Euro 3	No info	No comments
Niue	Unleaded	No info	No info	No info	• Imports from New Zealand	No info	No info	No comments
Pakistan	Unleaded (2003)	5,000 -7,000	No info	No date	No comments	None	No info	No comments
Palau	Unleaded (2006)	No info	No info	No info	• Imports all oil and petroleum products	Vehicle inspection undertaken by Ministry of Justice, Bureau of Public Safety	No info	No comments
Papua New Guinea	Unleaded (2004)	No info	No info	No info	No comments	No info	No info	No comments
Philippines	Unleaded (since 2000)	500	500	2016	• 50ppm petrol and diesel already available in the market	Euro 2	No info	• Euro 4 – January 2016
Republic of Korea	Unleaded (1999)	50	10	-	No comments	Euro 4/IV	Required	No comments
Samoa (Western)	Unleaded (2001)	No info	No info	Unknown	• Imports all oil and petroleum products		No info	No comments
Singapore	Unleaded (1999)	50	50	-	• Set to implement Euro V and 10ppm fuel sulphur requirement for diesel by January 2014	Euro 4/IV	Required	• Set to implement Euro V for diesel by January 2014
Solomon Islands	Unleaded (2006)	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments
Sri Lanka	Unleaded (2003)	2000	1000	No info	No comments	Euro 1	No info	No comments
Thailand	Unleaded (1999)	50	50	-	No comments	Euro 4/IV	No info	No comments
Timor-Leste	Unleaded (2008)	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments
Tokelau	Unleaded	No info	No info	No info	• Imports all oil and petroleum products		No info	No comments
Tonga	Unleaded	No info	No info	No info	• Imports all oil and petroleum products	No info	No info	No comments

Appendix

http://www.unep.org/Transport/New/PCFV/pdf/Maps_Matrices/AP/matrix/AP_Matrix_June2015.pdf

Updated June 2015

Status of Fuel Quality and Vehicle Emission Standards in Asia-Pacific

		Current and Planned Sulphur Levels in Fuel (max, ppm) (nationwide unless otherwise stated)				Vehicle Emission Standards and Enforcement		
COUNTRY	**Lead Status**	**Diesel (ppm)**	**Petrol (ppm)**	**50ppm Target Date**	**Comments**	**Emission Standards (Current)**	**Use of Catalytic Converters**	**Comments**
	(since 2006)							
Tuvalu	Unleaded (since 2006)	No info	No info	No info	No comments	No info	No info	No comments
Vanuatu	Unleaded (since 2006)	No info	No info	No info	No comments	No info	No info	No comments
Viet Nam	Unleaded (since 2001)	500	500	2018	No comments	Euro 2	No info	• Euro 4 – 2017 • Euro 5 – 2022
Total: 39 countries								

*Referring to vehicle age, emissions standards, and technology requirements.

References:

- Collated by UNEP Transport Unit from various sources and personal communication
- UNEP National Questionnaires, National Ministries, Fuel distributor and producer websites.
- Trade publications, Delphi Vehicle Standards Booklet; Clean Air Asia; Michael Walsh CarLines: http://www.walshcarlines.com/; http://transportpolicy.net/

For comments, corrections, and suggestions, please contact: clean.transport(at)unep.org

