Concawe
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Sulphur dioxide emissions from oil refineries in Europe (2015)

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Sulphur dioxide emissions from oil refineries in Europe (2015)

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ABSTRACT

This report describes the results of the 2015 survey into the sulphur pathways in European refineries. This includes the distribution of sulphur in products, the capture and recovery of sulphur in refineries and the emission of sulphur oxides as part of the refining process. The results of surveys carried out for the years 2002, 2006 and 2010 are also included.

In 2015 the 44 refineries considered in this report processed crude and feedstock amounting to 52% of the European refining throughput. The results confirm a downward trend in the sulphur content of major product streams, associated with a strong increase in sulphur recovered in the refinery process and a reduction of sulphur emitted from refinery operations.

The 2015 survey showed:

- A reduction in the amount of sulphur going out in fuel products from 30% of intake in 2002 to 23% of intake in 2015
- An increase in the amount of sulphur recovered as elemental sulphur from 48% in 2002 to 60% of intake in 2015
- A decrease in the amount of sulphur emitted to the atmosphere as a result of direct use in the refinery from 6% in 2002 to 2% of intake in 2015

KEYWORDS

Emissions, oil industry, petroleum products, refinery, sulphur, sulphur dioxide, survey, crude

INTERNET

This report is available as an Adobe pdf file on the Concawe website (www.concawe.org).

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SUMMARY

The Concawe Sulphur survey has been run at approximately 4 year intervals since 1979 and provides an overview of the distribution of sulphur across all of the main refinery product streams in relation to the refinery crude diet. Additionally it reports on sulphur emitted to the atmosphere and sulphur recovered as a product.

The results of the survey show a continued reduction in sulphur emitted to the atmosphere and an overall increase in sulphur recovery. In 2015 an estimated 60% of the sulphur in the refinery intake is recovered as elemental sulphur compare to 56% in 2010 and 45% in 2006. A further 13% is sequestered in products that are not burned. The amount of sulphur emitted by refineries themselves has more than halved since 2002, this is due to less oil burning, a reduction in the sulphur content of internal fuels, investments in desulphurization of products and sulphur recovery processes. The proportion of sulphur in products destined for combustion has decreased from 33% of intake in 2006 to 27% in 2010 and 23% in 2015 reflecting the progress made to comply with fuel and air quality legislation.

The annually averaged sulphur content in the crude diet for Europe continues to show an upward trend, increasing from 0.91% in 2006 to 1.01% in 2010 and 1.17% in 2015.

The sulphur content of fuel products closely matches the market requirements of fuels regulated by international or EU regulations (e.g. Sulphur in Liquid Fuels Directive and the Directive on Automotive Fuel Quality).

1. INTRODUCTION

Concawe has reported the distribution of sulphur between refinery products and refinery emissions at 4 yearly intervals since 1979 by means of what is known as the Sulphur Survey report. (See references Concawe (1984) [1], Concawe (1986) [2], Concawe (1991) [3], Concawe (1996) [4], Concawe (1998) [5], Concawe (2002) [6], Concawe (2007) [7], Concawe (2010) [8], Concawe (2016) [9])

The report provides information on the typical sulphur content of the main refinery product streams, the amount of sulphur recovered and the amount of sulphur emitted in the course of refining those products. Results from the Sulphur Survey are useful in assessing how the industry responds to regulation (e.g. on changing fuel specifications, environmental legislation, etc.).

2. REFINERY INTAKE AND OVERALL SULPHUR BALANCE

Refineries take in both crude oil and intermediate products for processing. The totals reported in the last four survey years compared with the total refinery intake in the EU-28, are given below. The Concawe surveys covered 43% in 2002, 63% in 2006, 68% in 2010 and 52% in 2015. These survey results are therefore considered to be representative of the industry in 2015.

Table 1 Refinery hydrocarbon intake

	2002	2006	2010	2015
Number of refineries participating in survey	46[1]	67	63[2]	44
Crude Intake, Mt	277	417	393	263
Other Intake, Mt	35	55	55	53
Total Intake, Mt	312	472	448	316
EU-28 Crude oil, feedstock and other hydrocarbons transformation input in refineries, Mt	726	478	658[3]	613[4]
Concawe/EUROSTAT %	43%	63%	68%	52%

The overall sulphur intake at the refinery and the distribution of sulphur output is shown in **Table 2** below. The output/emission categories are:

- Products destined for combustion, e.g. automotive fuels, bunkers
- Non-combustion products where the sulphur remains in the product and is not further converted, e.g. bitumen, lubricating oils
- Sulphur recovered from refinery streams as elemental sulphur and other sulphur products
- Sulphur recovered in non-oil products, e.g. gypsum
- Sulphur emitted from refinery processes and combustion

The largest sulphur output stream, for each year studied, is elemental sulphur from the sulphur recovery system. The next largest is the sulphur present in products.

The average sulphur content of the European crude intake increased to a value of 1.17% in 2015 compared to 1.01% in 2010 and 0.91% in both 2002 and 2006.

1 Concawe Report 02/07 reports 47 refineries and a total intake of 331 Mt/a – one survey return appears to have been counted twice in that analysis and was removed when preparing Concawe report 01/10

2 Two responses were not complete and 63 is the number of surveys taken into account in this report.

3 Eurostat data. Downloaded 19-10-2015. v3.1.10-20150929-5608-PROD_EUROBASE. Crude oil, feedstocks and other hydrocarbons. Transformation input in refineries.

4 Eurostat Energy Balance Sheets, 2014 data, 2016 Edition. ISBN: 978-92-79-59758-9. Transformation input in refineries.

The sectoral sulphur mass closure in 2010 was 99.5% which is very good and better than for the last two surveys, the closure widens slightly in this survey but remains good at 98.7%. The results for individual refinery balances are more varied due in part to the sensitivity of the calculated balance using average sulphur content.

Table 2 Refinery sulphur intake and output

		2002	2006	2010	2015
Intake	S in Crude kt (S)	2515	3788	3965	2984
	Other kt (S)	194	395	375	466
S content	Crude %	0.91	0.91	1.01	1.17
	Other %	0.55	0.72	0.68	0.63
Output	Products for combustion kt (S)	809	1361	1185	780
	Products for non-combustion kt (S)	233	493	526	459
	Recovered as elemental sulphur kt (S)	1289	1880	2426	2055
	Recovered as other sulphur compounds kt (S)	149	9	18	43
Emitted at Refinery	All sources kt (S)	150	156	164	68
TOTAL	OUT kt (S)	2629	3900	4320	3405
	IN kt (S)	2709	4183	4340	3450
	RATIO %	97.0	93.2	99.5	98.7

To illustrate trends in the distribution of sulphur between the different output modes the sulphur content is shown below as a percentage of the sulphur intake.

Table 3 Fraction of sulphur intake going to different sources (% sulphur)

		2002	2006	2010	2015
Output	Products for combustion	29.8	32.5	27.3	22.6
	Products not for combustion	8.6	11.8	12.1	13.3
	Recovered as elemental S	47.6	45.0	55.9	59.6
	Recovered as other S products	5.5	0.2	0.4	1.2
Emitted at Refinery	All sources	5.5	3.7	3.8	2.0
Balance		97.0	93.2	99.5	98.7

We observe that the survey shows;

- A reduction in the amount of sulphur going out in products for combustion (fuel products) from 29.8% of intake in 2002 to 22.6% of intake in 2015
- An increase in the amount of sulphur recovered (as elemental sulphur) from 47.6% of intake in 2002 to 59.6% of intake in 2015
- A decrease in the sulphur emitted to the atmosphere by refineries from 5.5% in 2002 to 2% in 2015

The refinery emissions to atmosphere of oxidised sulphur arise from several combustion sources. The survey includes emissions from Stacks, Fluid Catalytic Cracking Units (FCCU), Sulphur Recovery Units (SRU) and Flares as distinct sources while remaining emissions are categorised as Miscellaneous. The overall distribution of emissions from these sources is given in **Table 4** as a fraction of the refinery sulphur intake. It can be seen that the situation in 2015 shows a marked reduction in overall sulphur emissions compared to previous years, with the largest reduction in the Stacks component. This reduction is due primarily to a reduction in the amount of oil being fired as part of the refining process as shown in **Figure 4.**

Figure 1 shows that the proportion of intake sulphur retained in fuel products is steadily decreasing whilst the proportion in non-fuel products increases but at a lower rate. This is primarily due to legislation driven changes to fuel product specification that limit the sulphur content at the point of combustion.

Importantly, the emission from sulphur recovery has remained proportionately small despite an increase in sulphur recovered, and in 2015 has actually reduced. This is illustrated in **Figure 2.**