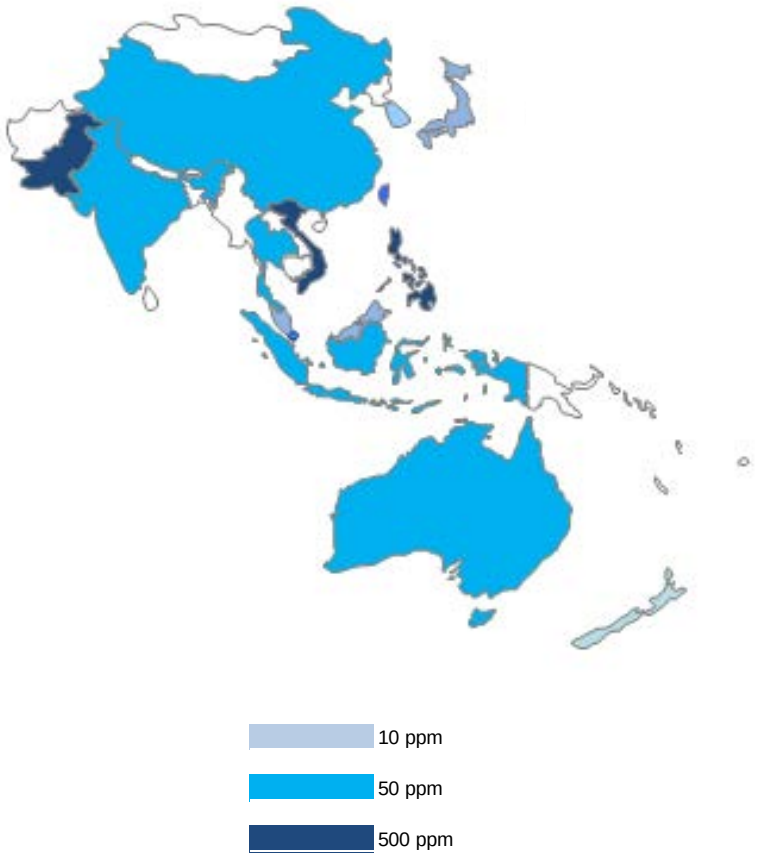
In-House Research Experience

Key Observations

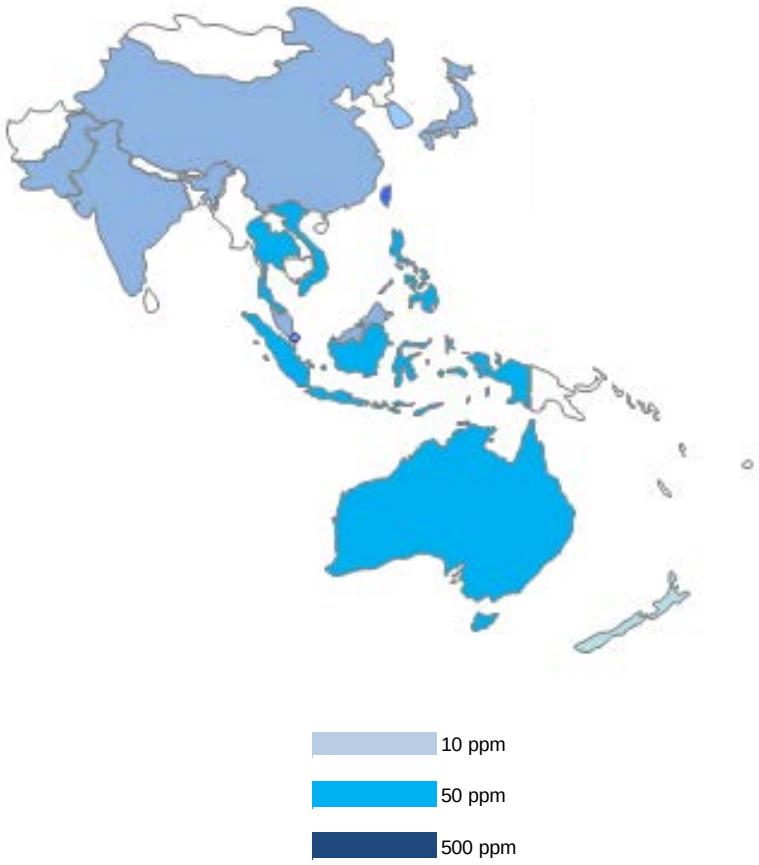
- All countries that requiring EURO 5 or 6 or similar specifications also require 10 ppm sulfur gasoline
  - The US is moving to ‘Tier 3’ gasoline in 2017 which includes a 10 ppm Sulfur mandate
    - California is already there
  - All EU countries and most of Eastern European countries have Sulfur limits of 10 ppm that are strictly adhered to
  - All Euro 5 & 6 standards require a 10 ppm gasoline sulfur limit
  - China and Saudi Arabia have the most aggressive tightening of sulfur limits in gasoline
- Some countries have very ambitious goals to tightening Sulfur regulations that will be nearly impossible to meet without significant refinery investment
- Countries that have gasoline with sulfur levels above 10 ppm will likely rely largely on local refineries for supply as virtually everyone is moving to 10 ppm or less. Meaning that Australia will easily be able to import 10 ppm gasoline if the local refiners choose not to invest.

Asia Fuel Specifications

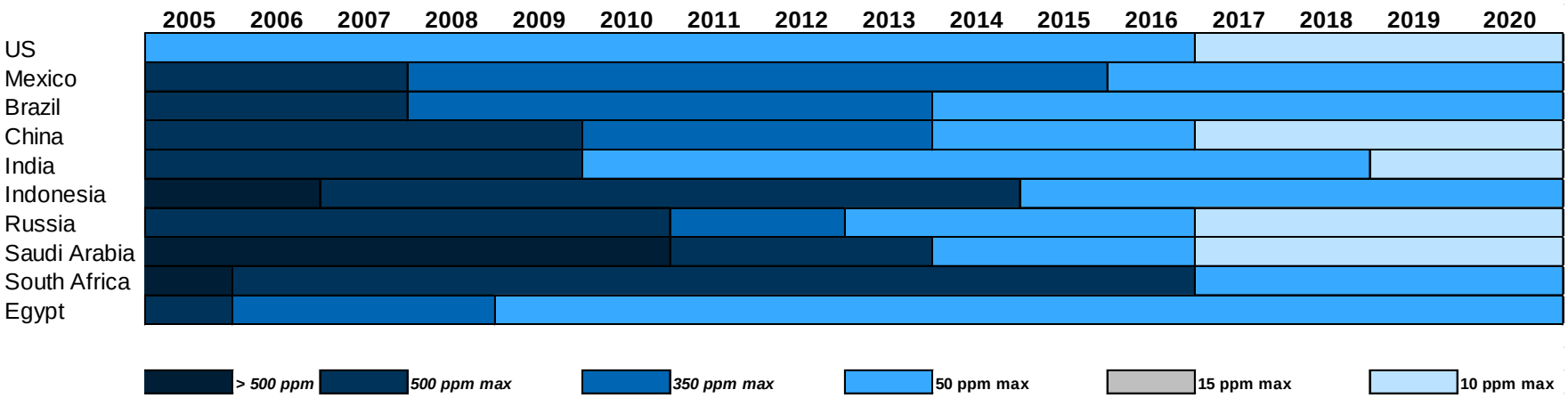
2015



2020

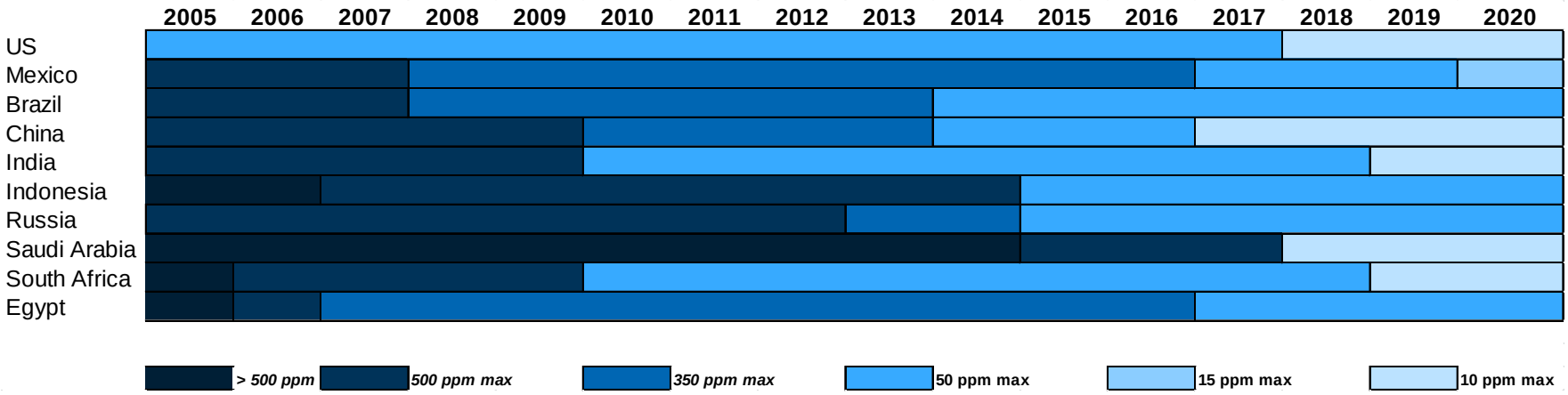


Gasoline Regulations

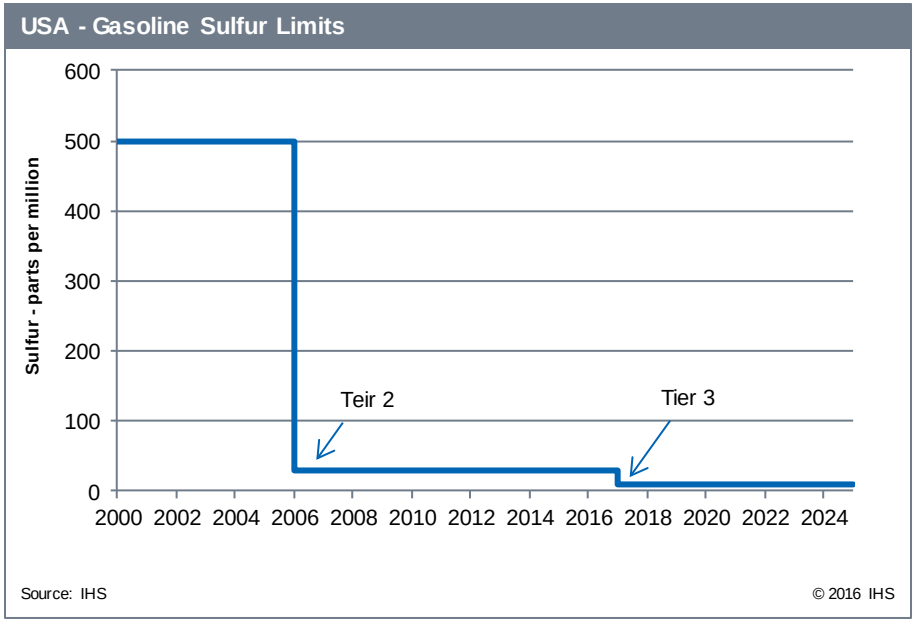


Notes:
Mexico has limited sulful levels in regular gasoline to 80 ppm max in Mexico City, Guadalajara and Monterrey & nationwide for premium gasoline, but not the rest of the country
South Africa has announced intentions to limit sulfur in gasoline to 10 ppm max in 2017, although it is unlikely to reach the limit as planned
Egypt announced a switch to 50 ppm in 2010, but has yet to meet the limit and specs vary and correspond to domestic refinery output