Figure 1 Fraction of intake sulphur retained in refinery products

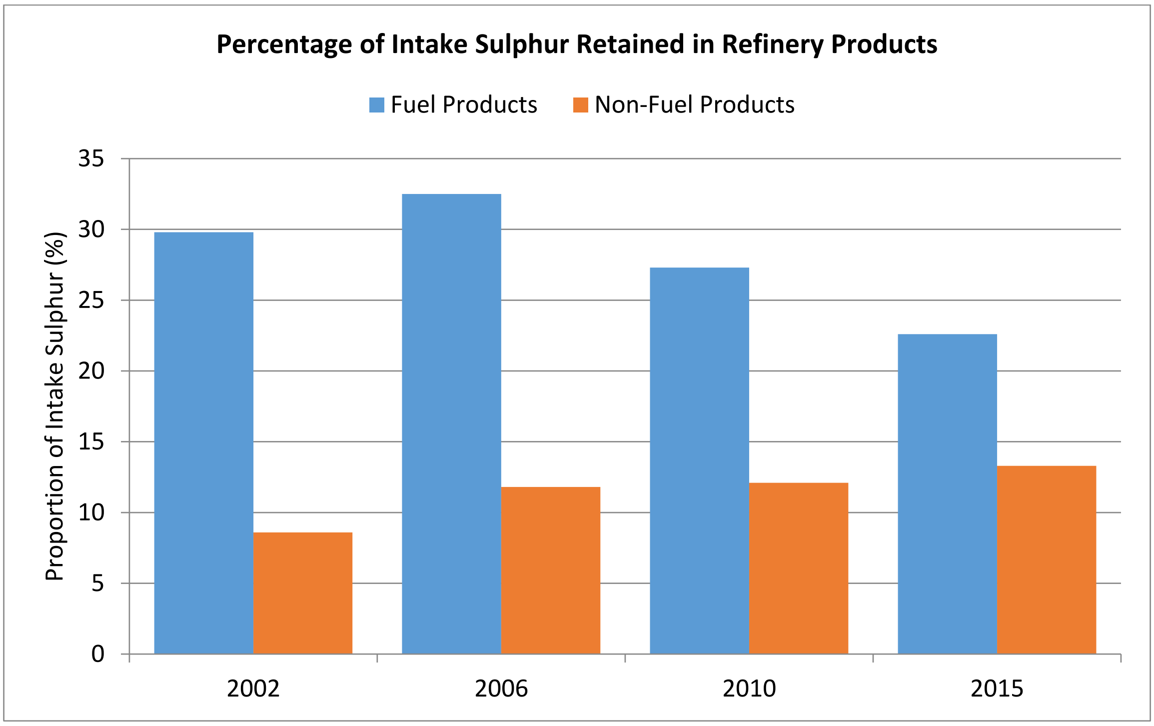


Figure 2 Fraction of intake sulphur recovered and emitted at the refinery

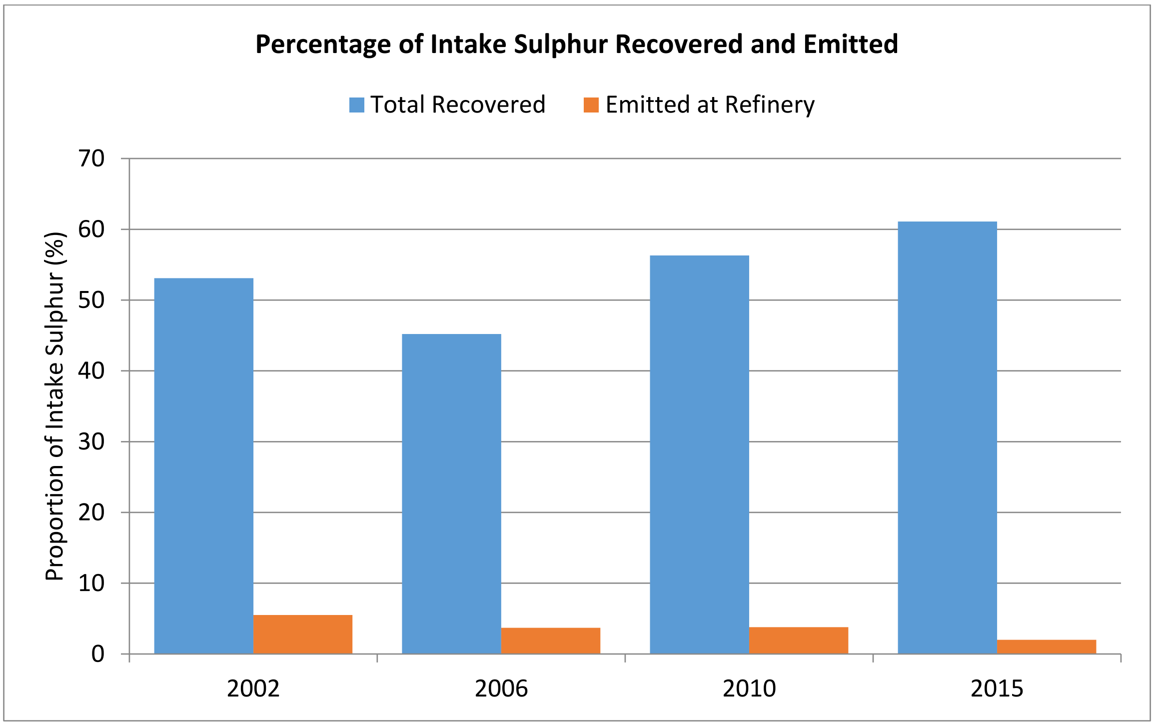
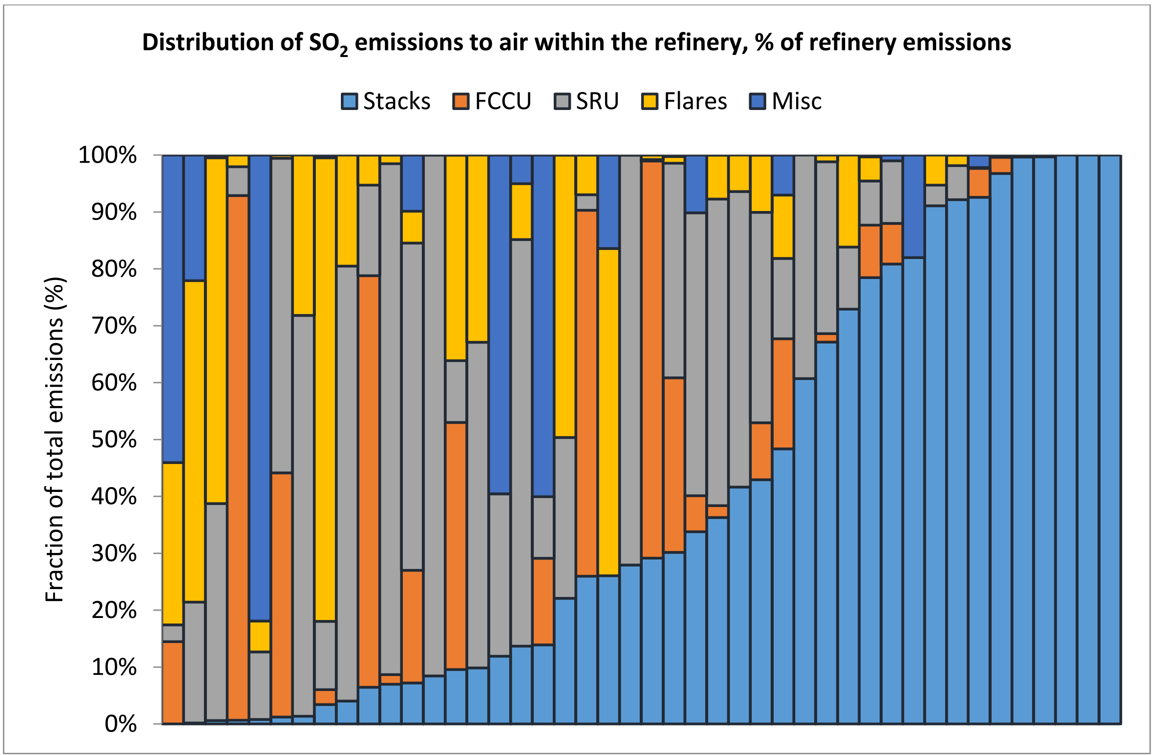


Table 4 Distribution of oxidised sulphur emissions between refinery sources as % of intake

Emissions from combustion % of sulphur intake	2002	2006	2010	2015
Stacks	3.1%	1.8%	2.3%	0.7%
FCCU	0.2%	0.4%	0.5%	0.4%
SRU	1.3%	0.6%	0.6%	0.4%
Flares	0.6%	0.8%	0.2%	0.3%
Miscellaneous	0.2%	0.2%	0.2%	0.2%
All sources %S	5.5%	3.7%	3.8%	2.0%

The figures above are industry-wide aggregates, on a single refinery basis the apportionment of emission sources is highly variable, i.e. some refineries do not have a FCCU, some refineries are natural gas fired and have low stack sulphur emission as a consequence, some have “cokers” which add to the miscellaneous emissions, while others are limited in the choice of combustion fuels available given the refining processes undertaken. This heterogeneity between refineries is shown for 2015 in **Figure 3**. Note that the results are ordered by stack emission as fraction of total emissions.

Figure 3 Distribution of refinery sulphur emissions between combustion sources

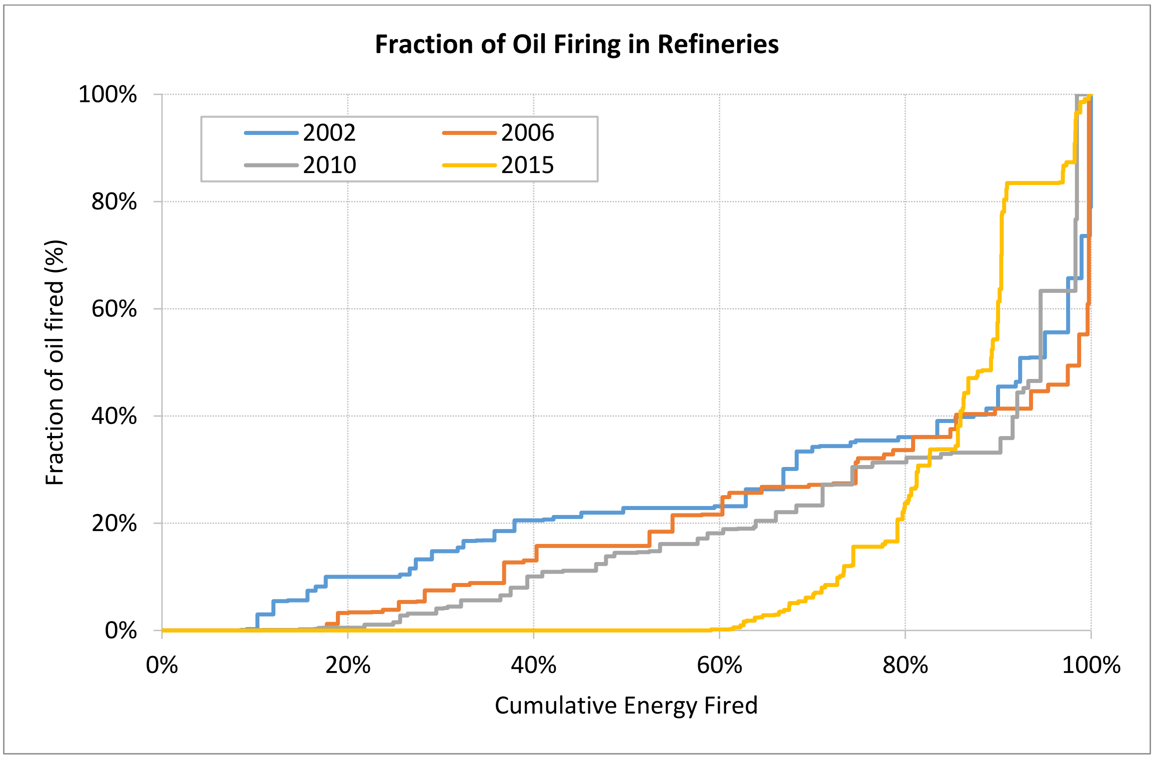


3. COMBUSTION EMISSIONS

Sulphur emissions as SO_2 from combustion units in a refinery are a direct consequence of burning refinery fuels. Refinery operation is adapted to suit changes in crude feedstock and product demand, therefore the mix of products generated within a refinery can vary significantly over time. Given the high level of interconnection between combustion and process units the fuels used in the combustion units also varies. The main fuels used are refinery liquid fuel oil, refinery fuel gas (RFG) and commercial natural gas (NG). There are other combustible streams that may have a low heating value due to their high nitrogen or carbon-dioxide content, the category "other fuels" encompasses such fuels.

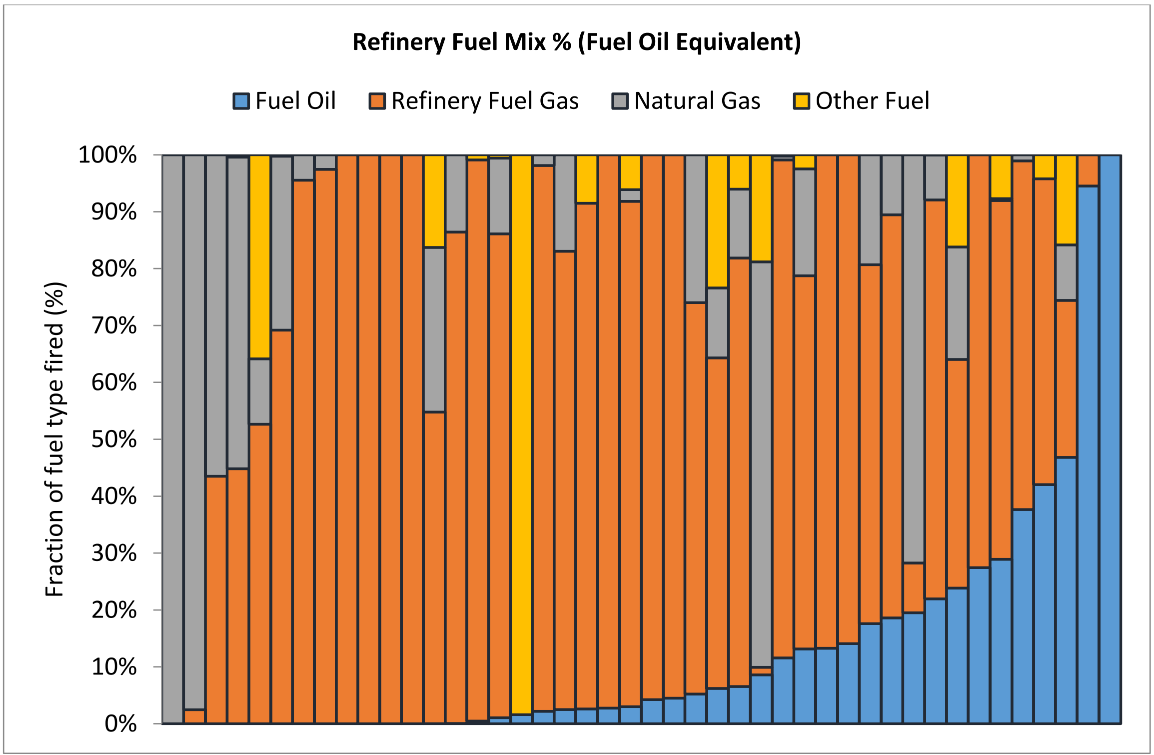
The amount of liquid fuel oil firing in refineries has been steadily decreasing as a result of emissions reduction requirements originating at EU and national level. This reduction also reflects changes in refinery configuration as a result of a changing product portfolio. **Figure 4** shows the evolution in oil use over the period 2002 to 2015. There has been a general reduction in oil firing over time with a marked reduction in the most recent survey, due largely to an increase in the use of refinery fuel gas. Currently, very few refineries have high oil usage and those that do include specialist refineries with no gas-producing distillation units.