Expected Implementation of Gasoline Regulations

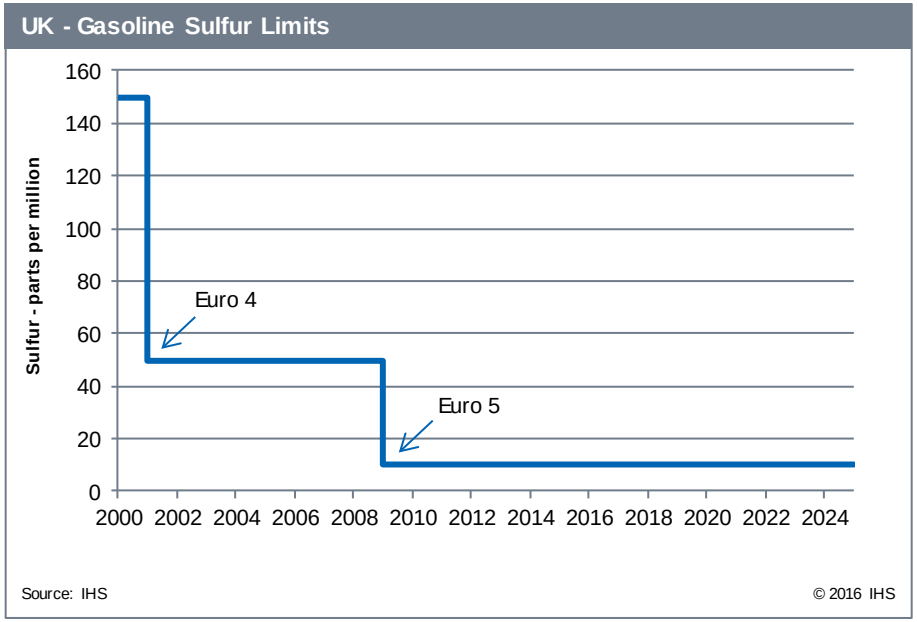


United States Gasoline Sulfur Specifications



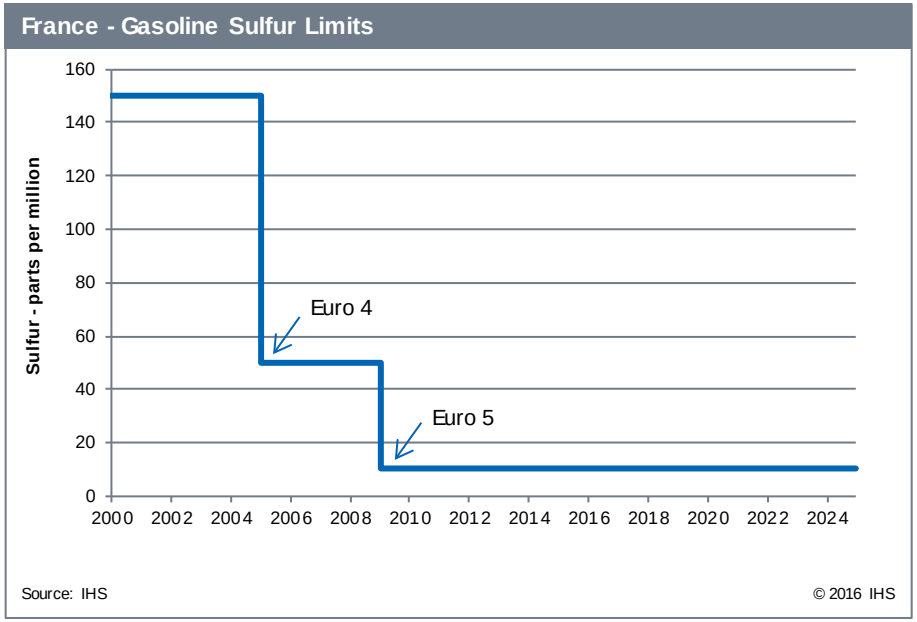
- In March 2013, the EPA proposed Tier 3 Motor Vehicle Emission and Fuel Standards, which would set new vehicle emission standards and lower the Sulfur content of gasoline beginning in 2017
- EPA Tier 3 regulations calls for a reduction in gasoline Sulfur content to 10 ppm from the current 30 ppm, inline with Euro 5/6 and more stringent even than the current California Air Resources Board (CARB) standard
- The US has a complex Sulfur credit system, which pushes back the date of full compliance by refiners which may provide a pathway for Australia

United Kingdom Gasoline Sulfur Specifications



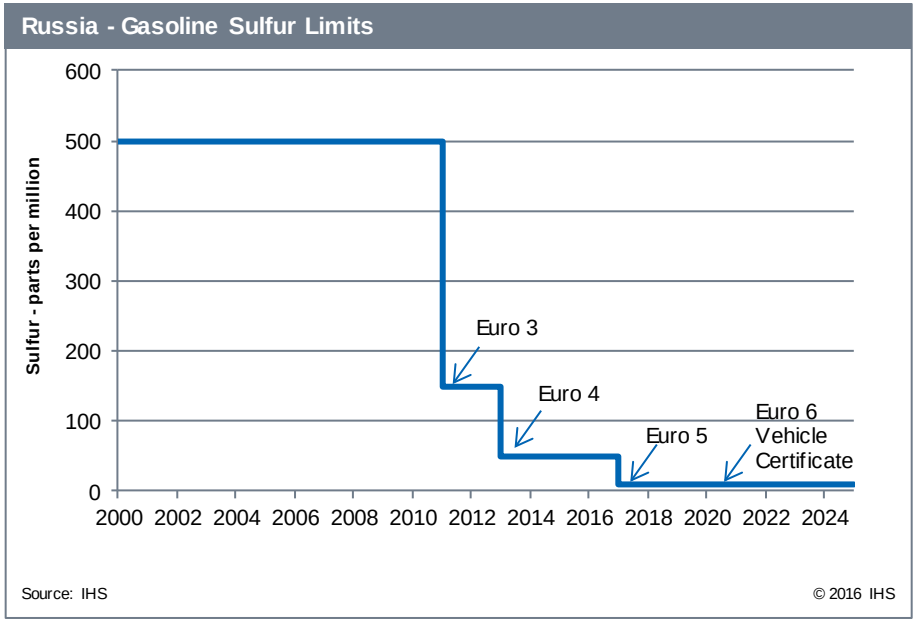
- UK adheres to EU fuel specifications
- Tax increases on fuels with over 10ppm Sulfur content moved the market to 10ppm motor fuels several years in advance of the EU's 2009 deadline

France Gasoline Sulfur Specifications



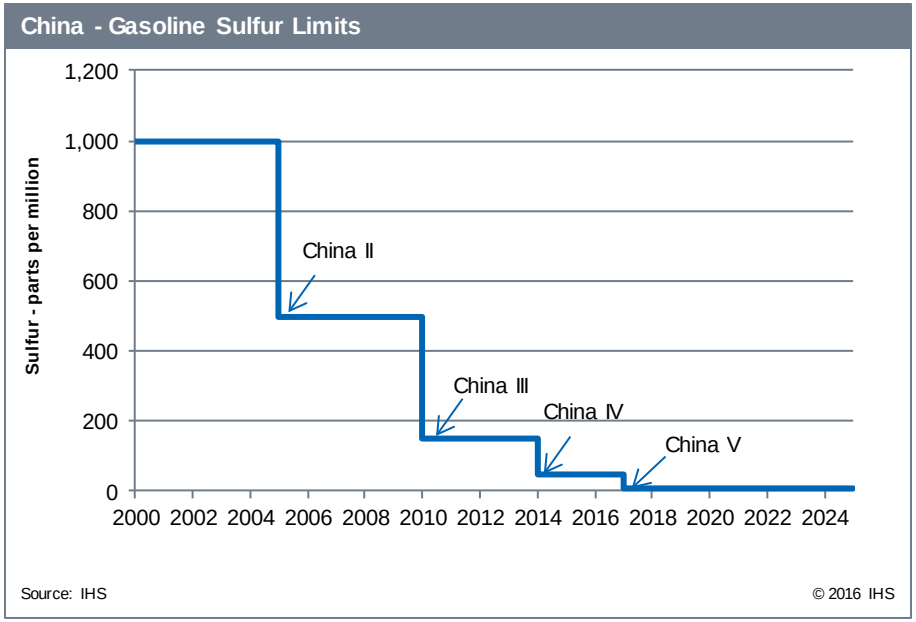
- France switched to low Sulfur fuels (50 ppm) in 2001, gradually phasing in 10 ppm grades, which have been available across the country since 2007
- As of January 1, 2009 all motor fuels sold in France meet European requirements for 10 ppm

Russia Gasoline Sulfur Specifications



- Russia has adopted a “class” system of fuels, which corresponds to Euro standards
  - Unlike Euro specifications, Russia’s specifications allow for 80 octane fuels as many engines in Russia still require low octane gasoline
- Despite the mandate, supplies of Euro 4 fuel to remote areas are currently insufficient, which will initially force consumers to continue to buy lower grades
- The transition to Euro 5 was originally set for January 2014, but was pushed until 2016 / 2017 mainly due to the lack of refinery investment in today’s depressed oil price environment

China Gasoline Sulfur Specifications



- Due to worsening air quality in many major cities in recent years, China has aggressively pushed ahead with stricter, cleaner fuel standards
- Refineries across the country are required to meet mandated Euro V standards by 2017
- Several cities and provinces, including Beijing, Shanghai, Guangzhou and Nanjing, have moved to Euro 5 standards, ahead of the other provinces
- However, some refineries, particularly in some inner provinces, are likely to fall behind schedule due to the delayed enforcement of the new standards by the provincial governments