Figure 4 Oil firing as a fraction of overall refinery fuel used in the combustion units



The proportion of fuels used in the refinery combustion units in 2015 is shown in **Figure 5**. Note that in some refineries the FCCU is an important energy source but coke is not included as a "fuel" in this chart (similar to previous sulphur survey reports) because its oxidation takes place in the FCCU regeneration section. Any additional fuel supplied to be burnt in an auxiliary CO boiler connected to an FCCU is included.

Figure 5 Refinery fuel mix as fuel oil equivalent (foe)



The sulphur content of oil used at fuel in refineries is shown in **Figure 6**. About 45% of the oil fired has a sulphur content of 1% or less and this fraction has been remarkably consistent over the surveys. The 2010 data showed an increase in the sulphur content of those fuels having more than 1% sulphur, bucking the trend seen since 2002 however 2015 appears back on trend with a marked reduction in sulphur content. **Table 5** shows the average sulphur content of refinery fuel oil as reported in the last four surveys. Refineries continue to reduce the amount of liquid fuel burned internally (**Figure 4**) and the sulphur content of this fuel is now decreasing.

Figure 6 Sulphur content of refinery fuel oil

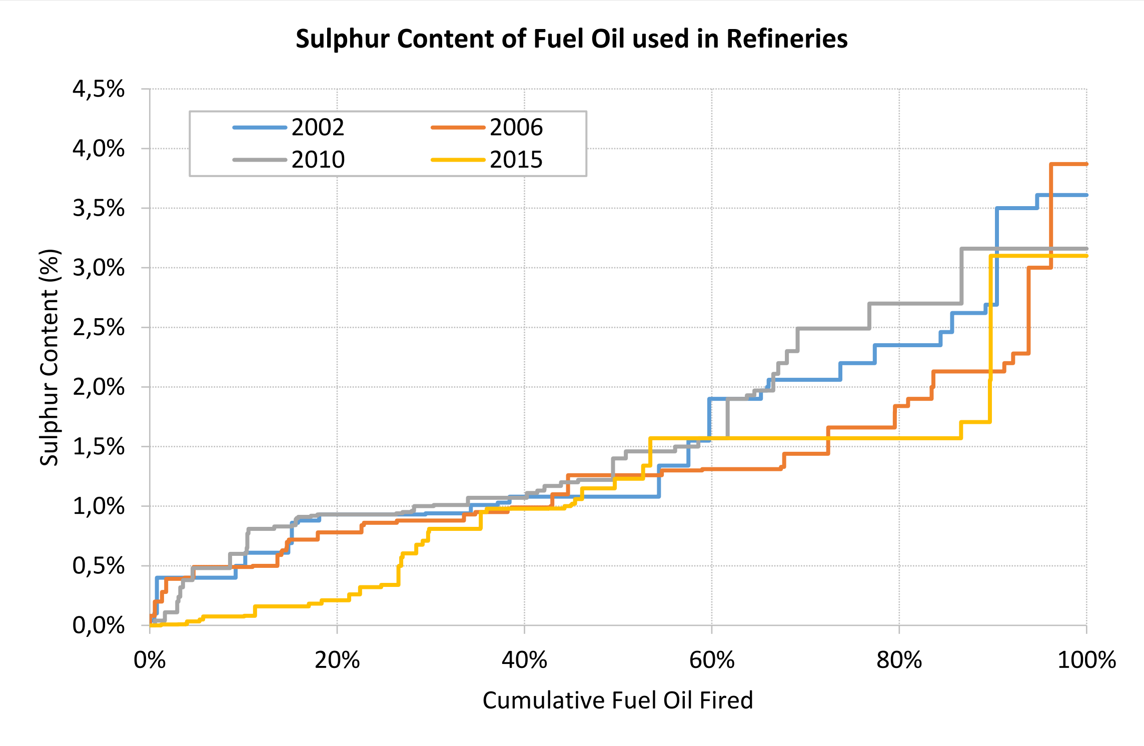


Table 5 Average sulphur content of refinery fuel oil

	2002	2006	2010	2015
Average Sulphur Content	1.34%	1.33%	1.63%	0.68%

A breakdown of fuel use by combustion plant size and fuel type is given in **Table 6**. The average sulphur content of the fuels in each category is also given. The fuel proportions are expressed on a fuel oil equivalent basis to allow direct comparison between the fuel types.

2015 shows a significant shift away from fuel oil to gaseous fuels, additionally the oil that is fired within the refineries is of lower sulphur content. The situation in 2015 is quite different from the situation in 2010 which was very similar to that in 2006 if it is accepted that “other fuels” are gaseous. The percentage of energy coming from oil has reduced from 20.7% to 13.3% and the average sulphur content of this same oil has reduced from 1.63% to 0.68% in just five years (2010 to 2015).

Overall the energy split between combustion plant sizes is becoming more consistent however the effect of refineries reporting using the “bubble” concept (where the fuel used and emissions from all stacks in a refinery are aggregated and reported as a single weighted figure) makes this data a guide rather than definitive. This could also help to explain why there is a historical inconsistency as noted in the previous report. The process of gathering more detailed stack information should help address this issue.

Table 6 Breakdown of energy use and fuel sulphur content by fuel and stack size

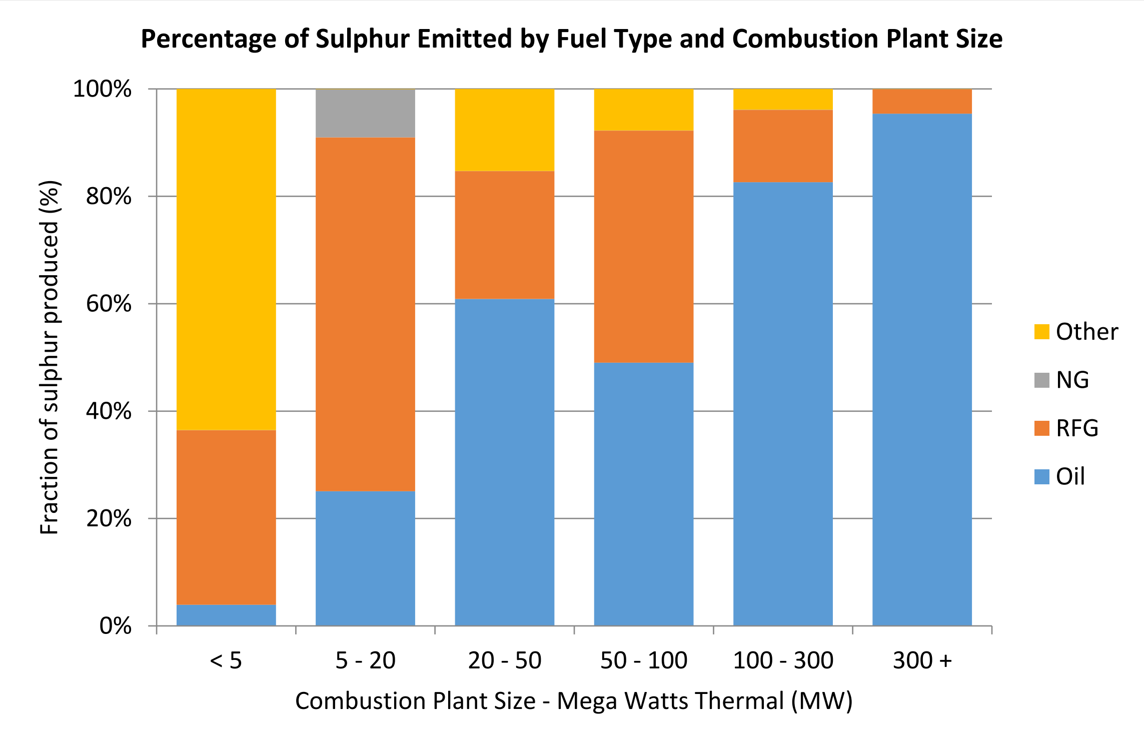
	2002		2006		2010		2015	
	Energy %	Fuel sulphur content %m	Energy %	Fuel sulphur content %m	Energy %	Fuel sulphur content %m	Energy %	Fuel sulphur content %m
Oil < 50MW	6.9%	0.75%	2.7%	0.95%	2.6%	0.94%	1.1%	0.63%
Oil > 50MW	16.7%	1.59%	16.5%	1.39%	18.1%	1.72%	12.3%	0.70%
All Oil	23.6%	1.34%	19.1%	1.33%	20.7%	1.63%	13.3%	0.68%
Gas < 50MW	29.3%	0.03%	22.7%	0.14%	11.8%	0.09%	13.9%	0.21%
Gas > 50MW	39.3%	0.04%	56.4%	0.05%	61.0%	0.06%	69.1%	0.04%
All Gas	68.7%	0.04%	79.2%	0.07%	72.8%	0.07%	83.1%	0.18%
Other < 50MW	2.9%	0.27%	0.5%	0.72%	0.6%	0.31%	0.1%	0.55%
Other > 50MW	4.8%	0.12%	1.2%	0.19%	5.9%	0.10%	3.5%	1.04%
All Other	7.7%	0.18%	1.7%[5]	0.34%	6.5%	0.12%	3.6%	0.84%

3.1. PROPORTION OF SULPHUR PRODUCTION BY PLANT SIZE

For the first time, a breakdown of sulphur by combustion plant size is available and shown in **Figure 7.** The data shows that higher sulphur fuel oil is generally fired in the larger combustion plants and is responsible for nearly all of the sulphur in units over 100 MW. Conversely, units below 20MW appear to predominantly burn refinery fuel gas (RFG) along with other fuels which tend to be lower in sulphur content.

[5] In 2006 some of these fuel streams may have been counted as part of the refinery fuel gas system.

Figure 7 Proportion of sulphur from each fuel type fired in each combustion plant size

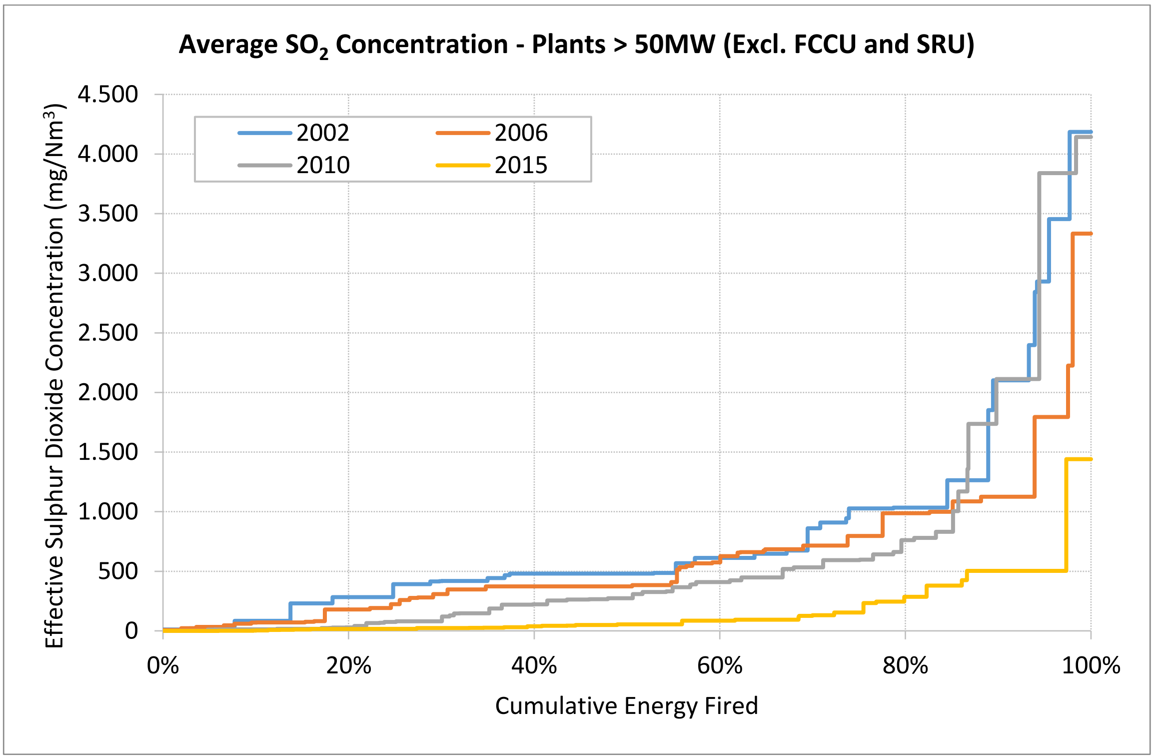


3.2. LARGE COMBUSTION PLANT SULPHUR CONCENTRATION

To assess how changes in SO_2 concentration have occurred, an estimate of the average concentration has been estimated for large combustion plants (> 50 MW). This was performed using the annual emissions, assuming representative fuel types, amount of fuel used and typical dry flue gas volume (Nm^3/kg foe at 3% oxygen). These properties are set out in Concawe report 10/01 [8] and reproduced in **Appendix 1**. The survey results are ordered by the value of the average concentration and plotted against the cumulative energy fired (fuel oil equivalent - foe) normalised by the total foe fired.