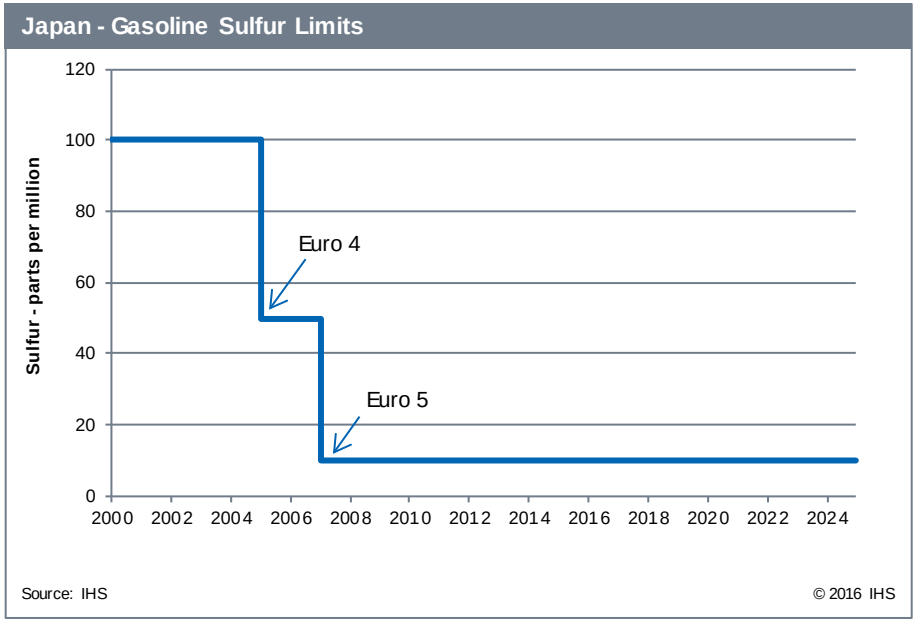
India Gasoline Sulfur Specifications

Indian Emission Standards - Fuel (Gasoline and Diesel) and Vehicles (Four-wheeled)			
Standard	**Reference**	**Date**	**Region**
India 2000	Euro I	2000	Nationwide
Bharat Stage III	Euro II	2005	Nationwide
Bharat Stage III	Euro III	2005	National Capital Region (NCR) & Delhi, Mumbai, Kolkata, Chennai, Bengalore, Hyderabad, Kanpur, Agra, Pune, Surat, Ahmedabad, Lucknow, Sholapur
		2010	Nationwide
Bharat Stage IV	Euro IV	2010	NCR & Delhi, Mumbai, Kolkata, Chennai, Bengalore, Hyderabad, Kanpur, Agra, Pune, Surat, Ahmedabad, Lucknow, Sholapur
		2011	Add: Pune
		2012	Add: Vapi, Jamnagar, Ankleshwar, Hissar, Bharatpur, Puducherry, Mathura, Aligarh, Rae Bareilly, Silvasa, Daman, Diu, Unnao
		2013	Add: Nizamabad, Medak, Mehboobnagar, Valsad, Karmal, Yamuna Nagar, Kurukshetra, Unnao, Diu,
		2014	Add: Mahabaleshwar, Ahmednagar, Hindaun, Dholpur, Kosi Kalan, Vrindavan
		2015	Add: All North Indian states of Punjab, Haryana, Himachal Pradesh, Uttarakhand, Chandigarh, Delhi and bordering districts in Rajasthan and Western Uttar Pradesh
		April 2017 (proposed)	Nationwide
Bharat Stage VI	Euro VI	April 2020 (proposed)	Nationwide

Source: IHS Energy from national sources

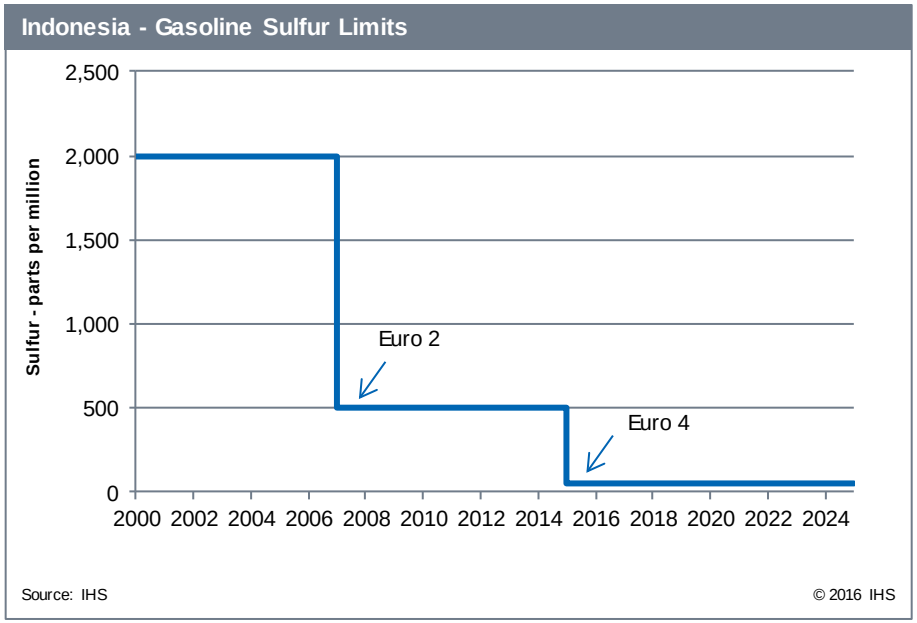
- India's national motor fuels specifications currently stand at Bharat Stage (BS) III, equivalent to Euro III
- India's vehicle emissions standards move in tandem with its fuel emission standards
- In 2015, BS IV was mandated in all North Indian cities & states & South cities transitioned in April 2016
- The mandate outlines a nationwide shift to BS IV by 2017
- The market is also considering a possible move to either BS V or BS VI by 2020
  - The outcome of the mandate hinges on the ability of domestic refiners to upgrade units to meet the new specifications, which will be very costly

Japan Gasoline Sulfur Specifications



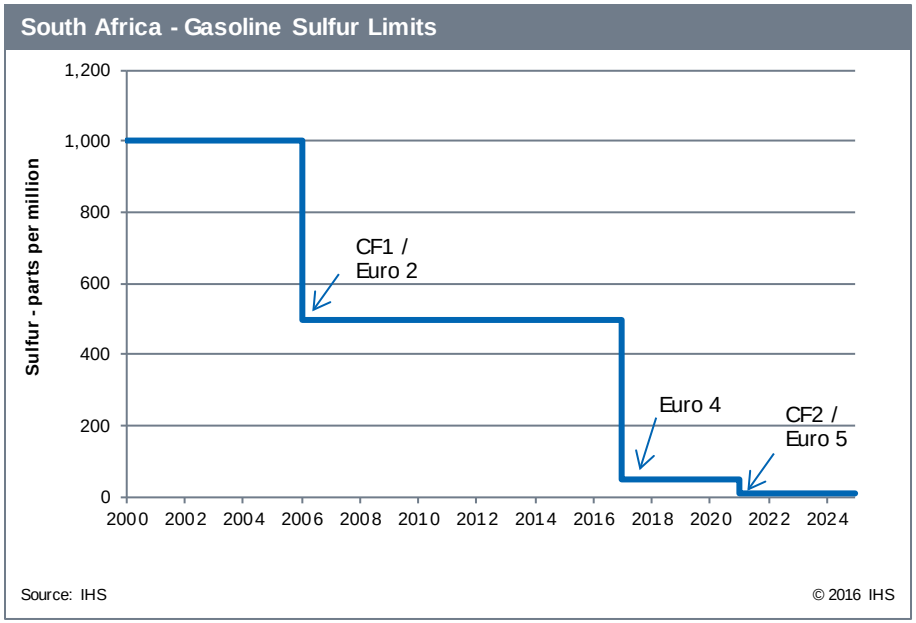
- Japan's gasoline and diesel specifications remained unchanged at Euro 5 equivalent standards (10 ppm), with those standards in effect since 2007
- No announcements have been made regarding the implementation of tighter standards, but Japan has historically moved in tandem with the European Union (EU)
- Japan is one of the leaders of stringent vehicle emissions standards and places pressure on domestic refiners to maintain a certain level of hydrotreating capacity to meet these regulations, but also protects them from off-spec imports from the regional market