Figure 8 shows how the average flue concentration of SO_2 in large combustion plants (LCP) has evolved since 2002. The results show a continued downward trend that now encompasses all reporting refineries (accepting that not all refineries are represented in each survey).

Figure 8 Estimated distribution of annual average LCP SO2 concentrations

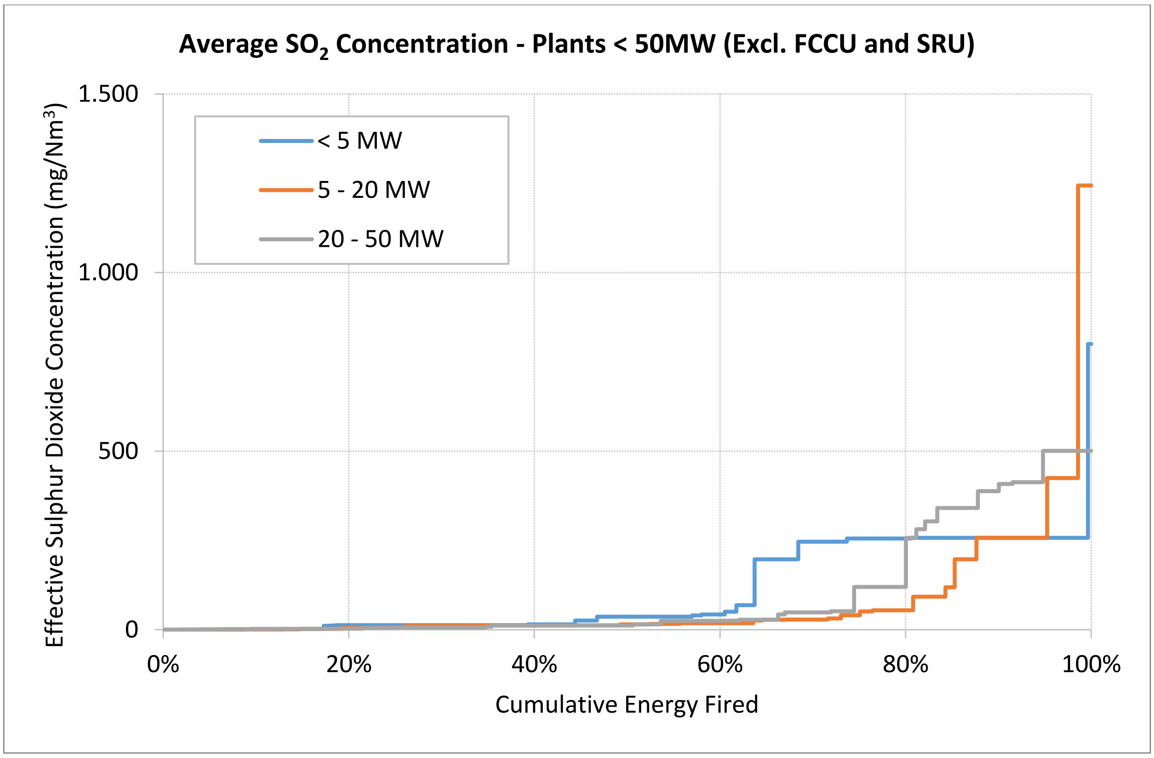


3.3. SMALL COMBUSTION PLANT SULPHUR CONCENTRATION

The 2015 survey included new data that enables analysis of combustion plants on a more disaggregated basis. Of potential relevance are the emissions from small combustion plants, those less than 50 MW in power.

Using the same formula as described for the large combustion plants, the average SO2 concentration of the flue gas for small combustion plants has been calculated for three categories of plants, and the results are shown in **Figure 9**. The results show a much lower concentration compared to large combustion plants, which is well correlated with the fuel mix seen **Figure 7**.

Figure 9 Estimated distribution of annual average SCP SO_2 concentrations

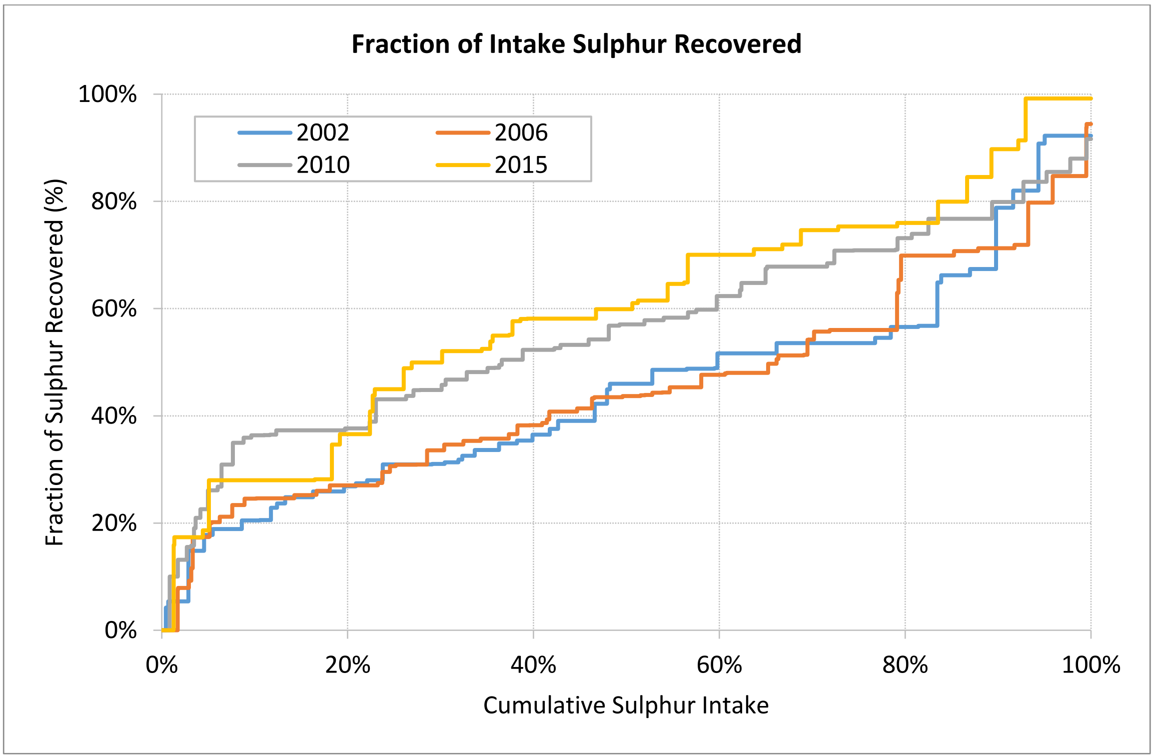


4. SULPHUR RECOVERY

Sulphur recovery is improving over time as shown in **Figure 10**. The observed reduction in both atmospheric emissions from the refineries and the product sulphur content with a given crude slate of similar sulphur content are clear evidence of this.

As shown in **Table 3**, the recovery in both 2002 and 2006 was calculated to be roughly 46% of the total sulphur intake. This increased to 56% in 2010 and has increased again to 60% in 2015. These last two increases are substantial as can be seen from the distribution of recovery achieved on a per-refinery basis shown in **Figure 10.** The difference in 2010 and 2015 compared to 2002 and 2006 is related to investment in technology and process resulting in improved sulphur recovery.

Figure 10 Fraction of intake sulphur recovered

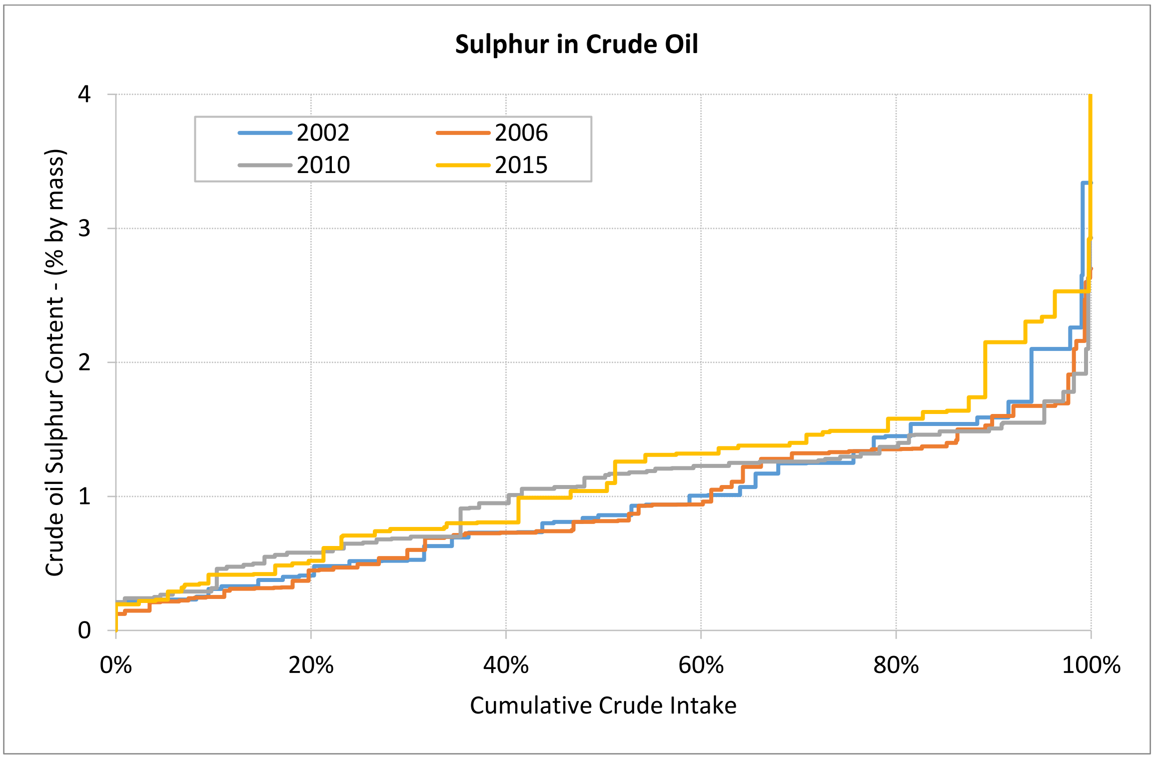


5. DISTRIBUTION OF SULPHUR IN CRUDE AND PRODUCTS

In 2010 nearly 30% of the sulphur entering the European refineries left in fuel products. This has now reduced to less than 23% but it remains important to examine the overall distribution of this sulphur as it accounts for nearly a quarter of the crude intake.

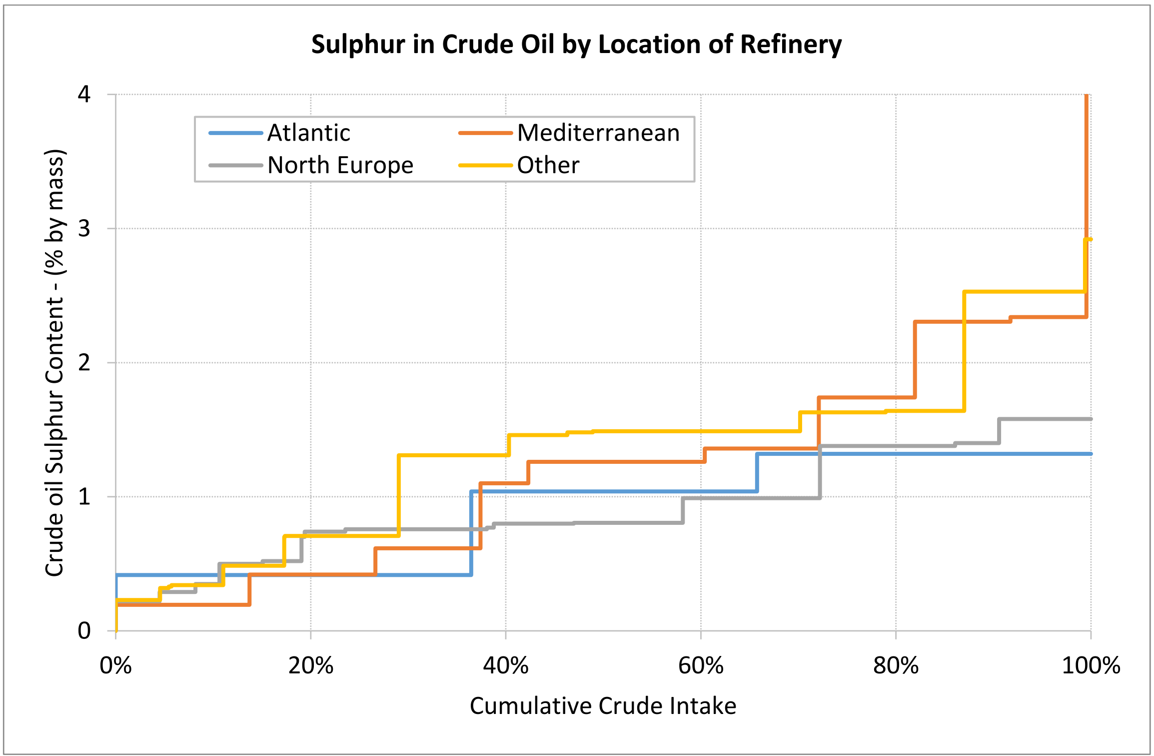
Figure 11 shows that the annual average crude slate for sulphur for Europe has hardly changed between 2002 and 2015. This is to be expected given that refineries are designed to cope with a relatively narrow crude diet and crude will be procured to meet this requirement. The average crude sulphur content in 2015 is 1.17% an increase from 1.01% in 2010 which in turn was slightly higher than the 0.90% in 2006 and 2002. A small fraction of refineries specialise in treating high sulphur crude, as seen by the sharp increases to the right of **Figure 11**.

Figure 11 Distribution of sulphur in crude oil



In keeping with previous reports, **Figure 12** presents a breakdown of the sulphur content of crude oil according to the geographic location of the refineries. The breakdown separates refineries situated in the Mediterranean area, those with an Atlantic coastline and those likely to take in crude through the northern European mainland ports and waterways. Central and eastern European refineries and refineries in outlying areas including Scandinavia are gathered into a fourth category. Relatively speaking, the refineries with access to the Atlantic coast and Northern Europe processed a greater proportion of low sulphur feedstock.

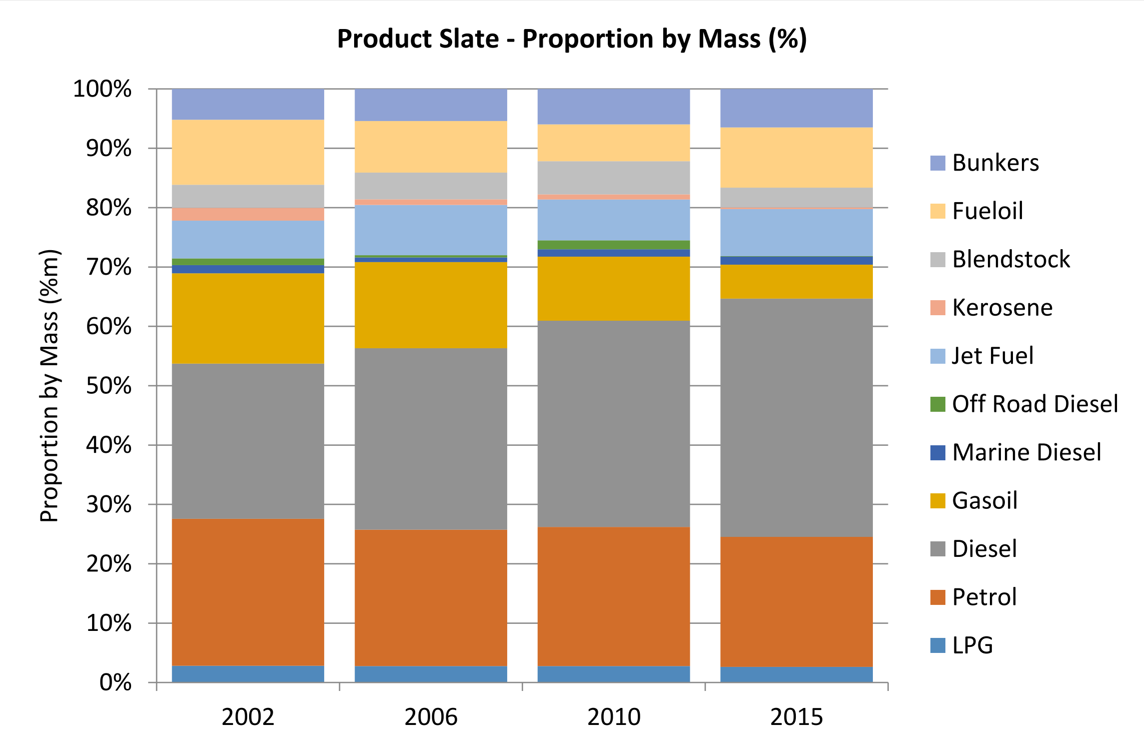
Figure 12 Regional variation in the sulphur content of crude oil



5.1. EVOLUTION OF THE PRODUCT SLATE

The product slate obtained from the most recent four surveys is shown in **Figure 13**. The main refinery products are road transport fuels, aviation fuel and heavy fuels (fuel oil and bunkers). There is a clear increase in the proportion of diesel produced; this is in response to increased product demand by European vehicle fleets. The petrol proportion has shrunk slightly however the largest reduction in proportional share has been the gas oil market. For the first time this is no longer the third largest product, instead reducing by two thirds since 2002 and accounting for less than 6% of the total fuel product. This is primarily due to a harmonisation in product standard between agricultural and road diesel as specified in the European Fuel Quality Directive that took effect in 2011. This has led to alternative products e.g. automotive diesel being marketed separately to the agricultural market.

Figure 13 Product slate from 2002 to 2015 - proportion by mass %

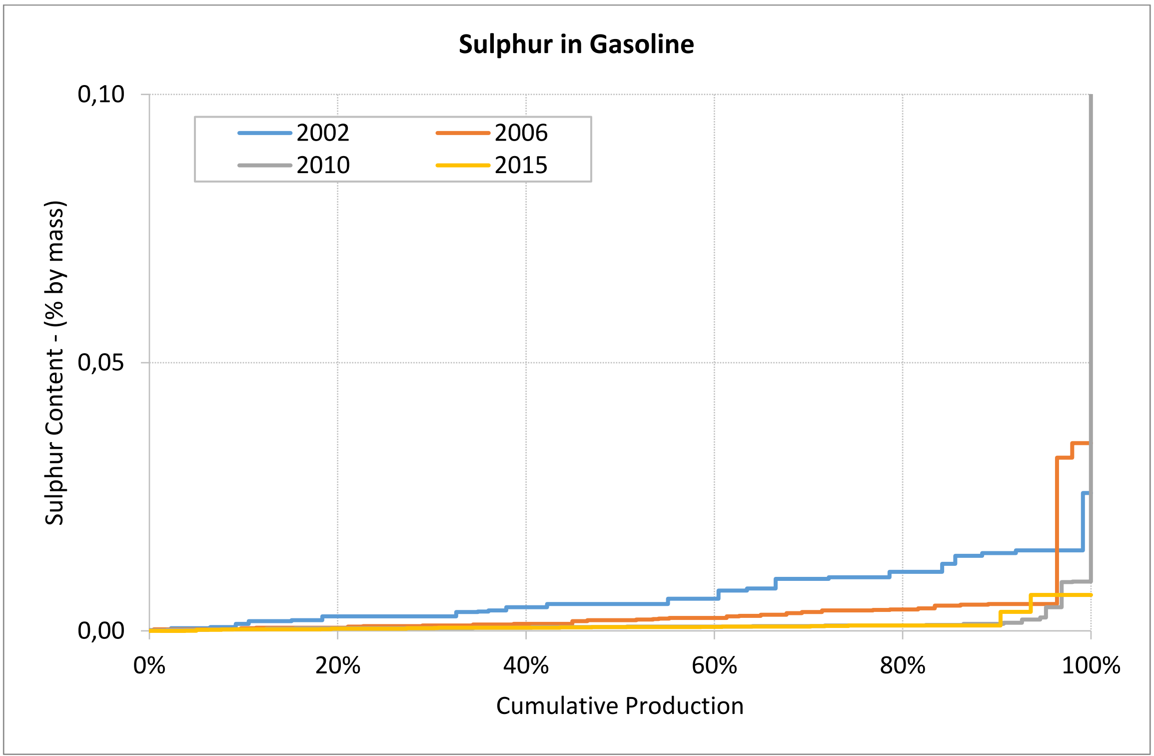


5.2. ROAD / TRANSPORT FUELS

Gasoline

Figure 14 displays the evolution of sulphur content in produced gasoline and shows a clear reduction in sulphur concentration in line with legislation. In this survey over 100% of gasoline possesses a sulphur content of less than 0.001% (10ppm). Whilst the survey includes products for export, 90% of the gasoline produced in 2015 met EU legislative requirements and could be utilised in the EU market place, the remaining 10% is likely destined for export outside the EU.

Figure 14 Distribution of sulphur in gasoline

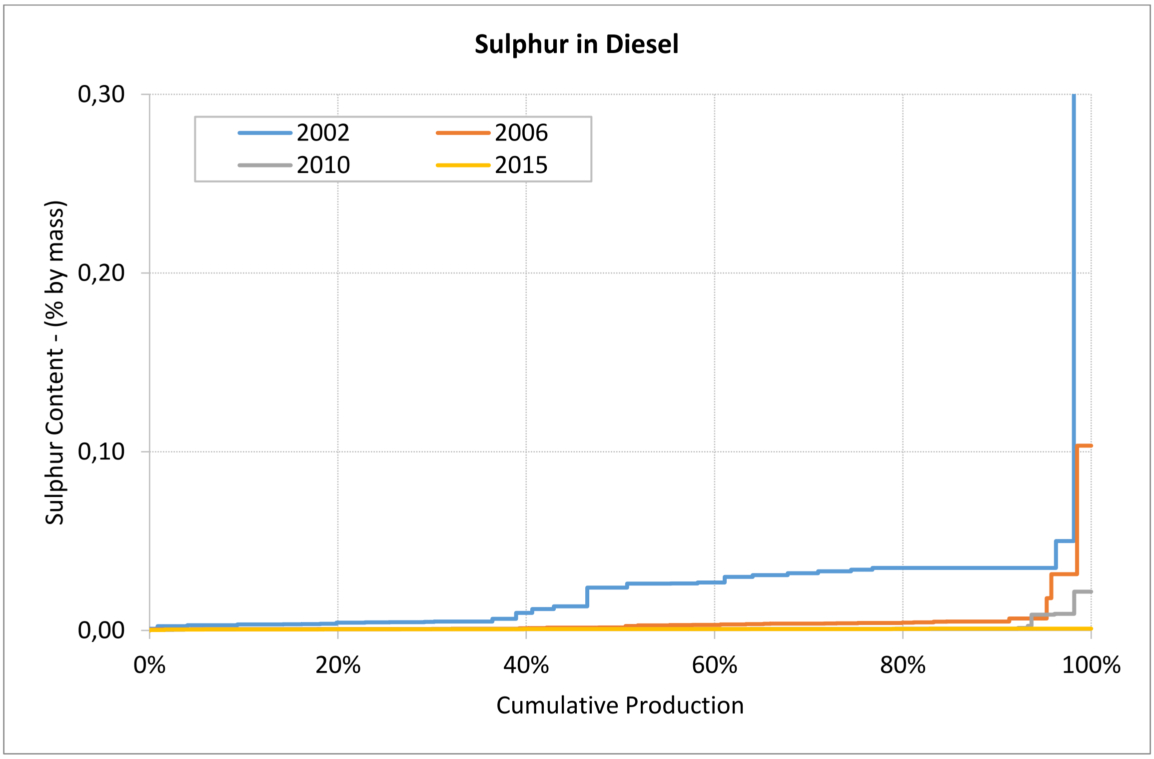


Diesel

In sulphur survey reports prior to 2010, the road diesel component was not presented as a separate item with the explanation that disaggregation was not reliable. Instead, all gasoil items were combined and reported as a general gasoil pool. Since the 2010 survey, the on-road diesel and heating gasoil streams have been disaggregated, although we must introduce the caveat that there may be some unappreciated inadequacies in the reporting from years previous to 2010.