Indonesia Gasoline Sulfur Specifications



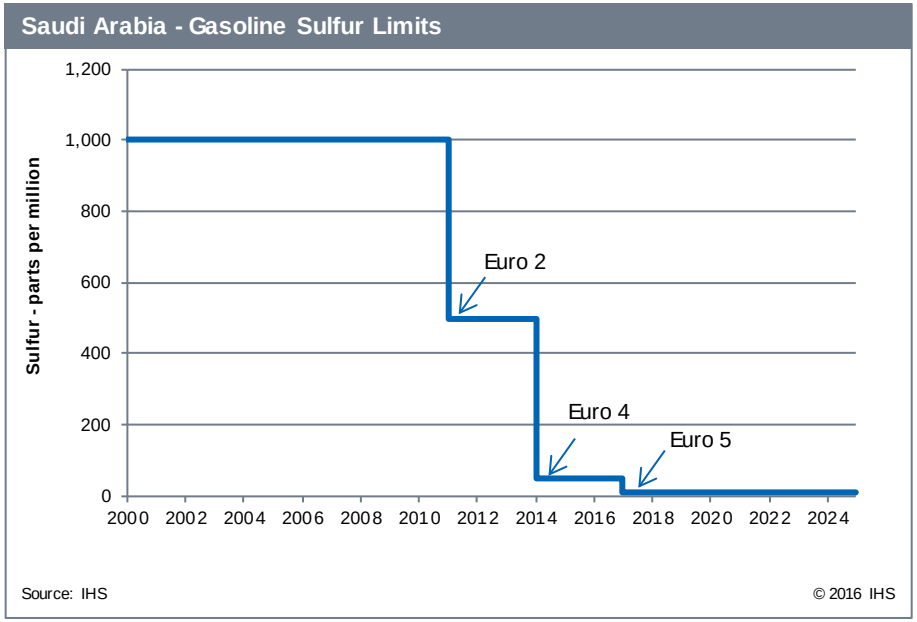
- Emissions and fuel specs in Indonesia have been required to adhere to Euro II standards since 2006
- The introduction of Euro 4 specification fuel went into place in 2015, but is not widely available or implemented

South Africa Gasoline Sulfur Specifications



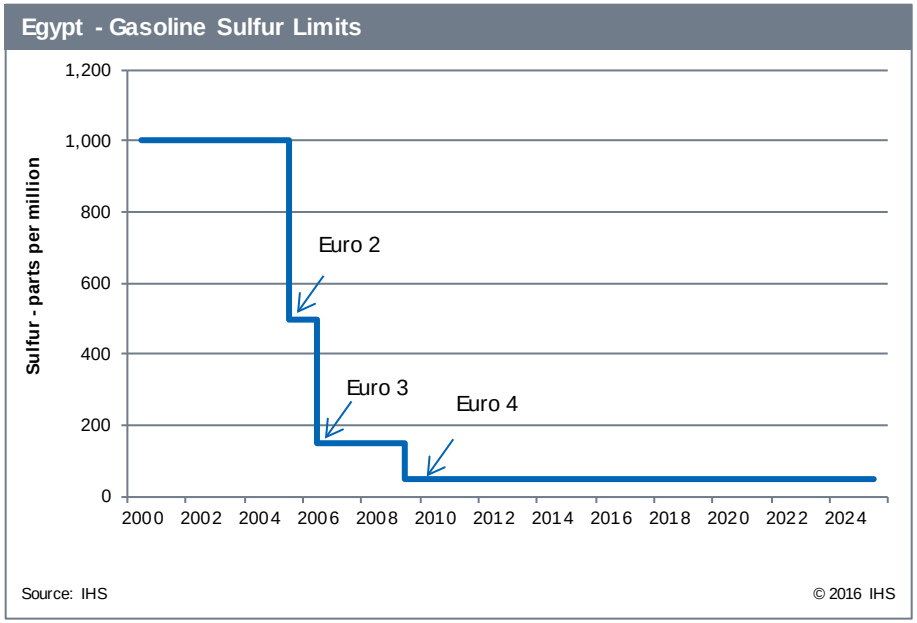
- The Clean Fuels 1 (CF1) specification currently in place limits Sulfur to 500 ppm for both gasoline and automotive diesel, corresponding to Euro 2 limits
  - Nevertheless, 50 ppm is already and increasingly available in the market
- The government initially planned to limit the Sulfur to 10ppm under the Clean Fuels 2 (CF2) by 2017
- The CF2 would necessitate substantial investment in South Africa's six refineries in order to produce this higher grade of fuel
- The 2017 compliance date will be delayed due to lack of clarity on the potential cost recovery mechanism
- IHS believes 50 ppm will become the new standard in 2017 and CF2 will be delayed until post-2020