Figure 15 shows the distribution of sulphur in on-road diesel. Similar to gasoline, the changes in sulphur content over time reflect the requirements of the EU market which have required successive reductions in sulphur content to the current 0.001% or 10ppm. Whilst the survey includes products for export, 100% of the diesel produced in 2015 met EU legislative requirements and could be utilised in the EU market place.

Figure 15 Distribution of sulphur in on-road diesel



Marine Fuel Oil / Bunker Fuel

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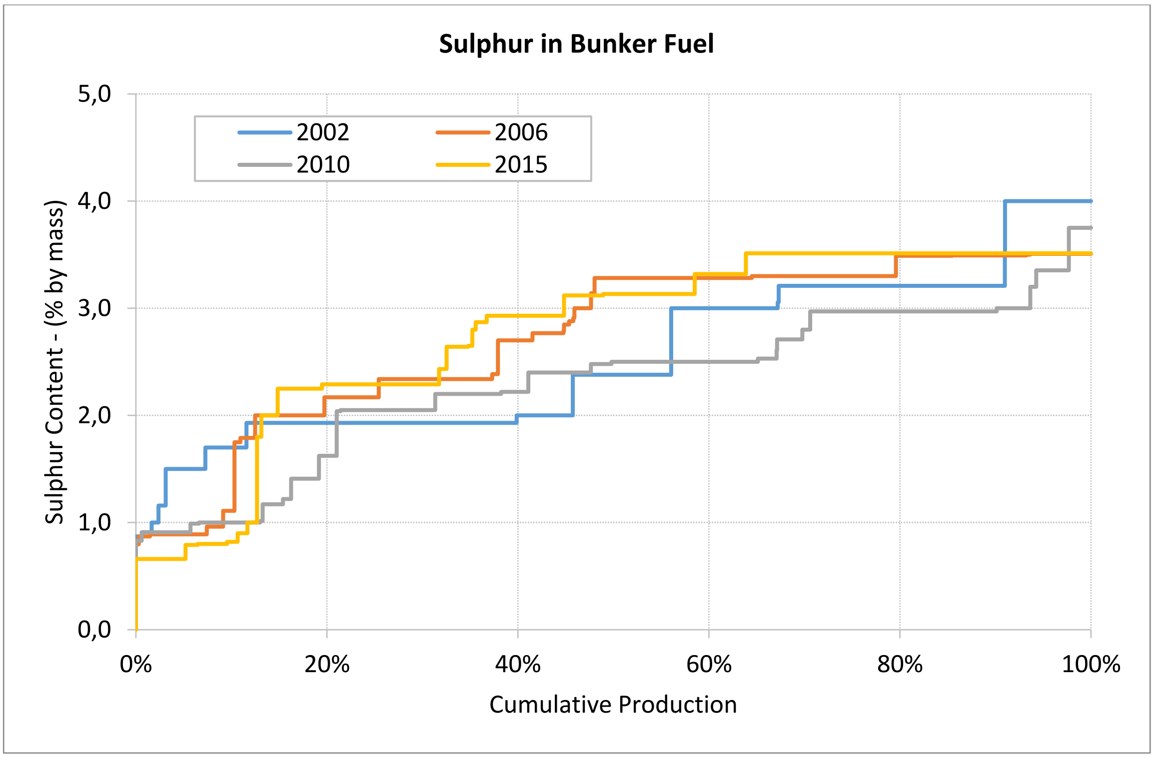
Figure 16 shows the distribution of sulphur in marine bunker fuel, an area which has experienced substantial legislative change since 2006. **Table** 7 shows the proportion of fuel that complies with each legislative category, produced by European refineries. Currently no refineries are producing fuel at or below 0.5% sulphur, a level which requires additional processing and cost. Not all refineries produce marine bunker fuel and the number of responses for marine fuels have varied in each survey: 17 in 2002, 27 in 2006, 26 in 2010 and 23 in 2015.

Table 7 Sulphur content of marine fuel oil/bunker fuel over time

	2002	2006	2010	2015
Mean Sulphur Content	2.2%	2.4%	2.2%	1.95%
Proportion At or Below 3.5% S[6]	91%	98%	100%	100%
Proportion At or Below 1% S[7]	3%	9%	13%	13%
Proportion At or Below 0.5% S[8]	0%	0%	0%	0%
Proportion At or Below 0.1% S[9]	0%	0%	0%	0%

[6] Global sulphur specification in 2012
[7] Maximum sulphur content since 2010 in Sulphur Emission Control Areas
[8] Maximum global sulphur content from 2020
[9] Maximum sulphur content since 2015 in Sulphur Emission Control Areas

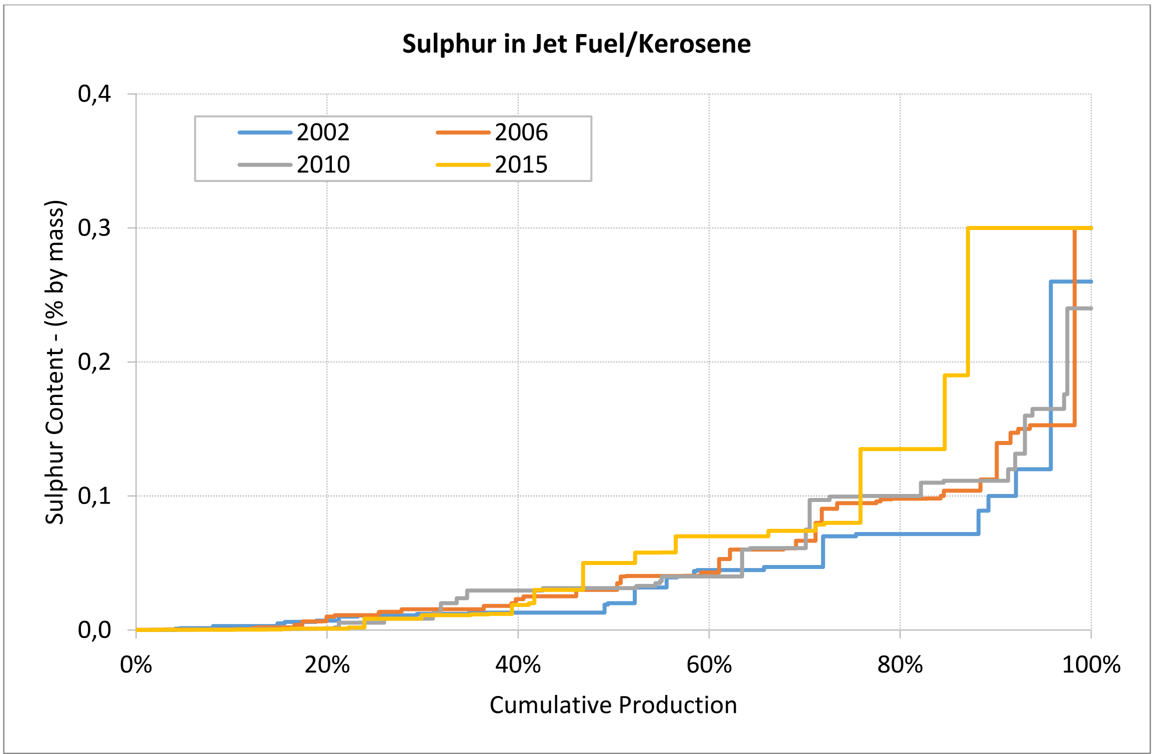
Figure 16 Distribution of sulphur in marine fuel oil (bunkers)



Jet Fuel / Kerosene

Figure 17 shows the distribution of sulphur in jet fuel and kerosene. All production covered by the surveys since 2002 have met the world-wide specification for jet fuel of 0.3%. 2015 shows a marked difference in distribution of production, this is probably due to a lower number of survey respondents compared to previous years rather than a change in refinery output.

Figure 17 Sulphur distribution in jet fuel and kerosene

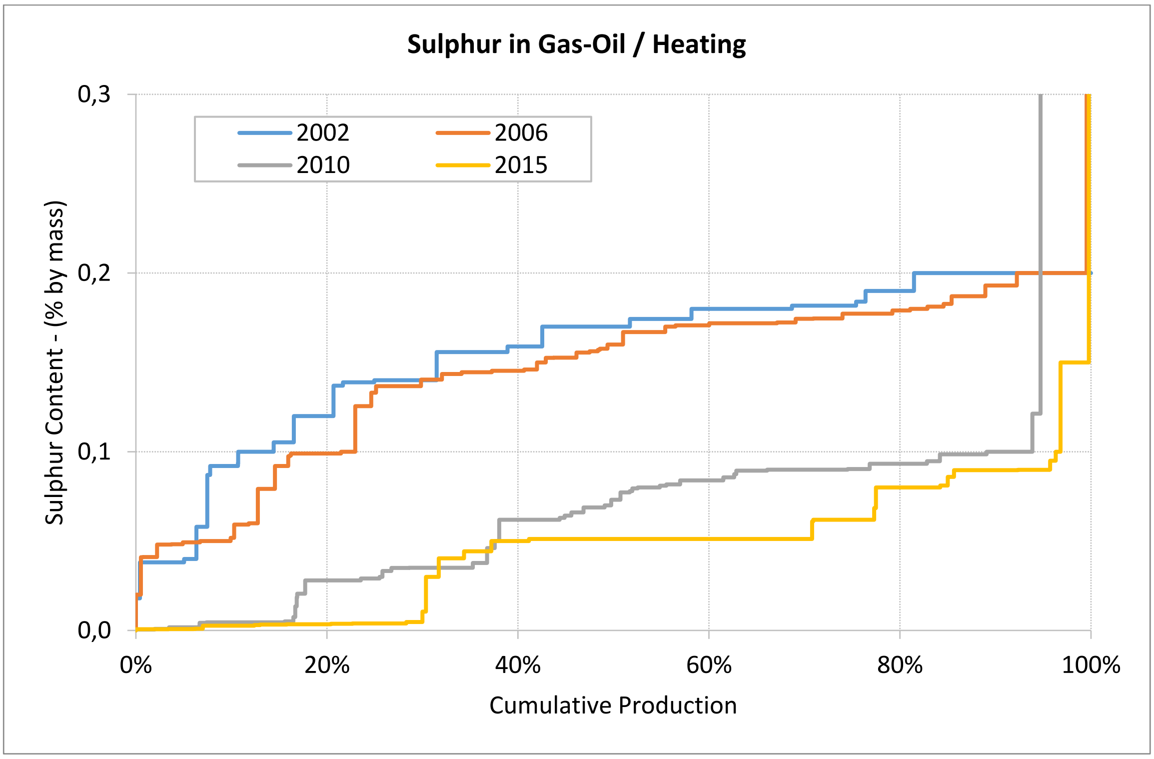


5.3. FUEL OILS

Gas-Oil / Heating Oil

Figure 18 shows the distribution of sulphur in gas-oils used for heating purposes. The EU sulphur limit for this combustible decreased from 0.2% to 0.1% in 2008. The survey shows very little evolution in the distribution of production prior to 2010 and then a very large change in response to specification. In 2015, 97% of production contains less than 0.1% sulphur. The production that exceeds this sulphur concentration is likely destined for export to markets outside the EU with higher permitted sulphur content.

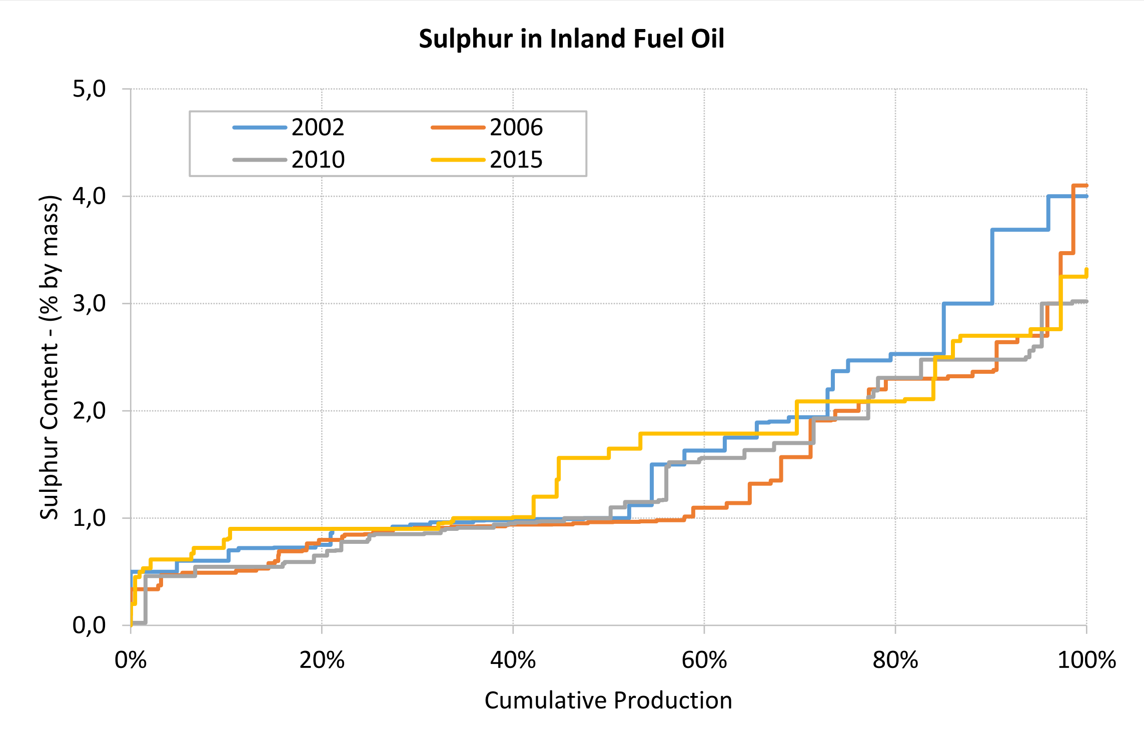
Figure 18 Distribution of sulphur in heating gas-oil



Inland Fuel Oil

Figure 19 shows the distribution of sulphur in inland fuel oil. Under the terms of the Sulphur in Liquid Fuels Directive, since 2003, heavy fuel oil must have a maximum sulphur content of 1% for general use in Europe. Fuel oil having a sulphur content greater than 1% but less than 3% can be used under permit, in installations with appropriate emissions abatement equipment, or it may be exported. The fraction of production that meets the 3% specification has steadily increased to nearly 100% of production while the production of fuel oil meeting the 1% specification continues to fluctuate. Production of fuel for the export market may account for the fuel containing more than 3% sulphur.

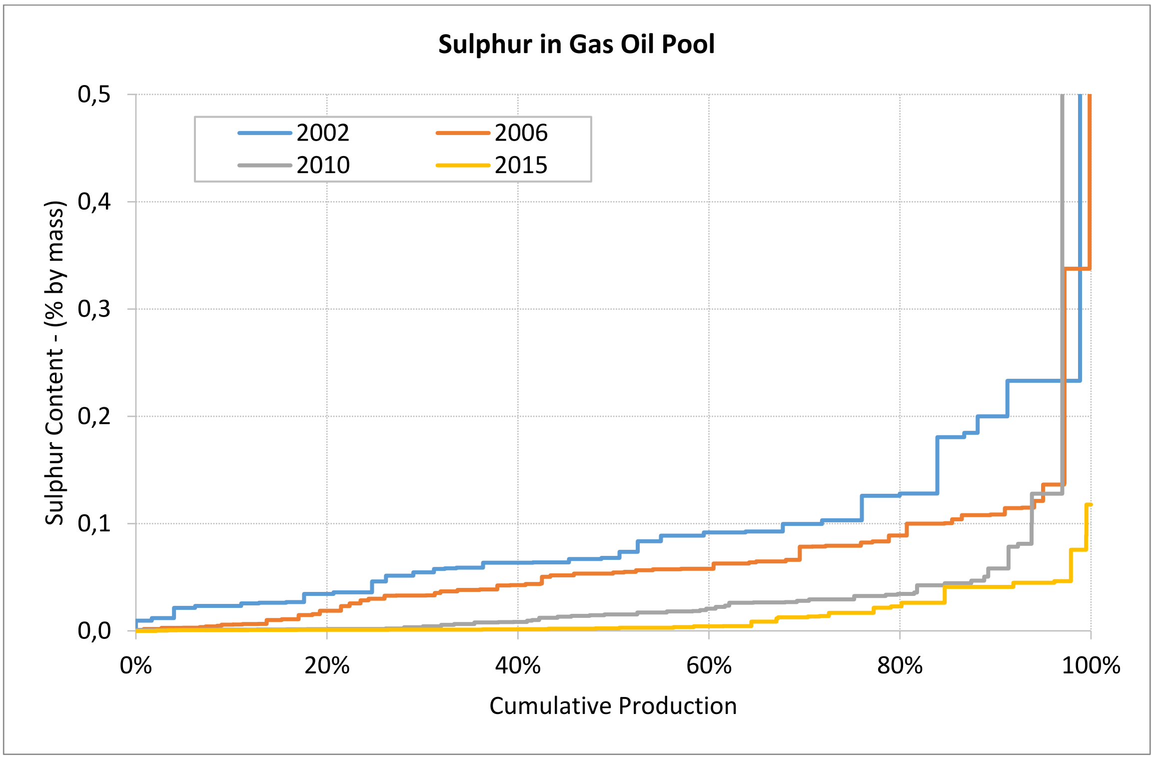
Figure 19 Distribution of sulphur in inland fuel oil



Overall Gas-Oil Pool

A generalised gasoil pool is reported here in **Figure 20** for consistency with reports before 2006. This pool comprises automotive diesel, off-road diesel, heating oil and marine gasoil. The sulphur content of this pool is calculated using weighted averages of each of the gasoil. The results show a progressive reduction since 2002 and a substantial change between 2006 and 2010 attributed to the 0.001% (10 ppm) automotive diesel and 0.1% heating oil, off-road and marine gasoil sulphur specifications. In 2015, the overall pool contains nearly 100% of production at less than 0.1% averaged sulphur content, a marked decrease over previous years.

Figure 20 Sulphur in the overall gasoil pool

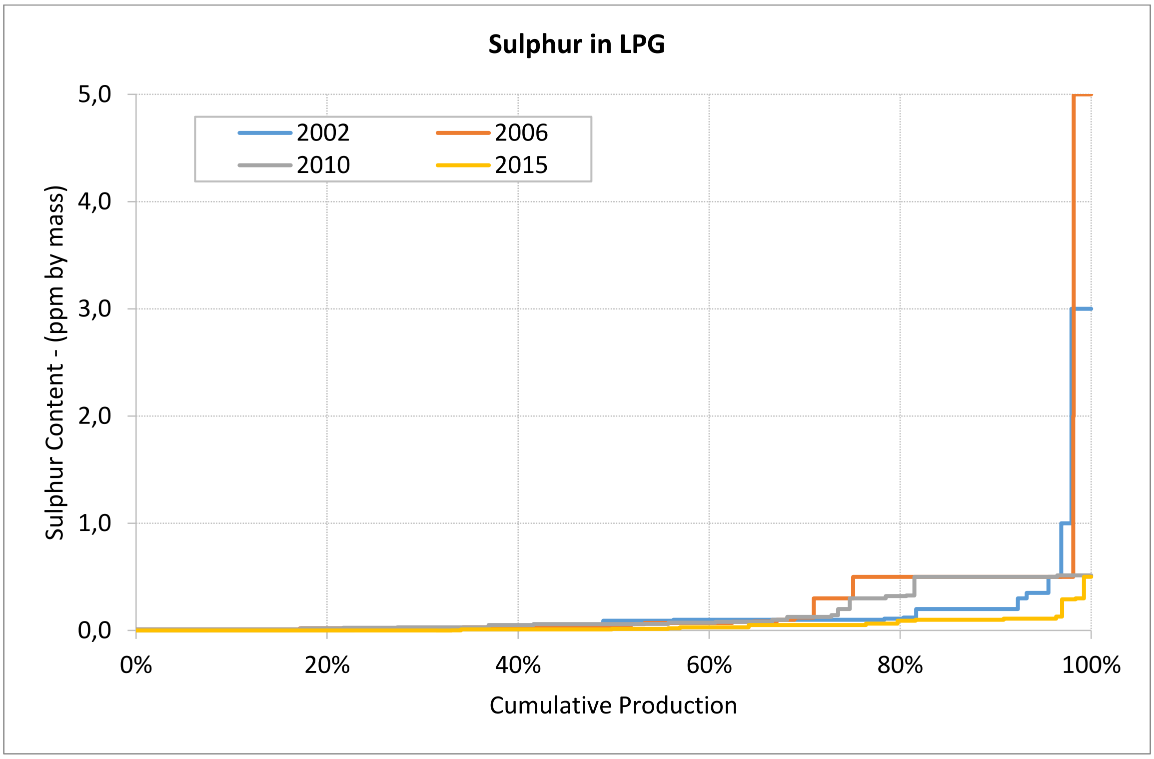


5.4. OTHER PRODUCTS AND INTERMEDIATES

LPG (Propane and Butane)

The sulphur content of produced butane and propane is shown in **Figure 21**. The 2015 survey continues a consistent reduction in sulphur with 97% of production below 0.2 ppm and 89% below 0.1ppm. This equates to roughly 0.00001% sulphur and as such, LPG remains essentially free of sulphur.