Saudi Arabia Gasoline Sulfur Specifications



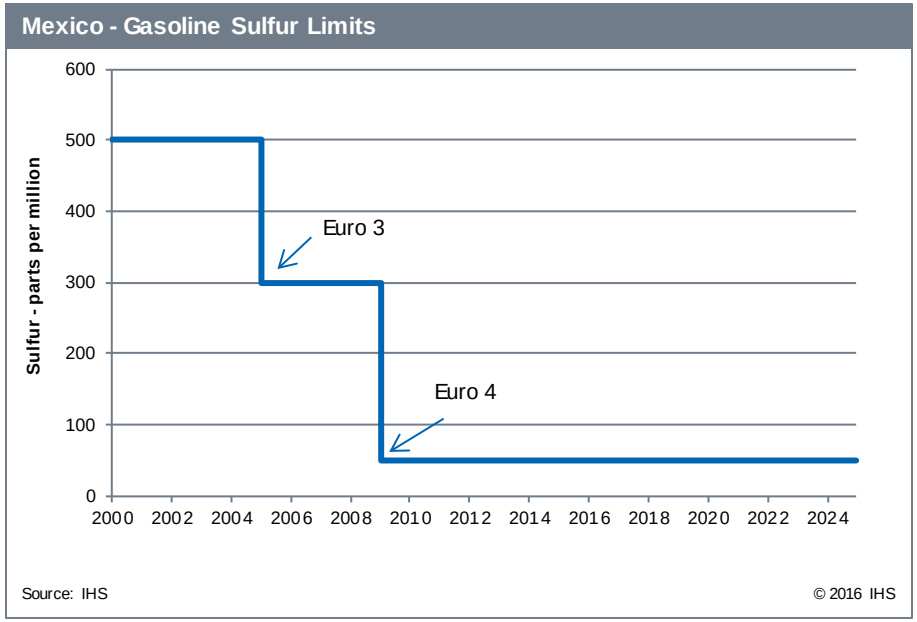
- Fuel specifications in Saudi Arabia have been progressively tightened in recent years
- In 2014, the Sulfur content permissible in gasoline and diesel was reduced to 50 ppm
- The Kingdom is aiming to adopt European standards for fuel quality and is seeking to reduce Sulfur content significantly to meet Euro 5 diesel and gasoline specifications
- By 2017, Saudi Arabia is aiming to have reduced Sulfur content in gasoline and diesel to 10 ppm

Egypt Gasoline Sulfur Specifications



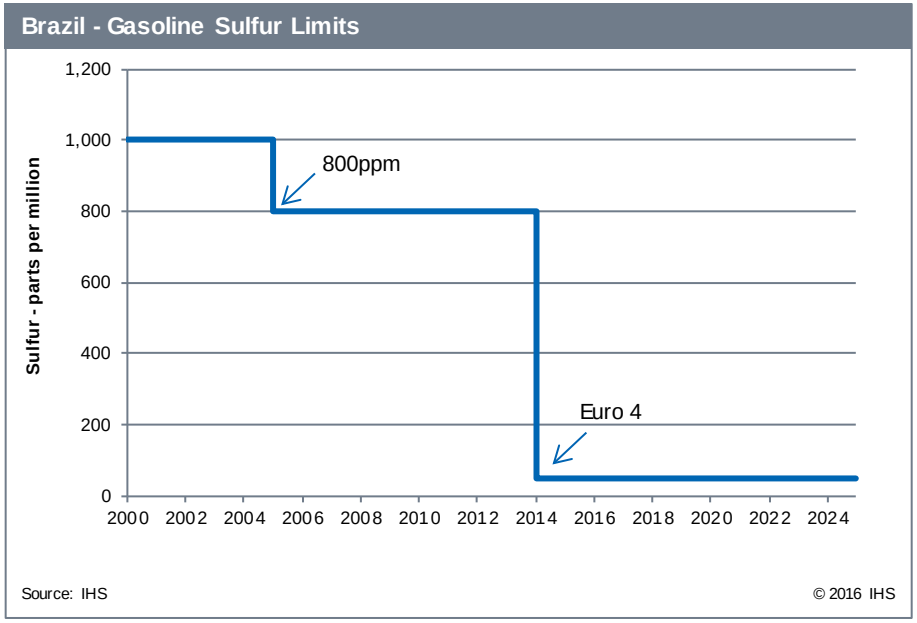
- While the chart shows current a maximum of 50 ppm of Sulfur in gasoline, Sulfur content varies and can be above 500 ppm in reality as it corresponds to the quality of Egyptian refinery output
- Upon completion (2017/8), Egyptian Refining Company's Cairo refinery expansion / upgrading project will be able to produce and supply low-Sulfur (Euro 5) transportation fuels to the domestic market
  - Changes in oil product specifications are not expected in the medium term, as major investments in refinery upgrades are unlikely to materialize apart from this project

Mexico Gasoline Sulfur Specifications



- The technical standards set ambitious goals for low-Sulfur gasoline and diesel distribution nationwide, with the target deadline originally established at 2009
  - As of 2015, gasoline Sulfur compliance is only partially met or still unattainable
- IHS estimates that full compliance for gasoline across the country could take place by 2016-17 and for diesel by 2018-19
  - ULSG units are advancing, but completion of the full project scope could be delayed without adequate funding

Brazil Gasoline Sulfur Specifications



- The maximum Sulfur content for all gasoline sold in the market was reduced from 800 ppm to 50 ppm in 2014
- These are enforced in urban areas and Euro 4 gasoline is becoming available throughout the rural regions as well
- New emission limits were introduced for new vehicles as part of the INOVAR program in 2015

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