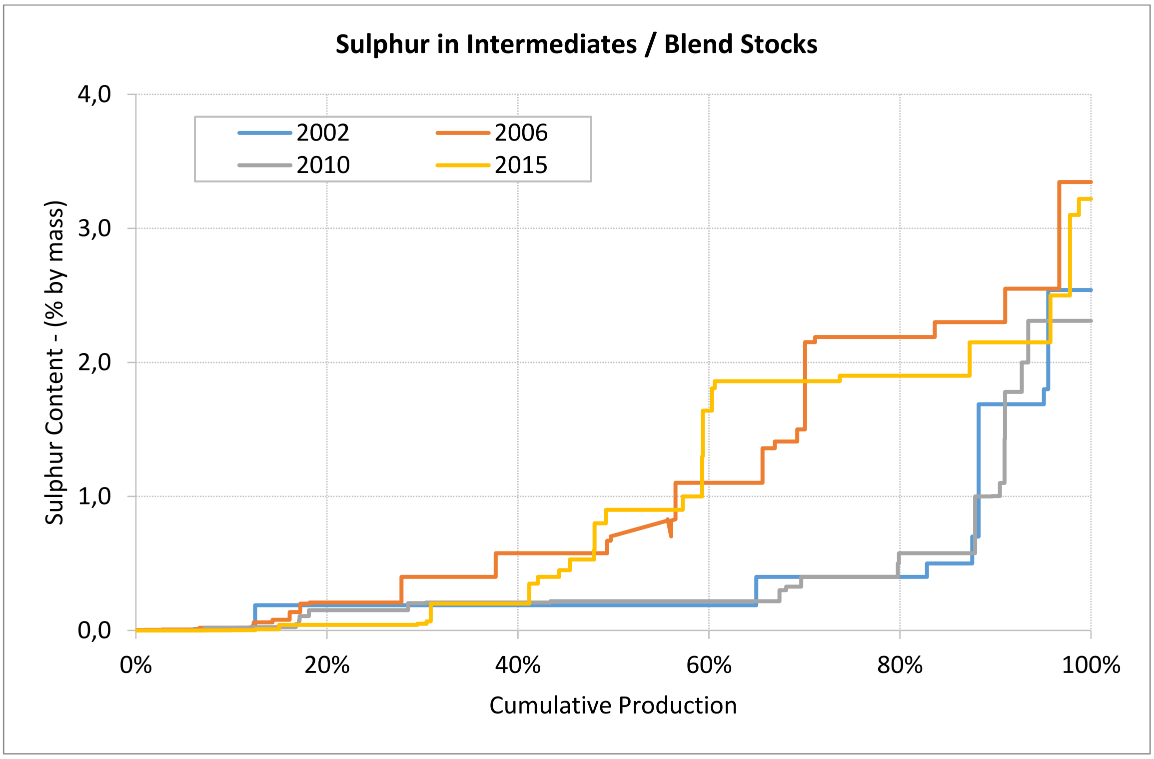
Figure 21 Sulphur content of LPG



Intermediates and Blend Stocks

Figure 22 shows the distribution of sulphur in intermediates and blend stocks. In 2010 a similar distribution was reported as in 2002 while the 2015 survey distribution is similar to the 2006 data. Given this wide but repeated variability it is likely that the year by year variation represents demand and opportunity in domestic and/or export markets rather than any structural change.

Figure 22 Sulphur content of intermediates and blend stocks



6. CONCLUSIONS

The sulphur survey responses for the year-end 2015 have been analysed and the results shown together with the responses for previous surveys in 2002, 2006 and 2010. A common methodology was used between all surveys with additional data being added to the report as more detailed questions are introduced to the survey.

The 2015 survey used responses from 44 refineries compared[10] to 63 in 2010, 67 in 2006 and 46 in 2002. The refinery intake from these 44 refineries is equivalent to 52%[11] of the EU refinery throughput in 2015. The survey provides an overview of the distribution of sulphur between the refinery products, the recovery of sulphur in the refinery process and the oxides of sulphur emissions to atmosphere from refineries.

The period 2002 to 2015 has seen the following trends:

- A continued downward trend in the sulphur content of major product streams associated with a strong increase in sulphur recovered in the refinery process.
- The sulphur leaving the refinery in fuel products has reduced from 30% to 23%.
- The sulphur leaving the refinery in non-fuel products has increased from 9% to 13%.
- An increase in the amount of intake sulphur recovered as elemental sulphur and other sulphur products from 53% to 61%, of this 47.6% in 2002 and 59.6% in 2015 is recovered as elemental sulphur.
- A decrease in the amount of sulphur emitted to the atmosphere from direct use in the refinery from 6% of the total intake to 2%.
- The sulphur content of fuels closely matches the market requirements of fuels regulated by international or EU regulations such as the Sulphur in Liquid Fuels Directive, Prevention of Air Pollution from Ships (Annex VI) and the Directives on Automotive Fuel Quality.
- The sulphur content of the overall crude slate has slightly changed and there remains a distinct geographic variation in the sulphur content of crude processed.
- The product slate continues to evolve with an increase in the overall proportion of middle distillates, especially on-road diesel. This is in response to market forces that dictate demand for specific products and legislation that dictates sulphur content and other quality criteria, both of which influence overall utilisation of the barrel.
- Refineries continue to reduce the amount of liquid fuel burned internally and the sulphur content of this fuel is closely monitored. Where appropriate, emissions abatement technologies are used to reduce sulphur emissions to the atmosphere.

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[10] Number of survey returns used in the analysis.

[11] Eurostat Energy Balance Sheets, 2014 data, 2016 Edition. ISBN: 978-92-79-59758-9. Transformation input in refineries.

7. GLOSSARY

CO	Carbon Monoxide
FCCU	Fluid Catalytic Cracking Units
Foe	Fuel oil equivalent
LCP	Large Combustion Plant
LCPD	Large Combustion Plant Directive
LPG	Liquid Petroleum Gas
NG	Natural Gas
OECD	Organisation for Economic Co-operation and Development
RFG	Refinery Fuel Gas
SCP	Small Combustion Plant
SO_2	Sulphur Dioxide
SRU	Sulphur Recovery Units

8. ACKNOWLEDGEMENTS

Concawe would like to express its gratitude to all its member companies whose contribution to the survey has made this work possible.

Concawe would also like to thank Aeris Europe for compiling this report and processing the individual responses from refineries.

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10. LIST OF FIGURES

11. LIST OF TABLES

12. APPENDIX 1. METHODOLOGY

This Appendix is reproduced from report 10/01 for the convenience of the reader. Specific data referred to fuels is from 2006.

The survey form comprises an Excel spreadsheet distributed to member companies.[12] The spreadsheet comprises 12 worksheets of which 7 are data entry forms and the others contain contextual and summary information. The survey requests inputs and outputs that allow a hydrocarbon and sulphur balance on the refinery to be made. Sulphur emissions through combustion are identified on a per stack basis using the size categories of the Large Combustion Plant Directive.

Fuel use is standardised on an energy rather than a mass basis using a fuel-oil equivalent figure. In previous reports a lower heating value of 40.24 MJ/kg was used for the oil; a value of 52.3 MJ/kg was used for gases and a value of 16.1 MJ/kg was used for the fuel category “other”. These figures were based on a 1998 analysis of fuel streams. As discussed below, these have been used again here for consistency and lack of a better approach.

One change to the survey in 2006 is that it sought data on internal fuel consumption in both mass and in energy units. All respondents provided mass data but only a few provided energy data. Some used global conversion factors (constant energy content for liquids, gas and other fuels), others reported different energy contents for fuels by combustion plant size. We note that the survey uses annual total emissions and so either total mass or total energy may comprise use of different fuels over the year.

The distribution of reported heating values for each survey fuel category (liquid, refinery gas, natural gas, other) is shown in **Figure A1**. This has been calculated by dividing the reported energy use by the reported fuel consumption in each reported category and counting the heating values falling into 2 MJ/kg wide bands. Average values have been calculated on both a weighted (amount of energy used) and on an unweighted (number of data points) basis. Results of the averaging are given in **Table A1**.

The fuel oil values are narrowly distributed about a weighted value of 42.03 MJ/kg (41.29 MJ/kg unweighted) which is slightly larger than the foe value of 40.24 MJ/kg used previously and is close to the IEA standard conversion of 41.86 MJ/kg.

The natural gas value is lower than for pure methane perhaps reflecting the high inert (N_2) content of some natural gases. The average value of 47.97 (46.2) MJ/kg is lower than the value used previously for gas of 52 MJ/kg. The refinery fuel gas value was surprisingly small 37.3 (41.81) MJ/kg on average but it is apparent that some low energy fuels were included in this category and this has depressed the mean value. These lower energy fuels would be better assigned to the category “other”. Heating values assigned to gaseous fuels ranged from below 18 MJ/kg to above 54 MJ/kg.

Similarly it seems that two types of “other” fuel are in use having heating values that are very low (10 – 14 MJ/kg) on the one hand and high (44 MJ/kg) on the other hand. The average is 18.29 (34.06) MJ/kg fuel which compares well with the previously used value of 16 MJ/kg.

[12] The 2015 saw a shift to an online submission system, however it was necessary to supplement this with the traditional Excel survey format for a number of refineries.

Figure A1 Distribution of heating value by fuel type, 2006 survey

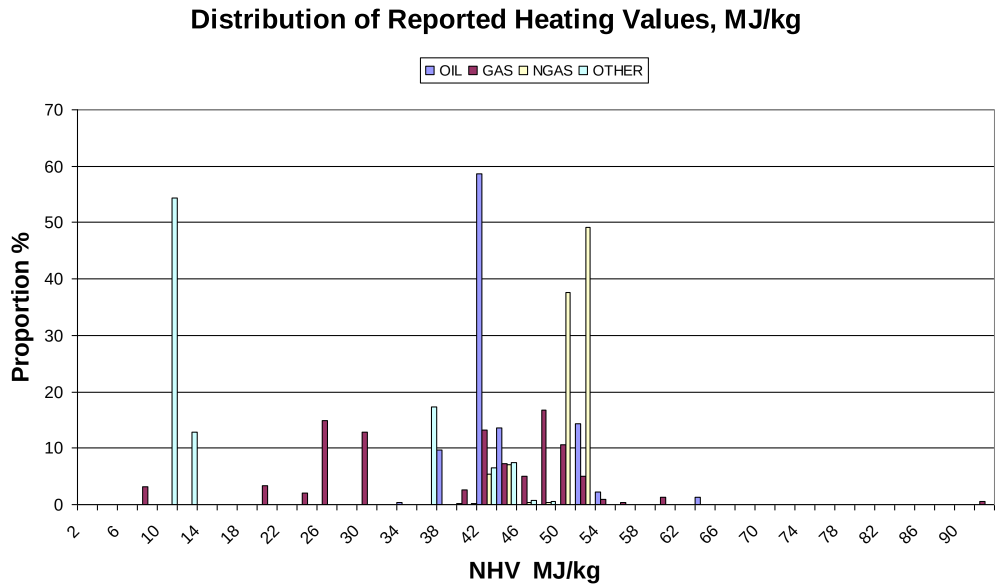

Table A1 Average lower heating values by fuel type (2006 report) compared with previous reports

Fuel	Lower Heating Value MJ/kg		
	weighted mean	unweighted mean	Used in this and earlier reports
Oil	42.03	41.29	40.2
Refinery Fuel Gas	37.34	41.81	52
Natural Gas	47.97	46.2	52
Other	18.29	34.06	16

To perform the survey analysis it is necessary to have a simple method of comparing fuel use in terms of energy content. The data collection was not adequate for this purpose and it was decided to retain the historic heating values, having also advantages of backward compatibility.

The assumptions will result a small margin of error in the estimate of total energy use. They may affect the refinery position in ranked charts but, because refinery name are not used in the study this has no consequence.

We note that the definition of fuel oil equivalent (foe) used in the sulphur survey analysis is different to the IEA definition (40.24 c.f. 41.86 GJ/t). In this appendix we use the standard value of 41.86 GJ/t.

The other aspect of fuel quality is the need to estimate combustion air requirements for the different fuels in order to determine equivalent bubble concentrations.

The commonly used conversion that the Large Combustion Plant Emission Limit Value of 1700 mg/Nm^3 for SO_2 corresponds to a fuel oil containing 1% sulphur by weight gives a dry combustion product volume of 11.67 Nm^3/kg fuel.

Values for dry flue gas volume used in previous reports (converted to the standard foe at 41.86 MJ/kg) were 12.5 for oil, 11.67 for both Refinery Fuel Gas and Natural Gas and 28.8 Nm^3/kg for “other” fuels. These compare well with calculations for some typical refinery fuels.

Table A2 Dry flue gas volume (3% excess oxygen) for several fuels on a fuel oil equivalent basis of 41.86 MJ/kg

Fuel Type	Lower Heating Value GJ/t	Standard Flue Gas Volume Nm^3/kg (foe)	Comment
Refinery Fuel Oil	39.7	12.6	H/C = 1.5 mol ratio.
Refinery Fuel Gas	47	11.67	Alkane mixture (10% C4)
Refinery Fuel Gas	49.7	11.4	Alkane mixture with 40% H2
Natural Gas	50	11.66	Methane
Natural Gas	39.2	11.86	13.7% Nitrogen, typical Benelux
FCC Coke	38	12.3	Low hydrogen
FCC Coke	40.7	11.9	High hydrogen
Low Joule Gas	4.19	16.94	High Nitrogen H2/CO mix
Low Joule Gas	1.88	27.0	5% HC

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